

DESIGN OF LOCKS



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Part I

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Lock complex Born in the Julianakanaal (March 1999)



The "Princess of Scandinavia" entering the Middelsluis in IJmuiden (October 1992)

Foreword

Water evaporates over the sea, the vapour condenses into layers of air, rains down over the land, is swept along by rivers and ends up in the sea. A cycle of nature that keeps the fields green, the rivers running and the sky varied. It also creates a substantial problem for a country that, for the greater part, consists of being a delta of the three largest European rivers.

One does not always realize that we live in a delta. Everything is well regulated. Sometimes the rivers are a bit high, sometimes a bit low but overall, well within acceptable boundaries. Sometimes the land is a bit wet and the pumping-stations have to work overtime. Every now and again we have a lengthy dry spell. A few trees die and the harvests are disappointing but this is also the case if it is too wet. Nature recovers miraculously fast from a wet or a dry time.

This is a delta that faces contradicting requirements. We want to keep the sea out but also be able to discharge the rainwater. We want to keep the fresh water at certain a level, per catchment /drainage area, per region, but we also want to navigate ships throughout the country by means of waterways as well as to and from the sea.

The answer is the lock. In a lock, water demonstrates its bearing force. Every ship that fits in the lock, no matter how heavily laden, is lifted to the required level effortlessly. In the lock, the water is also being fooled. The gates prevent the water from reaching its objective, levelling out, and yet ships are able to pass through.

Splendid technology, a lock. A coming together of civil engineering (how do you build a waterway), mechanical engineering (how do you build a lock gate) and electrical engineering (how do you move a gate). A lock is an intervention in nature, by humans (culture) and the result is often pleasing to the eye of those who appreciate a harmonious relationship between nature and culture.

You will find locks all over the world but you will be hard pressed to find as many locks per square kilometre as you do in the Netherlands. Besides, our country has a great variety of locks. Very small and extremely large, with a small drop and with a drop of thirteen metres, locks for ocean navigation, inland navigation, recreational navigation. So many minds, so many likings, so many locks, so many designs.

Design of locks has therefore become a sizable book that consists of two parts, twenty-three chapters and about one thousand one hundred and fifty pages. An impressive standard work for designers of locks who work for the Civil Engineering Division (Bouwdienst Rijkswaterstaat), engineering firms and for educational institutes where the profession is taught and learnt. It took many years of work, by experts of the Directorate General of Public Works, by a number of authors and by two editors-in-chief. In 1947, the standard work on locks by Josephus Jitta was published. Much has changed since then. Tremendous technical progress has been made. The problems largely remain the same, at least the nature of the problems, but the possibilities open to approaching them has increased immensely.

The Netherlands is still a delta; we still want to control the course of water. We call this water management. We still want to navigate. Actually, we would like to increase navigation, as it is the most environment friendly mode of transport.

Here is the book for designers of locks for the twenty-first century.
May it inspire many.

Jan Terlouw

(Chairman of the Royal Navigation Association Schuttevaer)



Photo 1.1 Pushtow navigation locks in Volkerak (October 1999)

Chapter 1 Introduction

1.1 Locks in the Netherlands

Transport across water is economically attractive and environmentally friendly in the Netherlands. Until the beginning of the 19th century, due to the lack of other forms of transport, just about everything was transported across the water. At present, haulage across the water is still the obvious means of transport when it comes to heavy and voluminous goods. The Netherlands has a closely-knit network of waterways, which makes many places easily accessible by water. The waterway network flows out to the sea and links the Netherlands with surrounding countries and distant foreign countries. Waterways are increasingly being used for recreational purposes. The waterways are either part of a river or basin or were artificially created as canal or storage basin, often in combination with water resource management functions. Locks are an indispensable part of the waterways as they bridge the various height differences that occur in landscapes.

The Netherlands has been using locks for many centuries. The continuous improvements in design yielded a wealth of information that, in the second half of the 19th century, resulted in a limited number of masonry lock types with mitre gates of wood or iron. Examples of these are the locks in the Merwedekanaal and the Zuid-Willemsvaart, the Middensluis of IJmuiden and the Oranjesluizen near Amsterdam.

As a result of the advent of new building materials such as concrete and steel early in the 20th century, as well as the scale expansion in shipping, completely new lock designs were developed with increased dimensions and other types of gates in the place of mitre gates.

Examples of locks in the interbellum period are the Noordersluis in IJmuiden with horizontal roller-bearing gates, the locks in front of the Maaskanalisation, the Twentekanaal and the Amsterdam-Rhine canal, which has both mitre and lift gates.

After World War II, the development continued with designs that met the new needs and requirements. Examples of these are locks in the Schelde-Rijn connection and the Amsterdam-Rhine canal for push-tow navigation, the sea lock at Terneuzen and the Kreekrak- en Krammersluizen with a salt and freshwater separation system, the locks in the Julianakanaal with stilling chambers for rapid levelling and the many locks for recreational purposes.

In the current designs (end of the 20th century), the possibilities of concrete and steel are further utilized and operation is improved. Interventions in nature due to the presence of locks are increasingly being better controlled. In addition, old locks are reconstructed more often. Examples of these are the Nieuwe Oranjesluis with sliding gates, the 2nd lock at Lith with pneumatically sunken heads, the Krabbersgatsluizen executed as aqua-duct ("Naviduct") and the lock reconstructions in Gorinchem and Andel with new outer heads. Some other examples are Kleine and Zuidersluis at IJmuiden and the old Oranjesluizen with new heads, chambers and operating system. A new desalination system was applied to the Bergsediepsluis. There is no doubt that the development in lock construction will continue.

Abroad, locks are often found in hilly terrain with very large drops over the locks and substantial water shortages. This is the antithesis of the Dutch situation which is characterized by the more often than not, limited drops over the locks. A further peculiarity of Dutch locks is the fact that they are highly diverse. This diversity mainly concerns the varying dimensions of locks (from extremely small to extremely large), the various target groups (sea, inland and recreational navigation), the variation in drops over the locks (from very small to 13 m) and the bilateral retaining structures in tidal areas, including the salt/fresh-water influences. The result of this is that there are hardly any standard locks in the Netherlands and every lock has to be separately designed.

The Dutch lock has to be extremely reliable, as a retaining structure and as a transit possibility for vessels. A lock requires a large investment and is the cause of a substantial intervention in nature, the consequences of which are noticeable for miles in the surrounding area. The required lifespan of a lock is considerable (about a century). All of this necessitates that due consideration is given to the design of a lock from a substantial number of different perspectives. This book, "Design of Locks" aims to provide a contribution to this process.

1.2 Objective

Hydraulic engineer Josephus Jitta wrote the standard work on locks in the 1940's ("Sluizen en andere waterbouwkundige kunstwerken in en langs kanalen", 1947). The book has become outdated due to developments in lock construction, even though many of the fundamental principles addressed in the book are still valid.

From the 1950' to date, findings in the design and realization of locks have been haphazardly documented, which makes it inaccessible to contemporary and future designers. Loss of this knowledge should be prevented. During the past 20 years, a great deal of improvement took place, in both project as well as general research, in many different fields related to the design of locks. In order to make this widely accessible, a systematic and coherent overview of the results is desirable.

"Design of locks" is intended to be a practically useable compilation of intellectual capital gathered on locks, using knowledge that was gained during the research, design and the construction of locks during the past decades. The topics that are addressed concern almost all technical aspects that can be distinguished in locks. Each subject is presented as such that, after a description of the most important elements and their mutual connection (or providing insight into the subject matter) these elements can be looked at in more detail. The elaboration contains as little as possible theoretical dissertation, extensive derivations or minor details but consists mainly of practical design specifications, recommendations, check lists, references, computer programs etc.). The designs are general (not concerning one specific lock) but whenever necessary, examples are provided. Please note that no attention is paid to the cost aspect; only technical matters are addressed.

The ultimate objective of "Design of Locks" is to enable groups of designers of the (Bouwdienst) Civil Engineering Division of the Directorate General of Public Works in every discipline concerned, to draft a complete preliminary design of a lock. The designer has to gain insight into generating alternatives and making sound choices in this. It should also be possible to design part of the final draft with this book. Furthermore, this book can be of added value to engineering firms, construction companies and educational institutes, though some prior knowledge is required.

1.3 Overview of content

The design of locks consists of a large number of aspects. For this reason, the chosen set-up for this book is as such that the various aspects of the design are separately dealt with in different chapters in order to enlarge the accessibility as much as possible. The cohesion between the aspects is addressed in a number of general chapters and in a large number of references in the chapters referring to other paragraphs in the book. Naturally, there are references to literature.

"Design of locks " consists of two parts with 23 chapters in all.

- Part one (chapters 1 to 9) contains the more general information necessary for the first phase of the preliminary design process. It addresses the program requirements, the design process, main dimensions of lock and lock approaches, the intake and discharge systems and the choice of lock gates, lock heads and the lock chamber.
- Part two (chapters 10 to 23) provides a more technical description of the various study topics as a continuation of the preliminary design process. It deals with steel and mechanical engineering,

concrete constructions and foundations, control and operation, sheet piling, guiding structures, bed protection and hydraulic loads. It also looks at particular subjects such as maintenance aspects, reconstructions, salt and freshwater separation systems and future developments. The necessary examples are provided.

See tables 1.1 and 1.2 for a brief overview of the contents. The best way for a designer to gain insight into a certain subject or to find answers to more specific questions is by means of the chapter headings. There is also an index on key words.

1.4 Credits

In 1988, the then Department of Waterways and Public Works (Rijkswaterstaat - Directies Sluizen & Stuwen en Bruggen) and Delft Hydraulics (Waterloopkundig Laboratorium) set up a working group within the framework of 'Bouwspeurwerk Constructies en Water', who drafted a paper for the compilation of a book about the design of locks.

The first activities were with regard to the development of general knowledge in the field of intake and discharge systems of locks and hydraulic loads on lock gates, by Delft Hydraulics. At the end of 1989, the late Mr. M. van der Schaft (B Eng) formulated the Project Plan and the Plan of Approach for the first draft of the book. A few chapters were subsequently written in 1992/1993.

In 1994, the project was restarted, led by Mr. H. Verwoert (B Sc) of the Civil Engineering Division of the Ministry of Waterways and Public Works. The project was named AROS (Algemene Richtlijnen Ontwerp Schutsluizen).

A supervising committee was established under the chairmanship of Professor A. Glerum (B Sc) and the committee had the following members: G.J.M. Hertogh (B Sc), P.H. Hiddinga (B Sc), D. Kranenburg (Eng), H. Verwoert (B Sc), J.T. de Vries (B Sc), A. Vrijburcht (dr. B Sc) and J. Weijers (B Sc). The supervising committee commented on the various contributions by the authors. In 1998, the project leadership was turned over to J.T. de Vries (B Sc). The financial means necessary for the funding of the book was mainly provided by the Civil Engineering Division of The Ministry of Waterways and Public Works (Bouwdienst) and to a lesser extent, the Road and Hydraulic Engineering Institute (DWW).

From 1994 up to and including 1999, employees and former employees of the Division Civil Engineering (Bouwdienst) wrote most of the chapters however; employees of the Road and Hydraulic Engineering Institute (DWW), Delft Hydraulics, FUGRO and the University of Twente also contributed. Tables 1 and 2 provide an overview of the authors in addition to a brief table of contents. Besides these people, countless other (unnamed) staff members of the Civil Engineering Division of The Ministry of Waterways and Public Works contributed. The final editing of "Design of Locks" rested with Professor A. Glerum (B Sc) and A. Vrijburcht (Dr. B Sc).

No.	Chapter	Content	Authors
1	Introduction	Locks in the Netherlands, Objective, Overview content, Credits	A. Vrijburcht
2	Program of Requirements	Preconditions, Functional requirements, User requirements, Maintenance requirements, Environmental requirements in use and construction phase, Permits, Standards, Checklist	A. Glerum, P.H. Hiddinga, S.D. Henneberque, D. Kranenburg, A. Vrijburcht
3	Design process	Phases of the design process, Preliminary design process	A. Glerum
4	Main dimensions of lock and lock approaches	Volume of navigation, Horizontal dimensions and levels in view of locking, Lock levels in view of water retaining function, Resulting horizontal dimensions and levels of lock, Horizontal dimensions and depth of lock approach with a view to locking, Lock approach, Horizontal dimensions with a view to functions	A. Boogaard, A. Glerum, P.H. Hiddinga, D. Kranenburg, A. Vrijburcht
5	Layout of the lock complex	Contradiction in requirements, Dimensioning and lay out of lock approaches, Connection of lock approaches, Examples	A. Boogaard, P.H. Hiddinga, A. Vrijburcht
6	Intake and discharge systems	Type of filling and emptying systems, Phenomena during chamber reversal, Dimensioning, Hydraulic design, Lockfill	A. Vrijburcht
7	Gates, operating mechanisms and sluices	Types of lock gates, Selection of lock gates, Gate operating mechanisms, Sliding mechanisms and lock paddle operating mechanisms	D. Kranenburg, A. Vrijburcht
8	Lock heads	Design and shaping of heads, Adjustment of poured concrete facilities, Alternatives for building and building methods, Pre-selection of alternatives	A. Glerum, D. Kranenburg, A. Vrijburcht
9	Lock chamber	Functional requirements, Alternatives in construction and building methods, Pre-selection from the alternatives	A. Glerum

Table 1.1 Brief overview of content part 1 of the book "Design of locks"

No.	Chapter	Content	Authors
10	Piping and outflanking	Factors of influence, Computation techniques for piping in granular materials, Practical aspects	M. van de Paverd, J. Weijers
11	Hydraulic load on lock gates	Hydraulic load due to initial lift, Hydraulic load due to gate movement, Hydraulic load due to external causes	A. Vrijburcht
12	Steel and mechanical engineering constructions	Design load, Constructional aspects of gate operating mechanisms, Constructional aspects of sliding mechanisms	D. Kranenburg, A. Vrijburcht
13	Concrete constructions and foundations	Cross section of lock, Regulations, Load components, Load combinations, Strength and stability of caisson, Details of concrete construction	A. Vrijburcht
14	Earth retaining structures	Design aspects, Loads, Types of retaining sheet piling constructions, Earth retaining lock approaches, chamber walls, Realization aspects	M.A. de Graaf, A. Vrijburcht
15	Guiding structures	Lay out of lock approaches, Types of construction, Design origins, Shipping, water and soil data, Calculations main construction, Construction details,	A. Vrijburcht
16	Bottom protection	Functions and requirements, Flow causes, Calculation bed flow velocities, Calculation surface layer rip-rap, Position and length rip-rap, Vertical construction of rip-rap, Other types of bed protection	A. Vrijburcht
17	Lay out of lock and lock approaches	Issues for the benefit of traffic organisation, Issues for the benefit of entering and mooring, Exceptional hydraulic issues, Constructional facilities and grounds, Small lock furnishings, Breakwinds	A. Boogaard
18	Control and operating	Operational management, Operating system, Operation, Electro-technical plant,	A. Vrijburcht
19	Maintenance	Maintenance aspects in program requirements, Maintenance aspects in preliminary design, Measures for limiting non-availability, Maintenance concept,	M.T. van der Meer
20	Reconstructions	Objective and kinds of reconstruction, Current situation, Determining reconstruction, Developing parts of reconstruction, Execution aspects, Examples	A. Vrijburcht
21	Salt/ freshwater separation systems	Locks without a salt/ freshwater separation system, Overview of measures and separation systems for salt/freshwater, Salt/freshwater separation with opened doors during exchange, Salt/freshwater separation with closed doors during levelling out and exchange	A. Vrijburcht
22	New developments	Technical developments, Synthetic lock gates, Design process, Functional design	R.C.A. Beem, G. Nagtegaal, A. Vrijburcht
23	Examples	Kleine en Zuidersluis IJmuiden, 2e sluis Lith, Prins Willem-Alexandersluis, Krabbersgatsluizen, Oranjesluis	L.M.G. Smink, A. Vrijburcht

Table 1.2. Brief overview of part 2 of the book "Design of locks"



Photo 2.1 Weir and navigation lock complex at Lith during high discharge of the Meuse, 27 December 1993

Chapter 2 Program of Requirements

2.1 Introduction

The Program Requirements (PR) contains the preconditions and the requirements that a structure – in this case a lock with accompanying lock approaches – has to meet in a specific situation, in both the construction and the use phase. The program comprises all factors necessary for drafting a final design. A preliminary design usually starts with less extensive and more general assumptions than the points of departure specified in this chapter. During the design phase, requirements will be added or dropped.

Preconditions are understood to encompass all data concerning the natural environment and the built up area (topography, soil and water level data etc.) in so far as this is of importance to the structure and its use. Future changes that could influence the functioning of the lock have to be provided as well.

The requirements include the functional use, maintenance and environmental requirements but also include the stipulations and limitations imposed by permits, standards, directives and other constraints.

A lock is built for navigation. Therefore, the functional requirements related to navigation are of primary importance: transferring vessels from one water level to another. The other functional requirements (related to flood control structure, water management and dry infrastructure) come into view when considerations start on fitting the lock into the environment.

The use and maintenance requirements relate to further elaboration on the functional requirements on the one hand, and the additional requirements on the other. In the case of environmental requirements, it mainly concerns additional issues that cannot be deduced from the required operational functioning of the lock, for instance not being allowed to drain during the construction period.

Even though the design process is initiated with certain Program Requirements (the preliminary design process starts with a more general program) this does not mean that it is written in stone. During the development, it could turn out that a certain requirement was so stringently formulated that it would lead to disproportionately high costs. Adjustment of this requirement would have to be considered. In addition to this, certain requirements could be incompatible. A comparative assessment would have to be made between the various interests. Some examples of this are provided in Par. 5.2, conflicting requirements. Moreover, during the design insights could develop that certain requirements would have to be made more stringent or require further development.

This chapter describes the Program Requirements for a lock with accompanying lock approaches in its totality. Specific requirements for certain sections are described at the beginning of a number of chapters (7: Gates, operating mechanisms and sluices, 8: Lock heads, 9: Chamber 14: Earth retaining structures and 16: Bottom protection).

Par. 2.10 contains a checklist on the Program Requirements as described in this chapter. In addition, it also states which preconditions and requirements have to be available during the preliminary design process.

2.2 Preconditions

2.2.1 Topography

By means of maps (land, water, river, sea, ownership, regional and zoning plans) a detailed description of the environment should be provided, including any planned changes to existing situations, in so far as this is of importance to the lock and adjoining lock approaches. Special attention should be paid to historical, natural and scientific values. The maps should also show sewerage, cables and mains as well as drainage facilities in the area concerned.

2.2.2 Existing lock (locks)

If the new lock is constructed adjacent to an already existing lock, which will remain operational, or if a lock has to be renovated, the following information must be provided:

- geometry and condition;
- present (and anticipated) lock use(age);
- present use of mooring facilities;
- present use of ground, water and roads;
- possible permitted limitations of this usage during the construction of the new lock or the renovation.

If there are any weir locks, hydroelectric power stations or other hydraulic engineering works in the vicinity of the newly planned lock, similar data of these structures has to be available.

2.2.3 Water levels (approx.)

This includes water levels, water flows, water waves, water quality and water temperatures. In particular, data on *water levels* are necessary for *exceedance and underrun frequencies*. There are guidelines and standards that indicate exceedance frequencies for determining the normative high and low water levels for passing a lock, and for the maximum and minimum lock levels (Par. 2.4.1.1), as well as for normative high water levels (NHW) for the water retaining structure (Par. 2.3.2 and 4.5.3).

These levels contribute to the geometry of the lock (capstone height, upper cladding of gates, underside of raised draw gates, fixed bridges, sill depth etc.) and to the load on various parts such as gates, heads and chamber.

The water levels mentioned in the previous paragraph have a small possibility of occurring. However, the more frequently occurring levels and variations in levels, such as the daily tidal curves have to be known in view of intake and discharge times etc. Knowledge about *rise and decrease velocities* could be necessary to prevent overload on the operating mechanisms so that both heads are closed in time in certain operational situations where it concerns locks with open gates (thereby shifting into locking process).

If the lock is also used for water intake and discharge, *long-term data* will have to be available: water levels and their durations in dry and wet seasons and years.

Water flows could be of importance to the lay out and set-up of lock approaches, for instance the flow pattern of a river near a lock approach that has to be created.

River discharges and weir control are contributory to the height and depth dimensions of locks in canalized rivers.

Subject to water levels and the change of this in time, information is necessary related to the *water quality* (chloride values, "aggression", pollution) and the *temperatures*. Both are necessary as functions of the time and the depth under the water level. The chloride values are contributory to the volume weight and thereby, to the load on the lock construction. It is necessary to take the lengthening/shortening caused by changes in water temperature into account where it concerns steel parts.

In order to determine the height of the gates and the height of the capstone, the outer head (in all cases) and the load on the gates, the *swell and wave data* (H_s and T_p) need to be available. The situations have

to correspond with the design level, in so far as it is not derived from the then assumed wind conditions (velocity, direction and fetch). Information on seiches, storm surges oscillations and rise in sea level will be required. Dimensioning the operating mechanisms requires insight into the swell and wind waves, which could occur under conditions, at which navigation is possible. In addition to ship waves, transitory surges caused by locks, weirs and other structures could play a role (for instance their force on vessels that are moored in the waiting areas and on gates in opened condition).

2.2.4 Wind

Wind records (velocity, direction and accompanying frequencies) are necessary for determining the rise in water level due to wind action, waves, forces on moored vessels and forces on gates and control portals. In addition, wind records are necessary in relation to possible hindrance experienced by vessels that are sailing into or out of the lock.

(Remark: Instead of forces on moored vessels, bollard forces are used as a function of the water displacement of the vessel. Possible wind velocities have been allowed for in these bollard forces, also see Par. 2.4.3).

2.2.5 Morphology

Particularly when locks are situated in and on rivers, estuaries and seas, morphological information (such as bedload transport and suspended-load transport) is required for the design of lock approaches. After all, the locks need to meet the required accessibility in the future as well. The amount of silt present on the beds of the lock approaches has to be known. Morphological forecasts are also a determining factor for sill-depths of locks in canalised rivers and on estuaries of which conditions are and will be altered (for example because of damming up).

Morphology is dynamic subject matter and the extrapolation of statistical data is hardly ever sufficient by itself. Closer investigation is usually required (scale or computational models).

2.2.6 Soil characteristics

Distinction is made between soil mechanical and geo-hydrological data as well as between pollution and silt data. Earth forms the foundation (reaction) but also contributes to the load (action) of the lock.

Representative ground and laboratory testing made it possible to derive soil mechanical parameters for strength, stiffness and stability calculations of concrete, sheet piling and bed defence constructions. Loads on walls and the bearing force and deformation (positioning) of steel and pile foundations must be taken into consideration. It not only concerns the behaviour of undisturbed earth, but also the earth used for filling and embankments. If the work is executed by means of temporary groundwater lowering, the soil mechanical investigation will extend to a distance from the lock where a groundwater lowering of 0.5 metres is forecast. This is necessary in order to make a correct prognosis about positioning and possible damage. During temporary drainage, other issues will also have to be considered, for instance the soil use and the kind (steel or pile) and the quality of existing foundations.

The geo-hydrological data includes issues like the rise as a function of time and the fluctuations caused by changes in the (open) water levels on both sides of the lock. A good description of the rise is necessary as the groundwater forms a load on both the walls and the floor and could cause lift in the construction as a whole. Furthermore, insight into groundwater flow is necessary. In some cases, it is not considered permissible for temporary or permanent (sheet piling) screens to obstruct the flow. In addition, (mostly non-stationary) flows between the outer/upper water level and the inner/lower water level will determine the rise change under the lock. Permeability plays an important role in pumping during construction.

It is absolutely necessary to know about possible ground pollution on the site of the lock and the lock approach in order to establish which earth is suitable for reuse after excavation and which soil should be removed and where it should be moved to (depending on the degree of contamination). Even toxic dumps at a considerable distance from the area where a lock is constructed, could be the cause of pumping limitations being applied in view of the relocation of toxic substances.

2.3 Functional requirements

2.3.1 Functional requirements regarding navigation

2.3.1.1 General

The functional requirements of a lock are mainly intended for navigation. The most important general functional requirement is that vessels have to be able to pass as rapidly and safely as is deemed socially (macro-economically) acceptable.

Speed expressed as passing time is used to indicate the extra time required by a vessel participating as part of a fleet (with a particular number and composition) to progress from one side of the lock to the other, compared to the situation if the lock would not have been there. In this sense, the word lock is understood to mean a coherent whole of the lock approaches, lock heads and chamber(s) as well as the lay out and facilities provided in this. The passing time is determined by the time necessary for waiting, sailing in and out, mooring and unmooring and the operational time (closing and opening the gates and levelling out the chamber). This time largely depends on the amount of traffic (being the lock load or the relation between the intensity and capacity of the lock).

Safe passage through the lock complex is determined by the degree of certainty in which navigation traffic can be dealt with (smoothly), without danger and/or damage to people, material and the environment and still guarantee quality of life in the direct vicinity.

The general functional requirement can be made more specific by the requirements below:

- *Normative vessel or unit, belonging to a given waterway class, have to pass through the lock quickly and safely.*

Vessel or unit referred to is statistically determined. The accompanying effective lock dimensions are the minimum dimensions for the lock. (For waterway classifications, normative navigation and dimensions minimum locks also see Par. 4.2 and 4.4.)

- *Normative combination of vessels, belonging to a given waterway class, have to pass through the lock quickly and safely.*

Normative combination is a statistical value that, in principle, leads to the corresponding minimum lock dimensions. Problems are encountered in determining the normative combination and often it does not lead to economically sound lock dimensions. Therefore, the following is a better option:

- *Normative quantities and fleet composition of vessels, belonging to a given waterway class, have to pass through the lock quickly and safely.*

In this case, the probability factor and frequency of these vessels is taken into account.

Per CEMT or recreational navigation class:

- Here, the composition of the fleet is of importance and the effects of scale expansion become more visible.

As a function of time:

- Here, the spread in the arrival of vessels at the lock is addressed and the general periodic characteristics of commercial navigation (seagoing vessels, inland navigation), a larger number by day than by night, more recreational navigation in the weekend than in the week as well as seasonal influences during the year are better reflected. For the design, the latter characteristic also makes it necessary to distinguish between the supply in a normative week in which commercial navigation is dominant and a normative week in which recreational navigation is dominant.

In most cases, a separate traffic survey has to take place for determining the design dimensions of the lock and the lock approach. The chosen design dimensions should adhere to the (planned) uniformity of the route as much as possible.

- *Above mentioned requirements apply here as well as in a forecasted situation for navigation.*

This could mean taking such things into account as reserving terrain for a possible extra chamber, the construction of the necessary minimal facilities that could be too expensive/impossible at a later stage (for example locks in Philipsdam) and the extension of a chamber.

Within the lock complex, three parts can be distinguished in a functional sense: lock approach, leading jetty and chamber.

2.3.1.2 Lock approaches

A lock approach can fulfil a number of functions.

- **Primarily as part of the traffic management in locking**

The lock approach is the navigation area between the connecting waterway and the lock complex, where approaching vessels have the opportunity to decrease speed and moor to a guiding structure if necessary (mooring is usually not an option for large vessels; they keep their position, whether or not with tugboats). With this, sufficient view and overview should be ensured both by day and by night. The lock approach should therefore be free of obstacles and not be situated in a bend. In addition, transverse and longitudinal currents in the lock approach should be avoided as much as possible, in view of the reduced manoeuvrability of the vessel when reducing speed and stopping. The same applies to crosswind (also see Par. 5.2, conflicting requirements).

The lock approach is functionally divided into:

- *The line-up area*

This area has to be equipped with proper mooring facilities and be situated as such that moored vessels are not an obstruction to departing vessels. This area is intended for vessels that will be locking through in the next locking process. From the mooring area, vessels should be able to enter the chamber quickly via the leading jetties. A mooring area is required per chamber and per side. The size of the mooring area corresponds with a completely filled chamber. A general guideline is a length of 1.2 or 1.3 times the chamber length. Existing locks with a low traffic load could deviate from this (see Par. 4.4). Width is the chamber width.

- *The waiting area*

This area is also equipped with mooring facilities. This area is only created at locks where the expected navigation intensity will be such that, on busy days, the mooring area will be too small for all the waiting vessels. This area is intended for vessels that will not be able to lock through at the next locking process after arrival. For a lock with one chamber, one waiting area per side is necessary or a communal area for a lock complex with several chambers. The normative vessel must at least be able to moor in the waiting area. The length is determined by traffic calculations (see Par. 4.7). Width is the chamber width.

- *Free area*

Meant to provide vessels with the opportunity to decrease speed and start manoeuvres to moor in the line-up or waiting area. Furthermore, the free area provides the opportunity to, where necessary, adjust the profile of the waterway to the profile of the lock approach. For stopping and mooring, the following length should be available; an indication of inland navigation is approximately 2.5 times the normative vessel length.

- **Stop over harbour**

Lock approaches for inland navigation could also be used as stop over harbours. If this is the case, distinction should be made in the lay out, facilities and dimensions of waiting areas as opposed to areas for locking through. In addition, limitations according to sailing times legislation ("Vaartijdenwet") should be taken into account. See Par. 4.8.1.

(Remark: "Vaartijdenwet" and abbreviation for "Het besluit vaartijden- en bemanningssterkte ten aanzien van vaar- en rusttijden" which is equal to the Sailing Hours and Crew Numbers Act. As an indication, a distance of about 30 km between stop over harbours is required).

- **Harbour of refuge**

Lock approaches for inland navigation situated on a dammed up river, could also function as harbours in which vessels find refuge in extreme situations. Generally speaking, this would only be the case during extremely high water (with high discharges and therefore high flow velocities in which the gates are lowered) or with extremely low water (incidental situations with very heavy ice in which the gates are lowered, without the occurrence of high discharge, in order to prevent the gates from getting stuck or being damaged).

In the case of flood or high water, there is a gradually deteriorating situation with increasing flow velocities, in which initially the smaller vessels and later the larger vessels, are unable to resist the current. This means that the requirement is not a widely spread network of places at short distances from each other but rather, a reasonable number of mooring facilities spread along the navigation route. This requirement is met by current free moorage in the upper lock approach with sufficiently high mooring facilities, situated on lock locations – as an indication – with a maximum distance between them of approximately 40 to 50 km.

In the case of low water, there is also a gradually deteriorating situation; a decreasing water depth will increase the need for moorage with sufficient (remaining) water depth. In both of these extreme situations, information supply and communication play an important role and in general, there is sufficient time to leave the endangered area in good time. Par. 4.8.2 deals with the lock approaches as refuge harbours in more detail.

- **Compulsory harbour**

Lock approaches could also be used for 'forcibly' keeping vessels in the harbour. For instance, this could be necessary if a vessel is prohibited from sailing after damage incurred by a collision. In practice, this hardly ever happens and if it does, it is easily dealt with in other locations. Therefore, separate mooring places are generally not required.

- **Hazardous substances**

A substantial number of inland navigation vessels loaded with hazardous substances require separate waiting areas at a suitable distance from non-congeners. There are special regulations for chamber arranging where it concerns vessels carrying hazardous goods together or together with non-congeners. Fire fighting regulations also require separate facilities on the lock grounds.

2.3.1.3 Leading jetties

The leading jetties form the transition area between the lock approach and the chamber and are meant to guide the vessels, by both mechanical and visual means, quickly and without damage, into the chamber from either the mooring area or from moving navigation.

The alignment of the leading jetty is straight, respectively parabolic and makes a geniculate and smooth connection to the short straight section in the continuation of the chamber wall.

The shape of the lineation could consist of uninterrupted waling or interrupted piling at short distances from each other. The successive wet cross sections in the changeover from leading jetty to chamber entrance should be (hydraulically) symmetric wherever possible in view of the navigation ability of the vessel. For leading jetty lengths and shapes as a function of the type of navigation, we refer to Par. 2.4.2.2.

2.3.1.4 Chamber and heads

A number of important parts of the primary function of the locking process take place in the chamber and the heads, namely:

- *the sailing in and tying up of one or several vessels,*
- *the untying and sailing out of one or several vessels,*
- *the closing and opening of gates and*
- *the levelling of the water level in the chamber.*

In order to execute this function for navigation quickly and safely, it is important that this is taken into account when determining the dimensions, shape and equipment:

- **The principal dimensions**

The main dimensions such as working length, width, sill depth and clearance are determined largely by traffic and are dealt with in Par. 4.4.

- **The design**

The preference is for a U-shaped prismatic reservoir profile with straight, smooth chamber walls (in which bollards, mooring bollards and ladders are attached) and in which the heads and the chamber make up a whole.

- **The facilities and equipment**

- *Lock coping (capstone height)*

The following functional aspects must be taken into account when determining the lock coping:

- sufficient height is necessary for physical guidance and orientation to prevent crossing of vessels that (could) enter the chamber from a (small) angle from hitting obstacles due to the coping;
- For comfort and personal safety, it is best if one is able to embark and disembark from a vessel lying in the chamber (at all times).
- From the vessel, inland and recreation navigation, one should be able to throw the hawsers around and remove them from the bollards/mooring bollards,

- *Bollards and mooring bollards*

Out of safety considerations, one should be able to tie the vessel to the chamber wall during leveling in order to absorb unwanted movement caused by flow in the chamber.

- *Stop stripes*

These stripes should be applied to the chamber walls as an indication of working, available length.

- *Distance indicators*

From the stop stripe, place 5 m distance indicators on the chamber coping and on the chamber wall over a length of 20 to 40 metres (depending on chamber length) in order to safely and quickly position the front and back vessels respectively. (Lit. [2.1]).

As a special function of a lock, mention should be made of the open lock, a function that is fulfilled when the lock is not performing as a lock most of the time. This is generally the case when, in both the linked waterway reaches, the water level variations are limited and the banks of the waterway are dimensioned to this. Only when large water level differences occur between the reaches, which result in vessel hampering flow velocities in the chamber, the changeover is made from an open lock to a locking process.

Open locks should pay special consideration to the higher navigation speeds when traffic passes through the lock. In order to limit the hydraulic resistance during passage, the wet cross section in particular will have to be adjusted (broader width and/or deeper sill).

Furthermore, it is required that the successive wet cross sections of the leading jetty to the chamber entrance are hydraulically symmetric in order to prevent loaded vessels passing with relatively high sailing speeds from suddenly being taken off course.

2.3.2 Functional requirements regarding the water retaining (structure)

Distinction has to be made between locks that are part of a water retaining structure as described in the Flood Defence Act ("Wet op Waterkering") and locks that are situated in other water retaining structures (also see Par. 4.5). The first category includes locks that are part of the water retaining function of the flood defences. The flood defences protect lower areas of the Netherlands and the flood plains along the large rivers. The second category includes locks that are positioned as a separation between two canal reaches (canal locks) and locks situated in a canalized river (locks parallel to weirs).

The Flood Defence Act does not provide unequivocal water retaining requirements for a lock. These can be obtained from the Guideline Flood Retaining Structures and Unusual Constructions (TAW-Leidraad "Waterkerende Kunstwerken en Bijzondere Constructies") (Lit. [2.8]). This guideline dictates that a lock

should be designed, constructed and maintained as such that the intended water retaining function during the planning period, given the current design and starting points, will be effectuated with sufficient reliability. The Guideline limits itself to positive water level differences (during high outer water threatening the land behind the water retaining structure).

For locks that also have to cope with negative water level differences, extreme situations of water retaining requirements will have to be drafted. Because possible consequential loss is generally smaller, larger frequencies for the occurrence of water levels can be used than is the case in positive rise. After all, the latter are based on exceedance frequencies of 1/1250 to 1/10.000 per annum. For negative rise, we have to consider 1/50 to 1/100, depending on the situation in which the lock is built and, in particular, the risk (= risk of failure x damage).

For locks belonging to the second category (not covered by the Flood Defence Act), similar requirements will have to be drafted for positive and – if appropriate – negative rises per lock or series of locks.

For locks covered by the Flood Defence Act, requirements are drafted in the previously mentioned TAW Guideline with regard to 1 overflow and overtopping, 2 strength and stability and 3 reliability of gate closure.

The first requirement is addressed in Par. 4.5. This is followed by a brief explanation of the second and third requirement. Information that is more detailed is found in Lit. [2.8].

2. *Strength and stability:*

The strength and stability calculations for locks should be made according to the NEN 6700 series, the directions in chapter 3 on the TAW Guideline 'Wet op Waterkerende Kunstwerken en bijzondere constructies' and the subdivisions concerned in the TAW Guideline for the design of river dikes part I and II (Lit. [2.23] and [2.24]).

3. *Reliability of gate closure:*

Two situations are possible in this. In the first situation, there are gates in the outer and inner head that are sufficient for retaining high water. In the second situation, only the gate in the outer head is sufficiently high to retain NHW (with accompanying waves) and the gates in the inner head are lower. For the first situation, there are no separate requirements for the reliability of closing. For the second situation, the following should apply to the closing of the high gates:

$$\begin{aligned} P_{fa} &\leq 0,1 \text{ standard, in which:} \\ P_{fa} &= \text{actual risk of failure due to failing gate [1/year]} \\ \text{standard} &= \text{design frequency [1/year].} \end{aligned}$$

Aside, note that where in the first situation no requirements are set for the closing with regard to water retaining, there certainly are requirements with regard to navigation function availability (see Par. 2.4.10)

2.3.3 Functional requirements regarding water management

2.3.3.1 General

Every lock has to meet navigation and water retaining requirements. In certain specific cases, the lock also has to play a part in water management. In this distinction can be made between a passive role, limiting water loss and salt penetration due to the locking process and an active role, in which a certain discharge or intake of water has to be let in or out.

2.3.3.2 Limiting water loss

In certain situations, (among others, the design Twente-Mittellandkanaal) it could be a requirement that the lockage loss does not exceed a certain quantity (converted to longer periods than one locking). The designer then has to choose between pumping the additional water back to the higher a reach(es), providing the lock with additional facilities or, a combination of both. This choice is determined by the investment and exploitation costs.

Providing the lock with additional facilities could include: using gates that limit the lockage water (this is the volume of water as a product of length, width and rise of the lock) as much as possible (so no mitre gates) or part chambers (an intermediate lock gate divides the lock into two smaller chambers), twin locks or water saving chambers. In the management sphere, one could consider limiting the number of locking activities (only lock with sufficient number of vessels).

Furthermore, requirements could be set for limiting leakage loss where the gates are connected to the heads. The degree of this limitation should be economically sound.

2.3.3.3 Separation of salt and fresh water or clean and polluted water

Locks situated near the sea could face requirements to keep the salt penetration on the inland area and the loss of fresh water as low as possible. These requirements should be well considered as stringent requirements and can result in extremely high costs. Distinction can be made between measures with a view to salt/fresh separation (for example a minimum number of locking activities), in systems with open gates during the exchange of salt and fresh water (for example pneumatic barriers) and in systems with closed gates during the exchange (for example Krammersluizen).

Management measures are less costly but yield limited effect, systems with closed gates during exchange are costly but also provide a very good separation, systems with open gates during exchange are somewhere in between. Also, see chapter 21.

When locks are situated on a separation between clean and polluted water, the management would like to prevent polluted water from contaminating the clean water whenever possible. In this, one cannot directly say that there is a density difference between the clean and polluted water. An example of this is the Oranjesluizen-complex with polluted water from the Buiten-IJ and clean water from the IJsselmeer. The fact that polluted water ends up in clean water is caused as follows. The lockage water (the volume of water of the length, multiplied by the width, multiplied by the rise of the lock) ends up in the lower reach after emptying. Further causes are the mixtures of water due to navigation propeller screws, the movement of water caused by ships in the chamber that is replaced by polluted water and by leakage at the gates.

2.3.3.4 Water intake and discharge

From a water management perspective, it is possible that there is a requirement for water to be taken along or through the lock to the other reach. The discharges and the possible division of this over time as well as the possible presence of a twin lock and the local situation will determine whether one of the following solutions is possible/financially attractive:

- 1 *via the intake and discharge systems – possibly adjusted to the discharge/intake,*
- 2 *via separate lock culverts or open watercourses next to the lock.*

Due to the flushing of water, flows could occur in the lock approaches that are bothersome or dangerous to navigation. In Lit. [2.1] recommendations are made with regard to flushing streams via separate lock culverts or water streams in the lock approaches of inland and recreation navigation locks. These recommendations are related to acceptable flow velocities for navigation, possibly creating part or completely flow free leading jetties, the positioning of mooring space with regard to discharge and extraction points etc.

Because of the forces on and manoeuvrability of vessels, there is strong preference for two symmetric culverts in relation to the axis rather than a culvert on one side. There are examples of one-sided solutions but these solutions concern, with the exception of the culverts of the sea lock at Terneuzen, open watercourses that debouch at a sufficient distance from the lock approaches. Here, the same requirements apply with regard to limited impediment for navigation. The specified flow velocities permitted are those for which extensive research into flow patterns and manoeuvring behaviour can be omitted. Lit. [2.1] addresses the permitted speed components depending on the place of extraction or discharge and the position of vessels. Here it is sufficient to remark that the permitted flow velocities are small. The permitted transverse flow component is around zero to 0.30 m/s, depending on the position of the vessel in the lock approach etc.

Similar information is not available for maritime navigation locks.

For a more detailed description of this subject for inland navigation locks, see Par. 5.3.4.

2.3.4 Functional requirements regarding the crossing, dry infrastructure

2.3.4.1 Roads

In our highly cultivated and built up country, most locks would have crossings with dry infrastructure, with roads as well as cables and mains. The result is that this has to be taken into account, both during the construction phase as during the use phase. Railway crossings hardly ever cross locks.

In the construction phase temporary facilities and measures, that effect normal use of the infrastructure as little as possible, are often required. General instructions cannot be provided; the solutions depend on the local situation and the requirements set by the authorities of the dry infrastructure.

The dry infrastructure and the necessary facilities (bridges etc.) are not only modifying in the use phase; the same applies to the location of the lock. If for instance, a bridge is planned near the lower head (also see point 3 hereafter), it could be necessary to 'move' the lock as such during the design that the lower head is located at the crossing of the waterway with the road. This will certainly apply to railways and, to a lesser degree, to motorways.

For local roads, which can be traced out with more flexibility (provided that the buildings are not an obstacle) it is much simpler to adapt the road alignment to the location of the lock than the other way around. Naturally, the joint costs of the wet and dry infrastructure will play a role as well as the interests of road traffic and navigation. A good example of weighing up the various solutions for road crossings with locks is found in the project description for Krabbersgatsluis near Enkhuizen (Lit. [2.9]).

In general, solutions are strived for within economic boundaries in which the crossing streams of traffic (land and water) do not hinder each other. In other words, solutions in which the traffic streams remain outside each other's free space profile. Furthermore, the view of operating personnel should be as clear and open as possible for the locking process. (In the case of moveable bridges, the road traffic must also be observed).

Solutions for crossing traffic streams are a tunnel, a fixed and a moveable bridge. Though these are the best solutions for meeting the requirements, a road tunnel under a lock has not been executed to date because the costs have been too high. However, this does not mean that this possibility should no longer be looked at. In Lit. [2.9], a tunnel under a lock (Naviduct) proves to be the best solution. This solution was chosen. It does however, concern a very complicated traffic situation (land and water).

A fixed bridge is a good solution but could result in limited view depending on the placement of piers. Fitting in a fixed bridge is often not possible, among other things, due to the required clearance and the accompanying access ramp length. For canals with large lift, such as the Juliana- and the Twenthekanaal, fitting a fixed bridge is not a problem.

In the case of a moveable bridge, traffic streams do affect each other mutually. Point 4 to 10 hereafter contain recommendations for limiting the influences. Sometimes the lock dimensions are enlarged when renovating a lock and the new heads are positioned outside the old lock in order to curtail obstructions as much as possible. If the bridge is once again positioned over a head (preferably the lower head), the existing road also has to be re-routed. Often, this is impossible or only possible with a lot of effort and cost. At the Zuid-Willemsvaart, this happens a number of times.

If a lock is lengthened, the lower head and the bridge can often be maintained and the road does not require re-routing. The result is that the upper head needs to be renewed outside the existing lock. A problem that could present itself is that the removal of the existing upper head could require a lot of effort (Julianakanaal) if it is equipped with energy dissipating chambers.

The required clearance for fixed bridges for inland navigation can be found in Lit. [2.25]. As stated in Par. 2.4.1.1, these are determined with regard to the water level that is exceeded 1% of the time. There

are no guidelines for shipping (yet). The cross section of the crossing road will have to be obtained from the road maintenance authority concerned.

In Lit. [2.1] recommendations are made for bridges over inland navigation locks. A summary follows below.

1. Situating a fixed bridge over a chamber does not only have the disadvantage of a smaller clearance at the higher level and loss of effective chamber length but it could furthermore influence the safety if, for instance, tankers are moored under the bridge.
2. The bridge and piers in fixed bridges may not impede the view of the lock approaches from the operating area. The distance between the piers and the chamber wall should be at least 1.5 metres.
3. Bridges should not be situated over the chamber or lock approaches, but over the upper or lower head outside the lock gates. In relation to larger clearance, positioning over the lower head is usually preferential. For moveable bridges over locks in tidal areas, passage over the lower head is not always the best solution and the positioning will depend on local circumstances. The bridge should be situated as such that replacement of gates is not rendered more difficult.
4. The underside of moveable bridges should be positioned sufficiently high that the waiting times for road and water traffic is acceptable. At yacht locks where many motorboats pass, it is recommended that the clearance chosen is such that the motorboats are able to pass under a closed bridge.
5. The movement times of the bridges should be quick (addition not mentioned in Lit [2.1]: This also depends on the length of the span. In general, the times vary between 30 and 120 s).
6. Given a larger traffic intensity of land and navigation traffic, it could be desirable to plan movable bridges over both heads.
7. Points 4 to 6 need to be researched on effectiveness by means of a cost effective analysis.
8. During open bridge, the all parts of the bridge need to be far enough outside the chamber wall that vessels cannot damage it.
9. At open bridge, the view of the lock approach from the operating area should be impeded as little as possible.
10. Design and height of guiding structures have to be such that the chances of damage are as small as possible.

The above mentioned applies to locks for inland navigation. For other locks, (such as for sea-going vessels) recommendations will have to be looked at critically and adjusted to the specific situation.

2.3.4.2 Cables and mains

In general, we strive for an integration of crossing cables and mains (the small infrastructure) in the lock and/or lock approaches, as long as this does not result in unnecessary risks for the locking process.

During construction, existing cables and mains will have to be moved temporarily if necessary or other facilities could be necessary in order to disrupt the performance as little as possible. This is executed under instructions of the authorities in charge of small infrastructure. Often, these authorities will function as customers in relation to the moving or execute the moving under own management.

To reduce costs, every effort will be made to consider the definite situation when planning the temporary diversions.

In the definite situation, the crossing itself will generally be under the bottom of the lock or the lock approaches.

If bridging is considered for certain reasons, for example because cables and mains need to be added later, the required clearances for inland navigation locks are derived from Lit. [2.1] and [2.2]. Certain cables and mains of third parties could be housed in cable manholes and tunnels for lock operation, which can be made larger to allow for this. Between the cable manholes, extra lead through pipes can be added to the lock floor for these cables and mains. This is only possible if your operation is not exposed to additional risks or hindrance. For the mutual influences on cables and mains, we refer to the NSTT-KIVI-report "Integrale leidingen tunnels" (Lit. [2.10]).

Cables and mains that cross a lock and/or lock approaches and the facilities that have to be made or provided for this, have to meet the following requirements:

1. The cables should not yield unacceptable risk for the lock, lock operation and navigation.
2. That which is unacceptable should be substantiated with a risk analysis.
3. Gas mains are not included in a lock.
4. Navigation must be unable to damage the cables and mains.
5. Where visual inspection is impossible (and this will generally be the case) the condition of the cables and mains will have to be established in a different way, certainly in those cases where failure will have serious consequences.
6. Cables and mains, with serious failure consequences, must immediately be disconnected or be free of electrical charge when necessary.
7. Replacement, expansion or maintenance should take place without prolonged hinder to navigation.

Furthermore, attention has to be paid to possible transmission lines that cross the lock or the lock approaches.

2.4 User requirements

2.4.1 Levels

2.4.1.1 Locking levels

Height and depth levels for passing through a lock is indicated with regard to normative water levels of the reach concerned. These normative (high and low) water levels have to be chosen as such that, on the one hand, navigation is not often confronted with an insufficient height or depth and on the other, sound economic costs. In addition to these normative water levels, maximum and minimum locking levels should also be set for a lock in relation to the dimensioning of the whole lock.

In determining the normative water levels and locking levels, the following topics also require attention:

- **Situating the lock**

With regard to the choice and location of the lock, there are three main types of locks. The distinction is characterized by the variation in water levels and the subsequent consequences for navigation (duration and frequency of obstruction). The distinction concerns locks:

- *In canals and between lakes*

In general, small variations in water levels and hardly ever obstructed;

- *In rivers (canalized)*

Fairly large and irregular variations and obstructions during longer time periods at extreme water levels;

- *In tidal areas*

Fairly large and regular variations and obstructions for short time periods at extreme water levels.

- **Accessibility**

For an economically sound design, the normative water levels should be chosen as such that the lock, with a loaded normative vessel with permitted draught and unreduced keel clearance or an unloaded normative vessel with permitted (minimum) height and unreduced overhead clearance, can still pass through.

In determining the maximum and minimum locking levels, the point of departure for passing the lock can be more stringent conditions, such as speed, draught and height limitations. Theoretically, it is not possible to operate the lock if water levels are higher or lower than these levels and navigation is obstructed. In practice, deviations from this are possible as an unloaded or partly loaded normative vessel or a smaller vessel is able to use the lock at levels below the minimum locking levels. General guidelines for locking levels cannot be given: establishing this is a matter for the client and the designer.

- **Smoothness and safety of dealing with traffic**

For parts and facilities that are designed for a smooth and safe traffic flow (for instance the construction height of guiding structures, bollards and mooring bollards), point of departure could be less stringent stipulations with regard to normative water levels because such parts and facilities could become extremely costly. This particularly is the case along (canalized) rivers where substantial and irregular water level variations can occur with incidental long-lasting obstructions.

The cvb (Lit. [2.1] and [2.2]) arrives at the percentages given in table 2.1 for normative water levels and locking levels.

sluices in	canals, lakes	rivers	tidal areas
maximum locking level	$\leq 1\%$	$\leq 1\%$	$\leq 1\%$ ¹⁾
accessibility:			
- high normative water level	1 %	1 %	1 % ¹⁾
- low normative water level	1 %	1 %	1 % ²⁾
smoothness/safety of dealing with traffic			
- high normative water level	1 %	10 %	1 % ¹⁾
- low normative water level	1 %	10 %	1 % ²⁾
minimum locking level	$\leq 1\%$	$\leq 1\%$	$\leq 1\%$ ²⁾

1) exceedance percentages

2) underrun percentages

Table 2.1 Percentages exceedance and underrun of normative water levels

For the user requirements of navigation related constructional parts for inland navigation, the following applies:

- The sill depth of a lock is determined in relation to the water level that is exceeded 1% of the time;
- The clearance of the lift gate and of a possible bridge across the lock is determined with regard to the water level that is exceeded 1% of the time;
- For the dimensions and facilities of guiding structures, protection structures, mooring posts and the height of the lock coping, situated on the river side of a lock, the normative water level applies that is exceeded or underrun 10% of the time. For the canal side of the lock situated on a river, as well as all other locations, the 1% value applies.

For locks with combined inland navigation and recreational navigation and locks solely for recreational boating, other norms apply with regard to normative water levels. It concerns:

- **accessibility**
The high/low normative summer water level in the period May to September that is exceeded or underrun during 2% of the time on the canal side and/or tidal side of the lock;
- **smoothness/safety of dealing with traffic**
The high/low normative summer water level in the period May to September that is exceeded or underrun during 10% of the time on the river side(s) of the lock.

Note: for further details we refer to the CVB (Lit. [2.1] and [2.2].

2.4.1.2 Design levels

- **Normative High Water (NHW)**

The retaining structure, that is to say at least one gate with accompanying head, is dimensioned on NHW with the then occurring waves as is stipulated in Par. 4.5. This is the water level in accordance with the stipulated design frequency (norm) in the Flood Defence Act ('Wet op de Waterkering'). NHW for the location of an existing lock or for a planned location of a lock can be obtained from RWS-RIKZ (tidal waters) and RIZA (inland waters).

For locks not belonging to water retaining structures, covered by the Flood Defence Act, NHW must be established by the dike or waterway authority concerned.

In relation to the rises (difference of water levels) over water retaining structures, the lowest inland water level that could occur together with NHW should be known.

- **Locking level high water gate**

This level, which is lower than NHW is of importance to locks that are equipped with only one (set of) gates dimensioned to NHW. The gates must be closed at this water level. At the lower signalling level the lock authority is warned so that measures for closing can be taken on time.

- **Locking level high water gate**

This level, which is lower than NHW is of importance to locks that are equipped with only one (set of) gates dimensioned to NHW. The gates must be closed at this water level. At the lower signalling level the lock authority is warned so that measures for closing can be taken on time.

2.4.2 Possible preference for separating different kinds of vessels

Specific requirements are set with regard to the separation of different kinds of vessels using the line-up and waiting areas, the leading jetty and chamber. These user requirements stem from safety considerations, legislation and manoeuvrability.

2.4.2.1 Separation in using line-up area, waiting area and chamber

Separation in using the line-up and waiting areas as well as the use of the chamber can be looked at from either a locking point of view or from a stop off for the night (inland navigation) perspective:

- **Separating vessels during locking**

- From a safety point of view, it is recommended that vessels positioning in the mooring space and waiting area (inland and recreational navigation) are separated in chamber arrangement and/or chamber assignment in seagoing, inland and recreational navigation.

In the mooring area and waiting area, this can take place by setting up separate mooring and waiting areas for inland navigation and, in addition, realizing a combined mooring/waiting area for recreation vessels.

Separate chambers are recommended for locking maritime navigation, inland navigation and recreational navigation.

If this is not economically sound, combined locking can be considered.

A combination of inland and seagoing navigation respectively recreational navigation is acceptable, subject to the safety being guaranteed; a combination of seagoing vessels and recreational vessels should be avoided.

In a combination of inland navigation and recreational navigation, a lock solution can be found, in which inland and recreational navigation each take up one side of a broader chamber or they are lined up behind each other with a certain safety margin (min. 5 metres) in a longer chamber (inland in front, recreation at the back).

- If a reasonable share of the inland navigation fleet contains hazardous substances (3 different categories of such ships are distinguished), a separate waiting area with its own facilities for these vessels is preferential, in which specific distances in relation to non-congeners apply. When arranging the chambers, regulations apply to tank vessels among themselves (depending on the number of tanks) and between tank vessels and non-tank vessels in relation to adhering to intermediate distances (see BPR with regard to locking through tank vessels) Lit. [2.4]).

For locking through maritime navigation with hazardous goods separate user regulations usually apply, in which a category classification is adhered to which makes distinction between loads, kind of vessel and the distances kept between congeners and other vessels.

Locking vessels with hazardous goods reduces the locking capacity.

- **Separation of vessels during over night stop**

The Sailing Hours and Crew Numbers Act ("Vaartijdenwet") which came into effect in January 1995, makes distinction in inland navigation according to exploitation form, namely continuous navigation and semi-continuous navigation and day navigation.

The two latter forms can request moorage space in the stay over area of the lock approach.

The difference between both forms of exploitation is expressed in the different forms of mandatory resting times for the crew and the number of moor time hours of the vessel. Due to the difference in departing times in the morning, vessels of both forms are to moor at separate locations in order to avoid hindering each other during departure. (Lit. [2.5]).

Congeners are able to moor lake-wide, upholding the required width for mooring and waiting areas and safety strips in the lock approaches. (Also, see Par. 4.7).

Point of departure being the mandatory rest hours for both forms of exploitation, at low lock load

during the night and depending on the number of chambers available, chambers will be closed during the (mandatory) hours for creating a rest area for vessels spending the night. The remaining locking capacity is for continuous navigation.

Semi-continuous inland navigation that use a tachograph can temporarily increase the number of hours in relation to the number of navigation hours in the "Vaartijdenwet" which is, in essence, spreading the arrival times uniformly over a twenty-four hours period. For this user group, separate, continuously available single-width mooring places need to be accessible in order to avoid earlier departing of vessels being moored on the inside. For calculations on the required length for stopping over facilities as well as the lay out in the lock approach, see Chapters 4 and 5.

2.4.2.2 Separation for use of the leading jetty

The separation for use of the leading jetty can be approached from variations in manoeuvrability and the preference for separate chambers per navigation category that can be distinguished, namely sea navigation, inland navigation and recreational navigation.

Mechanical guidance of the leading jetty during entering (especially with cross wind) is normative and most effective with gradual convergence. The resulting design however, is inconsistent with the manoeuvrability of an empty, departing vessel (especially with cross wind).

If the sailing vessel does not have an effective bow propeller or does not make use of tugboats, the sailing vessel will require sufficient space broadways to leave the lock on course after having passed the lock head. Distinction is made between the three kinds of navigation that use leading jetties.

- **Leading jetty for seagoing vessels**

The leading jetty should be as short as possible due to the possible assistance of tugboats. Indications: 'IJmuiden Noordersluis', leading jetty length approx. 25 m and 'Terneuzen Westsluis' length approx. 40 m. There are also locks without a leading jetty construction (Zandvliet-, Berendrecht, Boudewijnsdijk, Belgium); large rubber rolls protect the lock head.

- **Leading jetty for inland navigation**

The alignment of the leading jetty (or guide work) is straight, respectively parabolic and makes a geniculate and smooth connection to the short straight section in the continuation of the chamber wall.

The geniculation form is mainly intended for inland navigation with conventional bow shapes. The parabolic form is preferential when the inland navigation fleet contains relatively many push towing vessels or vessels with push prows. The jetty angle is about 1:4 to 1:6. The leading jetty length depends on the jetty angle and chamber width (CEMT Classification), also see Chapters 4 and 5 and for more details, see the CVB, (Lit. [2.1] and [2.2]).

Paying attention to the functioning of a guiding structure, construction in waling is preferential.

The height for the top wale, measured with regard to the highest normative water level, is kept at least at 1.5 m CEMT for class I, 2 m for classes II, IIa and III and 2.5 m for class IV. For class V, the height is keyed to the height of the lock head. In connecting to the guiding structure (or sheet piling) on the one hand to the lock head and the chamber wall on the other, the height of the guide structure should not be lower and it should have a gradual slope. This is to prevent possible damage to parts nearby from the overhang of vessel bows. The distance between the lower wale and the low normative water level should not be more than 0.2 m and 0.5 m to the minimum locking level.

As distance between the wailing a maximum of 0.5 m to 0.6 m can be adhered to for conventional bow shapes; in the case of relatively substantial push tow navigation of vessels with push prows, the distance between should not amount to more than 0.4m.

- **Leading jetty for recreational navigation**

The leading jetty angle comes to about 1 : 3. The leading jetty length depends on the jetty angle and chamber width, see Chapters 4 and 5 and for details, see the CVB, (Lit. [2.1] and [2.2]).

In combined use of the chamber by different kinds of navigation vessels, the leading jetty shape for the largest vessels is normative.

2.4.3 Mooring facilities in chamber and lock approach

2.4.3.1 Chamber

Bollards, mooring bollards, mooring pipes and toggles are means of securing that vessels use to tie up during levelling.

Design, size and positioning of the fixed or floating securing means depends on the vessel size and the vulnerability of the vessel type. In addition, proper guidance needs to be available during the fastening and loosening to prevent getting stuck. During levelling, the angle between the hawser and the chamber wall should not be too large to prevent loosening.

Normative water levels apply according to table 2.1 under 'smoothness/safety of dealing with traffic'.

Placing bollards and the like

The mutual vertical and horizontal distances (symmetrical on both lock sides) should be geared to the smallest normative vessel. The highest respectively lowest bollard/mooring ring is geared to the highest respectively lowest normative water level. Bollards are also placed on the lock coping.

Bollards for *maritime navigation* are usually only found on the lock coping. In maritime navigation, the large variety in vessel size is the determining factor for the optimal mutual distance between bollards. An indication is a mutual distance of 25 m. The distance from the bollard to the outside lock is approximately 3 m.

For *inland navigation* the horizontal distance between bollards is about 15 m, the first bollard is as close to the stop stripe as possible and between the first and second bollard at the lock head, there is a distance of about 10 m in view of rapid securing of the front or back vessel.

The vertical distance is about 1.5 m whereby the bottom mooring bollards are about 1.50 m above the low normative water level (distance to minimum locking level is 1.75 m at most) and the upper mooring bollards are as close to the lock edge as possible.

For empty class V vessels and push barges (draught about 2.5 m respectively about 4 m), pay attention to the shape (head) and load (direction of pulling) of the bollards on the lock coping surface as, during high water levels, the distance between the deck and the coping becomes so large that the steep hawser can slip off the bollard.

For *recreational navigation*, the mooring bollards (rows) are placed at horizontal distances of 5 to 6 m, with the first row close to the stop stripe. The vertical distance amounts to approximately 1.25 m whereby the bottom pen is about 1.25 m above the low normative summer water level (distance to min. locking level is a maximum of 1.50 m) and the highest pen is attached as high as possible.

For the use of *combined inland and recreational navigation*, we refer to CVB (Lit. [2.1]).

Fixed/floating bollards

For *inland navigation*, floating bollards are applied at a rise/fall larger than 6 m and/or a rise/fall velocity larger than according to CVB 2 m/min. In practice, a velocity of 1 m/min is more realistic.

In general, two execution forms are common, either the high and low bollard placed separately on a float for the benefit of unloaded or loaded vessels or, the bollards for both loading conditions are combined on a float.

In the first case, the low bollard for loaded vessels lies at 1.5 m above the water level. For unloaded vessels, the positioning of the low bollard is at 2.5 m (class I) 3 m (II, IIa, III) and 3.5 m (IV). 15 m applies to the mutual distance, whereby the high and low bollards are alternately placed one after another and the distance at the lock head amounts to 15 m at maximum. The high bollard should stick out above the coping at high water levels. If this is not possible, indicate on the coping which is the high and which is the low bollard in order to prevent mistakes being made when descending.

In a fleet composition with class V vessels and push barges, the height of the high bolder should be a compromise between the desired height for class V (4.5 m) and the height for the smaller classes but no lower than 3.5 m.

If the choice falls on the combined floater, the height above water level amounts to 2 m. (CEMT I, II) and 2.5 m (tot CEMT II, IV).

For *recreational navigation* and a rise/fall larger than 4 m and a rise/fall velocity larger than 1 m/min, instead of moor rings, a vertical mooring pipe or floating bollards are used with horizontal distances of 5 to 6 m.

For the *combined use of inland navigation and recreational navigation*, we refer to CVB (Lit. [2.1]).

Size of bollards and other means of securing

Bollards are positioned in the lock approaches for commercial navigation; toggles and mooring pipes are used for recreational navigation. For seagoing vessels, the bollards are maximally dimensioned at 1000 kN. For CEMT class I and II the securing means are dimensioned at maximally 100 kN and for class III and IV at 150 kN. At present, 200 kN is maintained for class Va,b and 300 kN for class VI.

The toggles for recreation vessels should be able to absorb 40 kN.

2.4.3.2 Lock approaches

Various mooring facilities are conceivable in the line-up and waiting areas of lock approaches, such as mooring posts, mooring piers, fixed or floating guides and guiding structures and/or in the shape of quay or sheet pile constructions with bollards or toggles secured on top. The height of these facilities (top bollard or wale) are indicated relative to the highest normative water level (see table 2.1) under the precondition that in the lock approach, where the maximum locking level could occur, the height in regard to that level is at least 1 m.

For constructions with *walings*, the distance between the bottom wale and the low normative water level will not measure more than 0.2 m and 0.5 m to the minimum locking level. The vertical distance in between is a maximum of 0.5 to 0.6 m, to prevent vessels from mooring too deeply. On all mentioned constructions, the height of *bollards and toggles* measures 1 to 1.5 m with respect to the low normative water level (table 2.1) and 1.75 to the maximum locking level. The vertical distance between the bollards / toggles adhered to is 1.5 m.

Mooring posts, mooring piers

This mooring facility is intended for inland navigation. The height of the top bollard with respect to the high normative water level measures 2.5 m for CEMT class I; 3 m for classes II, IIa and III and 3.5 m for class IV.

The horizontal distance between posts (likewise the distance between bollards) for classes I up to and including class IV measures approximately 22 m. However, the distance to the first respectively last post should measure half this distance (about 11 m) (the first post at about 10 m from the stop board).

Detached guiding structure

Horizontal girders or walings, that function as a continuous guide while vessels are moored, form a guiding structure of this kind. This frame of walings could be a fixed or floating guiding structure. A fixed guiding structure is applied in limited variations in the water levels, such as in canals. A floating guide structure is recommended for riversides or tidal sides of a lock, where the variation in water levels could be substantial.

In conjunction with the leading jetty (and the chamber wall), the height of the top wale should taper gradually. For horizontal distances between the bollards of the guiding structure, 15 to 17 m is usual, with the first bollard(s) at 10 m from the stop board.

Fixed guide structure

The height of the top wale with respect to the high normative water level measures 1.5 m for CEMT class I, 2 m for classes II, IIa and III and 2.5 m for class IV.

Floating guide structure

The height of the top wale of a floating guide structure for normal use does not depend on the water level. For waterways up to class V, a value of 2 m is recommended as front height (Lit. [2.22]). Point of departure is sufficiently smooth and safe traffic movement with sufficient user comfort.

Quaywall or sheet pile

For the (ground level) height of a quay or sheet pile construction in respect to the high normative water level, the following applies: 1.5 m for CEMT class I, II and 2 m for classes IIa, III and IV. These values are lower than those of a guiding structure due to the smaller drawbacks related to vessels protruding.

The horizontal distances adhered to between the bollards on the guide structure measure 15 to 17 m, with the first bollard(s) at 10 m from the stop board.

2.4.3.3 Leading jetty

Given the function and positioning of the leading jetty, it is not the intention that vessels use the leading jetty construction for mooring during the locking process. For the execution of repairs to the lock, the leading jetty construction or for replacing a lock gate, mooring facilities have to be provided for construction vessels. For details on vertical and horizontal positioning of bollards and toggles in the leading jetty construction, see Lit. [2.1].

2.4.4 Operating times

The CVB uses regime guidelines for commercial navigation, Lit. [2.6]. These desired operating times are based on economic considerations in which both the costs of waiting longer as well as the costs related to longer operating times are considered. These regimes state, depending on the permitted CEMT class and the hauled tonnage over the waterway, at which times and how long operations on a waterway should take place (table 2.2).

Regime	Passing tonnage (10 ⁶) tons/year	Minimum for CEMT-class (indicative)	Mo	Tue to Fri	Sa	Su	Hours/week
A	> 35	VI (main transport axis)	24	24	24	24	168
B	25 - 35	VI	18	24	20	16	150
C	15 - 25	Vb (two-barge push towing)	18	24	20	12	146
D	5 - 15	Va (motor barge)	16	16	12	8 ^{*)}	92 to 100
E	2 - 5	IV	16	16	10	0	90
F	0,5 - 2	IIa + III	12	12	0	0	60
G	< 0,5	I + II	10 to 12	10 to 12	0	0	50 to 60

^{*)}only operate on through waterways

Remark: In reading the table, the passing tonnage is the main criterion;
the CEMT class is a second option.

Table 2.2 Guideline operating regimes commercial navigation (hours/day)

The guideline provides the authorities a certain degree of freedom to adjust operating times according to conditions and/or possibilities. To that effect, the authorities should strive for uniformity in operation times along the route. On waterways with substantial recreational navigation, the operating times probably result in an operation that is more substantial. For operating times on waterways with only recreational navigation, we refer to the BRTN (Lit. [2.7]).

2.4.5 Levelling times

The choice in levelling times is an economic choice in which a comparative assessment is made between the interests of navigation, which would benefit from a shorter time, and the investments in the intake and discharging systems for which it is true that shorter times could lead to an expensive system. There are no guidelines but there is an extensive practical routine, which is provided in Par. 6.6.2. In short, the following levelling times are usual in the Netherlands:

- 8 to 10 minutes for inland navigation locks and small sea locks with gate openings and a rise/fall of 2 to 6 m. For extra long locks or a larger rise/fall, this could increase to 12 minutes; a smaller rise/fall requires less than 8 minutes. For lock culverts with an energy dissipating chamber (rise/fall between 6 and 12 m) the filling time is about 10 minutes;
- 11 to 15 minutes for large sea locks with a rise/fall between 1.5 and 5 m.

2.4.6 Operational management

2.4.6.1 Process descriptions

The operational management of a lock complex can be seen as a series of decisions (allow vessel, close gates etc.) that have to be operationally executed (Par 2.4.7). This operation is the physical infrastructure of installations and operating mechanisms with which the operational activities have to be realized.

Management serves to maintain the condition of the lock complex. Also see chapter 16 "Operating and management".

The decisions that have to be made are dependent on the nature of the lock. Process descriptions have to be drafted for every lock. Distinction is made between:

- **Normal locking process**

The normal locking process consist of two parts: the first relates to realizing the passage of vessels: levelling and opening and closing gates. The second concerns the directing or guiding of vessels (assigning chambers, directing to certain mooring areas etc.), in such a way in order to stimulate a smooth traffic flow in the lock complex . An additional process could be the opening and closing of bridges, including the necessary direction or guidance of land traffic. This process should be tuned to the passage of navigation.

- **Obstructions**

Obstructions are caused by high or low water outside the locking process, malfunctions in installations, collisions and calamities, high wind speeds, bad visibility and maintenance.

- **High water retaining structure**

Closing and later opening the high water retaining structure and implementing the required measures for navigation. The interests of the flood retaining structure should prevail over the interest of navigation.

- **Intake/discharge**

Possible intake/discharge of water with (possible) discharge restrictions to keep disruptions within acceptable boundaries where navigation is concerned.

- **Salt /freshwater or clean/polluted water**

Limiting the salt/fresh exchange (switching on and off pneumatic barrier) or preventing the mixing of polluted water with clean water.

The five process descriptions should result in a mutually related whole. A whole that is the foundation of the operation and management of the lock complex. An example of this can be found in the Program of Requirements, Renovation Zuider- en Kleine Sluis (Lit. [2.13]), whereby 4 and 5 also deserve attention.

2.4.6.2 Information for operational management

To operate and manage requires information. The information required depends on the results of the process descriptions mentioned in the previous paragraph.

The information could be provided from outside, such as: expected navigation, high water warnings, river discharge exceedance for which locks are raised. Running parallel, as well as supplementary to this, information is required that is obtained in and near the lock. It has to be established which parameters should be automated. Examples of necessary information in and near a lock are:

- number and characteristics of ships calling at the lock;
- visibility information;
- water levels in chamber and lock approaches;
- positions of gates, sluices and position of moving bridges;
- flow velocities;
- operating reports on power supply, installations and signalling.

2.4.6.3 Procedures and facilities for negative operational situations

Power failure, malfunctions, collisions, too high/too low water levels, calamities etc. are causes that could lead to adverse effects and/or obstructions to important functions of the lock: locking and water retaining. Procedures and facilities should be available for these negative operational situations.

- **Power supply**

Emergency power supply is required for vital parts of the installation so that, in case of malfunction, it can automatically take over the energy supply within minutes. A no-break facility is required for installation parts that lose data in case of power loss. In addition, emergency lights should be present.

- **Levelling**

In case a vessel is in danger of getting dangerously tied up in the hawsers, the paddles of the filling or discharging system have to be able to close as rapidly as possible, without this resulting in unwanted transitory surges. The facilities required to provide for this should be included in locks with a raise/fall of more than 1 m.

- **Collisions**

Vital lock parts that are not able to function properly after a collision, such as lock gates, should be easy to replace with spare parts. To prevent collisions with lock gates, a safety construction and/or a vertical white stripe (about 0.30 cm) should be positioned on the gate, at the lock axis on the chamber side of the gate for the benefit of judging the distance between the vessel and the closed door. In special cases, protective constructions to prevent collisions with gates can be considered. At locks where a stringent draught limitation has to be ensured, an acoustic depth gauge can be installed at the bottom of the lock approach, at sufficient distance from the gate.

- **Too low/too high water levels and inspections**

If a water level is expected that is either too high or too low, a warning phase can be introduced via a water level registration that will provide navigation with timely warning. As a preventative measure, regular inspections should be executed.

- **Problems with ice**

Depending on the economic importance of the waterway, measures have to be taken against ice problems at the gates. The application of pneumatic barriers at the bottom of the walls or gates and in the gate recesses, injecting large quantities of air in the gate recess under water, or special wall heating around the water line and at the gate sealing are effective solutions. For literature, see "Ijsbestrijding Kunstwerken" (Lit.[2.11]) and for further information, contact the 'Centraal Punt Ijsbestrijding' Bouwdienst Rijkswaterstaat.

2.4.7 Operating

2.4.7.1 Situating the control building

In the construction of new buildings for commercial navigation, central control is the preferred choice. For central control, the building with the control room is situated so that, on the one hand the view of the lock and the lock approaches is optimal at all occurring water levels and, on the other hand, damage by vessels is impossible. Possible 'blind spots' ought to be supplemented by cameras.

If possible, the control areas of a bridge and a lock are combined. The control area for the bridge is preferably situated on the side of the chamber opposite to the fulcrum of the bridge. The control room in front of the bridge should have a good view on the bridge and the traffic approaching the bridge (with or without other tools such as cameras). For the control building facilities, see Lit. [2.1].

2.4.7.2 Local control facilities

Control per lock head still occurs in existing, smaller lock complexes and new locks for recreation. Local control facilities could also be considered for new commercial navigation locks, with a view to maintenance and calamity situations, as a supplement to central control.

2.4.7.3 Means of communication

Every lock should be equipped with a VHF radio for communication between operating personnel and navigation. In the case of central control, emergency telephones in the line-up and waiting areas and a talkback system ensure communication is provided for waiting vessels. A broadcasting system could be considered, depending on lock size, navigation intensity and the number of recreation vessels. From a safety point of view, installing an acoustic installation for indicating the start of levelling is recommended. Naturally, telephone/telefax/e-mail should be available on a lock. See Par. 18.4.4.

2.4.7.4 Choice (partly) automated and self-service

In order to limit operational costs (maintenance and exploitation) on the one hand and speed and safety in dealing with and/or improving traffic on the other, it is recommended that (parts of) the operational process is automated where possible. The objective is to strive for uniformity in operational methods. For guidelines on self-service and automated lock control, see CVB (Lit. [2.1]).

2.4.7.5 Remote control of locks

Remote control of locks is found in just a few instances in the Netherlands, in recreational navigation.

2.4.8 Illumination, signalling and boarding

2.4.8.1 Illumination (for details, see Lit. [2.1])

Ship crews and operating personnel must take into account that comfort is decreased during locking that takes place through the night. Given the decreased visibility and orientation, extra effort is required. This effort has to be kept as low as possible in order to prevent decreased safety. For this purpose, suitable and economically sound illumination of the lock complex is essential.

The lighting has to be geared to the ever-increasing use of central control at locks and has to be aimed at places where activities (manoeuvres, tying and untying, going on land) are executed.

The locations drawing the attention of the individual captain for instance, are the free area, the line-up and waiting area, the chamber entrance, the chamber, lock grounds, chamber exit and the outlet area to the unlit waterway. The attention of operating personnel will particularly focus on the vessels in the line-up and waiting areas, inbound vessels, the chamber, the gates, the lock grounds and the sailing of outbound vessels.

Given the necessity of illuminating the lock and lock approaches, a number of general minimum conditions are set. This illumination is compulsory and could be included in the design plan:

- a clear view of the lock complex has to be provided for the benefit of orientation from the water;
- the illumination has to be sufficiently even;
- during arrival and departure dazzling, which is often caused by excessive glare of lock parts because of cameras etc., should be prevented;
- in the control building the illumination should be adjusted to the outside environment and images recorded as TV pictures should have such contrast and definition that the operating personnel is given sufficient information;
- uniformity in the illumination plan for the setup of light towers, height of points of light and light colour is desired.

In Lit. [2.1], as extension of these conditions, a number of specific recommendations are made that are of importance to the design.

- **Required illumination level**

For the average value of illumination intensity on horizontal surfaces of the above-mentioned lock parts, 10 lux is adhered to. On vertical surfaces that are more often more striking due to the perpendicular directional view, a lower value of 3.5 lux can be used.

At a number of critical parts of the lock (both for the captain and the lock master) a larger contrast is

desired and can be achieved by stronger illumination of areas that should be in the light or providing these with white markings. The latter is preferable. At critical lock parts such as gates and leading jetties, the vertical illumination strength should be higher: 7 lux. On the chamber and mooring area where accurate visibility is required, the previously stated values of 10 lux for horizontal and 3.5 lux for vertical apply. The waiting area and the free area, where illumination is mostly for orientation, require an illumination level of 5 lux horizontal respectively 3.5 lux vertical.

- **Surrounding illumination and guidance**

Misleading illumination in the surrounding area can give the captain a wrong picture of the course of the waterway that provides access to the lock chamber. This can be prevented if the waterway or the lock complex is illuminated over a sufficient length or by adapting the surrounding illumination to the illumination of the complex. For visual guidance, differences in illumination strength at crossings should not exceed a factor 2.

- **Uniformity**

For the uniformity (E) of the illumination, a minimum value of $E_{min}/E_{max} = 0.3$ should be adhered to for both vertical and horizontal areas.

- **Glare**

Unsafe situations due to dazzling should be avoided. The correct combination of armature, lamp and positioning is of importance.

- **Colour recognition and kind of lamp**

The colour of the light is one of the factors in the recognition of boards and signalling. Both white and yellow light can be used.

In the lamp choice of illumination, both high-pressure and low-pressure lamps as well as energy saving lamps qualify. In the application of low-pressure (monochromatic) sodium (vapour) light, colour recognition is impossible. If this is the case, separate illumination of traffic signs is recommended.

2.4.8.2 Marking

White markings are a good and inexpensive tool for obtaining sufficient contrast in the dark while using little light. Marking vertical surfaces, such as guiding structures and guard walls, to support the visual guidance of navigation is very effective.

2.4.8.3 Signalling

Signalling should be executed according to the stipulations of the Police Regulations on Inland Navigation ('Binnenvaart Politie Reglement' (BPR)) and the Rhine Navigation Police Regulations ('Rijnvaart Politie Reglement' (RPR)), (Lit. [2.4]). Signal indication and lock illumination choices should be adjusted to terrain illumination of the lock for the benefit of colour recognition; it should have sufficient attention value.

2.4.8.4 Boarding

Boards should be executed in accordance with the stipulations of the BPR and RPR, (Lit. [2.4]). The colour recognition could be (substantially) reduced due to the terrain illumination. Sufficient attention should be paid to adjusting the illumination or to separate board illumination.

2.4.8.5 Illumination plan

The user requirements for illumination should be incorporated in an illumination design plan.

The chamber depth (distance between low normative water level and the lock coping) and the chamber width are of great importance. In Lit. [2.1] examples are provided for a number of chamber width categories (5-13 m, 13-20 m, 20-24 m, larger than 24 m; chamber depth about 5 m) of the resulting

illumination characteristics (such as illumination strength and uniformity), departing from the relationship between lock design and the given characteristics of illumination installation (such as positioning and illumination facilities).

2.4.9 Power supply

In essence, power is obtained from the public network. In consultation with the local power company, assessments have to be made about where this is possible and whether the connection contains sufficient capacity or whether this will have to be adjusted. Of importance is the total capacity required, voltage variations and frequency of the energy to be supplied. In addition to capacity for lock operation, the capacity for construction (civil and steel) will have to be determined. It could be taken into consideration whether the cables for construction could later become part of the supply for the lock.

The lock complex should contain the necessary facilities for high tension, transformers and low-tension equipment. In addition, room is reserved and facilities provided for cable location lines from the low-tension area to the various lock parts (cable racks, cable channels, cable shafts, lead-through pipes etc.) Take into account the other cables and mains required for lock operation as well as those for third parties (Par. 2.3.4.2). For emergency power supply generators and no-break installations, see Par. 2.4.6.3.

2.4.10 Availability

2.4.10.1 Introduction

In the design and management of a lock complex, the objective is to achieve the largest availability for the locking of vessels. To use terminology that is more common: the non-availability has to be acceptably small. General guidelines cannot be given. On the one hand, because some facets that could determine the unavailability of the lock can only partly be influenced (example: heavy cross wind) , and on the other hand, because setting requirements can only take place after weighing up the extra investment costs as opposed to the benefits for navigation. This consideration can only take place in a concrete situation. The economic interests of the navigation route, the presence (or not) of alternative routes, of several chambers etc. have to be taken into account. For these and other issues, we also refer to the reports of the ONI-project (Lit. [2.14]).

In principle, prolonged malfunctions (up to several days) usually caused by collisions and maintenance, are more serious than shorter disruptions to which navigation is generally able to adjust with more flexibility. In planned prolonged obstruction, (maintenance) consider whether this could be executed in periods of less traffic (weekends, season). Not all obstructions are complete. Sometimes, navigation is able to pass within certain limitations.

2.4.10.2 Causes of non-availability

Non-availability could have the following causes:

- Water levels above and below locking levels;
- Too much (cross)wind, bad visibility;
- Malfunction of installations, operating mechanisms and operating;
- Collisions;
- Maintenance (and renovation).

These points are addressed in the following paragraphs.

2.4.10.3 Water levels above and below locking levels

Guidelines on the boundaries of locking levels are provided in Par. 2.4.1.1 (maximum and minimum locking levels). Overall, this results in non-availability smaller than 2% of the time.

The specific boundaries should be set on economic grounds.

2.4.10.4 Too much wind, bad visibility

The non-availability caused by this is determined by the local climatological conditions and by the boundaries considered acceptable for safe locking. The latter depends on the kind of vessel and the degree of load. What is more, locking is often possible to a maximum wind speed to prevent wind waves from forming a disproportionately large load on the operating mechanism (at mitre gates also at little or no difference in level). Rough figures about the non-availability due to wind are not (yet) available. The only possibility for limiting the non-availability is a good design of the approach jetties, which, for that matter, could result in this design creating higher wind wave loads on the gates.

2.4.10.5 Malfunctions of installations, operating mechanisms and operating

Based on the previously mentioned economic considerations, requirements will have to be drafted for the design of the lock or the series of locks for the acceptable risk of failure of these facilities. As an example, the values applied for the renovation of the 'Zuider- en de Kleine sluisin IJmuiden' are stated (Lit. [2.13]). Not available due to:

- malfunction installations : $\leq 0,5\%$ of the time
- malfunction operating mechanisms : $\leq 0,5\%$ of the time
- malfunction operation : $\leq 0,25\%$ of the time

The number of times that malfunction occurs could also be a determining factor.

Not every malfunction results in complete obstruction. The objective is to limit the duration of the malfunction as much as possible (alerting, responding, spare parts).

For emergency power supply and no-break installations, please see Par. 2.4.6.3.

2.4.10.6 Collisions

For non-availability due to collisions, at best a forecast can be made, based on the information available for similar locks with a corresponding navigation volume. As an example, the 'Zuidersluis bij IJmuiden' (Lit. [2.13]) is mentioned, where the non-availability due to significant damage due to collisions amounted to 17 hours per annum (about 0.2% of the time). Other locks could provide a different picture. Within economically acceptable boundaries, the objective will be to limit the collisions and consequences thereof. The accent is placed on gates (and operating mechanisms), moveable bridges and – to a lesser degree – on berthing jetties and guide structures.

Measures to decrease risk of collision are, among others:

- good design of approach jetties (Par. 2.3.1.3 and 2.4.2.2);
- positioning of the flooring of moveable bridges – in opened condition – outside the outer walls of the lock (Par. 2.3.4.1);
- anti-collision structures in front of the gates (Par. 2.4.11.1). This is an expensive facility that will only be applied in special cases;
- protection of operating mechanism on gates. Preventing collisions with the operating mechanism can be effected by fitting a tail end to the gate and connecting this to the operating mechanism (Renovation Oranjesluizen). An extended operating mechanism chamber could also be used so that the vulnerable cylinder rod cannot be hit in the lock (Middensluis IJmuiden).

Measures to limit the duration of the repairs (obstruction) are, among others, having the spare gates and spare parts available (Par. 2.5.2 en 2.5.3).

2.4.10.7 Maintenance

Just as with collisions, forecasts are the only available means for estimating the resulting non-availability. As an example, it is stated that the Middensluis in IJmuiden will be unavailable due to maintenance during about 2% of the time (Lit. [2.13]). Naturally, this will differ from lock to lock. A recommendation could be to choose a construction that requires little maintenance (steel and civil engineering constructions). Temporary waiting facilities could be considered in maintenance periods.

2.4.11 Protecting constructions from damage

2.4.11.1 Collision protection for gates

Mitre gates and pivot (leaf) gates must be fitted with wood fender on the outside surfaces of the opened gates to protect the construction from damage caused by inbound and outbound vessels. Wood fender can also be fitted to other gates in places where they might be hit by vessels.

In special circumstances (for instance Wijk bij Duurstede, Tiel, Belfeld, Panheel, Twenthe-kanaal) trap constructions are positioned in front of the closed gates. The energy of vessels that do not stop in time is absorbed here and the construction prevents the gates from being hit (see par. 17.3.3). For this purpose, cables (cable nets) and friction drums can be used. For the circumstances and setup of these constructions, we refer to Lit. [2.15]. It does concern expensive constructions for which the investments will have to be weighed against the risk of failure of the water retaining structure, the navigation interests etc.

Anti-collision devices protecting lock gates could be economically sound at high-lift locks.

2.4.11.2 Collision protection for concrete and sheet pile constructions

Construction surfaces against which vessels moor or along which they shave, have to be as smooth as possible in order to guide well and limit potential damage (construction and vessel). For inland navigation, a concrete structure meets the requirements. In the case of other construction materials such as sheet pile, the flat surface should be made of wooden or synthetic posts and rails wherever possible. This system can be limited to the day surfaces that vessels meet.

Additional facilities are necessary in places where concrete surfaces are interrupted or come to an end because of expansion joints, gate and ladder recesses. In the case of expansion joints, it will be sufficient to use (sizeable) bevelled edges, steel corner protection profiles should be applied in recesses. Corner guards made of tropical hardwood can also be fitted, especially where it concerns rugged navigation such as tug-pushed dumb barges and sea-going vessels. As protection from hawsers etc, the top of the wall should be fitted with steel capstone profiles. In locks for large ocean going vessels, floating wooden frames (the Netherlands) or rubber wheel fenders (Belgium) are used.

The facilities are intended to minimize damage to vessels and constructions, but also to prevent backing up and friction effects during mooring and unmooring of vessels with large side surfaces, thereby decreasing the pass through time.

2.4.11.3 Facilities against vandalism

Fences and other kinds of screening have to make unauthorized access to vital parts of the lock complex as difficult as possible.

2.4.11.4 Lightning protection

To prevent indefinable process steering due to lightning or electromagnetic interference for instance, the complete electrical installation will have to be protected from these dangers. To achieve this, the electrical installation will be designed according to the safety requirements stipulated in the NEN 1010, NEN 3140, NBD 4001, NBD'S 4003 to 4021, NEN 1131 and the SVEI-00-24.

2.4.12 Safety

2.4.12.1 Facilities for drowning persons

For rescuing people who accidentally end up in the water, ladders should be fitted to the chamber wall and to (high) smooth walls in the lock approach. At the upper end, these ladders are equipped with handgrips. For offering help from the quayside, life-saving devices (life buoy, hooks) should be present on the lock coping in a clearly visible place. Ladders in the chamber and the lock approach also have an accessibility function. For locations and distances, also see par. 2.4.13.2 and 2.4.13.3.

2.4.12.2 Safety facilities

Design and management of safety facilities of personnel will be executed in accordance with Health and Safety Regulations, construction regulations, labour regulations and safety regulations (CE directives). A number of facilities are mentioned below.

Railings are attached to the top of gates. If the lock coping is more than 2.5 m above minimum locking level, fencing is placed behind the bollards. This fencing is always desirable where it concerns recreational navigation and where tourists are allowed on the lock coping.

In the technical areas, workshops, bridges, control portals, rolling gate casings and the like, where work is executed and people walk around where there are differences in height in the surrounding area, railings are provided. From a height difference of 0.60 m or more with the surrounding area, a railing has to be provided at 1 – 1.10 m. Height differences of more than 12 m require the railing to be placed at a height of 1.20. Often, additional protection against falling is provided from height differences of more than 2.5 m such as safety lines, lifelines, harness belts and the like.

Steel ladders should not be in regular use. Straight stairs, a spiral staircase or step ladders should be installed. Ladders can be used between vertical (90°) and 75° and be equipped with simple round rungs. The ladder width is between 0.38 and 0.46 m and the step distance is between 0.25 – 0.20 m. If the ladder connects with the (landing) coping, the distance between the styles of the ladder should be enlarged to 0.60 and it has to be connected to the railing. If the ladders are higher than 3.60 m, they have to be provided with a safety cage. This cage has an inside measurement of 0.76 m and starts from 2.40 m above the ground. At ladder heights above 6 m, an intermediate landing is required.

Basement chambers that could possibly flood (for instance those of operating mechanisms of mitre gates) have to be provided with an exit that can be opened from the inside. In addition, sufficient natural ventilation will be required as well as plunger pumps.

The area in which the operating mechanisms are working need to be shielded from the environment to ensure that nobody gets stuck between machine parts. The lock complex should have sufficient and visible First Aid provisions.

2.4.12.3 Fire fighting

The facilities for fire fighting are based on the report "Verantwoordelijkheden van Rijkswaterstaat ten aanzien van brandbestrijding op sluizen" (Lit. [2.16]).

Point of departure is that the fire brigade should execute fire fighting. Additional stipulations could be:

- providing extinguishing agents at the lock as a supplement to what is available on board (powder fire-extinguishers);
- sufficient water with sufficient pressure on coping level. This could mean connecting to the public water facilities or that the fire brigade will boost the water to the desired level.

For vessels with dangerous goods (inland vessels showing blue conical daylight signs and B flag vessels for maritime navigation), separate measures will have to be taken, likewise in conjunction with the fire brigade (see par. 2.4.13.4).

Attention should be paid to suitable accessibility for the fire brigade, from the land as well as from the water.

2.4.13 Accessibility of lock and lock approaches

2.4.13.1 Lock Infrastructure

The lock terrain is connected to the public road network. The connection is not only measured on the comings and goings of operating and maintenance personnel but also on the arrival and removal of heavy, replaceable parts of the lock and lock approaches where this has not been provided for in the

transport over water and the corresponding wharf. Certain roads lead from the public road over the wharf to the places where these spare parts are installed/removed. In so far as this has not been provided for with fixed traversing setups, the areas and the surfacing/asphalting near the assembling and disassembling places need to be suitable for mobile hoisting devices. The latter also applies to the wharf and where applicable, to the storage areas for spare gates and spare parts. Besides, mobile hoisting devices and other construction equipment should be able to execute activities on both sides of the lock (maintenance of chamber, heads, unexpected activities to vessels in the chamber). The gates of small and medium sized locks are often changed with mobile hoisting devices. At large locks, this takes place by means of floating derricks; very large horizontal roller-bearing gates are self-floating.

2.4.13.2 Accessibility of vessels in the lock

For personal safety as well as comfort, ladders should be positioned on the chamber wall to allow persons on board to leave/board the vessel during the locking process (telephone, disposing of domestic waste, possible calamity). People overboard need to use the ladders. Therefore, ladders should be installed on both sides of the lock chamber, spacing at the most 30 m, and the first ladder at 5 m from the stop stripe (for further details, see Lit. [2.1]).

2.4.13.3 Accessibility of vessels in the lock approaches

From the lock approach, the embankment has to be accessible via mooring and waiting areas. This can be achieved by means of ladders and footbridges. This will depend on the facilities in the mooring area such as mooring posts/mooring piers, freestanding guiding structure (possibly floating) or a quay/sheet piling and the desirability thereof due to misuse (vandalism).

Footbridges should be positioned from the mooring posts/mooring piers at such distances that every moored vessel will have at least one connection with the embankment.

In the case of a freestanding guide structure, a footbridge should be installed in longitudinal direction, from which one or more footbridges continue to the embankment or to the lock coping. The latter is preferable in an area sensitive to misuse.

The width of walkways should be established in consultation with the local fire brigade and be such that fire fighting equipment and stretchers can be brought aboard. At guiding structures and sheet piling, ladders should be installed at distances of about 30 m, the first ladder being about 10 m from the stop board.

2.4.13.4 Accessibility of vessels with dangerous goods in the lock approaches

It is general rule that vessels transporting dangerous goods have a separate waiting area, aside from the regular waiting area, which has its own connection with the embankment. This waiting area has to be easily accessible to the fire brigade and ambulance, given the specific content of these moored vessels. If mooring does not take place along the embankment but along the guiding structure, mooring posts and mooring piers, walkways to the embankment have to be provided at such distances that there is a connection with the embankment from both the front and the stern of the vessel (Lit. [2.1]).

2.4.14 Supplemental client wishes

These wishes mostly stem from common regional management of locks and other structures. This could manifest in a certain preference for a certain type of gate, operating mechanism (hydraulic or mechanic) or switching gear. It has to be assessed whether this preference will result in the best approach of the whole (lock and other locks or structures to be designed).

2.4.15 Life span requirements

2.4.15.1 Design life span of lock complex

In general, locks are designed on a technical life span of 100 years. Distinction is made between those parts that are maintenance free during this life span and those parts that do require maintenance or

replacement. For the first category, the life span is 100 years. For the second, the life span is determined based on minimal cost investments and capitalized maintenance and replacement during a period of 100 years.

The first category contains, by and large, the fixed structures that are hard to maintain or replace, such as lock heads, chambers, fixed bridges, substructures of moveable bridges, wing walls, piping and out-flanking screens and control buildings.

The second category consists of gates, moveable bridges, operating mechanisms, electrical installation, guiding structures and possibly façade cladding and roofing material.

For renovated locks such as the 'Zuider- en Kleine sluis te IJmuiden', a life span extension of 50 years is estimated for the main structure, to which the rest is adapted (does not require a life span of longer than 50 years).

2.4.15.2 Steel parts

Possible solutions for realising a design life span of gates, sliding sluices, moveable bridges etc are:

- extra thickness material;
- conservation;
- cathode protection;
- combinations of the aforementioned.

The primary objective is that the construction does not collapse due to fatigue. The number of load changes and the tensions range has to remain below a certain level (S-n curve).

Another important point is corrosion speed. As an example, we refer to the report

"Corrosiesnelheden van behandeld en onbehandeld staal voor de zks" (Lit. [2.17]).

All the same, this does not alter the fact that at present, the accent of the life span approach is more on maintenance and conservation than on providing excessive thickness.

2.4.15.3 Electrical installations

In general, the life span of electrical installations is 15 years (cables 25 years), based on standardized design criteria related to specialized maintenance. Parts of the installation that are not housed in protective or conditioned environments in accordance with their design generally have a life span of 10 years at most.

2.4.15.4 Hardware and software

It is well known that hardware and software have an economic life span of 5 to 10 years. Despite the fact that software generally requires marginal adjustment to the new possibilities offered by hardware, the aim is to implement standard, upgradeable software that can be used during the total life span.

2.4.15.5 Sheet pile constructions

Material loss due to corrosion must be taken into account. The corrosion speed depends on the aggressiveness of the (ground) water, the kind of soil, the zone in relation to the water line (splash zone under water etc.) and the quality of the steel. Data regarding the corrosion speed can be found in EAU 1995 and CUR 166 (Lit. [2.18]). At the end of the lock's life span, sufficient material should be present for the strength and stiffness required for resistance/inertia moments etc. Corrosion loss should also be taken into account in the anchorage.

2.4.15.6 Guiding structures

It is usual to design the technical life span of these constructions to another time span that is shorter than that of the lock complex. An example is the 'Nieuwe Oranjesluis', where the design life span of guiding structures amounts to 50 years and the life span of the lock complex 100 years. The separate materials that make up the guiding structures each have their own life span. For examples, we refer to "Beleidsnota 5 van de Ontwerpnota Complex Nieuwe Oranjesluis" (Lit. [2.19]). The main elements such

as tubular piles, tubular girders and aprons with wooden friction wales are estimated to have a life span of 50 years.

For the dimensions of the steel construction, the total corrosion loss during the complete life span will have to be taken into account.

2.5 Maintenance requirements

2.5.1 Maintenance strategy

The maintenance strategy will mainly be based on the requirements regarding the safety of the retaining structure (par. 2.3.2), the availability for lock operation (par 2.4.10) and the life span (2.4.15). The external appearance of the structure will also play a role in the strategy (building inspection). With the exception of the safety requirements, which are fixed, it concerns an assessment between the aggregate costs of investments and capitalized maintenance, and the interest of obstructions for navigation. An example is to consider applying 2 horizontal roller-bearing gates per head for a maritime navigation lock (par. 2.5.2). The optimization of the materials, maintenance choices etc. within the given design life span of a lock is discussed in par 2.4.15. Environmental requirements necessitate certain maintenance activities to be executed in closed areas. Providing these facilities on site could be costly and it could be attractive to have these activities executed by third parties.

Overall, the objective is to incur a minimum of aggregate costs as well as provide the largest service provision to navigation. The latter includes a limitation of the number and duration of obstructions for maintenance (par. 2.4.10) and attention for limited passage during maintenance. Please refer to the modules of 'Raamwerk Onderhoud van Natte Kunstwerken' (Lit. [2.20]), which is drafted by the Civil Engineering Division of the Ministry of Transport and Public Works. At present, the following modules are available: "Keuze van onderhoud voor een puntdeur", "Damwanden" and "Ducdalven en remmingwerken".

Based on this strategy, maintenance plans, books and schedules will have to be drafted for the various parts. Supplemental to this, measures and procedures for navigation during maintenance will have to be drafted.

2.5.2 Spare gates

For regularly recurring maintenance (such as preservation with intervals of 10 years) and for repairs, spare gates are required. The spare gate replaces the gate that requires maintenance or repairs. Lift gates can be maintained on site, in raised position, if the lock is part of a lock complex with several chambers and sufficient locking capacity remains.

In principle, there should be a reserve gate for every type of gate. The number could be limited in a lock with several doors that are equal and even further reduced if there are several equal locks in one waterway (next to or behind each other). It has to be established however, that sufficient reserves are available given the chance of collision, the planned maintenance intervals and the duration of the maintenance.

The spare gates are stored in gate storage where in general, maintenance also takes place. Preferably, the gate is as ready for operation as possible, complete with lock paddle operating mechanisms, rolling platforms etc. The gate storage has to be easily accessible for exchange, has to be equipped with the necessary means (tipping construction etc.) to ensure and enable the execution of maintenance work. The most appropriate storage should be chosen, horizontal or vertical. The operational and spare gates will be provided with hoisting points while the necessary hoisting means will be available (hoisting hooks and beams etc.). On important navigation routes, gate docks can be included in the heads and used as gate storage areas. By means of dewatering weirs (stop log weirs) and pumps, the gate dock is drained for maintenance and repairs.

Examples of locks with two horizontal roller-bearing gates per head are the sea lock in Terneuzen, the one in Zeebrugge and the Zandvliet- en Berendrechtshuis in Antwerpen. The advantage of these expensive solutions is that, in case of damage, the spare gates can be operational immediately and the accessibility of the harbours behind is ensured to a large degree. This also has a large public relations effect for the recruitment and retention of shipping companies and other companies in the harbour concerned.

2.5.3 Spare parts and materials

The spare parts that need to be available on the lock depend on the durability, the vulnerability, the consequences of possible failure and the delivery speed for the parts and materials concerned.

Examples of spare parts are: sluices, operating mechanisms (at the Zuider- en Kleine sluis one set per lock) and/or large parts such as suspension links and cylinders, switching gear, motors, materials for bottom protection and spare aprons (normal, bollards and ladder aprons) for guiding structures. In addition, smaller non-durables will have to be available (gaskets and lubricants).

2.5.4 To lay lock open (or not)

Nowadays, it is no longer usual to lay open the complete lock for maintenance. The reasons are that it is often too costly (measures required against floating up) and that the main construction of chamber and heads are maintenance free, the probable exception being wood fenders for sheet pile constructions and floating frames at sea locks. The latter parts should be easy to replace. Incidental repairs to head constructions could be executed by divers or in diving bells.

Inspection and maintenance focus on gate supports (sill and side seals), fulcrums, and gate conduction, in other words, parts that are located in the head. There are two possibilities:

1. Lying open a head, for which stop log weirs or dewatering weirs and rabbets are necessary.
2. Removable pivot-inspection chambers and other local steel dewatering means for the fulcrums, support and gate condition. This also includes the dewatering stop logs for the gate recesses for lift and roller-bearing gates.

Gate supports and rabbets are also required for the drainage. These means for water removal are stored in the near vicinity in a highly accessible place and could possibly be used for several locks.

The choice between two possibilities depends on the inspection and maintenance frequency, the costs and the duration of the obstruction for navigation. Option 1, in which too much space is laid open is, in essence, usually only applied at smaller locks.

2.5.5 Accessibility for personnel

The objective is to have all parts that require inspection and maintenance easily and safely accessible to personnel. This can be aided by the installation of stairs, ladders, climbing irons, landings and walkways. High control portals could be equipped with lifts. Wherever permanent placement is impossible or in case of infrequent use, temporary or mobile facilities could be considered. Securing points have to be provided for temporary facilities. The accessibility of equipment is discussed in par. 2.4.13.1.

2.5.6 Monitoring

Monitoring is a permanent measuring and registration system for normative parameters for the condition of structures, the loads and stresses that they are submitted to and the degree in which corrosion processes have progressed. Even though the application in construction is still limited, it is necessary to keep up with the rapid developments. Monitoring is useful, certainly for places of lock structures that are difficult to inspect (for instance at soil facing side) and for erosion processes that are hardly visible on the surface (such as chloride penetration).

Cathodic protection can be used as a monitoring system at the same time.

2.5.7 Electrical installation, hard- en software

- All materials and components must be conditioned and positioned for easy access.
- In computer installations, both hardware and software must be built in modular form for the optimisation of corrective maintenance.
- Computer installations have to be equipped with control mechanisms to ensure that malfunctions and deviant process behaviour is recognised and traced in acceptable time.

2.5.8 Storage areas and workshops

Depending on the planned maintenance, there will have to be storage and workshops at or near the lock complex. These areas can be partly or completely combined with those of nearby locks or with central regional storage and workshops, wherever transport possibilities allow for this.

2.6 Environmental requirements in the use phase

2.6.1 Aesthetics

A lock is largely submerged and constructed below surface level and because of that, not emphatically present in the area. This does not apply to the control tower, possible lift gate towers, fixed bridges, balance posts, railings, parts of gates that stick out above the water and the vertical storage of spare gates. These elements require attention with regard to blending into the rural or urban landscape as well as to the design and colour balance. This always means involving an architect and usually also involves a landscape architect.

In the most extreme form, the application of draw gates or the vertical storage of spare gates could be unacceptable because it is experienced as being intrusive (destruction of the landscape) on the environment.

In the case of renovations, it could be desirable to make the chamber and heads fit in with the historic character of the lock and its direct surroundings, by using brick for instance. In appearance, the brick should be as close as possible to the kind of brick that was used in the past. The historical character could also determine that wooden gates are used instead of steel gates.

2.6.2 Environmental requirements with regard to building materials

Distinction can be made between building substances and materials that place a burden on the direct environment (for instance because of soil leaching or evaporation of hazardous substances) and those that, due to the method of extraction or manufacture, place a heavy burden on the environment elsewhere (eroding the tropical rain forest, energy consumption etc.). There are possibilities to limit the load on the environment here and elsewhere, by mainly working residues into concrete constructions.

Current legislation (a/o the 'Bouwstoffenbesluit' Building Materials Decree) and general government policy do not allow for a complete overview of materials that cannot be utilized or of raw materials that should preferably be used for manufacture. Below are some (well known) indications:

1. The use of tropical hardwood should be prevented as much as possible. This limitation does not apply to hardwood originating from sustainably managed forests.
2. For soil protection, no steel, lead or phosphor slags should be used. The materials to be used for soil protection should be suitable for recycling.
3. After replacement or demolition, all other material used for the lock should be eligible for recycling by means of reprocessing.
4. If preservation materials or cathode protection were chosen in order to realize the required life span of steel parts, attention should be paid once again to the measures for preserving (for instance possible radiation under conditioned circumstances) and to the direct environmental drawbacks of these materials (for instance anode material solution or sanding the preservation through sand transport).
5. Because of the policy related to the recycling of waste materials, consider a composition in which 20% of the gravel is replaced by concrete rubble granulates.
6. Materials used for the electrical installation should not contain any CFKs.
7. Lubricants should be prevented from contaminating the surface water if operating mechanism chambers are flooded. Sometimes, separate trays are constructed.
8. In choosing lubricants and hydraulic liquids, the use of non-toxic, biodegradable substances should be considered.
9. Processing of paints containing PAK (especially carbolineum, tar epoxies, tar carbonaceous products) is prohibited and there is a strict ban on gaskets, brake linings etc. containing asbestos.

2.6.3 Recreation

Hydraulic engineering works often form a public attraction. This makes it advisable to make locks open to the public, different to those for recreational navigation, whenever this is possible and not in violation with the safety of the public and of navigation and does not cause any hindrance to the lock operation or the lock company. In practice, this often means the construction of an access road, a parking lot, viewing platform or area, railings, fencing and placing information boards.

2.7 Environmental requirements in the construction phase

2.7.1 Required building site and final grounds

In the use phase, the requisite terrain consists of surface area for the lock, the lock approaches, the lock buildings and grounds for the storage of spare gates. During construction, a larger surface area could be required, certainly if the structure is built in a "classic" construction pit: an excavation between slopes with temporary draining. In addition to the space for the construction (work and storage terrains, site offices, work roads and the like), space will be required for slopes and the temporary storage of soil that will later be used for filling up the structure. (Please note that the classic construction pit is one of the least expensive methods for building the lock body; a chamber confined by sheet piling is the only option that is often cheaper).

If the local situation and buildings do not allow for a larger surface area than that necessary for the use phase, this could be a reason to abandon a construction method with a classic construction pit. Another reason could be that a temporary lowering of the groundwater level by means of draining is not allowed. (See par. 2.7.3).

A building site is not only a matter of surface, but also of accessibility. Existing roads have to be used as much as possible. In the permits for connecting to these roads, requirements must be set for the use of these roads for the execution of the work (axle loads, spillage and cleaning of wet soil transport etc.). In addition, attention has to be paid to accessibility of floating equipment in the successive work phases (installing gates, guiding structures etc.) as well as the possibilities for power supply from the existing public power network or from a network - set-up in an early stage – that is adjusted to the supply for the completed lock. Apart from that, situations could occur where power is already required for moving gates etc. before the final connection to the public network has been completed. For these and other situations, temporary use of generators should be considered.

2.7.2 Polluted soil

For every lock, soil analysis will have to take place to test for the presence of pollution in the soil and – if present – the degree of pollution. The Act on Soil Protection ('Wet Bodembescherming') applies to every activity executed with polluted soil or dredging spoils. Information on this is provided in the policy document "Rijkswaterstaat en de nieuwe Wet Bodembescherming", preliminary version October 1994 (Lit. [2.21]), (procedures, qualified authority, soil analysis etc.). If the terrain was a target of hostile action during the Second World War, it will have to be ascertained whether bombs, mortar-shells, mines and the like were left behind.

Hardly any limitations are imposed on the use of clean and almost clean soil; the excavated soil may be used in filling the structure at a later stage or it can be used for embankments on the terrain etc., providing that the physical quality allows for this. Heavily polluted soil can only be transported to specially designated depots equipped to deal with this.

Depending on the magnitude of the pollution, the transport and dumping costs could amount to a sizeable contribution in construction costs. It is of utmost importance to execute a soil analysis and to frame a soil balance of the terrain at an early stage. Substantially polluted soil could be a reason to limit excavation as much as possible during construction. This means that a classic construction pit is avoided or minimizing soil protection in the lock approaches

2.7.3 Groundwater withdrawal

For decreasing the groundwater level, requirements have to be met as set by the Province concerned in the area where the lock will be built. In many areas, groundwater withdrawal is only allowed to a limited extent or sometimes not at all. In the first case, the regulations generally stipulate that the withdrawal remains below a certain value, usually quantified in m³/annum. Experience has taught us that the draining required for a 'classic' construction pit, for a complete lock, usually exceeds this value. This is the opposite of a shallow construction pit for a reinforced concrete L-wall on a sheet pile screen

with batter piles. Before a design is drafted for the lock body, the requirements that have to be met in relation to groundwater withdrawal must be clear. If return pumping is considered, the requirements that are set for such solutions will also have to be at one's disposal.

2.7.4 Upkeep/maintenance of road and navigation traffic, cables and mains

If there are wet or dry infrastructure facilities at or near the place where a lock will be built, the general rule applies that during construction, nothing will detract from the use of these facilities and if it does, it will be as little as possible.

This could mean, for instance, that the new lock will be positioned with regard to an existing lock, allowing it to continue functioning as well as is possible. Naturally, attention will have to be paid to the construction method to be applied, the space this requires, the stability of the existing lock as well as optimal positioning of both locks with respect to each other in the use phase, when the new lock is also operational.

Temporary detours and adjustments could be required for the dry infrastructure. It could be attractive to investigate planned routes that would fit in with the new situation once the lock is completed.

General guidelines cannot be provided, the solutions depend on the local situation and the different requirements set by the authorities of the infrastructure. It is advisable to get in touch with the authorities in an early stage of the design phase.

2.7.5 Upkeep/maintenance of the water retaining structure

The TAW guideline "TAW-Leidraad Waterkerende Kunstwerken en Bijzondere Constructies" (Lit. [2.8]) specifies the following:

- *during execution, the safety of the water retaining structure during the closed season should at least be equal to the original safety of the water retaining structure. If execution takes place in the open season (15 April to 15 October), the crest height may be lowered to the level corresponding with the normative frequency of the summer high waters;*
- *the execution should preferably take place in the open season. In the various construction phases and the change over between phases, the necessary safety measures should be taken to guarantee the water retaining capacity.*

Execution in the open season is preferential according to the guideline but often this will not be –economically– desirable given the long duration of the execution. If this is the case, it will have to be demonstrated, to the satisfaction of the dike manager, that the temporary facilities meet the original safety requirements. Whether the latter is actually required, depends on the local situation and the envisioned implementation design: is the lock built in front of, on the spot of or behind the existing water retaining structure?

An example of building in front of a water retaining structure is the construction of a lock near a dam in a canalized or yet to be canalized river. The construction site is usually provided with a temporary water retaining structure, of which the safety does not have to comply with the previously mentioned original safety, but has to be adjusted to the risk (= frequency x damage) of the site being flooded. Often, the design level for such temporary water retaining is set at an exceedance frequency of 1 per 50 years. Whether this is correct will have to be substantiated by a risk analysis.

2.8 Permits and procedures at the construction of a lock

During the construction, renovation or similar activities related to a lock, the administrative legal aspects should be taken into account in addition to the technical aspects. The client should ensure that the required permits are obtained in good time and that the valid procedures were followed. In relation to the latter, consider a route mapping procedure, an environmental effects report or for instance, a zoning plan amendment. Common permits and procedures are summarized below.

2.8.1 Construction permits and zoning plan amendments

Applications for building permits have to be submitted to the local authorities concerned if a structure is to be constructed. A building permit could also be required for placing offices and similar constructions on a building site. The building contractor should organize the latter. The municipal executive (Mayor and Aldermen) decides on a building permit request within 13 weeks. The municipal executive could extend this period once, 13 weeks at maximum, for making an adjournment decision (for instance for a complicated construction). These times do not include the preliminary consultations necessary. For the benefit of the permit, drawings, calculations and possible implementation information, costs and the like have to be supplied.

Building permits are granted based on the Housing Act ('Woningwet') and it has a number of grounds for adjournment on deciding on a request for building permission.

A common ground for adjournment is the necessary amendment to the zoning plan related to the environmental planning for a lock and/or accompanying service building. If this is the case, the request for a building permit is also considered as a request for exemption from the zoning plan.

Another possibility is the adjournment by virtue of the Environmental Management Act (Wet Milieubeheer'). If an EA permit is required and this has not yet been granted, the applications for the building permit and the environmental permit should be submitted at the same time (unless the environmental permit had already been requested previously). If this is the case, a copy of the application should accompany the building permit application.

If, from the above-mentioned investigation, it appears that a zoning plan amendment is necessary, an article 19 procedure should be followed. This requires a processing period of about 30 weeks.

Besides this, it needs to be assessed whether a construction permit is required. This construction permit could solely relate to the works, though not construction works, or to the activities. The same applies to this permit where it concerns adjournment. Art. 46 of the Spatial Planning Act states the various possibilities in relation to when and how long the decision to grant a construction permit can be adjourned.

2.8.2 Demolition permit

It is possible that an application needs to be submitted for a demolition permit for the removal of constructions. The demolition permit could contain measures that have to be taken with regard to the safety on the demolition site and/or the points in time that demolition can be started. The municipal executive is the Competent Authority in this, the same as in the building and construction permits. The term in which they decide is also the same, 13 weeks, and there is a possibility of extending this period by 13 weeks.

2.8.3 Flood Defence Act

If a lock primarily is a water retaining structure, or if it is part of a dike ring, the Flood Defence Act applies ('Wet op de Waterkering'). This act is intended to guarantee safety at storm surge or high surface water and provides special procedures for accelerated construction of second line dike strengthening. Art 7 of the Flood Defence Act that:

The construction of a primary water retaining structure and the change in direction, shape, dimension or construction should occur in accordance with the plan approved by the dike management.

This plan must be submitted to the provincial authority concerned. The time required for this procedure is 4 months. The plan should include a number of issues, among which an explanation which shows that the water retaining ability is maintained for 100%. Furthermore, the plan should contain the measures taken in the interest of the advancement of landscape, nature or cultural historic values. Further description can be found in article 7 of the Flood Defence Act Structures.

A change to a primary water retaining structure is regulated in the Directive on the assessment of the effects of certain public and private projects on the environment (M.E.R. Besluit), which is part of the Environmental Management Act. Due to European legislation, this could change in the near future. At present, it is not clear how or when this amendment would come into effect.

2.8.4 Environmental Management Act (M.E.R.)

The Environmental Management Act stipulates that certain activities could result in harmful effects for the environment and for this reason, a 'Directive on the assessment of the effects of certain public and private projects on the environment' (MER) had to be drafted. These activities are listed in this directive (MER Besluit) and this is a tool used by the authorities to assist in decision-making. Sufficient environmental information must be available before decisions are made that could result in harmful effects on the environment. In addition, this Environmental Impact Assessment assists the initiator of a project that falls under the MER regulations in being aware of the environmental consequences of the development of the project.

The Environmental Management Act has the permit tool. Article 8.1 creates a permit obligation for executing or changing a structure, facility or plant, changing the operation thereof and/or having a facility in operation. A structure, facility or plant is a concept that is addressed in more detail in the 'Inrichtingen Vergunningbesluit Milieubeheer'. In most cases, the permit application is submitted to the Municipal Executive (Mayor and Aldermen) of the local authority concerned. The time required for the procedure usually amounts to 6 or 7 months (excluding preliminary consultations).

With regard to the permit application, take into account that there is a coordination responsibility with respect to the Pollution of Surface Waters Act (vwo). By simultaneous submittal of applications and the simultaneous processing through the various phases of the procedure, procedural and intrinsic adjustments are possible. If the two required permit applications are not submitted within 6 weeks of each other, the request is declared inadmissible.

There is also a coordination responsibility with regard to the building permit. This is regulated in article 52 of the Housing Act. The application for a building permit can be adjourned until the Environmental Management Act (wm) permit is approved and objections have not been raised against the draft decision. To conclude, there is a coordination responsibility with regard to the Act on Earth Removal.

Article 1.2 of the Environmental Management Act stipulates that the Provincial Authorities should formulate a Provincial Environmental Regulation (PMV). This regulation should contain guidelines for the protection of groundwater and regulations with regard to sound abatement. The PMV could also assign MER like activities. It is usual that the PMV has an export ban on industrial waste material to and from another province. The substances concerned could be specified on an appendix of the PMV. The Provincial Executive could grant exemption from this prohibition. In addition, it is common that the PMV stipulates measures with regard to soil decontamination.

2.8.5 Act on Earth Removal

The Act on Earth Removal (Ogw) applies to the removal of soil on the land, in the water and on the continental shelf. Consider the extraction of surface minerals or, for instance the excavation of dilapidated parts of water retaining structures. Article 8 of the Earth Removal Act states that in the case of earth removal (1) in the water of the North Sea, (2) in order in council designated national canals and (3) in the reclaimed land of the IJsselmeer, if and as long as these have not been allocated to provinces, the Ministry of Transport and Public Works is the Competent Authority. The Competent Authority for earth

removal on land or in provincial waters is the Provincial Executive.

The granting of permits is regulated in the provincial earth removal ordinance. The procedure takes 6 months to complete. In addition, there is a coordination responsibility with the Environmental Management Act, the Pollution of Surface Waters Act, the Housing Act (building permit), the Forestry Act and provincial regulations.

2.8.6 Pollution of Surface Waters Act

The objective of the Pollution of Surface Waters Act (Wvo) is to combat and prevent the pollution of surface waters. Likewise, this act also protects the underwater bed from being polluted due to the dumping of waste materials, among which dredging spoil. Discharge, whether direct or indirect, is generally only allowed if a permit has been granted and the stipulations are being adhered to. The Competent Authority in this is the authority that manages the surface water concerned. The procedure time for obtaining this permit is 6 to 7 months. There is a coordination responsibility with the Environmental Management Act permit and the Act on Earth Removal. (Coordination has already been discussed in par. 2.8.4.) The request has to be accompanied by information regarding the quantities of water to be discharged, the quality of the water, the quality of the soil to be dumped, the quality of the materials to be used, methods of execution and the like.

2.8.7 Groundwater Act permit

The Groundwater Act (Gww) dictates regulations with regard to the extraction and infiltration of groundwater. In the construction and reconstruction of locks, one of the activities requiring a permit could be withdrawing groundwater from in and around the construction pit and infiltrating groundwater into the ground as compensation. The basic principle is that every extraction and every infiltration is subject to a permit. The Competent Authority for this quantity management is the Provincial Executive. The time required for this procedure is 6 to 7 months (excluding the preliminary consultations required).

In provincial ordinance, small extractions could be exempt from permit. The boundaries and limitations applicable to extractions that are exempt from permit or registration vary considerably per province. Therefore, it is important to consult the provincial groundwater regulations. It also stipulates which information and documentation should be submitted with the permit application. In addition, the ordinance stipulates the way in which investigations should be performed to assess the permit application.

2.8.8 Water management Act

The Water Management Act (wwh) supplements the Pollution of Surface Waters Act (Wvo) and the Groundwater Act (Gww) and other legislation in the field of water management by stipulating how to achieve planning in this field (Policy document for water management, provincial water management plans etc). It also provides regulations for the operational quantity management of surface water (registration, permit, ordinance relating to the water level etc.). In most cases, the time required for the procedure is 3 to 4 months. The Competent Authority is the water quantity authority.

2.8.9 Soil Protection Act

Article 13 of this act has a responsibility stipulation:

Everyone that executes activities on or in the ground, as intended in article 6 up to and including article 11, and who knows or could reasonably have suspected that the soil might become polluted or affected, is obliged to take every measure that could reasonably be expected in order to prevent pollution or harmful effects or, if the pollution or harmful effects appear, is obliged to clean up the soil or to limit or undo the harmful effects and the direct consequences thereof as much as possible.

The Soil Protection Act has 6 tools:

1. reporting (on pollution);
2. ordinance (permit) at serious pollution;
3. approval decontamination plan;
4. decontamination and investigation order;
5. exemption;
6. release form.

Depending on the gravity of the pollution, one of the above-mentioned tools will be applicable. The Competent Authority is the Provincial Executive.

2.8.10 Nature Conservation Act

The objective of this act is to protect areas with substantial ecological value (nature reserve) against activities that could result in damage to these areas. Based on this act, a permit is required for activities in a protected nature reserve. The Competent Authority is the Provincial Executive. The procedure takes 6 months.

2.8.11 Management of Waterways and Public Works Act (Wet beheer rws-werken)

This act is to ensure that Waterways and Public Works are managed safely and suitably. Article 2.1 of this act states:

It is prohibited to make use of a waterway or public work, without permission from the Minister of Waterways and Public Works, for a purpose other than for which it was created:

- a. *creating or retaining works inside, on top, underneath or over;*
- b. *dumping, placing or positioning, standing or lying fixed substances inside, underneath or on top.*

The third paragraph of this same article reads:

The first article does not apply to:

- a. *the execution of usual maintenance;*
- b. *behaviour in the minor or major beds of a river or stream in the sense of the Rivers Act*

The Minister of Transport and Public Works is the Competent Authority. The procedure takes 3 to 4 months to complete.

2.8.12 Noise Abatement Act

A broad outline states that the total noise load is not allowed to exceed a limit of 50 dB(A) between 07.00 hours and 18.00 hours. In the evening and through the night, this limiting value is lower still. It should be taken into account that the local and provincial authorities also have powers in the field of sound and vibrations.

2.8.13 Provincial Road Ordinance

For activities on secondary roads (adapting, temporary detours etc.), a provincial exemption is required from the road authority. The application for exemption is submitted to the province. The total procedure time is about 2 months. Consultation with the province is required.

2.8.14 Building Materials (Soil and Surface Waters Protection) Decree

The Building Materials (Soil and Surface Waters Protection) Decree provides regulations with regard to the use of stony construction materials (and soil) and came into effect in its entirety on 1 January 1999. In addition, the Provincial Environmental Ordinance can also stipulate requirements for the use of secondary base materials.

2.8.15 Other permits and exemptions

The building site could contain cables and mains with permits or with exemptions. Quite often fishing permit(s) have been granted for (professional) fishing. Timely amendments, withdrawals and such will have to be organized with regard to all granted permits.

2.9 Standards and guidelines

This paragraph provides an overview of the principal standards and guidelines adhered to in the technical design of a lock. In the following chapters of the book *Design of Locks*, literary references regarding the standards and guidelines are provided and supplemented by other norms, guidelines, handbooks, and the like. A number of these were also mentioned in the previous paragraphs of this chapter.

2.9.1 Standards

General construction

NEN 6700	Technical principles for building structures - TGB 1990 - General principles
NEN 6701	Technical principles for building structures - TGB 1990 - Names and symbols for quantities
NEN 6702	Technical principles for building structures - TGB 1990 - Loadings and deformations

Concrete constructions

NEN 6720	Regulations for concrete - TGB 1990 - Structural requirements and calculation methods (VBC 1995)
NEN 6722	Regulations for concrete - Construction (VBU 1988)
NEN 5950	Regulations for concrete Technology, Requirements, manufacture and inspection
NEN 6723	Regulations for concrete - Bridges (VBB 1995) - Structural requirements and calculation methods

Foundation engineering

NEN 6740	Geotechnics - TGB 1990 - Basic requirements and loads
NEN 6741	Geotechnics - Realisation of foundations in woodpile
NEN 6742	Geotechnics – Realisation of foundations with prefabricated concrete pile
NEN 6743	Geotechnics - Calculation method for bearing capacity of pile foundation - Compression piles
NEN 6744	Geotechnics - Calculation method for shallow foundations

Timber structures

NEN 6760	Timber structures - TGB 1990 - General principles - Requirements and determination methods

Steel structures

NEN 6770	Steel structures – TGB 1990 -Basic requirements and basic rules for calculation of predominantly statically loaded structures
NEN 6771	Steel structures - TGB 1990 - Stability
NEN 6772	Steel structures - TGB 1990 - Connections
NEN 6788	The design of steel bridges - Basic requirements and simple rules VOSB 1995
NEN 6706	Design rules of steel bridges
NEN 2008	Regulations for fabricating steel bridges VVSB 1977
NEN 2062	Arc welding - Calculation of welded joints in unalloyed and low-alloy steel up to and including Fe 510 (Fe 52) which are predominantly statically loaded
NEN	Arc welding - Fatigue loaded structures - Calculation of welded joints in unalloyed and low-alloy steel up to and including Fe 510 (Fe 52)
NEN 2018	Cranes - Loads and combinations of loads
NEN 2019	Cranes, rules for calculation
NBD	Standards developed by the Civil Engineering Division primarily in the field of steel and mechanical engineering

Masonry structures

NEN 6790	Technical principles for building structures - TGB 1990 - Masonry structures - Basic requirements and calculation methods

Mechanical engineering

NEN 3560	Steel wire ropes - Requirements and methods of test for the examination of steel wire and steel wire ropes
NEN 6786	Rules for the design of movable bridges (VOBB)
DIN19704	Stahlwasserbauten: Berechnungsgrundlagen, Bauliche Durchbildung und Herstellung, Elektrische Ausrüstung
-	Machine regulations Nederlands Normalisatie Instituut, 1996
NBD	Standards developed by the Civil Engineering Division primarily in the field of steel and mechanical engineering

Electrical installation

NEN 1010	Safety requirements for low-voltage installations (all parts)
NEN 1041	Safety regulations for high-voltage installations
NEN 3040	Safety regulations for activities on or in the vicinity of low-voltage installations
NEN 1890	Functional requirements interior lighting
NEN 1014	Protection against lightning
NEN-EN 40	Lighting masts - Low-voltage, EMC directive

Structural Engineering (statutory)

-	Housing Act 1991 (Staatsblad 1991, nr. 680)
-	Construction Decree including supplementation (Staatsblad 1991, nr. 680) with Administrative regulations, Building regulations, Urban development regulations, Construction ban on polluted soil, Demolition regulations and waste policy, Execution requirements for construction activities, Fire safety, Accessibility
-	Ministerial Regulations concerning the Construction Decree
-	Legislation and regulations concerning the environment
-	Lift Institute regulations
-	Building regulations 1992 (MBV 1992)
-	Local fire brigade regulations

2.9.2 Guidelines*Hydraulic Engineering*

TAW	Technical Advice Committee Flood Control with: • Leidraad Waterkerende Kunstwerken en Bijzondere Constructies, 1997 (inclusief basisrapport) • Leidraad voor het Ontwerpen van Rivierdijken, deel 1 (bovenrivierengebied en deel 2 benedenrivierengebied) • Technisch rapport Zandmeevoerende wellen, 1999
EAU 1996	Empfehlungen des Arbeitsausschusses Ufereinfassungen, Hafen und Wasserstraßen
CUR 151	Geotextiles in civil engineering
CUR 161	Filters in hydraulics
CUR 174	Geotextiles in hydraulic engineering
CUR 190	Risk analysis in Civil Engineering, part 1: probabilistic design
RWS	• Rekenregels voor waterbouwkundig ontwerpen (Bouwdienst, Hoofdafdeling Waterbouw, 1990) • Handboek uitvoering bodemverdedigingsconstructies van losgestorte granulaire materialen (Bouwdienst, Hoofdafdeling Waterbouw, 1991) • Ijsbestrijding kunstwerken (Bouwdienst 1993) • Dynamisch gedrag van waterbouwkundige constructies (Dienst Weg- en Waterbouwkunde, 1996)

Shipping

CVB	Commissie Vaarweg Beheerders, Richtlijnen vaarwegen, 1996, en supplement 1998
BPR	Binnenvaart Politie Reglement, 1983
ONI	Beschikbaarheidseisen

Foundation engineering

CUR 162	Construeren met grond
CUR 166	Damwandconstructies
CUR 189	Cement-bentoniet schermen
CUR 98-9	Ontwerpregels voor trekpalen

Concrete engineering

CUR 37	Hoge sterkte beton
CUR 85	Scheurvorming door krimp en temperatuurswisselingen in wanden
CUR 128	Koelen van beton

Mechanical engineering (Civil Engineering Division)

NBD 06000	Eisen voor hydraulische bewegingswerken
NBD 08002	Richtlijn voor het ontwerpen van tandwielkasten en open tandwieloverbrengingen
NBD 08003	Richtlijn berekenen machineonderdelen van beweegbare bruggen
NBD bladen	Richtlijnen voor conservering en verf, electro-technische installaties en onderdelen, electrisch lassen, eisen aan materialen (gietstaal, smeedstaal, keramische bedekkingen, kunststof), tandwielkasten, staalkabels, niet-destructief onderzoek etc.

Electrical installations

CVB	Commissie Vaarweg Beheerders, Richtlijnen voor bediening van kunstwerken, 1996
ARTO	Algemene richtlijnen tunnelontwerp, 1990
RVV	Reglement verkeersregels en verkeerstekens, RVV 1990

Structural engineering

-	Handboek voor toegankelijkheid (Geboden toegang), 1998, Elsevier

Road design

RONA	Richtlijnen voor het ontwerp van niet-autosnelwegen
SATO	Handboek Specifieke Aspecten Tunnel Ontwerp

General

RWS	• Leidraad Energiezuinig Ontwerpen (LEO, Bouwdienst 1995) • Leidraad Duurzaam Ontwerpen (DUBO, Bouwdienst 1996) • Leidraad Afvalstoffen Rijkswaterstaat • Handboek onderhoud kunstwerken NI (Bouwdienst 1995) • Documentatiemap Beheer- & Onderhoudssystematiek voor Kunstwerken (Bouwdienst, 1999)

2.10 Checklist

2.10.1 Introduction

In the previous paragraphs, as complete a picture as possible was given of the Program Requirements necessary for the complete setup of a lock with corresponding lock approaches. In a later stage of the design process, after the preliminary design, program requirements geared to specific parts of the complex, such as gates, jetties and guiding structures are formulated. In those programs, more detailed items can be discussed than the general preconditions and requirements mentioned in this chapter, while points of departure could be added that are specific to the particular part concerned.

The preconditions and requirements mentioned in the paragraphs 2.2 up to and including 2.7 are summarized in a checklist in par. 2.10.3. The permits and standards from par. 2.8 and 2.9 have not been included.

2.10.2 Explanation checklist

The first column is for user ease. The user will have to ascertain which information he requires and which starting point (requirement) he has to take into account, where item numbers are provided.

The second column contains a short description. Some items appear several times. This was done to prevent the user from missing a certain item in a sequence of corresponding information/requirements. In these cases, the column "Comments" states that this item has previously been mentioned under another number.

The third column refers to the paragraph number, where the draft of the description is dealt with in more detail. Generally, it concerns a paragraph in chapter 2 and in some cases a paragraph in another chapter. If a more detailed description is not available, there is a horizontal stripe in this column.

The fourth column states whether an item is necessary for the preliminary design. Once again, please note that all information/requirements necessary for a complete lay out of a lock complex have come up in this chapter. Not all are required for a preliminary design. This column therefore states:

- X, if an item is necessary for the preliminary design
- ,if not everything concerning this item is necessary for the preliminary design, if for instance only a few indications are considered to be representative of the preconditions or only some directional indications of the requirements (see "Examples of" at the end of the paragraph).
- if it contains nothing, the item is not necessary for the preliminary design.

In the fifth and last column, comments are made with regard to further explanation, referrals to other item numbers etc.

Examples of:

- Item 7a: "Soil mechanical data (results of terrain and laboratory tests)". For a preliminary design, a limited number of soundings and borings are often sufficient. For a design, more data will be necessary.
- Item 15: "Possible requirements regarding locking and/or leakage loss". With regard to leakage loss for a preliminary design for instance, it will be sufficient to supply an indication of whether a requirement will be stringent or not. Possible numeric values for the leakage loss pursued can be quantified at a later stage.

Checklist

Item nr.	Description	See par. nr.	Preliminary design	Comments
	PRECONDITIONS	2.2		
1	Topography: Geometry description of the environment including maps of the expected changes, such as land, water, river, sea and title deeds as well as regional planning and zoning scheme.	2.2.1	X	
2	Possible existing lock that could remain operational or has to be renovated:	2.2.2		
2a	Geometry and condition;	id.	X	
2b	Current and anticipated use;	id.	X	
2c	Permitted limitations during the construction/ renovation.	id.	X	
3	Possible other hydraulic structures nearby:	id.		
3a	Geometry and condition;	id.	X	
3b	Current and anticipated use;	id.	X	
3c	Permitted limitations during construction/renovation.	id.	X	
4	Water levels:	2.2.3		
4a	Water levels with exceedance and underrun frequency levels	id.		For NHW etc, also see item 12
4b	Water level development (tidal curve etc.) within lock operation reach	id.		a/o For intake and discharge also see item 20
4c	Rising and lowering velocities	id.		a/o for overload operating mechanisms
4d	Historical water level data during dry and wet seasons	id.		a/o for discharging and intake
4e	Water flow	id.		a/o for layout of lock approaches
4f	River discharges/flood control regime	id.		
4g	Water quality (chloride content, "aggressiveness")	id.		a/o for volume weight, corrosion
4h	Water temperature	id.		a/o for lengthening /shortening steel parts
4i	Swell and wave data	id.		a/o for construction load and vessels
5	Wind data (speed, direction, frequencies)	2.2.4		idem plus wind action
6	Morphological data (such as bed-load and suspended-load transport) and forecasts	2.2.5		
7	Soil characteristics	2.2.6		
7a	Soil mechanical data (results of field and laboratory sampling)	id.		
7b	Geo-hydrological data (such as ground water level rise as a function of time, groundwater flow, results of pump test in case of ground-water lowering)	id.		
7c	Soil pollution where excavation takes place for lock and lock approach as well as in the general vicinity in case of possible groundwater lowering by pumping	id.		also see item 51
	FUNCTIONAL REQUIREMENTS	2.3		
	<i>Functional requirements regarding navigation</i>	2.3.1		
8	General: Design, build and manage the lock complex so that vessels of a given waterway classification index can pass rapidly and safely:	2.3.1.1		
8a	• Normative vessel (length, width, depth, height)	id.	X	Now and in the future
8b	• Normative combination of shipping vessels	id.	X	id.
8c	• Normative traffic and fleet composition, taking the spread of arrival times into account	id.	X	Now and in the future. A choice will have to be made between 8b and 8c, in which 8c is preferable.

9	Lock approaches:	2.3.1.2		
9a	Per lock (chamber) and per side (above and below) a lining up area is required that is situated as such that moored vessels do not form an obstacle to departing vessels, while the moored vessels are able to sail into the lock via leading jetty rapidly.	id.	X	
9b	The size of the lining up area is geared to a complete chamber fill (for existing locks with small amounts of traffic this is unnecessary). The width is equal to that of the chamber.	id.	X	
9c	Waiting areas are necessary if it is expected that, on busy days, lining up areas will not be sufficient. A waiting area is created per side of the lock complex (a common area if there are several chambers).	id.	X	also see items 22b, f and g
9d	At very least, a normative vessel should be able to moor here.	id.	X	
9e	With a view to the stopping and mooring, the free area is given a length of at least 2.5 times the normative vessel length (inland navigation) depending on the adjoining waterway.	id.	X	
9f	Is the lock approach also used as stay over harbour, refuge harbour or compulsory harbour?	id.	X	also see item 22g
10	Leading jetties:	2.3.1.3		
10a	Approach wall lengths and shapes are a function of navigation (sea, inland, recreational navigation). In combined use by various categories, the shape that belongs with the largest vessels is normative.	2.4.2.2	X	
10b	The successive wet cross sections in the change over from leading jetties to chamber entrance should be (hydraulically) symmetrical wherever possible.	2.3.1.3		
11	Chamber and heads:	2.3.1.4	X	also see items 22c, d and e
11a	The main dimensions are derived from the requirement to deal with traffic rapidly and safely (item 8) the max. and min. locking levels (item 20), the flood control requirements (item 12), as well as constructive integration of these elements (par. 4.6).	id.		
11b	In newly built locks, the chamber and the heads are given the same working width.	id.	X	
11c	If the lock mainly functions as an open lock, higher navigation speeds on passing through the lock should be taken into account.	id.	X	for example a larger wet cross section
	<i>Functional requirements regarding the water retaining structure:</i>	2.3.2		
12	Overflow and overtopping:			
	For determining the height of the gate plating and the capstone, the following is taken into consideration:			
12a	NHW (Normative High Water)	4.5.3	X	
12b	Rise in sea level	4.5.4	X	
12c	Settlement and settings	id.		
12d	Rise in the water level due to local wind action	id.	X	
12e	Rise in the water level due to seiches and weather caused oscillations	id.	X	
12f	Retaining height	4.5.5	X	
12g	Available water storage	id.	X	At overflow, the retaining height is a function of the basin capacity
13	Strength and stability:	2.3.2		
	Must comply with the stated standards and guidelines in par. 2.3.2 under point 2.			
14	Reliability of closing gates:	id.		
14a	If both the gates in both the heads are sufficiently flood retaining (item 12): no requirements.	id.		
14b	If only a sufficiently high door in the outer head, then the reliability of closing the gate needs to meet the requirement stated in par. 2.3.2 under 3.	id.		
	<i>Functional requirements regarding water management:</i>	2.3.3		
15	Possible requirements regarding lock and/or leakage loss	2.3.3.2		
16	Possible requirements regarding the separation of salt water and fresh water	2.3.3.3 chpt.21	X	

17	Water discharge or water intake through or along the lock? If affirmative, take into account flow patterns unfavourable to navigation and permitted current velocities as sketched in par. 2.3.3.4.	2.3.3.4		
	<i>Functional requirements regarding the crossing of dry infrastructure:</i>	2.3.4		
18	Roads:	2.3.4.1		
18a	During construction: required (temporary) adjustments to possible pre-existing facilities.	id.		18a and b could possibly be partly combined
18b	Expected road facilities in use phase	id.	X	
18c	Cross sections (profiles of free space) for 18a and b.	id.		profile of open space in case of tunnelling and lift bridges
18d	shipping clearance.		X	
18e	Is periodical, temporarily stopping road and navigation traffic acceptable?		X	choice between fixed and moveable bridge, bridge pillars and drop etc. could obstruct view
18f	Free view requirements			
19	Cables and mains:	2.3.4.2		
19a	During construction: required (temporary) adjustments to possible pre-existing cables and mains.	id.		19a and b could possibly be partly combined
19b	Use phase: under lock body or lock approaches or via bridging? With corresponding requirements.	id.		
19c	Combined lead-through of cables and mains for lock operation with lead-through for a third party?	id.		
19d	Requirements with regard to mutual influences (distances) cables and requirements regarding risks related to mains of the locking operation.	id.		
19e	Visual inspection necessary/possible.	id.		
	USE REQUIREMENTS	2.4		
	<i>Levels:</i>	2.4.1		
20	Lock levels:	2.4.1.1		
20a	Maximum lock level.	id.	X	
20b	Minimum lock level.	id.	X	
20c	High and low normative water levels in aid of speed / safety of dealing with traffic (10% exceedance and underrun respectively) on the river side of the inland navigation lock.	id.	X	Only for the guiding structures, mooring posts and capstone height on the riverside
20d	High and low normative summer water levels (May/Sept.) in view of accessibility (2% exceedance and underrun respectively) on canal c.q. tidal side of a lock with recreational navigation (possibly in combination with inland navigation).	id.	X	
20e		id.	X	
21	Design levels (water retaining structure)	2.4.1.2		
21a	NHW (Normative High Water)	id.	X	already stated under item 12a
21b	Lock level flood gate	id.		
21c	Lock level open lock	id.		change over locking process
	<i>Possible preference for separating different types of vessels</i>	2.4.2		
22	Possible separation in use of lining up and waiting areas and lock chamber	2.4.2.1		
22a	For safety reasons, it is recommended that vessels are separated according to category (sea, inland and recreational navigation) when mooring in the lining up or waiting areas, as well as during chamber arrangement and/or chamber assignment.	id.	X	
22b	In view of safety, is it necessary/desirable to create separate lining up and waiting areas for inland and recreational navigation?	id.	X	
22c	From a safety point of view, separate chambers of sea, inland and recreational navigation are preferable.	id.	X	
22d	If 22c is economically unacceptable, then combined locks, in which combined sea and recreational lock filling must be avoided.	id.	X	

22e	For a combination of inland and recreational navigation, consider:	id.	X	
	• a wide chamber with both kinds on one side; • a long chamber, in which both kinds are placed behind each other with a safety margin (min. 5 m) in between (inland navigation in front).			
22f	Are separate waiting places and chamber arrangements (with mutual safety distances) required for vessels with hazardous goods?	id.	X	
22g	Are stopping off areas necessary for semi, continuous and day navigation and/or continuously available mooring facilities for semi-continuous navigation (inland navigation)?	id.	X	
23	The shape of the leading jetties at the lock entrance as function of the type of navigation (sea, inland, recreational navigation)	2.4.2.2.	X	
	<i>Mooring facilities in the chamber and lock approaches</i>	2.4.3		
24	Chamber:	2.4.3.1		
24a	Required pattern for placing bollards, bollard recesses, toggles and mooring pipes as function of the vessel type (sea, inland and recreational navigation).	id.		
24b	Choice between fixed and floating bollards as function of vessel size, gravity flow and rising velocity during levelling. Required pattern of positioning in case of floating bollards	id.		
24c	Magnitude of force that mooring facilities (bollards etc.) have to be dimensioned to as a function of vessel size.	id.		
25	Lock approaches:	2.4.3.2		
	Mooring facilities could consist of mooring posts, mooring piers, constructions with wales (fixed or floating guiding structures) and quay or sheet pile constructions, provided with mooring facilities (bollards, bollard recesses).			
25a	Required distances between mooring posts and mooring piers.	id.		
25b	Required wale height with regard to normative high and low water levels.	id.		
25c	Choice between fixed and floating guiding structures as function of water level variations.	id.	X	
25d	Required pattern for positioning the mooring facilities.	id.		
25e	Magnitude of force that mooring facilities have to be dimensioned to.	-		
25f	Magnitude of the mooring force of vessels that mooring facilities have to be dimensioned to.	15.4		
26	Leading jetty:	2.4.3.3		
26a	Installing a limited number of bollards, bollard recesses for construction vessels.	id.		
26b	Magnitude of sailing up / mooring force of the vessels that have to be taken up in the leading jetty construction.	15.4		
27	Operating times (= opening times):	2.4.4		
27a	Desired operational times (hours/day, distinguishing from Monday, Tuesday up to Friday, Saturday and Sunday) for inland navigation as function of passing load capacity and CEMT classification.	id.	X	
27b	Desired operational times for shipping.	-	X	
27c	Desired operational times for recreational navigation.	2.4.4	X	
28	Levelling times:		X	
	Intended levelling times as function of the kind of lock (sea, inland, recreational navigation), gravity flow, horizontal dimensions and type of filling (gate opening, culverts).			
	<i>Operational management</i>	2.4.6		
29	Process descriptions:	2.4.6.1		
	Analysis of operational management for the benefit of drafting process descriptions (normal lockage, obstructions, flood retaining structure, taking in/discharging salt water/fresh water.			
30	Information for operational management:	2.4.6.2		
	Finding the necessary information for operating and managing, such as navigation volume and water levels, as well as the approximate necessary facilities for this.			

31	Required facilities and procedures for desired operating situations:	2.4.6.3		
31a	Which installation (parts) require emergency power supply and which parts require a no-break supply?	id.	X	
31b	At gravity flow larger than 1 m, the slides of the intake and discharge system must be able to close rapidly (without creating undesired transitory surges) if a vessel is in danger of getting tied up in the hawsers.	id.		
31c	Is a construction for collision protection of the gates necessary?	id.	X	
31d	Locks with a stringent draught limitation can be fitted with acoustic draught metre in the bed of the lock approach and at sufficient distance from the gates.	id.		
31e	Are measures required to cope with ice problems?	id.	X	Depends on economic importance of waterway
	<i>Operating:</i>	2.4.7		
32	Situating the operating building	2.4.7.1	X	
32a	Situate the central lock operating building as such that optimal view of the lock and the lock approach is obtained. If possible, position operating area on bridge where view of approaching traffic is combined with view of the lock. Preferably situate operating area on bridge, on the side of the chamber and opposite the fulcrum.	id.		
32b	Remove "blind spots" with cameras.	id.		
33	Local operational facilities:	2.4.7.2		
	Consider operating per head in locks for recreation, as well as – but only for maintenance and calamity situations – commercial navigation locks.			
34	Means of communication:	2.4.7.3		
34a	At every lock: marine telephone for communication between operators and vessels.	id.		
34b	Central Operation: usually emergency telephones at lining up and waiting areas and a talk-back system, possibly a public-address system.	id.		
34c	Recommended: acoustic signal at start of levelling.	id.		
35	Choice (partly) automated and self-service:	2.4.7.4	X	
	It is recommended that (parts of) the operating process is automated in view of operational cost and the speed/safety of dealing with traffic.			
36	Remote control locks:	2.4.7.5	X	
	Not very usual, with the exception of recreational locks.			
37	Illumination, signalling and boarding:	2.4.8		
37a	Required <i>level of illumination</i> in indicated places of the lock complex yet to be specified, taking into account any possibly misleading illumination in the surrounding area, avoid dazzling, the desired evenness of illumination and the colour of illumination for the recognition of boarding and signalling.	2.4.8.1, 2.4.8.5		
37b	Indicate which surfaces/areas need to be <i>marked</i> . White is a good colour for showing contrast at a low level of illumination, for example vertical surfaces of guide structures for guiding navigation.	2.4.8.2		
37c	<i>Signalling</i> according to BPR and RPR (Dutch traffic regulations for inland waters).	2.4.8.3		
37d	<i>Boarding</i> according to BPR and RPR.	2.4.8.4		
38	Power supply:	2.4.9		
38a	Possibilities offered by the public electricity network for accessing power during the construction and the utilization. If network capacity is insufficient, adjust or – for example during construction, place generator sets.		X	
38b	Emergency power supply units and no-break installation.		X	Already mentioned under 31a
39	Availability:	2.4.10		
39a	Analysing the causes of non-availability and indicating required boundaries in the design (in percentages of the time) in so far as these are economically sound and the causes can be influenced. The causes could be:	2.4.10.1, 2.4.10.2		Strive for the smallest possible non-availability

39b	Water levels above maximum and below minimum locking level.	2.4.10.3, 2.4.1.1		The resulting (< 2%) non-availability stems from the arrangement of these levels. Also see items 20a and b
39c	Too much wind: under which conditions is it still safe to lock?	2.4.10.4	X	The resulting non-availability is difficult to indicate.
39d	Malfunctions in installations, operating mechanisms and operating. Non-availability limits should be provided in the design of these parts.	2.4.10.5		
39e	Collisions (at best, a forecast of non-availability due to this is possible). Measures to limit collisions could be: • good shaping of leading jetties ;	2.4.10.6		
	• no parts of the opened moveable bridge protruding over lock chamber	2.3.1.3, 2.4.2.2 2.3.4.1	X	Already stated under items 10 and 23
	• possible collision protection constructions for gates;	2.4.11.1	X	Already stated under item 31 c
	• limit duration of obstruction, by having reserve parts and reserve gates.	2.5.2, 2.5.3	X	Also see items 46b and c
39f	Maintenance (at best, a forecast of non-availability due to this is possible)			Also see item 46
40	Protecting constructions against damage:	2.4.11		
40a	Gates can be equipped with wood fenders in places where they can be hit by vessels.	2.4.11.1		
40b	Consider whether anti-collision structures are worthwhile and economically sound (possibly in large high-lift locks).	id.	X	Already stated under item 31c
40c	Provide concrete surfaces that could be hit by vessels with expansion joints and endings, bevelled edges, steel corner protection, capstone profiles etc.	2.4.11.2		
40d	In locks for large vessels, apply drifting frames (or fenders).	id.	X	
40e	For sheet pile constructions the flat mooring (sailing in) area should be approached by positioning wooden or synthetic posts and regulators.	id.		
40f	To prevent vandalism, prevent access to vital parts of the lock complex by placing fences etc.	2.4.11.3		
40g	To prevent indefinable process management due to lightning strike or electromagnetic interference, electrical installations should be designed according to safety regulations standards stipulated in art. 2.4.11.4.	2.4.11.4		
41	Safety:	2.4.12		
41a	Install ladders in the chamber and lock approaches to rescue people.	2.4.12.1, 2.4.13.2, 2.4.13.3		
41b	Take measures with regard to the safety of the personnel in accordance with the Health and Safety Regulations (railings, steps and landings, escape routes, sufficient ventilation, First Aid equipment etc.).	2.4.12.2		
41c	Install measures for fire-fighting in accordance with the regulations of the Ministry of Waterways and Public Works and in consultation with the fire brigade. Provide additional facilities for vessels with hazardous goods.	2.4.12.3, 2.4.13.3, 2.4.13.4		Also see item 42b
42	Accessibility of lock and lock approaches:	2.4.13		
42a	Road connections between public roads, possible wharf, reserve gate storage and essential parts of the lock are needed. Where necessary, execute metalling/asphalting of roads to make them suitable for heavy transport and mobile hoisting devices.	2.4.13.1		
42b	For the accessibility of vessels in the lock and the lock approaches, install ladders and footbridges. For fire fighting and assistance, follow the procedures of the authorities concerned.	2.4.13.2, 2.4.13.3, 2.4.13.4		
43	Additional client wishes: These wishes have to be known in the early stages of drafting the Program Requirements. (It could be about a preference for a certain kind of gate, operating mechanism or switchgear).	2.4.14	X	

	<i>Mean life requirements:</i>	2.4.15		
44	Design mean life of lock complex: For the construction of new locks the mean life is, as a rule 100 years, and for renovation 50 years. Distinction is made between: • non-replaceable parts, such as lock body, fixed bridges, piping and outflanking screens with a required mean life of 100 respectively 50 years. • Well maintained / replaceable parts such as gates, moveable bridges, operating mechanisms, electrical installations, and guiding structures, of which the mean life is determined by the basic cost of the investments plus the nett cash value of maintenance and replacement during the 100 respectively 50 years.	2.4.15.1	X	
45	Mean life of specific parts:			
45a	Electrical installations generally have a mean life of 25 years, given reputable design criteria related to specialized maintenance. Installation parts that are not installed in a protective or conditioned environment in accordance with their design, have a life span of about 10 years.	2.4.15.3		
45b	Hardware and software have a mean life of about 5 to 10 years.	2.4.15.4		
45c	At the end of mean life, sheet pile constructions and its anchoring – taking corrosive loss into account – should have sufficient material present to meet the necessary strength and stiffness requirements for moment of resistance and moment of inertia.	2.4.15.5		
45d	These elements, from which guiding structures are composed, do not necessarily have the same technical life span. The elements that are easy to replace could easily have a shorter mean life.	2.4.15.6		
	MAINTENANCE REQUIREMENTS	2.5		
46	Maintenance	2.5		
46a	The <i>maintenance strategy</i> should be based on the requirements related to safety of the retaining structure, the availability to the lock company as well as the mean life.	2.5.1, 2.3.2, 2.4.10, 2.4.15		
46b	In principle, there should be a <i>reserve gate</i> for every gate. Reserve gates are stacked horizontally or vertically in a gate storage where, as a rule, maintenance (on an exchanged gate) takes place. Lift gates can generally be maintained when hoisted, provided that navigation allows for this. On important navigation routes, gate docks incorporated in the heads (for maintenance) could also be used as storage space. It is recommended that a reserve gate is kept as complete as possible when stored.	2.5.2	X	
46c	Locks should have sufficient <i>spare parts and materials</i> on site.	2.5.3		
46d	Decisions must be made – for the benefit of inspection and maintenance of broken parts of the gates - on whether <i>the heads</i> should lay open or whether pivot inspection chambers or other local de-watering methods will be used	2.5.4	X	
46e	Parts that require inspection and maintenance must be made as <i>accessible as possible</i> , for instance with the aid of stairs, climbing support or footbridges. High control portals could be provided with lifts.	2.5.5		
46f	Consider <i>monitoring</i> the parameters that describe the condition of construction parts and/or loads that work on this and/or the degree of damage.	2.5.6		
46g	<i>For electrical installations, hardware and software:</i> • Materials and components should be set up conditioned and accessible; • Hardware and software must be modular for optimizing corrective maintenance; • Equip computer installations with control mechanisms for timely recognition and tracing of malfunctions and deviant process behaviour.	2.5.7		
46h	Depending on the scheduled maintenance, set up <i>storage areas and workshops</i> at or near the lock complex (or in combination with other locks nearby).	2.5.8		

	ENVIRONMENTAL REQUIREMENTS IN USE PHASE	2.6		
47	Aesthetics:	2.6.1		
47a	In view of design, colour balancing and blending in with the environment, always involve an architect and sometimes a landscape architect early on in the process.	id.	X	
47b	Lift gates, vertical storage of reserve gates and high, fixed bridges could be less acceptable (horizon pollution).	id.	X	
47c	During renovations, it could be desirable to blend in the parts that come into view with the historical environment. For example, finish the chamber and heads with bricks and install wooden gates.		X	
48	Environmental requirements with regard to building materials: Par. 2.6.2 contains a summary of guidelines in relation avoiding the application of certain materials.	2.6.2		
49	Recreation: Consider whether parts of the lock complex should be made accessible to the public for recreational purposes, providing that it does not pose any safety hazards (for public and navigation) or a disruption for the lock authority.	2.6.3		
	ENVIRONMENTAL REQUIREMENTS IN CONSTRUCTION PHASE	2.7		
50	Available construction site and final grounds:	2.7.1		
50a	The sites must be available on time. Construction requires more surface than the space required in the use phase, certainly if excavation is executed on inclines. This could be a reason to choose for different construction methods, for instance a building excavation (between sheet piling). Limited surface could be a reason to abandon horizontal roller-bearing gates.	id.	X	
50b	The construction site has to be accessible on time (links to the public road network and possibly a wharf) and connected to public power supply (if not possible on time, generators should be considered). Using the public road for work traffic could be subject to certain requirements.	id	X	
51	Polluted soil: Legislation on soil protection applies (Act at Abandoned Waste Sites). The presence of pollutants and the degree in which it is found largely determines the soil balance (recycling it in the work or other projects, transporting it to specially designed depots) and with that, the costs involved. The costs could be a reason not to choose for construction methods that require a lot of excavation and earth moving. Toxic waste dumps could result in restrictions on draining, even at large distances.	2.7.2		
52	Withdrawal of groundwater: Whether the withdrawal of water is not permitted, permitted to a certain degree or allowed is a large factor in determining the construction method and with that, the costs involved. Return pumping could be a solution, but this also requires a permit from the provincial authorities.	2.7.3	X	
53	Maintenance/upkeep of road and navigation traffic, cables and mains: The requirements, set by the authorities, to temporary adjustments and detours of existing infrastructure during construction have to be known.	2.7.4		Also see items 2, 3, 18a and 19a
54	Maintenance of flood control structure: All interventions and modifications to existing flood control structures require approval from dike authorities. Par. 2.7.5 provides the specifications in the TAW Guideline on Flood Control Structures and Special Constructions (TAW-Leidraad Waterkerende Kunstwerken en Bijzondere Constructies) in relation to the execution of activities in or near flood control structures during the open and closed season (resp. 15 April - 15 October and 15 October - 15 April)	2.7.5	X	

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Photo 3.1 Civil Engineering Division, Utrecht branch



Photo 3.2 Civil Engineering Division, Zoetermeer branch

Chapter 3 **Design process**

3.1 Introduction

The objective of the design process is to achieve an optimal design of a lock and lock approaches that meet the program of requirements in technical, economical and three-dimensional respect, via a structured procedure. A number of phases can be distinguished in this process and are described in more detail in par. 3.2. The completion of each phase is validated against the program requirements and this determines the decisions with regard to the next steps to be taken. This could result in adjusting the program requirements: theoretically, a design process is a cyclical process that is used to optimise the process result.

Previously, mention is made of "economically optimal". The program requirements largely determine the economic benefits of the lock complex. This certainly applies to the functional requirements with regard to navigation. Then again, there is the cost. The designer has to pursue the sum of the investment costs and the cash value of exploitation (including maintenance) and replacement during its life span and the cash value of demolition at the end of the life span being minimal. Minimizing the total cost remains the objective of the designer during the complete design process.

Besides this, the total cost could be reason to adjust certain facets of the program of requirements. Of the design process, mainly the preliminary design is discussed in this book. For this reason, this phase of the design process is addressed in more detail in par. 3.3.

This chapter deals with the traditional approach to designing a lock. Chapter 22 "New developments" presents an alternative method – called the 'functional design' – that starts from the main functions that a lock has to fulfil and with that, seeks an economic optimum over the life span. With this method of design, in addition to the existing requirements with regard to water retaining and constructional safety, formal reliability requirements are developed for locking, water level control and cross channel connection. All of these requirements are integrated in the design process.

3.2 Phases of the design process

3.2.1 Phase overview

A lock has the following successive phases:

1. Initiation phase
2. Definition phase
3. Preliminary design phase
4. Design phase
5. Preparation phase
6. Realisation phase
7. Use phase
8. Renovation phase (possibly)
9. Demolition phase

Observing the phase division and planning of the first six phases is necessary because otherwise it generally results in unmanageable deviations in time and technical project management that cost the principal extra money.

The list above does state the maximum number of phases. For practical reasons, well-founded deviations are possible, for instance in the case of plan studies whereby only broad outlines of preliminary designs are made (with the corresponding inaccuracies).

In essence, phases 1 up to and including phase 5 make up the design process but during the execution phase, the designer plays an important role (in making working/detail drawings and in guiding the management).

Phases 8 and 9 can actually be subdivided into sub-phases 1 to 6, whereby the whole process is covered again from initiation through to execution, while a use phase follows a renovation.

Paragraphs 3.2.2 up to and including 3.2.7 take a closer look at phases 1 to 6 that together make up the design process. The preliminary design is given a more extensive description as the accent of this book lies on this phase of the process.

In order to provide the descriptions use was made of the CUR-publication 166 "Sheet pile constructions" ("Damwandconstructies") (Lit.[3.1]) and "Program of Requirements, second lock Lith". Certain parts of the text were copied literally.

3.2.2 Initiation phase

After the initiator or principal has determined that a lock could be a possible solution, the principal will take the initiative to commission a study to assess the feasibility of the project in a given situation. The feasibility could concern a lock complex (one lock or several parallel locks) or it could concern a navigation route in its totality, which could include one lock or several successive locks. If the project is feasible, a general program of requirements outline will be drafted based on the results of the study.

Often, structural works are a continuation of policy documents, such as in the field of Traffic, Transport and Water, and/or strategic documents for the development of planning. This is followed by a cost-benefit analysis with considerations based on functional analysis. In some cases, the initiative has to go through the statutory Environmental Effects Report Procedure. Based on the results of the feasibility study etc. the initiator or principal decides whether to proceed or stop. If the decision is to "continue", the definition phase is entered.

3.2.3 Definition phase

Based on detailed analysis of the requirements and the wishes of the principal, which could partly derive from urban and rural planning study results, the designer drafts the program of requirements for the lock complex. Chapter 2 indicates which preconditions and requirements have to be taken into consideration before the next phase, the preliminary design, can be addressed. As previously stated, some of the information and requirements will only become necessary in the design phase.

3.2.4 Preliminary design phase

In this phase, a number of possible solutions (variants) in the lock complex are developed into rough designs. The elaboration should be such that a well-founded choice can be made between the possible solutions generated. This necessitates a level of detail that is equal for all the solutions. In the rough outlines, all determining aspects have to be taken into consideration for each choice. Strength, stability and deformations have to be subjected to the same design criteria, as would be the case in the final design, even though it usually only concerns rough calculations. In addition, attention has to be paid to the execution, construction time, construction costs as well as the other costs (exploitation which includes maintenance, replacement and demolition).

Based on the assessment criteria for the complete structure, a choice is made between the various solutions. The assessment criteria could include: the degree in which navigation and other requirements are met, construction time, costs and sustainability. In some design manuals, technical feasibility is stated as criteria.

It seems sensible to only compare feasible solutions in the variant document. At most, differentiation can be made between structures that have been previously realized and structures that are new.

The latter could be provided with a risk consideration, of which the results are included in the variant assessment.

The preliminary design consists of the following activities:

1. In view of managing design quality, a product quality plan is drafted based on a List of Critical Parts and Qualities. This plan has to stay "alive" from preliminary design up to and including execution.
2. Working out further details of the overall project requirements in requirements per discipline, as formulated in the Program of Requirements.
3. Listing the possible technical solutions to main issues such as geometry, intake and discharge systems, gates and operating mechanisms, heads, chamber and guiding structures.
4. Research into technical solutions in relation to construction and the technical and financial aspect.
5. Detailing feasible solutions into variant solutions that include rough design calculations.
6. Drafting cost estimates for feasible solutions in the band width of $\pm 20\%$ conformity with "Points of departure in drafting estimates" from the Project Estimates Infrastructure ("Uitgangspunten bij het opstellen van ramingen" uit het Project Ramingen Infrastructuur (PRI) van Rijkswaterstaat) (Lit. [3.3]).
7. Collect additional information for the design phase.
8. Drafting a rough operation plan.
9. Drafting a variation document for the benefit of the decision document "Preliminary Design Document". A document of this kind will be made for selecting the gates.
10. Supply information for permits and procedures.
11. Formulating the decision document "Preliminary Design Document", which completes the design phase. The document contains:
 - details on overall project requirements per discipline;
 - criteria for the assessment of variants;
 - the likely variations with cost estimates;
 - a motivation for choosing one of the variants.

3.2.5 Design phase

After the principal has made a decision, the chosen variant is worked out in more detail in this phase. In general, this encompasses the following activities:

1. Quality document in relation to the product quality of the design.
2. Determining the points of departure for the design calculations.
3. Optimising the chosen variant.
4. Making the final design calculations.
5. Making the design drawings.
6. Adjusting cost estimation (to a band width of $\pm 10\%$).
7. Making management and maintenance plans.

8. Mapping out the execution strategy (including measures, facilities) in the shape of an execution plan for quality control during the execution, with a product quality document.
9. Document an approach plan for the preparation phase.

3.2.6 Preparation phase

In this phase, the specifications and accompanying drawings are drafted. These serve as contract documents to the agreement between the contractor and the principal.

Invitation for tenders and contract awards are subsequently prepared. Between these two points in time, the designer could be required to assess alternatives raised by the contractor or – if it concerns a performance specification – assess the submitted designs in their totality.

Usually, the objective is to grant the construction of the complete lock in one contract. It is also possible to draft several specifications and grant them successively. The specifications could be classified according to disciplines (for instance civil engineering, steel constructions and operating mechanisms) but also within one discipline (for instance civil engineering divided into lock body and guide structures). The choice between the various kinds of contracts depends on the strategy of the principal: in the case of one contract, the coordination of very diverse activities lies with the contractor, whereas in the case of several contracts this is the responsibility of the principal.

3.2.7 Realisation phase

In this phase, the duties of the designer could consist of making detail calculations and working drawings (or, if these have been subcontracted, checking the drawings) and guiding management.

In the latter case the designer, on behalf of the principal, keeps control of the quality of the executed work, which includes monitoring time and cost.

If the work is executed according to quality assurance, the supervision of the designer will limit itself to monitoring the quality plan checks set by the contractor on previously established points in the program execution. These inspections could also be "audits" that are executed by independent external experts.

At the end of the execution, documentation should be available about the details of how the lock complex was actually constructed (final drawings, base-line etc.). In addition, all maintenance regulations developed during the realisation phase should be incorporated in a maintenance outline (see par. 19.5).

3.3 Process preliminary design

3.3.1 Introduction

During the preliminary design phase, a number of variations are developed and compared with each other. This comparison should yield one variant as being the most suitable variant for further elaboration in the design phase.

The variations are different translations of the program of requirements into concrete general designs of the lock complex. Concrete and general in the sense that it can be established to which degree the program requirements are being met and whether the requirements for strength, stability and deformation and a cost calculation with a margin of $\pm 20\%$ are being met.

We emphasize that it concerns global designs that should be equally comparable and a cost indication with relatively large margins. This means for instance, that reinforcement drawings do not have to be made of walls and floors of concrete constructions but thickness does have to be determined with regard to maximum moments and transverse force along economically sound considerations.

Par. 3.3.2 describes, by means of a flow chart, how the preliminary design can be completed in successive steps. For instance, steps like the intake and discharge system, the gates and the operating mechanisms. Most of these steps are subdivided into sub-steps. For each sub-step, indications are provided as to which preconditions and information from the program of requirements should be used for this subdivision in so far as this has not been specified in the previous steps.

Par. 3.3.2 relates to a lock complex without additional functions with regard to water management (limiting water loss, separation of fresh and salt water, water intake and discharge). In par. 3.3.3, indications are given in relation to which extra preconditions and information from the program of requirements should be used for the different sub-steps if the lock complex is given a water management function.

Alternatives are possible for many of the steps for the lock subdivisions concerned. Par. 3.3.4 provides examples of when these alternatives within a sub-step can be compared and when it is necessary to include the consequences for the subsequent sub-steps in the comparison as well (for instance, the comparison of two types of gates is only possible if attention is also paid to the heads, that are different for each type).

Par. 3.3.5 provides the general choice criteria for selecting alternatives while par. 3.3.6 gives a number of indications in relation to limiting the amount of work required for this selection ("taking along" several variations for a certain sub-step to all subsequent steps could result in a lot of work).

3.3.2 Flowchart for preliminary design of lock complex without requirements for water management

Figures 3.1 to 3.4 show how sequential steps in a preliminary design are developed and which elements from the program of requirements are used as points of departure for each step.

The complete design is divided into the blocks 1 to 12 (from geometry to operation), whereby most of the blocks have a subdivision into successive (sub-) steps, for instance 1a to 1l. Sub-steps were not made for blocks that usually relate to a very general approach in the preliminary design phase.

The design process progresses according to ascending numbers and letters, unless an arrow indicates that there should be a change over to or return to another block or another sub-step in that block. In order not to make fig. 3.1 too full (cluttered), it does not indicate where the forks to the blocks in fig 3.2 to 3.4 occur. The last three figures do state which step in fig 3.1 should be completed before this can be started, as well as after which sub-steps the change over back to certain steps in fig. 3.1 takes place.

Most blocks end with an arrow pointing in the direction "Part of end product". By means of optimal compilation of all the parts, a complete preliminary design has been arranged. Block 2, for which there is no "Part of end product" block in fig. 3.1 because the arrows refer to blocks 1 and 3, naturally also belongs to this preliminary design.

In many of the steps, various solutions are possible. These will have to be compared to each other before continuing with one solution. In some cases, a choice will not be possible just yet because various principles for solution can lead to different effects (and especially different costs) in the subsequent steps. The variant selection is addressed in par 3.3.4 to 3.3.6.

Geometry (block 1 in fig. 3.1) is, first of all, the design and the horizontal and vertical dimensions of the lock complex, required for performance. However, complete dimensioning does not only include effective dimensions (such as passage width), but also the thickness of construction parts like walls and floors. This means that the geometry is complete once those from blocks 5 to 8 and 10 have been added to block 1 (those from 2 to 4 have already been added according to fig. 3.1). This could mean, for instance, that for determining longitudinal stability of the heads (1h), the construction thickness of the floors and walls should be available from 6b. However, for a preliminary design an estimate is often sufficient for similar exploratory calculations, as these will be verified later in the preliminary design or the final design. All the directional arrows related to similar activities are not shown in the figures. Design is a cyclical process in which dimensions are frequently estimated in the early stages, verified on strength and stiffness and subsequently adjusted if necessary. Please note that in the preliminary design, the issue is not to determine the reinforcement but to provide the structure with such a thickness that the maximum moments of transverse force can still be economically included. Optimisation takes place in the design. At this stage, it concerns determining the costs with a margin of $\pm 20\%$.

The figures provide key words of the preconditions and requirements to be introduced.

In actuality, in the key word "separation of different kinds of vessels" (at 1a) includes that which is stated in general in par. 2.4.2 and in chapter 4 and that which is more specifically included in the program of requirements for a lock complex.

3.3.3 Influence of water management requirements on the flowchart

The following possible functional requirements regarding water management can be distinguished in par. 2.3.3:

- a. limiting water loss;
- b. separation of salt and fresh water;
- c. water discharge and intake.

The following addresses these points successively.

a. Limiting water loss

If this is a requirement, it will have to be included in the following steps (see fig. 3.1 to 3.4):

1a and 1b (one lock or several locks next to each other, with or without intermediate gates):

In periods of limited navigation, (in volume or dimensions) it could be attractive to have disposal of smaller lock surfaces in order to limit lockage water.

2 (filling/emptying):

In large water level differences and stringent requirements for water loss, side ponds could be considered that will have to be integrated in the intake and discharge system. The high costs of such a system will have to be weighed up against the cost of pumping the water back to the high reach from the low reach. Due to the small water level differences in our country, side ponds will not really come up for consideration unless the water loss requirements become more stringent in the future. A less expensive system was built near Maasbracht, where half of the chamber content of the lockage water is emptied

into an adjacent chamber via a lock culvert. The application of this water saving system does result in simultaneous raising and lowering of chambers and this will not always comply with demand.

3a (selection type of gate):

Lift gates enclose the effective space for navigation tighter than mitre gates, which limits lockage water. Horizontal roller-bearing gates are also unfavourable because of the extra part of the lockage water that is in the gate recess. This can be avoided by pushing the gate in the direction of the lock chamber (Krammer). This is an expensive solution.

Certainly in the case of negative water level differences, mitre gates do result in larger leakage loss than most other kinds of gates.

b. Separation of salt and fresh water

This requirement, as well as the degree of separation required, could have an influence on the following steps:

1a and 1b (one lock or several locks next to each other, with or without intermediate gates):

It could also be attractive here to have disposal of small lock surfaces during periods of limited navigation.

1d (sill depth):

As explained in chapter 21, fixed sills in locks to 6 m wide and moveable sills in larger locks could belong to the alternatives for this problem definition.

2 (filling and emptying):

For stringent requirements with regard to the degree of salt/fresh water separation, systems are required that completely determine the levelling process as is the case with the Duikkerken system. These very expensive systems will also have consequences for the geometry of the lock body and the lock approaches (e.g. deepened bottoms, sufficiently wide for a salt lift trap and culverts). For a description, see chapter 21.

c. Water discharge and intake

Water discharge and intake has to be included at the following steps:

1a (one lock or several locks next to each other):

If there are several locks next to each other it is possible, in periods of limited navigation volume, to use one lock for locking and the other lock(s) for flushing water, for instance via the gate openings for filling and emptying.

2 (filling/emptying):

For flushing, consider using the normal levelling regime for filling and emptying facilities (for one lock outside the regular operating hours or in case of no expected navigation). It is conceivable to increase the maximum flow through capacity of the levelling facilities with a view to the flushing discharge.

For larger flush discharges or for locks intensively utilized by navigation, separate culverts or water-courses will have to be made for flushing. These will mainly have an impact on the geometry of the lock approaches. For the restrictions that are imposed on flow pattern or flow velocities in view of navigation hindrance, we refer to par. 2.3.3.4.

3.3.4 Variants

In many of the steps, variant solutions are possible for the requirements set. In this, distinction can be made between alternatives that can be compared with each other within the step concerned and more frequently, the variants that have to be taken along to one or several of the following steps as the variants have consequences there as well. The following provides some examples of both categories.

Examples of alternatives that can be compared in one step:

5a *Chamber, selection and method of construction.*

Subject to the construction method geared towards building the heads, a choice can be made without this having large consequences on the successive steps. The principles for solutions and the choice criteria are described in chapter 9.

7 *Guiding structures.*

Subject to the being adapted to the abutment walls, choices can be made from the different solution principles within this part of the project without this affecting the other steps.

Examples of alternatives, for which subsequent steps also have to be investigated:

1a *Geometry, one lock or several parallel locks?*

The choice cannot be made until after further investigation has been executed (in the subsequent steps). Please note however, that several parallel locks are generally only an option in the case of substantial navigation volume or in case of a pointed preference for separating the different types of navigation.

1b *Geometry intermediate gates?*

An intermediate gate will have consequences, among others, on the program for discharge and intake system and possibly on the number of spare gates.

1d *Geometry capstone height, gate height, sill depth.*

Chapter 4 explains that in addition to the solution whereby the capstone height and the sill depth are equal for the complete lock, while the tops of all gates are at the same level, a number of other alternatives could be generated (different levels per head etc.).

If these variants are compared with each other, one cannot limit this to the lock body. The cost of gates, spare gates etc. also have to be included in the consideration. Where it concerns locks with small water level differences, during both locking as well as retaining extreme water levels, as a rule the preference will be for equal height and depth levels. For the remaining, see chapter 4.

1g *Geometry stop logs?*

Stop logs are synonymous to laying open. The choice to lay open can only be made after the structural and financial consequences for the lock body have been investigated. Please note that laying open the chamber is of little use and that for the maintenance of trunnions, supporting frames in the heads etc. currently the choice is often made for local means of dewatering (pivot inspection chambers etc.).

2a *Filling/emptying, selection system.*

A choice can only be made if the construction costs of the various possibilities are known. This mainly concerns the gates and the heads (with culverts and energy dissipating chambers). As indicated in par 6.2.2, for economic reasons preference is given to gate openings in water level differences of up to 6 m.

3a *Gates, type selection.*

The selection of type is inextricably bound with the design and therefore with the cost of the heads.

3.3.5 Selection criteria

In the previous paragraphs, examples are provided of the steps in which the variant solutions can be generated. Variant solutions from which, either in the step concerned or after several subsequent steps have been worked out in general, a choice will have to be made. Selection criteria could be:

1. The extent in which the program of requirements is being met. In certain solutions, not all requirements will completely come into full play. A crossing tunnel or in certain cases a high bridge for land

traffic is often the best solution for dealing with navigation and land traffic. Based on other assessment criteria (such as cost) moveable bridges are often chosen, which places a certain limitation on both kinds of traffic. Other examples of conflicting requirements – for which generally a compromise has to be found – are:

- Navigation (swiftness of completion) versus morphology (limiting sedimentation) in the design of the lock approaches. An example is found in working out the details of the mouth (design and size) of lock approaches of Lith (Lit. [3.4]).
- Locking swiftness versus water management requirements (limiting water loss and salt penetration). An example related to water loss can be found in the documentation for the locks in Zuid-Willemsvaart and the Twenthe-Mittellandkanaal (Lit. [3.5] and [3.6]).
- Mooring safely and swiftly versus flush flow in the lock approaches. Directions on how to deal with these contradictory requirements are provided in par. 2.3.3.4 and 5.3.4. Par 5.2 also addresses a few of the conflicting requirements.

In actual fact, finding compromises for conflicting requirements as well as adjusting requirements due to high cost results in the readjustment of the program of requirements.

2. Meeting the requirements set for strength, stability and acceptable deformation.
Often these requirements are derived from the standards, guidelines and recommendations (par. 2.9), but for certain lock parts supplemental requirements will have to be set, such as the acceptable deformation of the heads in view of the movement and sealing of the gates.
3. Meeting the durability requirements as formulated in par. 2.4.15, life span requirements.
This actually falls under criterion 1, the extent in which the program requirements are met. For durability however, it holds that a cost compromise may not lead to a shorter life span than the required life span, with the exception of those parts for which replacement is desirable, possible and financially attractive. (See par. 2.4.15.1).
4. Feasibility.
As previously stated, this is not really a point for comparing variants: there is no sense in comparing variants that cannot and probably will not be executed with variants that can be executed. If there is doubt about the feasibility of a certain variant, this should be investigated in a separate study. The reason that feasibility is stated as a criterion here is because this point is brought up in many books and reports.
5. The experience with the recommended solution.
New ideas advance construction as well as society. On the other hand, there are certain risks involved when compared to familiar solutions. These can partly be overcome by studies and research for which financial means have to be reserved. In addition, there is the possibility of unexpected, undesirable effects for which costs have to be made. This requires a risk analysis that results in a balanced cost estimate of the 'new' part. Another issue that plays a part is the fact that, for the cost estimate in traditional solutions, figures gained through experience can be used while this is not possible in the case of completely new constructions.
6. The construction time could play a role in the selection as well as in the financing scheme. For instance, soil improvement under the lock body could result in a longer construction time than that for a pile foundation. A longer construction time, also of parts of the whole, could cause increased construction interest payments and/or later than planned operation.
7. The objective should be to keep to the minimum of total costs, that is to say the sum of the investments, of the cash value of exploitation (including maintenance), replacement during the life span as well as the demolition. The cost of engineering and research also have to be included.

Per part, possibly in relation to the other parts (and/or steps in the design process) and in addition to these general selection criteria, more tailor-made assessment criteria will have to be adhered to.

3.3.6 Selection

As stated in par 3.3.4, variations are possible within almost every step of the design process. In order to compare these variants to each other, they often have to be taken along to the next step (mitre gates require other heads than rolling gates do).

Especially for this "take along necessity", an avalanche of variants could occur for the complete lock complex. The largest danger is found in the corresponding design and assessment activities. The amount of work is limited by the fact that not every variation from a certain step has technical and financial consequences for all the subsequent steps (the choice in gates for instance does not have any influence on the control building and the construction of the chamber and guide structures etc.).

All the same, the objective will be to limit the amount of design work. Possibilities for this are:

- Select per step whenever possible (as this prevents the avalanche effect).
- Where this is not possible – because the influence on the subsequent steps is too large – it is often sufficient to make rough estimates of the technical and financial consequences for the subsequent steps where these are relevant.
- In comparing the alternatives, only involve the successive steps in the (cost) consideration that are influenced by the alternatives. The other steps can then be left aside.

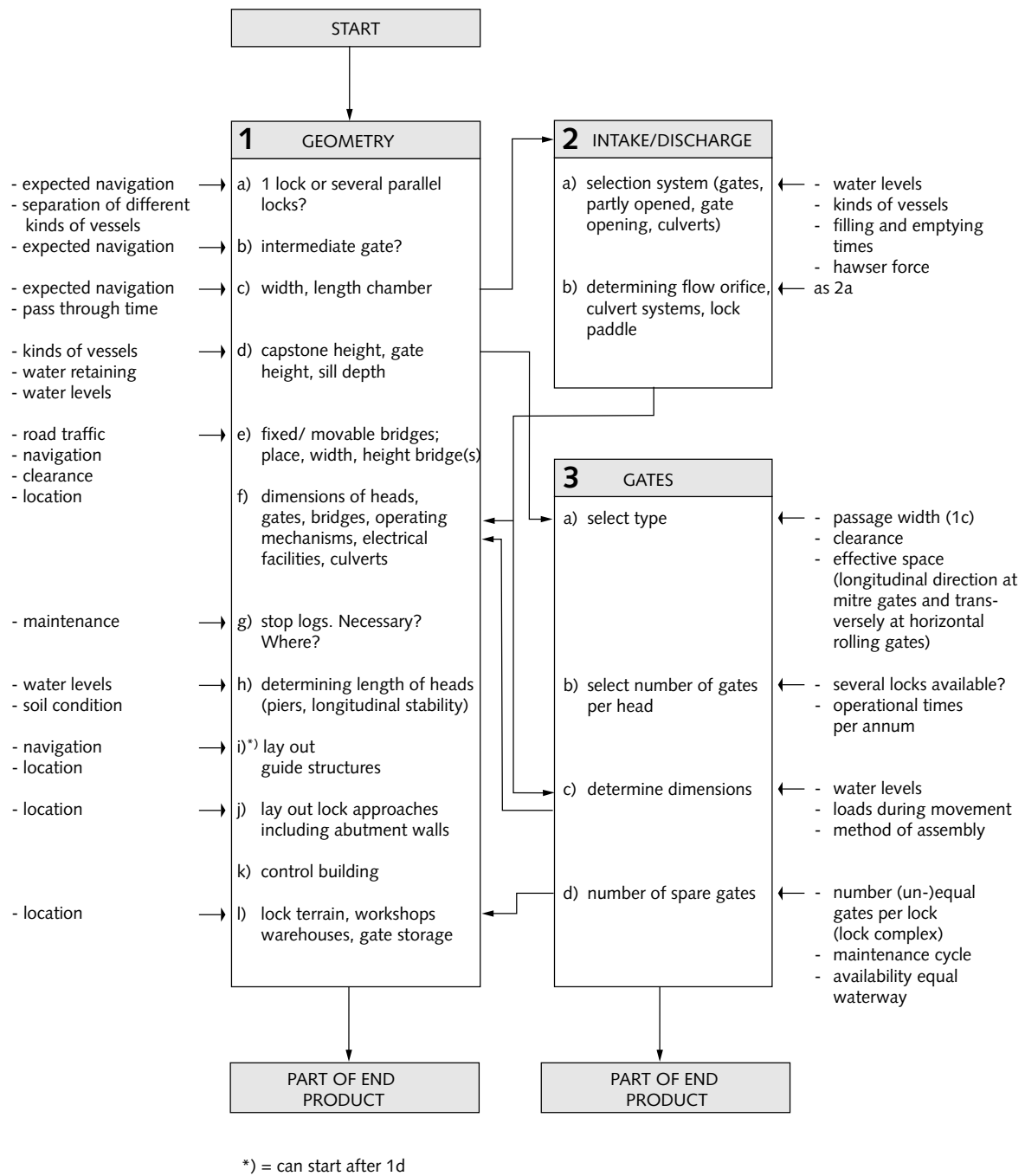
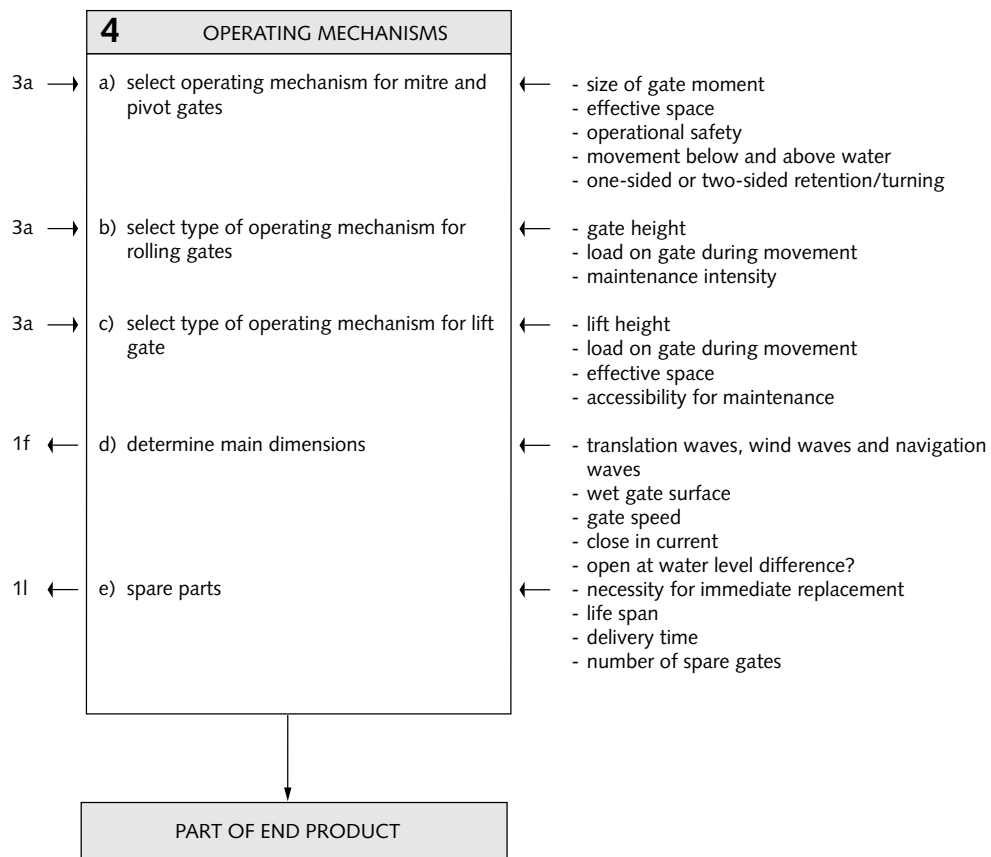


Figure 3.1 First page of flowchart preliminary design

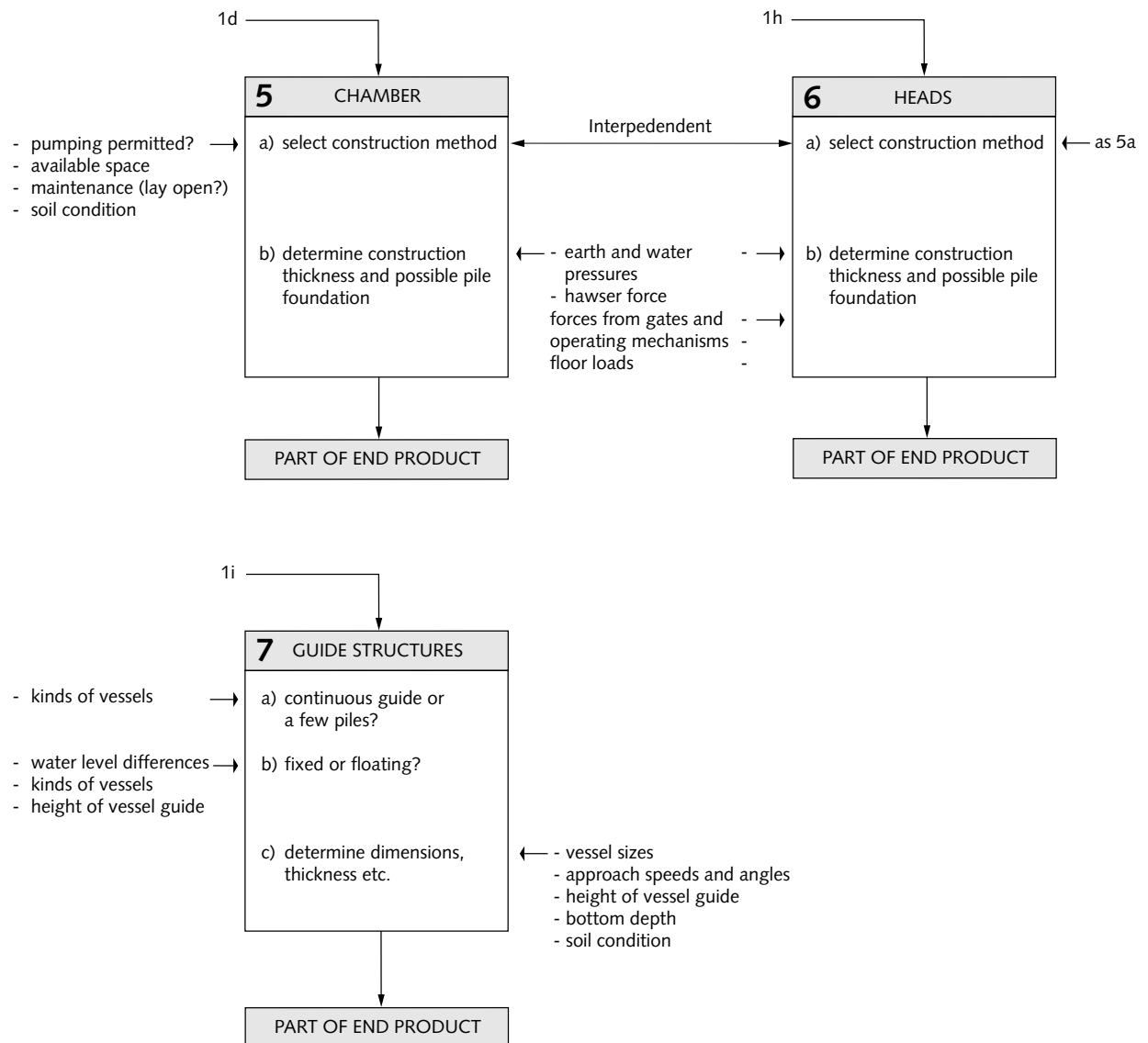


Legend:

"3a →" means: 4a to c is related to 3a from fig. 3.1

"1f ←" means: result 4d is required for 1f from fig. 3.1

Figure 3.2 Second page of flowchart preliminary design



Legend:

"1d→" means: block 5 follows after 1d from fig. 3.1

Figure 3.3 Third page of flowchart preliminary design

8 OUTFLANKING AND PIPING SCREENS

Connect : after 1 h
 Intake from P.v.E. : - water level differences
 - soil condition
 Relation to : 1j (abutment walls)

9 ILLUMINATION, MARKING, SIGNALLING, BOARDING, MEANS OF COMMUNICATION

Connect : after 1i
 Intake from P.v.E. : - regulations as to that (par. 2.4.8)
 - location
 Relation to : 1l (lock terrain)

10 BOTTOM LINING AND BANK REVETMENT OF LOCK APPROACHES

Connect to : after 1j
 Intake from P.v.E. : - water levels wind waves
 - waves and currents, turbulence due to navigation
 - intake and discharge flows

11 POWER SUPPLY

Connect : after 9
 Intake : - power requirements from 1e, 1k, 1l, 2b, 4 and 9
 - connecting possibilities public network
 - emergency power requirements
 - execution requirements

Note: Sometimes the available power from the public net is the starting point (precondition) for the design and there is no "Connect : n 9"

12 OPERATING SYSTEM (ELECTRICAL INSTALLATIONS, SOFTWARE)

Connect : after 11
 Intake from P.v.E. : - process descriptions (par. 2.4.6.1)

Note: Blocks 8 to 12 also end in a PART OF END PRODUCT

Figure 3.4 Fourth page of flowchart preliminary design

Literature

- [3.1] 'Damwandconstructies', CUR-publicatie 166, Gouda, mei 1994 (2e druk).
- [3.2] 'Programma van Eisen tweede sluis Lith', Bouwdienst Rijkswaterstaat, Utrecht, december 1993.
- [3.3] 'Uitgangspunten bij het opstellen van ramingen', Project Ramingen Infrastructuur (PRI), Rijkswaterstaat (uitgangspunten worden jaarlijks bijgesteld).
- [3.4] 'Voorhavens tweede sluis Lith', Hydraulisch/morfologisch nautisch onderzoek', WL Q 568, april 1994.
- [3.5] 'Sluizen in de Zuid-Willemsvaart; Sluis Schijndel/Sluis Helmond', WL Q 389, november 1990.
- [3.6] 'Twenthe-Mittellandkanaal, projectnota', Ministerie van Verkeer en Waterstaat, september 1994.



Photo 4.1 Princess of Scandinavia entering the Middelsluis at IJmuiden, 1 July 1992

Chapter 4 Main dimensions of lock and lock approaches

4.1 Introduction

In order to decide on the economic feasibility and the technical execution of the project, the main dimensions of the lock and the lock approaches have to be determined at an early stage of the design process. The main dimensions consist of the horizontal dimensions (length and width) of the chamber and lock approach and the elevation levels of the lock (sill, bottom, capstone, upper gate cladding, passage etc.).

The starting point for the designer is the program of requirements for the design, which stipulates the preconditions, the functional requirements and the use requirements related to maintenance and the environment (chapter 2). Aside from the functions for navigation (par. 2.3.1), the functional requirements also concern requirements for water retaining, water management and the crossing with land traffic (par 2.3.2 to 2.3.4).

As part of the preliminary design, the designer will first generate a number of variants for the lock (par 3.3). Many factors and considerations rapidly provide a direction for suitable solutions that are feasible. Matters that arise here are the main dimensions of the lock, or the choice for several locks, whether the lock should have separate facilities such as an intermediate head, side ponds, flushing possibilities or a salt/fresh water system etc. This chapter is intended to provide the designer with rules and methods for determining the main dimensions of the lock and the lock approach. Some attention is paid to the possible necessity for several chambers. As indicated in a previous sentence, the presumption is that the lock does not require separate facilities.

Because the lock should be viewed together with the infrastructure of which it is a part and the vessels that have to pass through the lock, the most important characteristics of waterways and vessels are described first (par 4.2).

The lock will have to be able to process a certain volume of navigation safely and rapidly, in other words, have a certain locking capacity. The expected navigation supply is derived from forecasts of future shipment of goods and developments in the fleet, particularly in relation to dimensions (par 4.3).

This navigation volume is the base for the required locking capacity of the lock, which is largely determined by the *horizontal dimensions of the lock* and the speed of processing the volume of traffic.

Par. 4.4.2 presents a number of methods for determining the horizontal dimensions for a certain locking capacity.

The *vertical dimensions of a lock* (water depth and elevation levels) are also part of determining the capacity of a lock if it is expressed in transport tons. Larger draught and larger clearance allows more goods to pass through the lock per ship (and therefore per locking). Vertical dimensions from a nautical point of view (sill levels, lock coping and guide structures) are addressed in paragraphs 4.4.3 to 4.4.5. The most important non-nautical function of the lock is water retention. This determines the retaining height of at least one lock head and its gates (par. 4.5).

Based on the particular nautical and water retaining dimensions as well as constructional considerations in the previous paragraphs, the *resulting horizontal dimensions and levels* of the lock are determined in par. 4.6.

In order to realize the required locking capacity, the designer also has to establish the resulting *horizontal dimensions of the lock approaches*. This is to enable safe and rapid processing of incoming, outgoing and waiting vessels (par. 4.7). The use of lock approaches for resting/stopping over has become more important since the "Sailing hours and Crew Numbers Act" has come into effect. This could result in

having to provide (many) extra mooring spaces in the lock approach that further determine the horizontal dimensions of the lock approach.

In the next chapter (Chapter 5, Lay out of the lock complex), the various horizontal dimensions and levels are brought together and placed in the existing infrastructure in order to provide a complete picture of the lock complex. Please note that in chapters 4 and 5, distinction is made between maritime navigation, inland navigation and recreational navigation. Little attention is paid to economic considerations.

4.2 General

4.2.1 Classification of waterways

Waterways can be distinguished according to user group: maritime navigation, inland navigation and recreational navigation. Often, various user groups are found per waterway, such as maritime navigation with inland navigation or inland navigation with recreational navigation. The waterway is classified in the waterway classification according to user group, for instance in CEMT classification. The classifications can be summarized as follows:

User Group	Waterway classification
Maritime navigation	Limited classification (Lit. [4.2])
Inland navigation	CEMT (Lit. [4.1])
Recreational navigation	CVB guideline (Lit. [4.3]), classification BRTN

Table 4.1 User groups and waterway classification

Maritime lanes

The Dutch situation does not have suitable classification for waterways intended for large sea-going vessels. For international navigation, a familiar standard is the Panama Canal whereby the 'Panamax' is the largest ship that is able to pass through (dimensions 235 x 32.2 x 13.5 m³).

PIANC (International Navigation Association) defined a number of standard navigation vessels (see Table 4.4 and Appendix A4.5). This is a good supplement to the CEMT waterway classification for inland navigation and can be used for waterway classification.

Inland waterways

The most well known classification of waterways is the classification of the ECMT (European Conference of Ministers of Transport, or CEMT (Conference Europeene des Ministres de Transport), Lit. [4.1]. The CEMT classification (Table 4.4 and Appendix A4.5 with classes I to VII) actually is an accessibility classification for a number of standard inland navigation vessels. Standard vessels that could be mentioned are Penice (I), Campinois (II), DEK-schip (Dortmund-Ems-Canal) (III), RHK-schip (Rhine-Herne-Canal) (IV), GRS-schip (Big Rhine barge)(Va), push barge (Va,b, single barge en VIa,b,c, > single barge).

In the Netherlands, the CVB (Commissie Vaarweg Beheerders) formulated the Guidelines on Waterways (Lit. [4.3]). These guidelines provide dimensions of waterway sections, based on CEMT classifications, for waterway classes I to Vb. Class IIa was added for reconstruction projects. In these guidelines, dimensions related to free space for straight waterways are presented for a standard double strip, a narrow double strip and one-way profiles with width allowance for wind and curves. The dimensions concern bottom width, the width at a water depth equal to the draught of the loaded standard vessel plus the width of the unloaded vertical stabilizer, the water depth and the clearance. The water depth for a normal profile corresponds to 1.4 times the draught of the standard vessel and in the case of the narrow profile, this is 1.3.

For the Dutch situation, it is strongly recommended to adhere to this univocal CVB classification for waterways up to and including class V. The authorities will occasionally deviate from this only on the issue of permitted draught and clearance, based on policy considerations (economic interest), international agreements or technical possibilities: for instance, navigation with 3 or 4 layers of containers or Rhine clearance of 9.10 m above Normative High Water.

In practice, waterways can also be indicated as suitable for a certain "loading capacity class". For dimensioning waterways and structural works, this is not a suitable quantity measurement if it does not provide the corresponding vessel measurements. One or several of these measurements will usually limit the physical accessibility.

The CD Rom 'Vaarwegkenmerken in Nederland' (ViN) (Lit. [4.12]) provides univocal maximum permitted vessel dimensions for every waterway in the Netherlands. This is a highly practical source of information.

Recreational waterways

The CVB also classified the recreational waterways in classes in the Guideline (Lit. [4.3]) namely ZM1 to ZM4 (sail/ motorboats), M1 to M4 (motorboats) and BV1 and BV2 (traditional fleet). The classes correspond with standard dimensions of sailboats, motorboats and historical vessels. For various waterway classifications, dimensions of waterway sections are provided for normal and narrow profiles. Furthermore, there is an intensity profile for heavy traffic. Besides these guidelines, it is recommended that normative vessels and combinations thereof are determined case by case, as (future) local fleet composition can vary substantially.

Dimensions of waterway sections of mixed navigation (commercial and recreational navigation) are subject to the regulations that apply to merchant shipping waterway sections. Both user groups are taken into account in the CVB where facilities and equipment are concerned.

4.2.2 Classification of vessels

Marine vessels

The group marine vessels consists of an extremely varied group of vessels such as large ocean going vessels (tankers, bulk carriers, container ships, freighters, roll-on roll off vessels, passenger ships etc.) dredging and construction vessels, coasters, supply ships, naval vessels, fishing vessels, marine/inland navigation vessels (length up to 135 m), seagoing tugboats etc. Large locks at the coast have to consider all these different vessels.

There is no real classification available for ocean going vessels, aside from the previously mentioned Panamax vessels. An overview of the dimensions of sea-going vessels can be found in the Lloyds Register of Ships.

For smaller sea-going vessels that also participate in inland navigation, the sea/inland navigation vessels, the PIANC classification can be used. In 1996, PIANC initiated the standardization of these vessels by defining three vessel classes that closely link up with the CEMT classification for inland navigation. Table 4.2 provides an overview of this.

CEMT class	R/S class (River/Sea)	vessel dimensions (m)			minimum bridge passage height (m)
		length	width	draught	
Va	1	80-90	11.4	3.5-4.5	7.0
VIb	2	110-120	15.0	3.5-4.5	9.1
VIb	3	135	22.8	4.0-4.5	9.1

Table 4.2 River/Sea class ships

These ships, also called low-profile coasters, are generally a bit wider and deeper than the inland navigation vessels with the same length. The vessel dimensions according to this Table are very usable for renovation projects. For the construction of locks in new waterways, PIANC recommends larger vessel dimensions, such as summarized in Table 4.3.

R/S klasse (River/Sea)	maximum permitted vessel dimensions (m)			minimum bridge passage height (m)
	length	width	draught	
1	90	13.0	3.5 of 4.5	7.0 of 9.1
2	135	16.0	3.5 of 4.5	≥ 9.1
3	135	22.8	4.0 of 4.5	≥ 9.1

Table 4.3 River/Sea class ships for lock design

Inland navigation vessels

- The CEMT waterway classification is actually a vessel classification for inland (cargo) vessels. The classes are identified by Roman numerals I up to and including V (see Table 4.4 and Appendix A4.5). As long as it concerns single motor vessels, it is easy to determine what kind of vessel belongs to a certain length x width dimension. Classes V and larger contain varied vessels however. There are indications that in the near future, an 'intermediate class' will come into being for motor vessels of 135 x 17 m² that are now classified in CEMT class VI waterways. The variety of vessels is a complicating factor in determining the necessary chamber dimensions.

CEMT class	type vessel	length L (m)	width B (m)	draught T (m)		clearance H (m)
				empty	loaded	
I	Spits - Peniche	39	5.1	1.2	2.2	5.0
II	Kempenaar- Campinois	55	6.6	1.4	2.5	6.0
(IIa) **)	Hagenaar	56 of 67	7.2	1.4	2.5	6.3
III ***)	Dortmunder	67 of 80	8.2	1.5	2.5	6.3
IV	Rijn-Hernekanaalschip	85	9.5	1.6	2.8	6.7
Va	Big Rhine barge Push barge	110	11.4	1.8	3.5	6.7/8.8 *)
Vb	Pushed convoy	186,5	11.4	1.8	4.0	8.8
VIa	Side-by-side formation	110	22.8	1.8	4.0	8.8
VIb	Pushed barge train	186,5	22.8	1.8	4.0	8.8

*) 6.7 m is for waterways with little container transport, 3 layers of containers; also high enough for 70% of the unloaded vessels.

8.8 m is for waterways with substantial (> approximately 10.000 TEU per annum) container transport, 4 layers of containers; also high enough for 90-95% of the unloaded vessels

**) (IIa) only at reconstruction of existing waterways or structures

***) III length 80 m is CEMT class IIIa

Table 4.4 CEMT class vessels

- In the Traffic Objective Model that is used for forecasting the expected navigation (VTM, see par. 4.3.3) a classification is used based on ten loading capacity classes. Appendix A4.5 contains a table that shows the differences and similarities between CEMT classes. Per loading capacity class, a 'standard vessel' has been defined, as actual vessel measurements are required for dimensioning. Uniform 'normative vessel equivalents' (fictitious vessel of 125 tons) are used for calculations in VTM.
- For navigation statistics, at various counting points data is gathered in the IVS (Information Processing System) of the Directorate-General of Public Works and Waterways. In addition to other characteristics of the vessels, the loading capacity, the dimensions and the navigation type are recorded. A coding is used for the latter (1 to 89, see Appendix A4.5). It is important to know the vessel type in view of navigation characteristics (such as manoeuvrability, vulnerability, etc.) that have an influence on the lock design.

The Dutch inland fleet contains vessels with all kinds of dimensions that can be well classified in width classes, almost corresponding to the widths of CEMT standard vessels. In these (normative) widths, the lengths (see Figure 4.1) and draughts have a wide range. The older model ships such as the 'Spits' and the 'Kempenaar' are often found on smaller waterways (CEMT class I and II). In addition to large vessels, we also find many vessels from the smaller classes on the larger waterways. All in all, the variety of vessel dimensions is larger on the larger waterways than on the smaller waterways.

Figure 4.2, taken from Lit. [4.9] provides an example of the fleet composition as it is found in the Netherlands: the first graph applies to a waterway with maximum accessibility of loading capacity class 7 (CEMT IV), the second graph applies to class 8 (CEMT V). The most important characteristics for fleet

composition are therefore the normative vessel in the waterway classification ("accessibility") and the average loading capacity. For cargo vessels, the maximum length dimension is set at 110 m and the maximum width at 11.40 m. The maximum coupled length amounts to 180 - 185 m.
(Note: Developments do not stand still, see previously mentioned vessel of 135 x 17 m²).

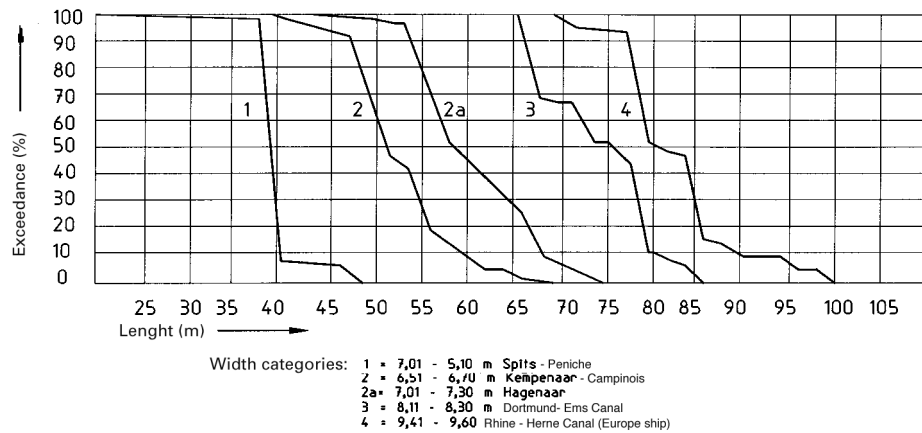


Figure 4.1 Exceedance curves of vessel length

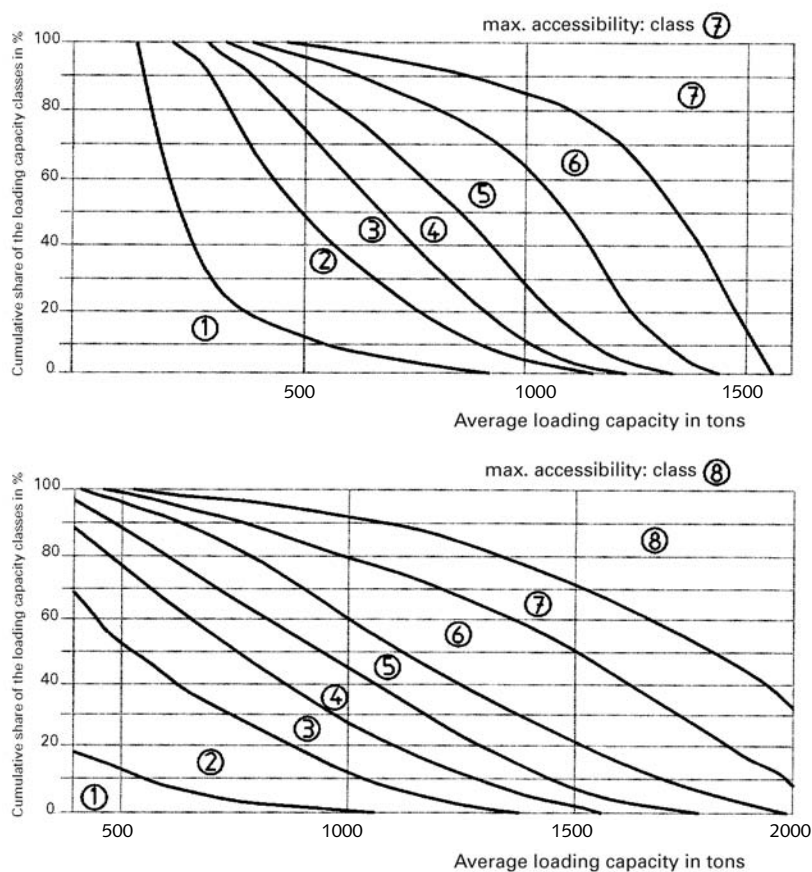


Figure 4.2 Cumulative share of the loading capacity classes as function of the average loading capacity for accessibility class 7 (CEMT class IV) and accessibility class 8 (CEMT class V)

The scale expansion in inland navigation is often characterised by the increase in average loading capacity. Figure 4.2 illustrates the connection to fleet composition:

- at constant waterway classes the average loading capacity increases (horizontal axis), because the share of the larger vessels in the fleet increases and the share of the smaller vessels decreases;
- at increasing the waterway loading capacity from 7 to loading capacity 8, the average loading capacity increases considerably and the 1st point needs to be addressed again.

For guidance: on the Meuse route (suitable for CEMT classes Va and Vb limited, loading capacity class 8) the average loading capacity was well in excess of 1000 tons in 1996.

The charter fleet (also called the traditional fleet) actually belongs to inland navigation because it is commercial navigation (as opposed to recreational navigation). With regard to dimensions, these vessels are usually classified in CEMT class (dimensions of 20-35 m in length). The manoeuvrability of these vessels does not differ much from other inland navigation vessels.

Recreational navigation vessels

For recreational navigation, the classification can be used as specified by the CVB in the Guidelines. Because of the very large diversification of dimensions that occur in the Dutch recreational fleet, the classification is rather arbitrary but nevertheless, quite usable. Distinction is made according to sailing boats, motorboats and traditional boats even though the traditional boats really belong to small inland navigation (derived from BRTN).

Category	class	height (m)	draught (m)	width (m)	length (m)
Sailing boats	1	8.50	1.25	3.00	9.00
	2	12.00	1.50	3.50	10.00
	3	12.00	1.75	3.75	11.00
	4	>>12.00	1.90	4.00	12.00
Motorboats	1	--	0.90	3.50	10.00
	2	2.75	1.10	3.75	12.00
	3	2.75	1.40	4.00	14.00
	4	3.40	1.50	4.25	15.00
Traditional boats	bv1	>>12.00	1.20	5.50	25.00
	bv2	>>12.00	1.40	6.50	30.00

Table 4.5 Recreational navigation classes

4.2.3 Specific vessel characteristics

Marine vessels

In general, at low speeds and in limited areas marine vessels have less manoeuvrability than inland navigation vessels. This is why they often require the aid of tugboats in order to manoeuvre in lock approaches and locks. Tugboats require extra manoeuvring space for working around a ship. This has consequences for horizontal dimensions and the lay out of the lock and lock approaches, as well as the guide structures. However, some of the marine vessels, in particular those that sail on a tight time schedule, often have extra steering aids: not only do they have strong bow propellers, they also have athwart ship 'thrusters' working across the stern. This makes them less dependent on tugboat assistance.

Cargo carrying marine vessels usually transport similar cargo as do inland navigation vessels; some vessels transport hazardous loads. Marine vessels with hazardous loads can be recognized by the red light that they shine at night and the red flag that they show during the day. In general, every sea lock (IJmuiden, Terneuzen etc.) has detailed requirements for locking these kinds of vessels (for instance distance and separate locking). These safety measures are usually detrimental to the locking capacity of the lock.

Ocean going cruise ships can be considered as regular marine vessels that are generally well equipped for rapid and safe manoeuvring.

Inland navigation vessels

Inland navigation vessels are generally able to manoeuvre well (also because of bow propellers) and the crew has substantial experience in passing through locks; the deck equipment is geared for this. Vessels are often equipped with bow propellers or headed screw propellers. Figure 4.3, taken from Lit. [4.13] shows the degree in which different classes are equipped with a bow screw propeller. The tendency is that in time, most small vessels will have a bow propeller and in addition, will have increased power capacity installed. Bow propellers supply enormous improvement in vessel manageability at locks (idling, manoeuvring).

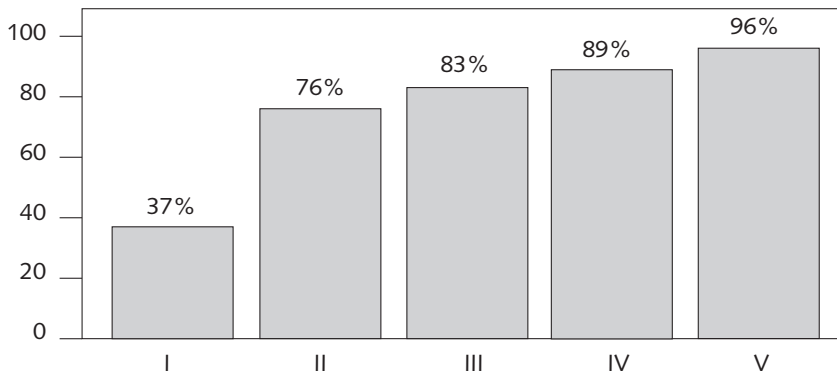


Figure 4.3 Percentage of Dutch fleet equipped with bow propellers (CRB 1995)

Empty motor vessels and container ships (especially with empty containers) are sensitive to (cross) wind; they are able to compensate for the sensitivity to a large degree with their headed screw propellers. This does require additional expertise as crosswind complicates sailing. Empty (tug-pushed) barges are also very sensitive to wind but they generally do not have headed screw propellers. Empty multiple barge convoys therefore belong to the most risky waterway users. Loaded vessels are hardly affected by crosswind; by contrast, they experience more hindrance from currents (more so than empty vessels), for instance due to flushing at a lock.

Almost all vessels currently have a VHF radio. Via VHF radio contact with the lock, the captain can often prevent having to moor in the lock approach (by decreasing speed well before time).

Vessels carrying hazardous goods have to maintain large safety distances from other vessels, or even lock separately. This requires more room in the lock approaches and in the lock and it has adverse consequences on locking capacity.

An increasing number of vessels sail on a just-in-time schedule (JIT ships). In general, these are container ships and cruise ships. For these vessels, unexpectedly long waiting times for passage are disastrous. If there are many JIT ships, the necessity of larger locking capacity requires investigation.

The dimensions of cruise ships in inland navigation correspond with CEMT Classes I–V. They are usually very well equipped, in view of passenger comfort and safety, and because they often sail according to a strict schedule. It does occur that the waterway authority grants priority-locking rights to these vessels.

Recreational navigation

Most recreational vessels are (very) small and relatively vulnerable in comparison to commercial navigation. The crew on recreational vessels often lacks expertise and experience. At locks, this can be seen in unpredictable sailing behaviour, bad communication and mooring problems. Recreational navigation is highly concentrated in the summer season (generally only during a few months). The traffic intensity fluctuates substantially and depends on weather conditions, school holidays and local circumstances.

4.3 Volume of navigation

4.3.1 General

The volume of navigation is expressed in:

- the fleet composition (types and numbers): inland (cargo-) navigation, recreational navigation, and marine navigation;
- the intensity: number of vessels per unit of time, varying over the day, the week, the year.

The navigation volume is a derivative of the transport requirement. This is why it is necessary to forecast the future volume of traffic through a lock before the lock is designed. Table 4.6 provides an overview of the most important issues that a designer could be faced with.

Waterways for	Vessel categories	Goods transport	Passenger transport
marine navigation	marine vessels, cruise ships suppliers, roll-on roll off vessels, sand/ballast barges, fishing vessels, large construction vessels	various goods such as coal, petroleum and oil products, ore, agricultural products, containers, cars, sand etc.	cruise ships and (sometimes) ferries
inland navigation	freight vessels inland navigation, sea going barges passenger ships, yachts (small and large) large construction vessels	various goods such as sand/gravel/cement, coal, oil products, ore, agricultural products, containers etc.	cruise ships, charter vessels (traditional vessels) and small yachts
recreational navigation	yachts (small and large) small construction vessels	----	holiday-makers

Table 4.6 Volume of navigation

For determining the normative navigation volume, choose a basic year (for instance 1992, navigation volume from historical data) and a forecast year (for instance 2015). We then endeavour to make a forecast of the navigation volume in the forecast year.

A structured method of forecast is only available for inland navigation and is described in par. 4.3.3. It will often be necessary to use other avenues to obtain a reasonable picture of future navigation volume (par. 4.3.2, sea locks and par. 4.3.4, recreation locks). On balance, the changeability of the navigation volume is an important factor in selecting the normative volume of navigation (par. 4.3.5).

4.3.2 Forecasts for marine locks

The composition of the marine fleet is very diverse while the total number of vessels that pass through marine locks is often not very substantial. In fact, a separate forecast has to be made for every category of vessels; there is no model available that is generally applicable to all categories. For the locks at IJmuiden (Lit. [4.18]), the forecasts were formulated on the volume of navigation based on existing counting information at the locks (IVS and CESAR) which was analysed and extrapolated. In addition, experts were interviewed.

4.3.3 Forecasts for goods transport with inland navigation

The AVV Transport Research Centre, which is part of Rijkswaterstaat, manages a series of three different models for forecasting the transportation of goods in the Netherlands:

- the Transport Economic Model (TEM II)
- the Traffic Production Model (VPM)
- the Traffic Assignment Model (VTM)

With these three successive models, one is able to 'zoom in' on a waterway or a lock, which is one of the links in the large waterway network, from a macro-economic scenario.

Transport Economic Model (TEM II)

This model serves to formulate a forecast for all the goods transported in the Netherlands on the long term, for all means of transport. The starting point of the TEM II model is a basic year for which all the transport information is well known and it uses this information to calculate the transport for the forecast year, which would be roughly 15 to 30 years in the future. The basic year and the forecast year are adjusted every 3 to 5 years. The model contains the transport requirements that are generated by the manufacture and consumption in various regions. The transport is then assigned according to TEM II, per type of goods as well as origin/destination, to the transport modalities available (modal split): road haulage, navigation, rail or pipeline. The economic forecasts of the Central Planning Bureau (CBS) are used for the development of manufacture and consumption (per region). These forecasts are based on assumptions regarding government policy and global developments. Various growth scenarios can be distinguished, varying from pessimistic to optimistic. The result of TEM II is an overview of transportation of goods, expressed in tonnage per annum.

The Traffic Production Model (VPM)

This model serves to convert the forecast transport over water (in tonnage per annum) into traffic volume (number of inland navigation movements). Based on observational data (recorded in CBS files) it determines how the current transport is realized (vessel dimensions). Taking into account the expected fleet developments as well as the forecasted transport, the number of trips and the transported weight is calculated and serves as input for the next model, the VTM. The forecast is given for an average week by dividing the annual total (from TEM II) by 50.

The Traffic Assignment Model (VTM)

This model (Lit. [4.15]) serves to determine which route the inland navigation vessels will be sailing, in order to obtain a forecast of the navigation volume per route. It is assumed that the captain will select a route that will require the least amount of time and the shortest travelling distance. This is determined by means of the 'resistance' yielded to navigation by each part of the waterway network. The resistance follows from the information included in the model per part of the waterway, per lock, per bridge ('link'). The present model has been brought up to date with the changes that have taken place in the waterway network since 1986. For forecasts for the year 2015, the expected *future* waterway adjustments were included in the model. By providing the week capacity of the network 'links', the model can be utilized to signal whether the network has sufficient capacity to process navigation flow. For that purpose, the relation between the intensity I and the Capacity C for the average week and the normative week are tested by the following rule of thumb, the relation between the acceptable intensity and the capacity per week: $I_{\text{perm.wk}}/C_{\text{wk}}$.

The result of the VTM is the navigation volume per average week (1/50 of annual volume). This output is sufficiently detailed (fleet composition, average loading capacity, quantity loaded/unloaded per direction, kind of vessel etc. is provided) to calculate the processing of traffic in the surveyed waterway or lock. With a view to the established limitations of the current VPM and VTM becoming out of date and the desired possibility open to answering topical (policy analytical) questions, a new forecast model for inland navigation is currently being developed: the "Model System Inland Navigation".

4.3.4 Forecasts for passenger traffic and recreational navigation

Regular passenger services

Passenger transport with fast passenger ships is rising strongly. These services mostly intend to offer an alternative to road transportation. On routes with locks, this results in transport delays and therefore it does not offer an alternative to road transport. It is difficult to create a reliable forecast for this type of navigation, as there has been very little experience with this on the Dutch inland waters (1998).

Recreational navigation

An important tool for making a forecast for a recreational navigation lock is the annual publication called 'Signaal-telpuntennet Recreatievaart' issued by the AVV Transport Research Centre of Rijkswaterstaat.

This publication presents the traffic count (recreational navigation) at 25 counting points in the Netherlands, together with the corresponding counts from previous years. The traffic count results are accompanied by extensive analysis and conclusions on trends.

A forecasting model for recreational navigation is being developed. Once this model is operational, the designer will have to be prepared for his forecasts being strongly influenced by unpredictable factors such as 'consumer behaviour'. 'Pessimistic' and 'optimistic' estimates will have to be taken into account. It is recommended that the counts that become available (annually) be used as a point of departure. Given a proper inventory of current and planned developments for recreational navigation (yacht harbours, new waterways), one is able to reach a reasonable forecast by means of extrapolation. It is also sensible to consult branch experts on this.

Cruise ships (and sail charter ships)

These vessels do not generally appear at Dutch locks in large quantities but they could have an influence on dealing with navigation, for instance if they have right to priority locking. Forecasts on traffic containing these vessels could be made on business considerations but once again, the whimsical nature of the consumer will play a large role. The most suitable and reliable sources of information will have to be found case by case.

4.3.5 Navigation volume varying in time, normative navigation volume

The navigation volume always shows fluctuations in time. It is not unusual to count 30 vessels in one hour at a counting point while 15,000 vessels pass there per annum. The latter does correspond with a less than 2 vessels per hour *average over that year*, which is 15 times lower than the maximum hour volume.

With the aid of certain calculation methods used to test the volume of navigation against the (presumed) lock capacity, the speed (waiting times etc.) with regard to the desired swiftness can be tested.

A normative navigation volume is required based on a chosen normative period. In the Netherlands, it is usual to choose the week as the normative period for inland navigation as inland navigation clearly has a weekly cycle. For marine navigation, a month is used as normative period and for recreational navigation, a day cycle is used. A combination of marine /inland navigation requires a monthly cycle and inland/recreational navigation a weekly cycle.

The result of the Traffic assignment model is the navigation volume for inland navigation for an average week, as this is calculated as 1/50 of the annual volume. In order to obtain a normative week in the forecasted year (number of vessels per hour), starting from the forecasted navigation volume of an average week, with a realistic course of the volume in the time, the following method is often used. It consists of two steps:

1. determining the shape of the navigation volume (indexed distribution in time, expressed in numbers per hour);
2. determining the navigation volume by 'inflating' this distribution to a forecasted navigation volume.

ad 1.

The *shape* of the navigation volume in time is derived from the (recent) volume counts that are available in files such as IVS. With programs such as 'KARPER' or 'SCHEEPVAART', the traffic observed at the desired places and times can be extracted in the desired format. The progress of intensity in time is determined by, among others, the operating times. If these times change, the distribution for the forecast year will also have to be adjusted.

ad 2.

Vessel counts are usually available on a monthly basis. Therefore it is usual to, quite arbitrarily, choose the busiest month with regard to vessel counts. If there is a lot of recreational navigation, a month is chosen in which the commercial navigation is at a maximum as well as a month in which the pleasure cruising is at a maximum. We then have two normative weeks that should be calculated. Dividing the month's volume by factor 30.5/7 supplies the navigation per week (assuming an average of 30.5 days per month).

This (current, normative) navigation supply also represents intensity ($I_{\text{current, normative}}$) that is to say a certain number of vessels per week. This intensity will be higher than in the corresponding average week ($I_{\text{current, average}}$)

Given this relation, the intensity ($I_{\text{forecast, normative}}$) in the normative forecast week can be determined as follows:

$$I_{\text{forecast, normative}} = (I_{\text{current, normative}} / I_{\text{current, average}}) \times I_{\text{forecast, average}}$$

The last mentioned intensity ($I_{\text{forecast, average}}$) becomes available as output of the Traffic assignment model in the shape of the number of vessels of the passing fleet with a certain (forecast) average loading capacity.

4.4 Lock chamber, horizontal dimensions and levels in view of locking

4.4.1 Introduction

The navigation volume determines the required number of chambers, the required length and width of the chamber, the sill depth and capstone and (sometimes) the clearance. Possible influence on the water retaining function on capstone height is addressed in par. 4.5.4.



Photo 4.2 Push-tow navigation locks in the Kramer

The number of chambers and the length and width of the chamber are determined by four issues namely:

- the intensity of navigation volume (navigation supply and pattern)
- the assignment of vessels over the lock complex
- the dimensions of the normative vessel
- the fleet composition.

When dealing with traffic, it concerns issues such as the capacity of the lock and the locking time of vessels. The capacity of a lock is the maximum navigation volume (expressed in the number of vessels, or loading tons) that can be locked through per time unit if the lock continuously locks with full chambers. The passing through time of the vessels is the extra time it requires from the captain in comparison to the situation without a lock present in the waterway concerned.

A few remarks in advance:

- A lock should always be seen as part of a larger whole, which is a lock complex, a transport route or a network of waterways. It would make no sense for instance, to build a lock with substantially deviating dimensions or capacity in an existing route.
- The decisions on the construction of a lock and the desired dimensions of the chamber are not only based on the cost of the lock (construction and exploitation) and cost for the navigation. As a rule, a planning expert executes a social and economic assessment. The final choice is made by the principal (usually the government). This chapter does not pay any attention to this assessment. With the help of a simulation model described in par. 4.4.2.3, the Cost Effect Analysis (CEA), designer is able to investigate and express in valuta the extent in which the costs of the lock would increase, and the decrease in cost for navigation, if the lock design is changed (chamber dimensions, extra chambers).

- The effective (or nett) horizontal dimensions still require an additional allowance to obtain the actual chamber dimensions. This allowance is necessary, as vessels have to maintain a certain distance from the lock gates (see par. 4.6.2 and 4.6.3).

4.4.2 Effective horizontal dimensions

4.4.2.1 Dealing with navigation at the lock

A lock is part of a waterway in which the normal, nearly undisturbed sailing is interrupted. Between the lock and the connecting waterway sections there are lock approaches where vessels have the opportunity to decrease speed and, if necessary, wait for shorter or longer periods before entering the lock. The functions of the different parts of the lock complex are discussed in par. 2.3. Dealing with traffic at the lock is a process of frequent interaction between individual vessels and lock personnel, as well as interaction between the vessels themselves.

The lock personnel draw up a schedule for every locking process and strive to obtain optimum speed and safety. This involves a large number of factors:

- the various dimensions of the vessels,
- the necessity to separate certain vessel categories, both in the lock approach and in the chamber (recreational navigation, commercial navigation, vessels carrying dangerous goods),
- current navigation load,
- geometric limitations,
- different chambers (if present),
- weather conditions,
- special regulations (for instance because of savings on lockage),
- vessels that are spending the night.

The lockkeeper has to weigh up the different considerations and often has to think one or two lockage moves ahead. The efficiency of lockage, in both large and small locks, is determined by the skill and experience of the lock personnel in particular.

The first requirement for drawing up a planning is proper communication with the vessel (VHF radio, signalling). At large locks, the lock personnel often have (electronic) planning boards at their disposal. After initial contact, the personnel record the vessel information. For the lockage plan, the important issues are the horizontal dimensions and whether the vessel is transporting 'dangerous goods'. Sometimes, vessels have rights to priority locking. With this information and the above mentioned factors, the lock personnel makes a locking plan and informs the vessel on:

- which chamber to use (if there is more than one chamber),
- the order of sailing in, and
- the place that the vessel should occupy in the chamber.

The complex process that is sketched above is a large determining factor in the capacity of a lock (complex). What follows are descriptions of some methods used to determine the horizontal dimensions required for dealing with the volume of navigation quickly (and safely). Passing through the lock 'sufficiently quick' means that passing through the lock should not require too much time, including possible waiting time. An average passing time of up to about 30 minutes is generally considered acceptable. However, if this increases to more than 45 minutes for instance, the locking capacity of the lock urgently needs to be enlarged.

4.4.2.2 Minimum locks and capacity locks

The necessary chamber dimensions mainly depend on:

- the dimensions of the largest vessel;
- the volume and pattern of navigation;
- optimal chamber filling with several vessels;
- the marine, inland or recreational navigation purpose.

Marine navigation locks

The chamber dimensions for large marine locks are generally based on locking one normative vessel. Because the normative vessel seldom presents itself, the lock will often be used to lock several smaller vessels at the same time. This could also be a determining factor for chamber dimensions, certainly if the volume of navigation is large and differentiated in composition. In that case, the same method can be used as the method for inland navigation (see below).

Inland navigation locks

In the Netherlands, navigation volume of less than 5,000 vessel passages per annum is considered a small volume of navigation. If this is the case, it will suffice to have a chamber that is large enough to lock one normative vessel at a time. Such locks are designated as a 'minimum lock' (cvb Guidelines). The lock, by means of vessel dimensions, therefore determines the accessibility of the waterway behind. Par. 4.4.2.6 provides an overview of the horizontal dimensions of the minimum lock chamber as recommended by the cvb.

If the volume of navigation is large (for instance more than 10,000 vessels per annum), a chamber that can lock several vessels at the same time is required, or if the volume exceeds 50,000 vessels per annum, several chambers are necessary in order to realize the required transit capacity. This kind of lock is designated as a "capacity lock".

Recreational navigation locks

The methods for determining horizontal dimension correspond with those for inland navigation. The lock will usually be designed as such that several smaller yachts can be locked simultaneously. In addition, it is useful if a single, large construction vessel can also use the lock.



Photo 4.3 A bustle in the yacht lock in the Volkerak

4.4.2.3 Methods for determining chamber dimensions of a capacity lock*Traffic study*

If there is a large volume of navigation, a traffic study will have to show the necessary dimensions required by the capacity lock. This paragraph concerns inland navigation locks, but the method is also applicable to marine and recreational navigation.

The traffic study uses one or more models to determine the capacity of a lock with certain dimensions.

By executing an (re)iteration process, whereby the models are applied a number of times, the desired chamber dimensions can be established.

This (re)iteration process is as follows:

1. It starts with an assumption of preliminary chamber dimensions and number of chambers.
2. For the provisionally chosen lock complex and a normative volume of navigation, one of the models is used to determine the value of characteristic parameters to test the design at hand on:
 - the average passing through time (particularly important to the captain because of costing, route planning, keeping agreements with 'the shore');
 - the permitted intensity;
 - the necessary waiting space (-length), mooring costs;
 - the locking time cost for navigation, per week (possibly converted to cost per annum).
3. These parameter values are tested against guidelines, historical information and against the navigation forecasts, which show whether the provisional chamber is too large or too small.
4. The preliminary chamber dimensions etc. are subsequently readjusted and the value of the test parameters is set, until the desired optimum is reached (iteration cycle).

In order to obtain some insight into determining the lock capacity, a few methods are described below in which the previously mentioned iteration process will be recognisable.

Nomogram method

The Nomogram method is used to determine the capacity of a chamber of certain dimensions. The model is described in Lit. [4.8] and in Appendix 4.1. The locking process is presented as a series of successive timeframes. These timeframes are the times that are required for sailing in, operations (move gates, levelling) and for sailing out. For the operating personnel the locking process is a cycle that consists of locking up and locking down. Based on observations and studies, tables and graphs have been compiled for sailing in and sailing out times, number of vessels per chamber, operation times etc. The nomograms can be used to investigate whether a chamber with certain horizontal dimensions can process the volume of navigation. The model provides a lot of insight but is also quite time-consuming.

VAT model

The required waiting area in the lock approach, which is closely linked to the capacity of the chamber, is calculated according to the VAT model. The model is an analogy of the liquid flowing through a cask or vat. The analogy does not correspond exactly as locking is an intermittent process. Due to the presence of mooring areas at the locks, the influence of discontinuity is levelled off in order to make statements about the necessary waiting places. The most important input in the model is the supply pattern of vessels and the lock capacity. The model supplies the average and the maximum number of vessels staying over, the average waiting time for those staying over and the required length of the waiting area. A drawback is that this method does not provide any insight into the passing through times and passing through costs, which schematizes the fleet too much.

Simulation model SIVAK

The 'passing through time' is the normative quantity for the economic assessment of a capacity problem at a lock. This is the extra time that it costs the captain to pass through the lock in comparison to a situation without a lock. This extra time is made up of waiting time, locking time and the staying over time (this is the extra waiting time if a vessel is not able to lock through at the next locking). At present, it is quite possible to accurately determine the passing through time by means of navigation simulations at the locks with the model SIVAK (Simulatiemodel voor de Verkeers-Afwikkeling bij Kunstwerken) Lit. [4.11]), Appendix 4.2. This method has important advantages over previous models and is therefore recommended. The features of SIVAK simulations are:

- discrete, stochastic process;
- vessels are individual navigation participants with individual arrival times, sailing behaviour and dimensions;
- particularly useful for a large diversity in vessel dimensions and sailing behaviour;
- very suitable for complexes with more than one chamber.

For a certain period, the complete traffic flow in and around the lock is simulated in detail and converted, whereby the results are statistically processed. The model can be used to express changes in the use

and design of the structure in passing through times and passing through costs and in the demand for waiting space for both navigation and road traffic (in the case of low, movable bridges). Based on unit costs, SIVAK calculates how much the passing through time is costing navigation.

Rough review of lock capacity

Besides the above-mentioned models, an initial rough review of the lock capacity can take place by rule of thumb. One of the parameters to test the efficiency of chosen chamber dimensions is the lock capacity. The capacity of a lock is the maximum volume of navigation (expressed in number of vessels, or tons of load) that can be locked through per unit of time under the applicable conditions, if the lock is in continuous operation with full chamber(s).

In general, the chosen time for a time unit is one hour. The capacity C of the lock can then be expressed in the following formula whereby the cycle time consists of an uplock and downlock:

$$\begin{aligned} C \text{ (vessels/hour)} &= 2 \times \text{max. number of vessels in chamber} / \text{cycle time} \quad \text{or} \\ C \text{ (tons loading capacity/hour)} &= 2 \times \text{max. number of vessels in the chamber} \times \\ &\quad \text{average loading capacity of fleet} / \text{cycle time} \end{aligned}$$

The capacity per lockage can vary considerably because, owing to various conditions during locking, one chamber filling is far more efficient than another. The capacity is therefore defined as the average of a large number of lockings with full chambers. If the fleet composition changes, the result could also change substantially. In particular, if the fleet consists of many vessel types and dimensions, the capacity cannot be determined by using simple means. A simulation is required for obtaining a reliable result.

For a rough estimate of the capacity, the following rule of thumb can be applied:

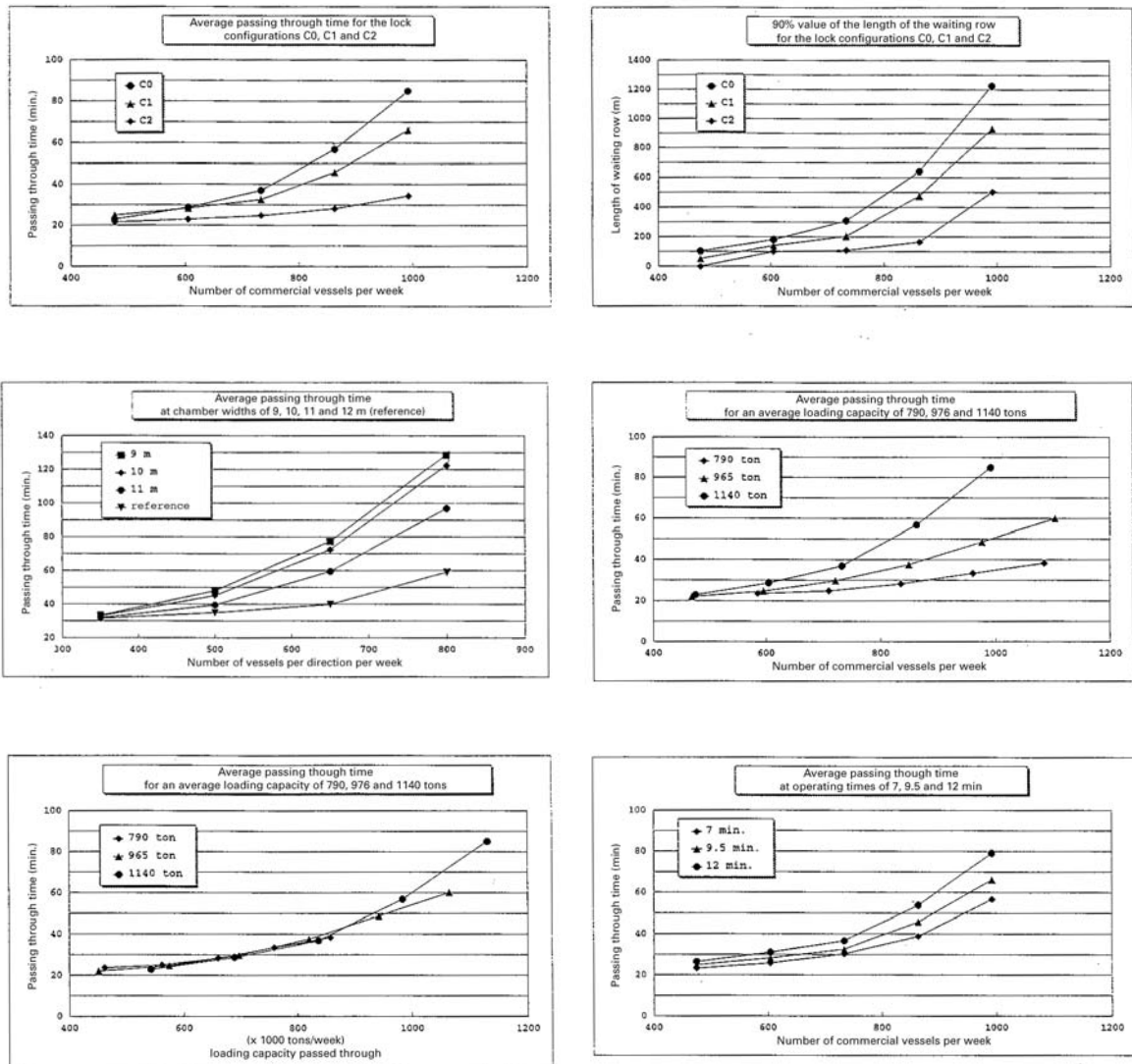
$$\begin{aligned} \text{If the volume of navigation is highly irregular:} \quad &0.55 < I_{\text{perm.wk}}/C_{\text{wk}} < 0.65 \\ \text{If the volume of navigation is very regular:} \quad &0.75 < I_{\text{perm.wk}}/C_{\text{wk}} < 0.85 \end{aligned}$$

To this end, the capacity C (vessels/hour) with the necessary corrections should be converted to the capacity per week C_{wk} (vessels/week) by multiplication with the number of available operating hours per week.

The capacity per week C_{wk} is compared to the *permitted intensity per week* $I_{\text{perm.wk}}$ in relation to the indicative values derived from the relation between $I_{\text{wk}}/C_{\text{wk}}$ and the average passing time. This comparison yields the permitted intensity per week $I_{\text{perm.wk}}$. If this permitted week intensity deviates considerably from the desired, normative week intensity established, the designer will have to select new chamber dimensions and the process will have to be repeated.

4.4.2.4 Influence of various factors on the passing through times

The effect of different measures on the average passing through time of the lock can best be researched and made visible by means of simulations. The following reflects the results of systematic series SIVAK simulations for possible changes/measures at a number of locks (among which lock complex Heel). The results discussed are examples and therefore not generally valid. See Figures 4.4 to 4.9.



Figures 4.4 to 4.9 Results of SIVAK simulations, influence of various factors on passing through time

Influence of effective width and length of the chamber

At substantial navigation volume, the main consideration is the efficient use of the chamber surface. Sometimes when selecting the dimensions for length and width, it could be useful to take into consideration that two standard sized vessels should fit in the chamber next to each other or behind each other (taking safety margins into account). The existing lock complex Heel (two chambers of each 16×134 m²), which has insufficient capacity, can be expanded in several ways. Figure 4.4 plots the average passing through time for this lock complex as a function of the number of commercial vessels per week with an average loading capacity of vessels of 1140 tons. Line C0 is the current situation, line C1 is one lock that has been extended to 200 m and line C3 is an expansion with a third chamber of 200×12.5 m². It emerges that a third chamber is effective: even with more than 1000 vessels per week it results in sufficiently short passing through times. In Figure 4.5, the 90% value of the queue length is set as function of the number of commercial vessels per week. This yields a corresponding picture. The length of the queue is of importance in relation to the necessary investment of well-equipped mooring locations in the lock approach.

For the Kleine Sluis IJmuiden (chamber of 12×105 m²), the width of the lock was varied to values of 9, 10, 11 and 12 m at a constant chamber length. Figure 4.6 provides the average passing through time as a function of the lock width. The differences in passing through time for the various lock widths are considerable.

Influence of sill depth

The sill depth has an influence on the permitted draught of the vessels and is therefore an economic factor of importance to the captain. Furthermore, the sill depth has an effect on the swiftness of the waterway: a small, shallow entrance to the chamber results in substantial hydraulic resistance and in the creation of translation waves on entry that could result in hindrance for other vessels. This is detrimental to the speed of sailing in and out and results in an increase of average passing through time.

Influence of increasing the scale of the fleet

The scale increase can be characterised by an increase in the average loading capacity of the fleet. Changes in the fleet composition have an influence of the way in which (combinations of) vessels fit in the chamber. The extent of this influence can only be properly determined by means of a simulation.

In Figure 4.7, the average passing through time has been set out as a function of the number of commercial vessels per week for an average loading capacity of 790, 965 and 1140 tons for the current lock complex Heel (two chambers of each 16 x 134 m²). The larger the average loading capacity becomes at an equal number of commercial vessels, the longer the average passing through time. Figure 4.8 provides the average passing through time as a function of the load already passed through for the previously mentioned three loading capacities. It appears that the passing through time at constant, passed through load hardly changes at a different average loading capacity.

Influence of operating times

The total passing through time of lock Heel amounts to an average of about 30 minutes, of which the closing time is in the vicinity of 10 minutes. The operating time is the time required for opening and shutting the gates (a few minutes) plus the time required for levelling (5 - 10 minutes). Increasing the speed of the gate movement generally does not result in capacity gain. Conversely, the levelling time can be substantially influenced by the selection of the levelling system. In Figure 4.9, the average passing through time was set as a function of the number of commercial vessels for the operating times of 9, 9.5 and 12 minutes. Given a large navigation volume, for instance 1000 commercial vessels per week, the average passing through time decreases more than the operating times.

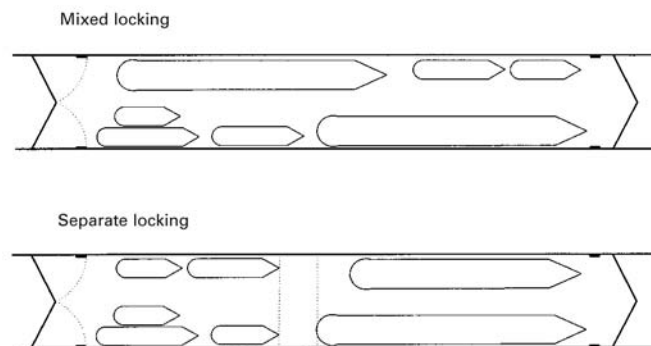


Figure 4.10 Mixed and separate locking

Influence of mixed- separated – apart locking

In mixed locking, all types of vessels are together in the same chamber but this is not always permitted. In the case of recreational vessels and/or vessels transporting dangerous goods, special locking is required. In separated locking, the recreational vessels or the vessels with dangerous goods are kept at some distance from the regular commercial vessels in the same chamber. In apart locking, the recreational vessels or the vessels carrying dangerous goods are in a chamber without commercial vessels. In general, this leads to loss of capacity: longer sailing in times and less efficient utilization of space. Usually, the safety also decreases. The differences are difficult to quantify but levels can be given (Table 4.7).

aspect	mixed locking	separate locking	apart locking
capacity	reference	slightly less	much less
safety	reference	much less	slightly less

Table 4.7 Influence of mixed-separate-apart locking

Influence of the number of chambers (1 respectively 2)

If there are two (or more) chambers available, the different categories (regular freighter, dangerous goods and recreational vessels) can easily be kept separate by directing the vessels to an own chamber. However, the recreational navigation chamber does have to meet the specific requirements set for this category.

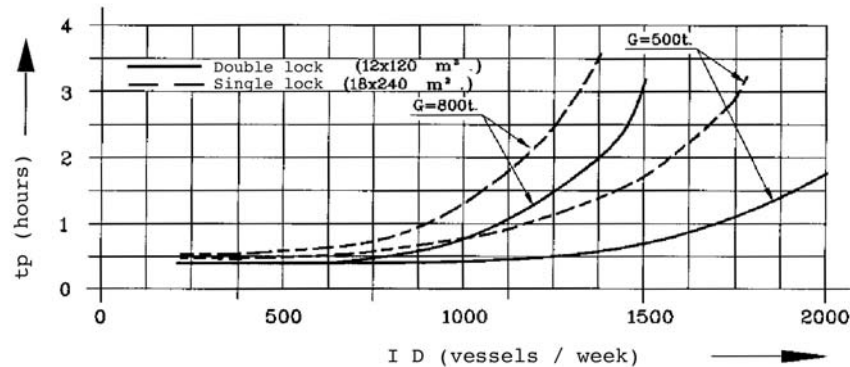


Figure 4.11 Average passing through times as a function of the navigation intensity per week

For regular commercial navigation, it has been proven that a lock with two chambers is more efficient than a lock with one large chamber, even if the large chamber has a larger surface area than the two smaller chambers together. This can be concluded from Figure 4.11 whereby the average passing through time has been set out as a function of the navigation intensity per week for a double lock (12x120 m²) respectively a single lock (18x240 m²) and for vessels with an average loading capacity of 500 respectively 800 tons. This confirms the supposition that the locking capacity does not simply follow on from the chamber surface.

Influence of part chambers

Some long locks have an intermediate gate. This is often intended for locking with a 'small' chamber if there is little navigation, which could be of importance to water management. With regard to safety, the intermediate gate could also function as a necessary separation for navigation categories (for example vessels transporting dangerous goods). Each case will have to be investigated and assessed to determine whether the use of intermediate gates will lead to actual improvement.

Influence of measures to limit lock discharge

In summer, some elevated canal reaches are faced with a shortage of water because on the one hand, too much water goes through to the lower reach due to locking while there is insufficient supply in the upper reach. The lock design could provide facilities such as extra culverts that connect adjoining chambers with each other so they can be each other's reservoirs or pumping stations for pumping water back. In addition, water-saving locking regulations can be established. These are focused on locking through more vessels (than usual) at the same time (better 'chamber filling'). For navigation this results in longer passing through times on average (due to longer waiting times), while the authority will have to provide more length for waiting facilities (often in simplified form due to its temporary use).

In order to assess the costs for the captain and the authority, the effects need to be quantified by means of simulation. It has emerged that a lock regulation for low load locks with incidental water shortages is a good solution, certainly with prior knowledge of approaching vessels. By contrast, the effect on high load locks is smaller; in those cases, pumping back lockage water is the correct solution.

4.4.2.5 Forecast of required lock capacity

For the principal, the question is usually not only how large the new lock should be but also in which year it should be available, given the transport forecasts and the time required for completing the procedures and the construction. Furthermore, the principal would often also like to be familiar with the global effects of alternative forecasts in this context. For answering this question, a method was developed with the aid of the SIVAK simulation model whereby a range of navigation forecasts are calculated

(average loading capacity and average annual passing load capacity), the passing through times and the demurrage, if so desired for different variants for the future lock. This method is called the Forecast-Lock Capacity-Effect-method (PSE).

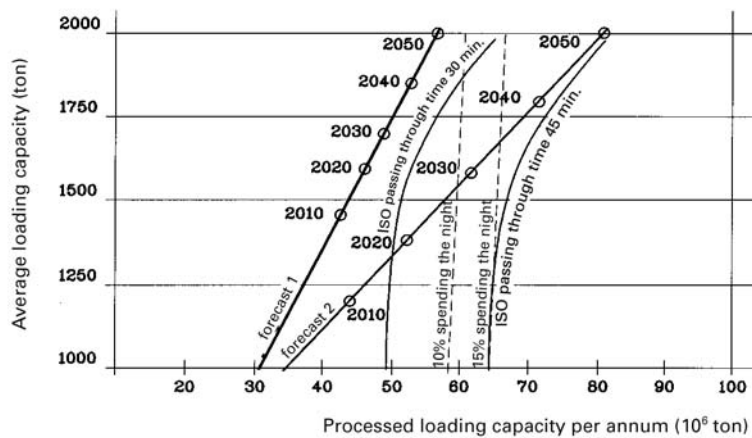


Figure 4.12 Example of average load capacity as a function of already processed loading capacity per annum at a given lock configuration.

Figure 4.12 provides a (slightly simplified) result of such a systematic series of simulations for a lock design. In the figure, the average loading capacity (characterises the scale increase in fleet) was set out as a function of the total amount of passing load capacity per annum. The figure comprises of three kinds of lines:

- two (fictitious) forecasts, one slightly more optimistic than the other. Next to these forecast lines, the corresponding dates are stated;
- two 'iso passing through timelines' that indicate when (at further increase in navigation) the average waiting time of 30 respectively 45 minutes is exceeded;
- two lines that indicate when the number of vessels spending the night (demurrage) becomes larger than 10% resp. 15% of the total supply.

For trials on passing through times, values were used that were derived from the field (locks in the Meuse) (Table 4.8)

assessment	passing through time (minutes)	stay over / demurrage (% of volume)
acceptable, not critical	< 30	< 10
critical phase: problems occur regularly	30-45	10-15
unacceptable, problems occur constantly	> 45	> 15

Table 4.8 Assessment of passing through times

Lengthy passing through times particularly result in extra costs for navigation. If many vessels spend the night, it also results in additional costs for the authority, as waiting areas have to be equipped for this purpose.

Figure 4.12 leads to the following conclusions:

- if the navigation increases according to forecast 1, the locking capacity will be sufficient for the long term; actually, the lock is too large because the lowest criterion (30 minutes passing through time) is never reached;
- if forecast 2 becomes reality, lengthy (average) passing through times will start occurring from about 2018; however, they will not exceed the upper limit of 45 minutes (= unacceptable). The substantial increase in passing through times after 2020 should be reason to start measures for improvement.

- the number of vessels staying over reaches a critical point in 2028 and from 2034, it will be unacceptably high. Taking into account a construction period of about 5 years, construction should start in about 2025.

This method, based on SIVAK simulations, offers possibilities to test the capacity of lock design on future developments. Please note that in this assessment, costs were not taken into consideration.

A drawback of the stated method is that for every new variant of lock characteristic or navigation volume, a completely new simulation has to be executed.

4.4.2.6 Guidelines for effective horizontal chamber dimensions

In the early stages of the design, there is often a need for an initial estimation of the lock dimensions without actually executing navigation studies etc. For this reason, this paragraph provides some brief guidelines for horizontal dimensions for, in succession, sea locks, inland locks and recreation locks with distinction according to navigation volume.

Marine navigation locks

There is no literature available for rule of thumb chamber dimensions for marine locks. The following differences in relation to regular inland navigation should be taken into account:

- with regard to the length of the chamber:
 - Sea-going vessels enter the chamber very slowly as they have limited stopping powers while they are hardly able to use their propellers at limited keel clearance.
 - The water in the chamber slows sea-going vessels, with large blocking of the wet cross section of the chamber, down considerably.
 - Space is often reserved for tugboats in front of and behind the sea-going vessel.
- with regard to the width of the chamber:
 - There are hardly any guide structures in front of the lock entrance.
 - Sea-going vessels manoeuvre very cautiously as they are hard to steer; once in the chamber the assistance of tugs is often no longer possible.
 - At limited keel clearance under the vessel, sufficient width is required next to the vessel.
 - Vessels that are sensitive to wind (car carriers, container ships) require extra width due to the (mostly) unavoidable angles of approach owing to cross wind.

Par. 4.4.3 states that a small keel clearance is often chosen at marine locks. For sufficiently rapid and safe sailing in and out of marine vessels however, the wet cross section of the chamber (width x depth) at minimum locking levels should be at least 25 to 30% larger than the cross section of the normative vessel. This results in the fact that lock width cannot be separated from minimal keel clearance above the sill.

For marine locks with a low navigation volume, an initial approach is:

- the length between the gate recesses = $1.15 \times$ length of normative vessel;
- the effective length of the chamber = 1.10 to $1.15 \times$ width of the normative vessel at a minimal keel clearance of 10% of the water depth above the sill in fresh water. (Note: effective width is the width between the chamber walls or – if applicable – between the floating frames).

If the lock has filling openings in the chamber walls at the gates, this length cannot be viewed as effective chamber length. In practise, it seems to be possible to, under stringent conditions, incidentally allow vessels to pass through with extremely small margins (experience IJmuiden and Terneuzen). There is no limitation on clearance.

Inland navigation locks

The dimensions of an inland navigation lock chamber are mainly determined by the economic interest of the waterway that the lock is situated in, expressed in navigation volume (Table 4.9).

Economic interest	design method
Locks in waterways with little navigation, low economic interest	CVB guidelines for a 'minimum lock' for singular normative vessel (see below)
locks in waterways with substantial navigation, substantial economic interest	with navigation study, for 'capacity lock'; test design on passing through times etc. (see 4.4.2.6)

Table 4.9 Design rules for minimum and capacity locks respectively

For effective chamber dimensions of a minimum lock (for little navigation volume) for inland navigation, the guidelines are stated in the CVB (Lit. [4.3]) and in Table 4.10.

waterway class	dimensions normative vessel (m)	effective chamber length 1) (m)	effective chamber width 2) (m)	sill depth 3) (m)
I	39 x 5.1 x 2.2	43	6.0	2.8
II	55 x 6.6 x 2.5	62	7.5	3.1
(IIa)	67 x 7.2 x 2.5	75	8.0	3.1
III	67 x 8.2 x 2.5	75	9.0	3.1
(IIIa)	80 x 8.2 x 2.5	90	9.0	3.1
IV	85 x 9.5 x 2.5	95	10.5	3.5
Va	110 x 11.4 x 3.5	125	12.5	4.2
Vb	186.5 x 11.4 x 4.0	210	12.5	4.7

Definitions:

- 1) length between the stop stripes (also see 4.4.2.2)
- 2) width available to vessels, including their own wood fender (also see 4.4.3)
- 3) sill depth = normative draught (idle) + keel clearance (0.6 m for classes I to IIIa and 0.7 m for classes IV to Vb)

Table 4.10 Dimensions minimum lock

Table 4.10 of the minimum lock is tantamount to the relation of the wet lock cross section above sill with a vessel cross section of 1.3 to 1.5. Wood fender used by the vessel (about 2 x 0.2 m) has been taken into account in the dimensions of width, the effective chamber width is about 1.10 x width of the normative vessel (for class I and II this is 1.15). The effective length of the chamber is about 1.12 x length of normative vessel.

Large push-tow locks of CEMT class VI for double push-tow units of 24 m wide yield a width relation of $24/22.8 = 1.05$. The lock has to be equipped with extremely good guiding structures to prevent any jamming and it has to have sufficient keel clearance under the lock sill. Given the relation between the wet cross section above the lock sill and a vessel cross section of 1.3, at a draught of 4 m this results in minimum keel clearance of 0.95 m.

It is impossible to determine dimensions for capacity locks without a more specific navigation volume study (for instance with the SIVAK simulation model). For a preliminary, global indication, see Table 4.11.

Navigation volume (vessels per annum, both directions together)		indication of lock required; fits in the chamber:
to 5.000		minimum lock; see CVB guidelines [3] one 'normative' (=largest) vessel
5.000-25.000	large diversity in fleet	1 small vessel plus 1 normative vessel
	small diversity in fleet	2 normative vessels
25.000- 50.000	large diversity in fleet	2 small vessels plus 2 normative vessels; vessels side by side in the chamber
	small diversity in fleet	4 normative vessels; vessels side by side in the chamber
more than 50.000		2 chambers

Table 4.11 Indication of required inland navigation lock as function of the navigation volume

The widths of the larger locks are standard dimensions with values of : 9, 10.5, 12.5, 16, 18 and 24 m. These values are (naturally) adjusted to other lock dimensions elsewhere on the route.

Locks for recreational navigation

The horizontal dimensions of a yacht lock do not only depend on the navigation volume of yachts, but also on large construction vessels that have to be able to pass through the lock, as well as on the substitute lock function with regard to commercial navigation. The horizontal dimensions should preferably be determined by means of simulations. Effective dimensions for initial approach are given in Table 4.12 and are derived from the CVB guidelines

Navigation volume (yachts/annum)	Determining chamber dimensions
about 10.000	- normative vessel length and width: exceeded by 30% of the vessels; - chamber width: double the width 30% -yacht + 1 m, but no more than 8 m; - chamber length: double the length 30%-yacht;
10.000 - 25.000	- chamber width 8 m and chamber length between double the length 30%-yacht and 60 m; - if more length is required, width also increases: 10 to 12 m
> 25.000	simulations will yield a width of 10 -12 m at a length of 80 - 120 m

Table 4.12: Indication of required navigation lock as a function of the navigation volume

4.4.3 Sill levels

4.4.3.1 Components of minimal water depth above the sill

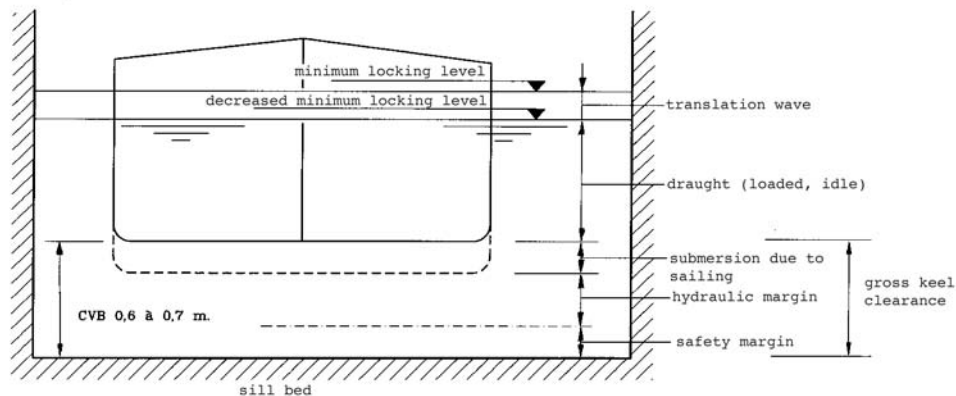


Figure 4.13 Components of minimal water depth

The level of the sills can be determined by subtracting from the minimum locking levels (Min.S) (see Figure 4.13 and the explanation below):

1. a margin for translation waves, seiches, surges and suchlike
2. the normative draught of the vessels
3. the submersion of the vessel owing to its sailing speed
4. a hydraulic margin
5. a safety margin

There could be further constructional or hydraulic reasons to select another level.

In practise, the following concepts are used:

Minimum locking level (Min.S):	This is the lowest water level at which locking can be effected for the normative vessel (see par. 2.4.1.1)
Decreased minimum locking level:	This is the minimum locking level minus the margin for translation waves, seiches and surges
Gross keel clearance:	This is the sum of the quantities 3, 4 and 5. It is the space (height) between the lowest point of the loaded, normative vessel that is lying idle and the sill or lock bottom at lowered minimum locking level.

The gross keel clearance consists of a number of quantities, which are partly quantifiable. The designer will have to make the best estimate possible of the various factors in order to make the correct choices in a specific case. For the minimum locks of the classes I – V, the CVB provides a gross keel clearance guideline of 0.6 to 0.7 m.

The minimum locking level (Min.S) of the lock is generally determined by the water level at the lower head (single sided lock) or the outer head (double sided lock). The issue of importance is how often and how long this level is reached or underrun. It can sometimes be acceptable to wait a few hours for a lock in a tidal area, while it is unacceptable that a lock along a river has insufficient depth for weeks. Considerations are included in the CVB guidelines (Lit. [4.3]) and are summarised in chapter 2.

In general, a water level that is underrun for 1% of the time is a good choice for a minimum locking level (Min.S), subject to it being used in combination with the normative draught and the required keel clearance. At lower water levels, it could be considered to keep the lock accessible to vessels with smaller draughts. The management makes the final decision.

Margins for translation waves, seiches, surges and suchlike

At the lowered minimum locking level, various time phenomena are taken into account that, in a time of tens of seconds, could result in a few decimetres of level fluctuation. This concerns translatory waves, seiches, surges and suchlike. Please note however that sometimes, the depth decrease and suchlike that are a result of the translation wave is accounted for in the safety margin (part of the gross keel clearance, see Figure 4.13). Each case should be separately assessed to see which possible causes there are for translation waves (and other level fluctuations) for instance:

- lock waves caused by filling/emptying locks in the same waterway;
- depression of the water level waves caused by passing vessels;
- translation waves caused by vessels sailing through a narrowing (the lock head, for instance);
- translation waves caused by manipulations with propulsion or hydro-electric power stations;
- surges and seiches.

It is incorrect to add these waves to each other: a probability distribution will have to be made of the simultaneous occurrence of these factors as well the otherwise already chosen (lengthy) minimum locking level (Min.S).

Normative draught

The normative draught is selected based on the economic considerations and the depth of the connecting waterways. It is assumed that a vessel, lying idle and loaded to maximum capacity, is almost lying level (draws equally deep front and back).

Submersion owing to sailing speed

A sailing vessel lies deeper than a vessel lying idle. This 'submersion' is mainly determined by the sailing speed and the wet cross section of the vessel and the waterway (lock head). Large vessels will always enter slowly because they have to stop once they are in the lock. It does happen that an incautious captain enters with considerable speed given a long lock chamber.

After locking, one generally wants to *depart rapidly*. When sailing out of a lock with a large lift on the upstream side, the water depth in the chamber is extremely large, which results in the sailing vessel experiencing little resistance. This in turn results in the vessel arriving at the head sill at a relatively high speed where the wet cross section is much smaller than in the chamber, which allows the vessel to submerge considerably here. This problem does not occur when sailing out through the lower gate as then, the wet cross section of the chamber and the head are level. If there is a large submersion above the lock sill (for instance departing from the deep lock chamber) this has to be separately calculated.

It is incorrect to calculate the occurring submersion during entering and leaving the chamber with a stationary method such as the Schijf Method. The WAROS program (WATERbeweging ROND Schepen, Lit. [4.10], Appendix 4.3) is suitable for this purpose. This is a one-dimensional, non-stationary calculation model for the flow velocity, water level fluctuations, vessel submersion, trimming and minimal keel clearance for vessels that sail through the waterways with intermittency. WAROS calculates the sailing speed from the capacity entered. The researcher/designer has to select the sailing in capacity based on interviews and/or practical observations.

Hydraulic margin

The relation between the wet cross section of the vessel and the chamber in combination with the sailing speed are the determining factors of the hydraulic resistance that the vessel experiences. The space below the vessel is part of the wet cross section and has an influence on the steering of the vessel. The hydraulic margin is intended to make it possible for extremely broad vessels (broad in relation to the lock chamber) to enter and leave the chamber at a reasonable speed. For a normative vessel that enters a minimum lock, the speed amounts to about 0.5 m/s. If the hydraulic margin is very small, it is possible that a large vessel sailing into a relatively narrow lock head from a large lock approach or from a deep lock chamber, suddenly experiences extreme submersion or a sudden increase/decrease due to translation waves (quantifiable with WAROS, see previously).

Safety margin

This margin has the character of an 'uncertainty margin' and is necessary because each of the previous factors has a limited accuracy. This applies to the water levels as well as the vessel draught (is the vessel lying unevenly?) and the submersion. Of importance is also whether serious damage occurs if a vessel does collide with the sill. In general, a margin of a few decimetres will be included in the level calculation.

4.4.3.2 Guidelines for minimum gross keel clearance

Marine locks

There are no general rules for the gross keel clearance in *marine locks*. Details to be mentioned here are:

1. Salt and fresh water not only create density currents but also differences in draught;
2. Large sea-going vessels generally use caution when sailing into a lock, if necessary with tugboat assistance; the sailing speed is very limited and therefore, so is the extra submersion.
3. Large sea-going vessels have such draught that the necessary excavation depth for the construction of a lock, just like for inland navigation locks, becomes an important cost factor in selecting the lock depth.

The first factor is taken into consideration by using the vessel draught in fresh water as point of departure. The second and third factor enable acceptance of a small keel clearance, for instance 10% of the draught (compare inland navigation locks with 20%). The small keel clearance encounters large hydraulic resistance. For this reason the lock has to be made wider, in order to facilitate sailing in and out at reasonable speeds.

Under pressure of scale enlargement of the vessels, quite often vessels with very small keel clearance are locked through, with permit, as can be seen from the following example (*Noordersluis van IJmuiden*). The inner and outer sills are at the same height. At the outer head the tide is used for extra water depth: the extremely large vessels are locked through at rising tide, at a water level of NAP or higher. The water depth at the *inner* head is 14.50 m (sill on NAP – 15 m and canal level NAP –0.50 m). At the inner head, the vessel is in fresh water, which makes the draught larger than the nominal saltwater draught (factor 1027/1008 for density of water outside and inside the lock). A vessel is permitted if it draws outside 45 feet (13.72 m). The draught at the inner head is 13.97 m. The keel clearance is therefore only $14.50 - 13.97 = 0.53$ m or less than 3% of the draught. It is emphasised that this small keel clearance is only safe because just before every lock through of a vessel with large draught all factors of importance are measured, such as actual draught of the vessel, the measure of evenness of load and the density of the water at both heads. Given the maximum draught permitted, the vessel may not be wider than 42 m (wet cross section of the lock is 50 m wide). For broader vessels, the rule applies that for every 5 cm more in width, the draught must be 2.5 cm smaller (to 45 m wide at 40 feet (12,18m) draught). The latter is viewed as the 'normal' draught, which corresponds with a keel clearance of 19% (at a width clearance of 11%).

Inland navigation locks

The CVB guidelines (Lit. [4.3]) also contain guidelines for the level of the lock sill. Based on practical measurements at locks with a flat floor and at locks with large difference in level between the floor and the upper head, the CVB recommends choosing the gross keel clearance (see definition above) for the minimum lock as follows:

CEMT class I, II and III:	0.60 m
CEMT class IV and V:	0.70 m

The keel clearance measures about 20% of the draught. In an existing situation, where it comes down to the question what the largest permitted draught is (admittance policy), it is possible that a smaller keel clearance is acceptable, based on closer research (executed with the WAROS calculation program for instance), provided that strict requirements are set for the sailing in speed.

Recreational navigation locks

A keel clearance of 0.40 m can be adhered to for yachts in all cases (CVB guideline).

4.4.3.3 Further consideration with regard to sill level

In general, navigation requires the largest possible lock depth in view of the permitted draught. If a captain is permitted to load 0.20 m deeper provided that he enters the lock slowly, he will accept the condition gladly. Usually, this is not taken into account at the lock design but it could be a factor in the admittance policy.

It makes no sense to make the lock that deep that the permitted draught is larger than the connecting waterways, unless the waterway depth will be increased in the future. Possible tunnels under the waterway could make it 'impossible' to deepen the waterway (for instance the Noordzeekanaal). Because of the construction costs, the depth will be kept as shallow as possible. The difference in construction costs will have to be weighed up against the differences in the sum of transportation costs (larger draught = cheaper transport).

If the lock is situated on the boundary of salt (brackish) and fresh water, the sill height has a large influence on the salt/fresh exchange. It could be attractive to have an adjustable sill on the fresh water side (see chapter 21).

Lastly, the filling and emptying system (see chapter 6) can have an influence on the levels of the sills. After all, if a sill (and the lock floor) is lower, there is more space (height) available in the gate for a well-formed width of passage. Besides, a deep lying fill opening is favourable because the filling propulsion also flows under the vessels. Both factors decrease the ensuing hawser forces.

From this it should be clear that, even in the same waterway, the optimal sill depth does not need to be equal everywhere as requirements can differ locally.

4.4.4 Level of the chamber floor

Usually, the chamber floor is built at the same level as the lowest sill, or a little lower. There are a few reasons for placing the chamber floor lower.

- If the chamber walls are independent constructions (executed as anchored sheet piling or deep wall) the chamber floor does not have to consist of concrete slab as a rubble layer will suffice. This layer has to withstand the forces of screw propulsion, return current and filling current to prevent loose stones from ending up on the sill or resulting in local decrease of depth. This is an optimization issue: if the floor is deeper, a lighter stone will suffice (example: Nieuwe Oranjesluis in Amsterdam).
- In a levelling system via the gates or the heads, the filling/emptying system should largely run in a longitudinal direction through the lock. Current forces and longitudinal gradients that could exert considerable hawser forces on the vessels in the chamber accompany this flow. In principle, the deeper the chamber floor the smaller the hydraulic forces and the sooner levelling can be effected. On the other hand however, it is a case of the larger the depth the higher the costs.

4.4.5 Capstone height, in view of navigation

4.4.5.1 Introduction

'Capstone' is the word traditionally used to indicate the top of the lock coping. In common usage, this is also synonymous for 'height of the chamber wall'. The capstone height is determined by two factors:

1. nautical requirements in connection with the maximum locking level;
2. water retaining function of the lock in connection with the normative high water.

Naturally, cost also plays a role. Given these two factors, the capstone is not placed higher than necessary. The first factor is addressed in this paragraph, the second in par. 4.5.

The maximum locking level is the water level above which locking is no longer permitted. Normative high water is the highest water level that should be retained. Usually, locking is not possible in this situation. If normative high water is much higher than the maximum locking level, the upper head is made higher than the lock coping and the lower head. If normative high water is not higher or just a little higher, both heads and the intermediate lock coping are built at equal height. This is discussed in more detail in Par. 4.5.

4.4.5.2 Nautical requirements

The height of the chamber wall above the maximum locking level is mainly determined by the requirement that it is supposed to supply visual as well as physical guidance. At marine locks, there is generally no need for physical guidance.

For *visual guidance* (orientation), both the chamber walls have to be of equal height (as usually is the case for different reasons). For visual guidance, it is favourable if the chamber wall always is higher than the bow of the vessel. Often, this is not feasible but there are other ways to provide the captain with the necessary visual guidance (markings, for instance).

The *physical guidance* means that the vessels should be able to sail by without risk, if need be with sliding and grating. On the one hand, protruding parts of the vessels should damage nothing on the lock coping and on the other hand, vessels should not incur damage because they are sliding on part of the lock instead of along part of the lock. The latter could occur if a gentle sloping push prow connects with a low chamber wall (or guide structure) at an unfavourable angle. The factors that determine the protrusion and the damage probability are therefore:

- the height of the chamber wall above the water: the higher the wall the smaller the chance of damage;

- the shape and height of the vessel bow. Push prows are highly disadvantageous. Vessels with push prows are mainly found on the larger waterways;
- the angle between the vessel and the chamber wall: the larger the angle, the larger the probability of damage. In a lock of 24 m wide, a class IV vessel can have an angle of about 10° to the chamber wall. Much larger angles are possible at the lock entrance. Vessels with larger bow propellers will hardly ever have larger angles because they are more manageable. An empty dumb barge is usually the most unfavourable vessel, certainly during cross wind.

The height of the chamber does not have a considerable influence on handling the (mooring) forces, if well designed mooring rings and bollards are present (see chapter 17).

It is clear that a high chamber wall always provides the best guidance. For the capstone level of every lock and the navigation volume, the optimum between construction costs and damage probability should be found. Besides this, attention should be paid to safety: the height of the chamber wall is important to embarking and disembarking. It is difficult however to establish guidelines for this because the height of (various parts of) vessels vary greatly. In this regard, sufficient and proper steps are important for the embarking and disembarking.

4.4.5.3 Guidelines for capstone height

Marine locks

Marine vessels are much higher in structure than inland navigation vessels and, for physical guidance as described for inland navigation in the previous paragraph, very high chamber walls would be required. Usually, it is sufficient to place floating frames along the chamber walls. These floating frames function as both fenders and guides.

Because of the superstructures of marine vessels, the hawsers have to be tied to the bollards on the lock terrain. This is not a problem as generally speaking, there is a flatman present to place the hawsers around the wall bollards. Therefore, it is not necessary to have the lock coping at a certain (high) level for hawser handling.

Nautically there are no reasons to place the capstone level higher than necessary for keeping the lock coping dry at maximum locking level. From a water retaining function (second or reserve retaining structure), it is possible that the capstone needs to be higher.

Inland navigation locks

Published by the CVB guidelines summarised in Table 4.13.

CEMT class	Height of lock coping above maximum locking level	
	chamber wall	lock head
I - IV	1.5 m	same as chamber
V	2.5 m	4.5 m

Table 4.13 Height of lock coping

The large height for class V is based on the assumption that a large part of class V vessels have a push prow. If these guidelines are followed, also during maximum locking levels, it is virtually impossible for 'overhang' to occur. In the CVB 'Guideline for Locks on waterways of CEMT classes I-IV', graphs are included for the various bow shapes, heights and angles from which it can be determined how far a vessel would protrude.

The probability that push prows will cause damage if lower values are adhered to than the values stipulated in the CVB guidelines, is not large. Furthermore, the question is how the cost of such damage weighs up against the costs of such high chamber walls. The outcome generally is that the guidelines provided for class V (2.5 and 4.5 m) cannot be adhered to. Lower heights are chosen.

With regard to the damage probability, we would still like to point out that the maximum locking level is reasonably rare. If the average level is 1.0 m lower for instance, this means that in average circumstances the guideline of 2.5 m is being met if the chamber height is on 1.5 m above the maximum locking level.

An example of this is that at the second lock at Lith (CEMT class Vb) the choice was made for a height of 1.5 m above maximum locking level.

Recreational navigation locks

For these locks, a capstone height is given with respect to the normative high summer level. Recreational navigation consists of both very small vessels (day tourism) and larger vessels of 10 to 15 meters or even more. For the smallest vessels, a height of 0.75 to 1.0 m is acceptable. Even for larger yachts, 1.0 m is suitable if the height is not less than 0.5 m above the maximum locking level.

4.4.6 Clearance

4.4.6.1 Introduction

In general, the clearance at locks is related to fixed bridges across the lock or to lift gates. The level of the underside of the fixed bridge or lifted gate is determined by the clearance. If this makes the lock too expensive or results in other problems (horizon pollution), it would be better to choose a different type of gate.

In choosing the place and height of bridges, the cost of the connecting roads must be taken into consideration as a function of construction height. Different locations are possible for the bridge (also see par. 2.3.4.1):

- over the upper head: usually difficult/expensive to create sufficient clearance;
- over (part) of the lock: advised against as it results in a decrease of effective chamber surface;
- over the lower head: usually the greatest clearance at the least cost, because the height is measured with respect to the lower water level.

General guidelines for the height of a *moveable bridge* cannot be given: per case, the optimum of the costs will have to be determined for:

- the construction, maintenance and operation of the bridge;
- the waiting road traffic;
- possible delays experienced by navigation.

Guidelines for fixed *bridges and lift gates* can be provided. See the next paragraph.

4.4.6.2 Guidelines for clearance

For a construction (bridge, lift gate) over the upper head of the lock, calculations are made with the maximum locking level. If the construction is over the lower head, the high normative water level for the lower reach is taken into account for the clearance (also see par 2.4.1.1). The normative height of vessels in view of passing underneath is called 'clearance' or 'mast low draft'. For an initial approach on the clearance, point of departure can be the cvb guidelines. The clearance of inland navigation vessels is chosen as such that this is exceeded by only 10% of the inventoried fleet (early in the nineties). It is recommended that the most recent fleet inventory obtainable for that route is used in actual situations and based on that, possibly through extrapolation, the normative clearance is selected.

CEMT class	type of vessel	clearance (m)
-	sail yacht	12.0
-	motor sailer	3.4
I	Spits - Peniche	5.0
II	Kempenaar - Campinois	6.0
IIa	Hagenaar	6.3
III	Dordtmund-Ems-Canal	6.3
IV	Rhine-Herne-Canal vessel	6.7
Va	Big Rhine barge	6.7 / 8.8 *)
Vb	Double push prow vessel	8.8
*) 6.7 m Is high enough for 3 layers of containers as well as for 70% of unloaded vessels of this class. 8.8 m Is for waterways with substantial container navigation; Suitable for 4 layers of containers as well as for 90 - 95% of the unloaded vessels.		

Table 4.14 Guidelines on clearance

Between the structure (bridge, lift gate) and the highest point of the vessel a safety margin of 0.30 m is kept. The clearance, measured from the normative water level is therefore calculated as follows:

$$\text{Clearance (m)} = \text{mast lower (air) draft (m)} + 0.3 \text{ m safety margin}$$

For class V, the clearance for 3 layers of containers becomes 7 m and for 4 layers of containers 9.10 m. These values correspond with the CEMT recommendations. The clearance of 9.10 m is also the agreed height for bridges across the Rhine (measured in respect of the Normative High Water level (NHW)). Please note however, that the required clearance for container vessels is currently under debate (1998). This could lead to larger recommended heights.

4.5 Lock, levels in view of water retaining function

4.5.1 Functional requirements for the lock as part of the water retaining structure

Locks are part of the water retaining structure. As stated in par 2.3.2, this translates into requirements concerning:

1. the permitted overflow and overtopping;
2. strength and stability;
3. reliability in closing the gates.



Photo 4.4 High water at weir and lock complex at Belfeld

The first requirement is a determining factor in the retaining height of the lock, in particular the level of the upper gate cladding of the outer (upper) head and for the capstone height of that head. At least this is the case if navigation guidance does not require a higher wall and therefore a higher capstone level. The second requirement is examined more closely in chapters 7, 8, 12 and 13.

Often, the same level is set for the top of the inner (lower) gates and those of the outer (head) gate. If that is the case, there are two complete water retaining structures present and there is no need, from a water retaining function, for extra requirements to be set in relation to closing reliability. (Lit. [4.5]).

From a cost perspective, it could be attractive to use lower inner gates and walls for that head as well as for the chamber. If this is the case, there is only one full water retaining structure and requirements have to be set for the closing reliability. According to the TAW 'Guideline' (Lit. [4.5]), the following then has to be met:

$P_{fa} \leq 0,1 \cdot \text{norm}$, in which:

P_{fa}	= actual risk of failure due to failing closing device (1/year);
norm	= design frequency (1/year).

Even though this is not expressly stated in Lit. [4.5], it is recommended that P_{fa} is divided by n if n is found in lockable structures in the water retaining structure. Please note that Lit. [4.5] relates to structures that are covered by the Flood Defence Act and that corresponding standards will have to be set for

other locks. Paragraph 4.5.2 provides a description of the locks that fall under the Flood Defence Act and the locks that do not.

The point of departure for the gate height of at least one gate per lock is Normative High Water (NHW). Paragraph 4.5.3 indicates what this standard is based on and which sources of information it possibly derived from. Based on NHW and other data, such as rise in sea level, settings, seiches and local rise in water levels due to wind action, the upper gate cladding is determined in par. 4.5.4. One of the facets, the retaining height, in relation to the limitation of wave overtopping and overflow is addressed in par. 4.5.5.

4.5.2 Locks as part of the water retaining structure

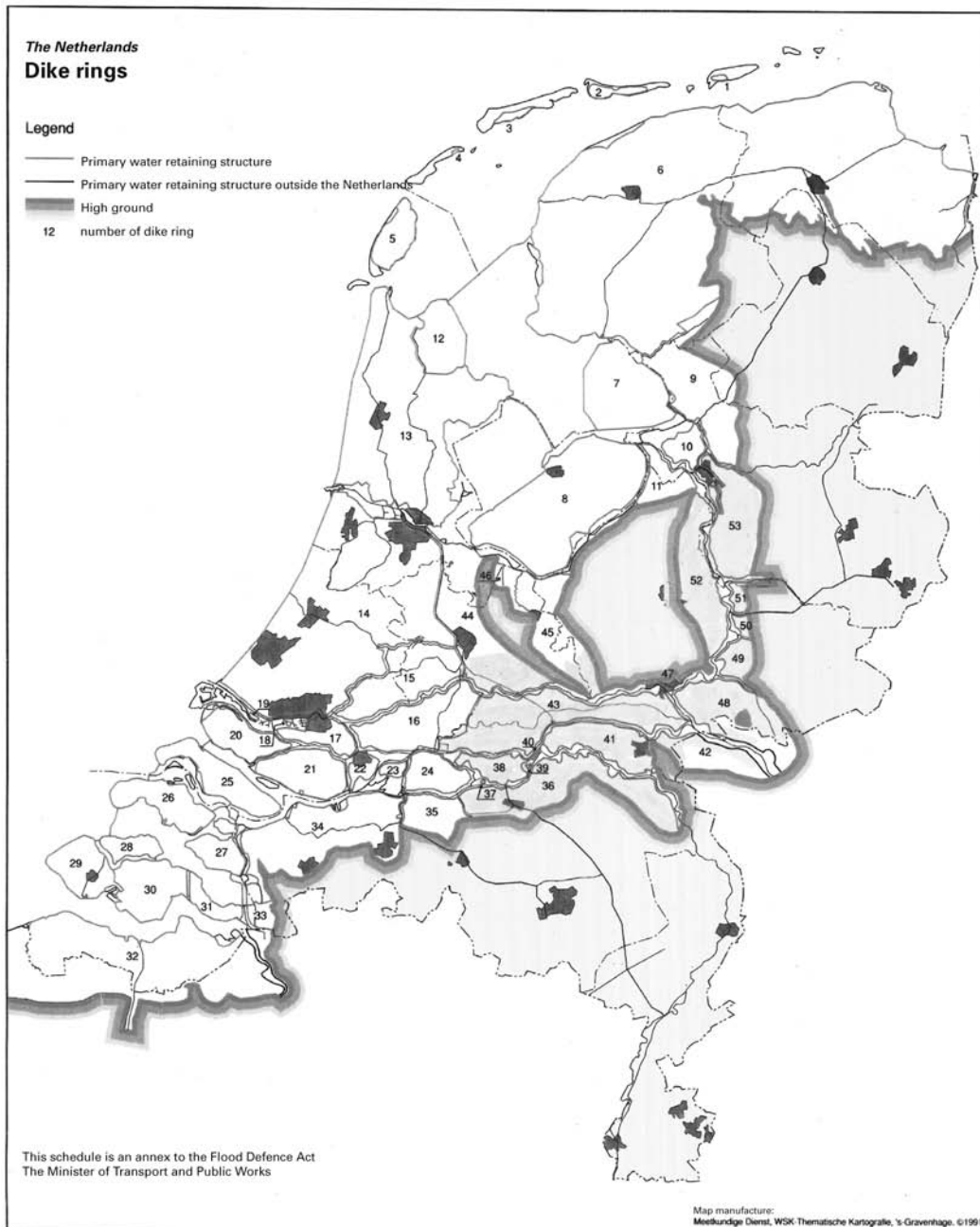


Figure 4.14 Dike rings in the Netherlands

Locks are part of a water retaining structure. For determining the retaining height of a lock, it is important to distinguish between areas of primary water retaining structures and non-primary water retaining structures because high water levels have been legally stipulated for the primary retaining structures whereas this is not the case for the non-primary structures (Lit. 4.21).

Locks in primary water retaining structures

To protect the Netherlands against high inside and outside water, there are water retaining structures in the shape of dunes, dikes and dams. Dunes and dikes are found along the coast and the islands, dikes are found along all the rivers, canals, lakes and suchlike and dams are situated in the sea arms, between the lakes and in the rivers/estuaries usually with lockable openings.

The lower part of the Netherlands (Groningen, Friesland, Flevoland, Noord- en Zuid Holland, Utrecht and Zeeland) and near the large rivers (parts of Gelderland, Noord-Brabant and Overijssel) consist of a sequence of dike rings (Lit. 4.21). The dike ring encloses a piece of land and consists of a closed ring of dikes and possibly dunes, this being the *primary water retaining structure*. There are also dike rings that are not closed, but these dike rings link up with higher ground. In total, there are 53 dike rings in the Netherlands. The primary water retaining structure protects the enclosed land from flooding at high storm surge, high surface water of the large rivers or high water in the IJsselmeer. It is called a primary water retaining structure because it has a direct influence on the safety of large parts of the Netherlands. Inside the dike ring, we find drainage sluices, guard locks and/or pumping stations for excess water, sometimes inlet sluices for dry periods and often navigation locks for navigation inside the dike ring. The dike rings are shown in Figure 4.14. An example of a closed dike ring of hard sea dikes is dike ring area 30, Zuid Beveland, at threat from the Wester- en Oosterschelde.

Locks can be included in the primary water retaining structures. An example in the coastal area is dike ring area 32, Zeeuws Vlaanderen, with the lock complex of Terneuzen. Another example for the upper river area is dike ring area 43, Betuwe, Tieler- en Culemborgerwaarden with the lock complexes of Tiel and Ravenswaay.

Locks in connecting water retaining structures

Between the dike rings of the primary water retaining structures there often are *connecting water retaining structures* (dams) that mostly include flood control structures, guard locks, drainage sluices and/or navigation locks. These connecting water retaining structures are considered primary structures. Examples of connecting water retaining structures are the Afsluitdijk, the Haringvlietdam and the Oosterscheldedam.

A lock is usually taken up in the connecting retaining structure. Examples in the coastal area are the lock complex at IJmuiden between dike ring area 13 (Noord-Holland) and 14 (Zuid-Holland) and the Krammersluizen in the Philipsdam between dike ring area 25 (Goeree Overflakkee) and 27 (Tholen). In the IJsselmeer area, between dike ring area 13 (Noord-Holland) and 8 (Flevoland), we find the Krabbersgatsluizen at Enkhuizen in the Enkhuizen / Lelystad dam section.

Locks in non-primary water retaining structures

Inside the areas of primary retaining structures (thus inside the dike rings), there are many non-primary retaining structures (dikes) along the watercourses. There could also be water level differences in these canals that need to be bridged by means of locks for the benefit of navigation. Examples are the Oostersluis in the van Starckenborghkanaal in Groningen and the lock in Leidschendam in Rijn/Schiekanaal.

In higher parts of the Netherlands (Drenthe, Veluwe, Twente, Achterhoek, Limburg and the southern part of Noord-Brabant) there are no primary retaining structures. However, the water retaining structures (dikes) along the rivers (for instance the Maas in Limburg), brooks and streams, canals and suchlike have to likewise protect the country against high river discharges.

In a navigable river, in addition to a weir, there are one or two locks present. (Example: locks at Belfeld in the Maas). A lock separates canals that intersect with a river. (Example: Lock Panheel between Kanaal Wessem-Nederweert and Maas). A lock separates the reaches with different levels in the canals. (Examples: locks in Born and Maasbracht in the Julianakanaal).

4.5.3 Hydraulic preconditions

According to the Flood Defence Act, the high water levels for the area of *primary retaining structures* have to be established. These water levels are stated in the publication "Hydraulische randvoorwaarden voor primaire waterkeringen" (Rijkswaterstaat DWW, Sept. 1996, lit. [4.21]). This act relates to the protection against outside water: the sea, the large rivers and the IJsselmeer, due to storm surges at sea, high river discharge and waves.

The stated publication provides *test levels* for many locations along the various dike rings and along the connecting retaining structures. The test level is the high water level at which the dike or the structure is tested and supposed to withstand. The test level applies for a certain period, such as test level 2000 for the period 1995-2000. The test levels provided in the publication are for the dike rings along the seacoast, the upper river and tidal river area, the Vecht / Zwarte Water area, the IJsselmeer area and for the connecting retaining structures between the dike rings. For the design of a structure, the test level has to be refashioned to a level that corresponds with the end of the lifespan of the structure (for instance 2100) by taking into account an increase in high water due to the rise in seawater level and tidal change or with human intervention in the area.

Along the *seacoast*, high water levels are caused by storm surges at sea. *Design levels* are used for the hard seacoast while *calculation levels* are used for the sandy seacoast. Design levels correspond with a certain design frequency and are valid for the year 1985. They are deterministically defined through extrapolation of measurements of water levels in the coastal area concerned and from the incline of the exceedance line Hook of Holland (design level NAP +5.15 m at 1/10.000 year). Calculation levels for sandy coasts (dunes) are created by summation of 2/3 of the decimated height at the design level. (Remark. Decimation height is the difference in level at a 10 times smaller exceedance probability). The test level 2000 for instance, such as stated in the publication, is the design or calculation level from 1985 increased by a 15 year rise in high water. To determine the level for the design of a hydraulic structure in 2035, the design level is increased by 50 years increase in high water (=2035 - 1985). As examples of design frequencies, we mention the dike ring area Walcheren with a frequency of 1/4,000 years and the dike ring area Noord-Holland met 1/10,000. The significant wave heights and wave periods are provided with the test levels.

In the *tidal river area*, the high water levels are caused by a combination of high river discharges and storm surges at sea. The *NHW* values (Normative High Water) are used for the dike rings in this area. The *NHW value* is also linked to an exceedance probability that is equal to the design frequency of the dike ring area concerned and is representative for the year 2035. The *NHW* levels are probabilistically derived through the execution of a large number of calculations of combinations of storm surges at sea and high water discharges of rivers. For the value of the test level 2000, the *NHW* value must be decreased by the effect of 35 years increase in high water (=2035-2000). For the hydraulic preconditions of the design of a hydraulic structure in 2085 for instance, 50 years of high water increase (= 2085-2035) above the *NHW* value is required. Examples of the exceedance frequency in the dike ring area Zuid Holland is 1/10,000 years and in the dike ring area of West Brabant 1/2,000 years.

In the *upper river area* and the Vecht/Zwarte Water area, the high water levels are only caused by high river discharges. The *NHW* values are also used for dike rings in the tidal river area and with a frequency of 1/1,250 years. The *NHW* values came about through extrapolation of measurements, calculations related to changing geometry of the river over the years and from analyses of more rapid discharge of precipitation to the river. The *NHW* value is equal to the test level and this level can be used for the design without any correction, if there are no expected interventions in the river.

For the *IJsselmeer area*, dike crest heights are given that depend on the geometry of the dikes and correspond with different exceedance frequencies (for instance Noordoostpolder 1/4,000 years). The values are calculated from combinations of the possible IJsselmeer level (among others due to high discharge wave IJssel) and the rise in water level due to wind action.

Nearly all sea arms occurring in the Netherlands are closed off by means of a dam that includes either a storm surge barrier or a lock. These dams then connect two dike rings. For these *connecting water retai-*

ning structures, test levels are provided together with wind wave heights and wind wave periods. The river area also has connecting retaining structures. The test levels once again relate to an exceedance frequency that corresponds with the dam section concerned, for instance Afsluitdijk 1/1.430 years, Oosterscheldedam 1/4.000 years, locks at IJmuiden 1/10.000 years and storm surge barrier Hollandsche IJssel 1/10.000 years.

High water levels for the areas *outside the primary water retaining structures* are not always immediately available. For the Maas, the maximum water levels are determined through extrapolation of measurements (supply Borgharen 3.650 m³/year), from calculations with storm surge models with the proposed new length and width profiles and extra supply from the tributary rivers and suchlike, possibly supplemented by new hydrological calculations (Commissie Boertien).

In canals with a drainage function, maximum water levels are usually determined from extrapolation of existing measurements at an assumed exceedance probability. If necessary, results have to be supplemented with a one-dimensional flow calculation of the area and with analyses and changes in the discharge regime.

4.5.4 Level of upper gate cladding and capstone

The level of the top of the outside/upper gate and the capstone height of the outside/upper head is determined by the normative high water level, sea level rise, settlement of the lock, local rise of the water level due to wind action, long-periodical waves (seiches etc.) and the degree in which wave overtopping and possibly overflow are acceptable.

The TAW Guideline 'Waterkerende kunstwerken en Bijzondere Constructies' (Lit.[4.5]) provides the following formula for the retaining height:

$$h_{kr} = NHW + h_{zsr} + h_{zkl} + h_{opw} + h_{sbb} + w$$

with	h_{kr}	= the construction height of the structure;
	NHW	= Normative High Water (along the upper and tidal river area), design level (along hard seacoast) or calculation level (along sandy seacoast) (see par. 4.5.3);
	h_{zsr}	= sea level rise and increase of the water level due to morphological developments during the planning period, in so far as this has not been taken into account in the NHW;
	h_{zkl}	= settling and setting during the plan period;
	h_{opw}	= rise in the water level due to local wind action;
	h_{sbb}	= rise in the water level due to seiches, rain oscillations and surges;
	w	= retaining height in relation to wave overtopping and overflow.

The following can be added to the text above as taken from the Guideline, which applies to all kinds of water retaining structures present in the primary retaining structure:

- h_{kr} :
For the construction height of the structure, please read: the upper cladding of at least one of the gates (or gate pairs if it concerns mitre gates) and that of the corresponding head and the adjoining lock terrain. As described in par. 4.4.5 and 4.6.4, the capstone and the lock terrain are often built at a higher level for other reasons (navigation).
- NHW:
As stated in par 4.5.3, this level is usually a fixed value for primary water retaining structures. For other areas, normative high water is more difficult to establish.
- h_{zsr}
Besides rises in seawater levels, water level changes in the plan period could also occur due to artificial level adjustments in canals and lakes.
- h_{zkl}
Settlements due to gas extraction and (the after effects of) mining activities could also occur in the plan period.

- h_{opw} and w
Wind activity could lead to a local rise in water level and in waves in front of the lock gate. This depends on the wind direction and strength at the time of NHW, the geometry, clearance and the aspect of the area in front of the lock. The incoming waves reflect against the vertical wall, which can result in a standing wave pattern of considerable wave height in front of the gate. The effect is enlarged by the application of a funnel-like entrance. The measure of reflection is also determined by the size of the retaining height (at lower w a smaller reflection).
- w :
The Guideline provides calculation rules for determining the retaining height. The following paragraph contains a summary of these rules. The paragraph ends with a rule of thumb for an initial approach to the retaining height during the preliminary design.

4.5.5 Retaining height

The retaining height in relation to overtopping and overflow depends on the waves in front of the gate (the incoming waves without reflection and suchlike) on the scour resistance of the facilities behind the gate and the existing basin capacity. In this instance, facilities include things like bottom and bank protection, transitional constructions and suchlike. If the lock terrain is at the same height as the top of the cladding, like the marine lock in Terneuzen for example, the scour resistance of the terrain or the acceptable damage should also be taken into consideration.

In the Guideline (Lit. [4.5]), three methods are given for determining the retaining height:

1. based on the overtopping discharge that is acceptable for bottom protection;
2. based on the overtopping volume that can be stored behind the lock (basin capacity);
3. a further reduction of the retaining height determined according to 2, by allowing both overtopping and overflow, at least in so far as the available basin capacity has not been exhausted by the overtopping.

These methods are complementary. In establishing the retaining height according to 1 (scour resistance), it is necessary to check whether the available basin capacity is not being exceeded. If the retaining height is established on the basis of the available storage capacity (2 and possibly 3), it is necessary to check whether undesired scouring takes place.

In a calculation according to **method 1**, an overtopping discharge (in l/m/s) is determined that is still permissible for the anticipated bottom protection. At this discharge the overtopping factor is read as α in graphs that are included in the Guideline. The retaining height then follows from:

$$w = \alpha \cdot H_s + 0.30 \text{ m, in which:}$$

$$H_s = \text{significant wave height}$$

$$0.30 \text{ m} = \text{safety margin for the uncertainty in the graphs}$$

The largest value of α is 1.2; this applies to scour sensitive situations, for instance cut-offs in dikes, which are also addressed in the Guideline. In general, there will not be scour sensitive situations at locks (unless parts of the uncladded lock terrain is affected by wave overtopping) and α will therefore be smaller than 1.2. Besides, it is conceivable that bed protection is enhanced or expanded in the following design phase, which will further reduce α . This is a matter of cost consideration.

The Guideline contains two graphs for the overtopping factor α (vertical axis) as function of the overtopping discharge (horizontal axis), one for the coast and one for river regimes. The first graph contains curves for the various values of H_s (from 0.5 tot 3.0 m), the second graph contains curves for the upper and tidal river areas respectively. The tidal rivers are subdivided into those with tidal regimes and those with river/transition regimes. For drafting the graphs, the point of departure was that waves are perpendicular to the gates and that the frontal face of the gate is vertical. Closer investigation is required for angled wave incidence and for other gate shapes.

In a calculation according to **method 2**, the maximum volume is determined that can be stored in the basin behind the lock without this resulting in a flood risk or other hindrance for the surroundings.

Subsequently, the basin storage capacity (m^3) is divided by the lock width. The quotient is V_B (m^3/m) the total permitted overtopping volume during a high-water period per width unit of the structure. If there are several structures in the retaining structure of the basin, the sum of the width should be taken into account rather than the previously mentioned lock width, if there is a corresponding retaining height and wave attack.

At the permitted volume V_B the overtopping factor is read α_{komb} from the graphs in the Guidelines. The retaining height then follows from:

$$w = \alpha_{\text{komb}} \cdot H_s + 0.30 \text{ m.}$$

In the graphs, the basin capacity factor α_{komb} (vertical axis) is provided as a function of the permitted overtopping volume V_B (horizontal axis). The curve indicated by the relation depends on the situation being considered: upper river, tidal river, transitional regime and coast. Several curves are given for the coastal situation, namely for the significant wave heights of 2 to 8 m. Once again, the underlying calculations start from perpendicular waves on vertical surfaces. Deviating configurations require further research.

The calculation according to **method 3** is executed if the previous calculation (method 2) shows that the maximum basin capacity is not being used for the overtopping. The graphs for method 2 show that the overtopping factor α_{komb} is equal to nought, which makes the retaining height 0.30 m. It could be considered to allow overtopping by further reducing the retaining height, if this is not accompanied by erosion problems. Graphs for further reduction have also been included in the Guideline. However, the retaining height can never be lower than nought.

The system as described above for determining the retaining height of structural works in primary water retaining structures can also be applied to locks in other retaining structures. The issue is the system concerned and not the numeric value, for instance that which was processed in the graphs.

For an initial estimation of the retaining height during the preliminary design, the following practical rules that have been applied up to now can be used as a point of departure:

- For a lock in a canal (no wind waves): $w = 0.30$ to 0.50 m
- For a lock in a canal with high translation waves: $w = 0.60$ m

4.6 Lock, resulting horizontal dimensions and levels

4.6.1 Introduction

In paragraphs 4.4 and 4.5, the effective dimensions of the lock were treated according to navigation and flood control requirements.

The presented length and width measurements of the lock can be denoted as 'effective' or 'nett' dimensions. Extra allowances have to be added to these 'nett' dimensions in order to obtain the 'gross' horizontal lock dimensions. For the chamber length, this allowance consists of the stop stripe distance, which is the distance from the stop stripe to the closest gate recess. A vessel is not allowed to protrude past the stop stripe. For the chamber width, the allowance consists of possible friction wales or floating frames and a margin for inaccuracies in the execution or for the deflection of walls. Please note that in the case of SIVAK simulations (see par. 4.4.2.3) margins for the length and width are taken into account per vessel in chamber arrangement. These margins can therefore be ignored.

Starting from the gross chamber dimensions, the dimensions for the complete lock, including the heads, have to subsequently be determined. Other nautical and water retaining requirements are also of importance here, such as the discharge and intake systems, the type of gates (chapter 6 and 7 respectively), whether to include collision constructions near the gates (chapter 17) as well as constructional considerations such as the length of the head in relation to the overall stability (chapter 13).

Furthermore, vertical dimensions are of importance to the design: the depth and the height. Different levels are traced back to the navigation and water retaining structure requirements in paragraphs 4.4.3 to 4.5.5, including the necessary safety requirements (such as keel clearance and safety margin). These levels can be considered as the gross dimensions. From these different levels, the definitive levels of the sills, the capstone and the top of the gate cladding can be derived.

Here are a few definitions related to a number of the concepts that will be used in the following paragraphs.

- The gate chamber is the recess in the wall that houses the gates when the gates are in an open position.
- The gate recess is the recess in the wall in which the tip of a pivot or roller bearing gate rests in a closed position (this is opposite the gate chamber) or which the sides of a lift gate are in when in a closed position.
- The length of the gate chamber (gate recess) is the dimension of the chamber (recess) in the longitudinal direction of the lock.
- The depth of the gate chamber (recess) is the horizontal dimension perpendicular to the lock axis.
- The length of a gate is calculated in the direction of the gate span, the thickness is the horizontal dimension perpendicular to this.
- Piers are part of the head walls, where there are no gate chambers (piers are therefore on both sides of the gate chamber (recess)).
- The length of a pier is the measurement in the longitudinal direction of the lock.
- The stop stripe is a marking on the chamber wall that indicates the distance to the gate chamber (the gates), where vessels in the chamber are not permitted to be.

4.6.2 Length

4.6.2.1 Overview

The effective nett chamber length is the distance from the stop stripe on the lock wall up to the gate chamber at the other head. In the case of separate high tide and low tide gates there will be 2 stop stripes whereby the effective chamber length is the distance between the stop stripe in front of the high tide gate and the other high tide gate chamber situated at the other head or between the stop stripe in front of the low tide gate and the low tide gate chamber at the other head.

The gross chamber length is the length between gate recesses. This is the effective chamber length plus the stop stripe distance (distance from the stop stripe to the gate recess situated nearby).

The length of the complete lock is the distance between the outer sides of the heads, this is the sum of the lengths between of the upper head, and all chamber floorslabs and the lower head. The head consists of the gate chamber (or two gate chambers) and the piers.

For the discharge and intake system of the lock, it is important to know the length between the gates in view of the locking volume of the lockage water.

4.6.2.2 Stop stripe distance

The purpose of the stop stripe distance (distance between the gate chamber and the stop stripe) is:

- 1) Reducing problems for vessels that are caused by possible fill flow (intake through upper head). This only applies to the upper head (in case of double sided retaining locks it applies to both heads) and depends on the type of intake system.
- 2) Reducing the possibility of the vessel colliding with the gates due to:
 - Human error, such as stopping too late when sailing in;
 - Vessel movement due to water displacement in the levelling process or opening/closing the gate
 - Vessel movement due to strain and clumsy handling of the hawsers during levelling;
- 3) Reducing the chances of the vessel colliding with an elevated sill at the upper head.

At 2) please note that some types of gates are more vulnerable than other types of gates. Mitre gates are particularly vulnerable from the non-retaining side, certainly when the water level is equal on both sides. There is also considerable difference in the water displacement that is generated when the gates are opened (and the vessels start moving). This water movement is relatively strong in the case of a single, pivot leaf gate.

The stop stripe distance is not sufficient to prevent the gates from being bashed in the case of technical malfunction of a vessel (for instance 'go astern' is not successful). In this case, only a collision structure can limit the damage (see chapter 7). Collision structures are not found in marine locks as sailing in takes place cautiously (often with tugboat) and marine locks are often equipped with rolling gates that are relatively collision resistant when compared to other types of gates (very stiff owing to double cladding). Collision structures are hardly ever applied at other types of locks.

The disadvantage of a large stop stripe distance is a larger water surface (intake and discharge volume) and high construction costs. It is difficult to weigh these costs up against higher safety or increased hinder. For this reason, considering relevant factors, the most common length used in the Netherlands is: a distance of 2 – 5 m. Here is a closer specification.

For marine locks, there are no guidelines available for the distance between the stop stripe and the gate chamber. Given the large variety in dimensions and manoeuvrability (stopping capacity) of marine vessels, the lock personnel will often provide indications on how far each particular vessel is allowed to sail onwards. The personnel will (have to) pay attention to the vessel not protruding in front of a culvert outlet. Attention should also be paid to vessels that have a bulb stem that stands out far. Estimating the risks and possible consequences (for instance lengthy obstructions) play a large role.

For inland and recreational navigation locks, the cvb guidelines are followed, with a few additions. The stop stripe distance has various lengths.

- 1) At the top door with intake via the gate openings:
 - The stop stripe distance is determined by the hinder of incoming water; in general, a distance of at least 3 – 5 m is desirable.
- 2) At the head gate with intake via the lock culvert with stilling chamber:
 - The stop stripe distance is determined by the disruption caused by incoming water. The distance of the stop stripe to the downstream side of the stilling chamber is at least 3 – 5 m, and with that, the length of the stilling chamber to the gate chamber.

- 3) At the tail gate or head gate with a bottom filling system:
- Stop stripe distance in waterways with CEMT class I and II, minimum lock: 1 m
 - Stop stripe distance in waterways with CEMT class III and higher, minimum lock: 2 m
 - Stop stripe distance in waterways with CEMT class III and higher, capacity lock: the CVB does not provide a guideline for this. It is recommended that a larger distance is chosen, for instance 3 – 4 m, for a wide lock.

Furthermore, the following applies:

- In tidal areas, stop stripes are applied for both the ebb gate as well as the floodgate.
- At safeguarded lock gates, the distance to the trap structure is at least 1 m.

These guidelines for the stop stripe distance are not based on thorough research but are general accepted practise in the Netherlands.

4.6.2.3 Length of the gate recesses

The length of the gate recesses is determined by the type and size of the gates and the required clearance in the gate recesses.

The largest length of the gate recess is necessary for pivot gates and mitre gates, which are parallel to the lock axis when open.

The gate thickness is a function of the width of the lock and the size of the retaining lift. For an initial approach, point of departure could be the following relationships between gate thickness and lock width:

- pivot gate: 1:6 to 1:8
- mitre gates: 1:16 to 1:20
- lift gate: 1:6 to 1:8
- rolling gate: 1:4 to 1:5

The required clearance between the gate chambers and recesses as well as the space required for movement of the pivot and mitre gates can be found in chapters 7 and 8.

4.6.2.4 Length of the lock head

One head can contain several gates. This is the case for instance, if mitre gates are used in a situation where the lift over the lock can change direction. It is also possible to consider placing two gates per head with a view to operational safety and/or maintenance. Because of the increased reliability of gates and operating mechanisms, this is hardly ever done nowadays.

In broad strokes, a head consists of a gate chamber with a pier on each side or it consists of two gate chambers, an intermediate pier and a pier on each side. The length of these piers is a function related to the bearing forces on the gates, the mooring facilities to be installed on both sides of the gate, the possible stop-log rabbets (and the force transmission from these stop-logs), possible collision structures as well as the spring width of the lifting towers. A general rule cannot be given but for a preliminary design, one could say that the length of a pier "on both sides" varies from 2 m for a lock of 9 m wide to 4 m for a lock of 24 m wide. For the same lock widths, an intermediate pier varies between 3 m to 5 m.

The total length of a lock head (in the longitudinal direction of the lock) must also be designed for overall stability. For locks on steel foundations, this check particularly concerns the tail head that, unlike the upper and intermediate heads, cannot transfer horizontal forces to the adjoining chamber floorslabs. With pile foundation, every head has to be independently considered as force transmission to adjoining constructional parts cannot be taken for granted. In general, stability in a longitudinal direction is not a problem and the heads do not require extra length for this reason. In the Netherlands, heads are generally designed symmetrical to the gates. In special cases, it could be beneficial to the overall stability to place the gate downstream from the heart of the head (the downward load then increases due to the larger water mass above the floor).

4.6.3 Width

Par. 4.4.2 indicates how the effective width of a lock is determined from the navigation requirements. In modern locks, the width of the chamber is equal to the width of the heads. A few allowances have to be added to the effective width in order to obtain the constructional dimensions. If the effective width is determined with SIVAK (simulation), it already includes a small, extra width (0.1 m) for a wood fender that is used by the vessel.

In locks where the walls have been provided with fixed fender ribs and wales, for instance in cases of chamber walls constructed of steel sheet piling, the width has to be increased by twice the thickness of the fender ribs: two times 0.20 = 0.40 m.

For the dimensions between the clear faces of the walls, the effective length is increased by $2 \times 0.10 = 0.20$ m for inaccuracies in construction and for the possible deflection of the walls. The margin should actually be a function of the wall height, certainly in view of deflection, but in practice, a margin of 0.20 m in total is used for all locks.

In marine locks that have been equipped with floating frames (rubber fenders in Belgium), the width between the walls is equal to the effective width plus 0.20 m (deflection) margin plus twice the width of a floating frame and the space required for the approach constructions.

Outside the clear faces of the lock, the gate chambers are found. The depth of these chambers/recesses (perpendicular to the lock axis) is described in chapters 7 and 8. Different from other gate types, the chambers for roller bearing gates largely determine the space that the lock takes up. These chambers have a depth of 1.4 to 1.65 times the chamber width.

4.6.4 Levels

4.6.4.1 Level of the sills

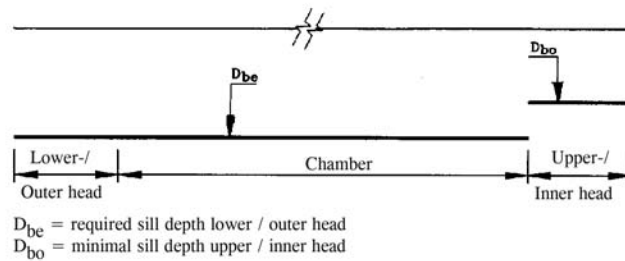
The sill level is the level with regard to the design level (NAP) of the upper side of the floor of a lock head. Naturally, this concerns the highest part of the floor.

Par. 4.4.3. explains how, starting from nautical considerations and the minimum lock level, the desired level of the lock sill at the inner head (unilateral retaining lock) or the outer head (bilateral retaining lock) are determined. The lowered minimum lock level is determined by subtracting the minimum lock level (Min.S) from the margins for translation wave heights, seiches and surges. The level of the lock sill is determined by subtracting the draught of the idle vessel and (for inland navigation) a keel clearance of 0.6 to 0.7 m from the lowered minimum lock level.

This keel clearance is a combination of the submersion of a sailing vessel, a hydraulic margin and a safety margin. The level of the lock sill at the upper head (unilateral retaining lock) or the inner head (bilateral retaining lock) is determined by starting from the lowest prevailing water level at which locking still has to take place instead of the minimum lock level (Min.S).

Below and in Figure 4.15 the sill depth of the lower head or of the outer head is indicated as D_{be} , while the upper head or the inner head are indicated as D_{bo} . There are two solutions in relation to the construction depth of sills in the complete lock.

Sill levels



Possible solutions

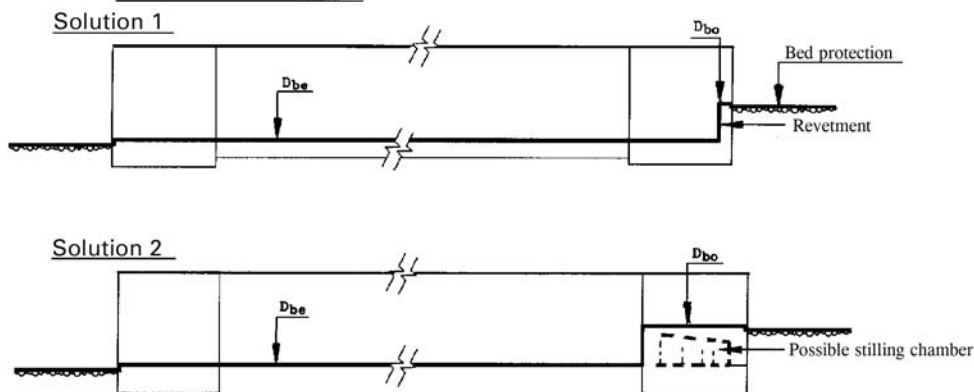


Figure 4.15 Sill levels

Solution 1

For both heads (upper and lower head at unilateral retaining or outer and inner heads at bilateral retaining), the lowest level (D_{be}) is adhered to. The level of the chamber bottom is at the same level or slightly lower (considerations in par 4.4.4). There are two advantages if both heads are on one level:

1. gates are interchangeable, provided that the top of the gates are also on one level;
2. one spare gate or one set of gates is sufficient.

For retaining the bed protection/apron (see Figure 4.15) and the soil under the upper canal reach, a revetment will have to be made at the end of the upper head. This could consist of poured concrete wall or a sheet-piling screen set to the correct level (a combination with the seepage screen is conceivable). The disadvantages of this solution is that the upper gate and the upper head have to be designed heavier than strictly necessary, while the space between the upper gate and the revetment could start acting as an undesired silt or sediment trap.

Solution 2

Level D_{bo} is adhered to for the sill of the upper head and level D_{be} is adhered to for the lower head. The gates are no longer interchangeable but the other disadvantages stated at solution 1 no longer apply. By filling the chamber through the openings in the upper gate, relatively high filling flow can result in unwanted hawser forces. At large lift on the other hand, where filling via openings in the gates is no longer possible, use can be made of the raised sill of the upper head by introducing a stilling chamber.

4.6.4.2 Upper level of gate cladding and capstone

4.6.4.2.1 Capstone level in view of navigation

Par. 4.4.5 states how high the capstone should be above the maximum locking level ($Max.S$) with a view to navigation. The point of departure for this height is good guidance and mooring possibilities for vessels. The height above ($Max.S$) for recreational navigation amounts to 0.75 to 1.00 m for inland navigation CEMT class I to IV 1.50 m and for class V 2.50 m. There are no set guidelines for marine locks.

The capstone height applies over the complete length of the lock, with the exception of class V locks. The CVB recommends 4.50 m above $Max.S$ at the heads instead of 2.50 m. The same applies to the chamber because of push prows. As a rule, a height of 2.50 m is sufficient for class V instead of the 4.50 m unless research shows that the percentage of push prows is (or is becoming) dominant. For the construction of new locks it is recommended that verification takes place as to whether the relatively large and therefore costly guide heights for class V locks (2.5 and 4.5 m) are really necessary. If, for instance, the average upper (outer) water level is 1 m below $Max.S$, consider situating the capstone level of the chamber at $Max.S + 1.5$ m. It is a case of weighing up the chances of push prows crossing the lock coping against the construction costs. The chance of crossing can also be translated into (damage) costs.

4.6.4.2.2 Upper level gate cladding and capstone with a view to water retaining

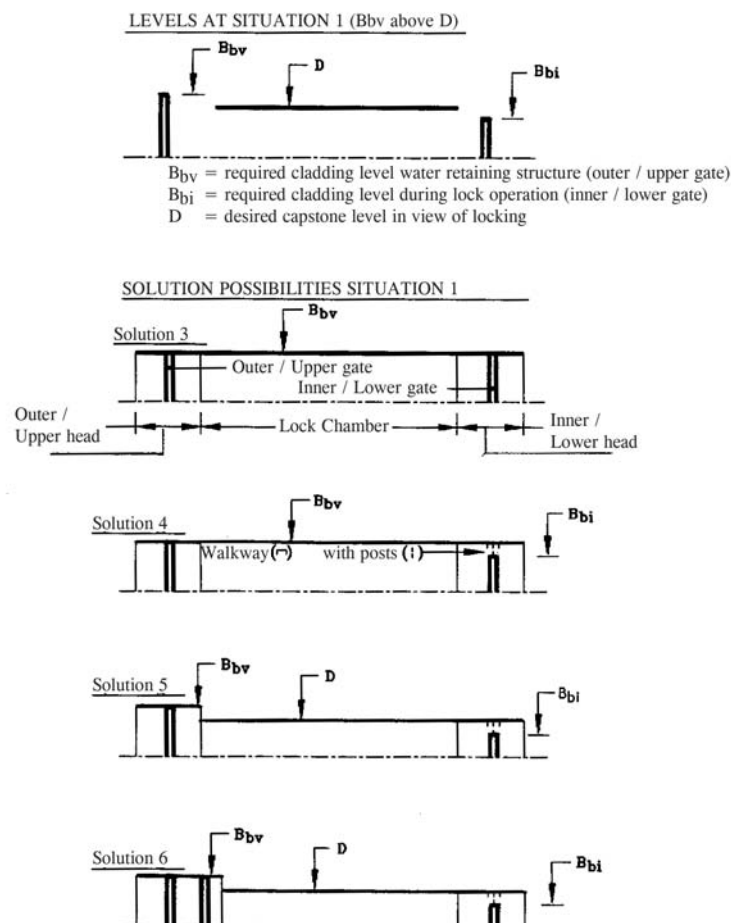


Figure 4.16 Upper level of lock, situation 1

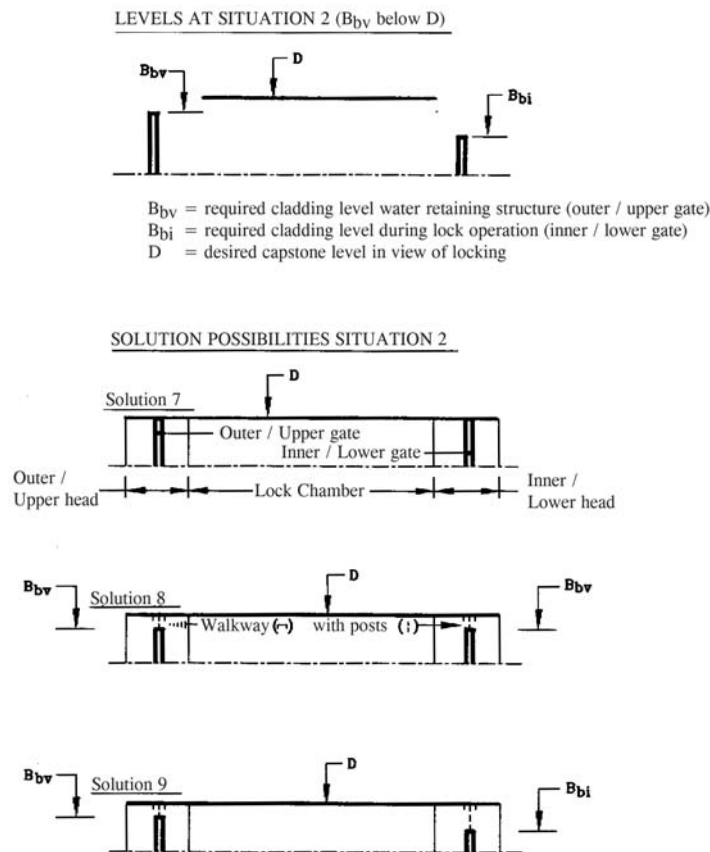


Figure 4.17 Upper level of lock, situation 2

Par. 4.5.4 and 4.5.5 provide indications on the required levels for the top of the cladding of the outer or upper gates and the capstone of that head for a water retaining function.

The gate of the inner or lower head can be constructed at a lower level with the top of the cladding at $Max.S$, increased by a retaining height for the prevention/limitation of overtopping due to possible wind and translation waves. The minimum retaining height measures 0.3 m. Often, 0.5 m is applied for locks, but even this value needs checking to see if this is sufficient for local wind and translation waves at $Max.S$.

4.6.4.2.3 Combining navigation and water retaining requirements

In the following consideration, a number of possible solutions are discussed in order to integrate the different levels in a lock design. The following letter designation is used:

- B_{bu} = top of cladding outer or upper gate ensuing from the water retaining requirement;
- B_{bi} = top of cladding inner or lower gate ensuing from the requirement that none or only one limited wave overtopping could occur at a water level equal to $Max.S$;
- D = capstone height ensuing from navigation requirements.

Depending on the situation, it could be necessary to increase the height of the heads for horizontal rolling gates to above the recommended dimensions above $Max.S$, to ensure that the operating mechanisms remain dry and functioning even at a water level this high. This extra constructional aspect is not dealt with separately in the rest of this consideration.

There are two possible scenarios:

- 1 Level B_{bu} is higher than D
- 2 Level B_{bu} is lower than D

The solutions for situation 1 (numbers 3 to 6) are provided in Figure 4.16, those for situation 2 (numbers 7 to 9) in Figure 4.17. It is assumed that the desired capstone level is the same across the complete length of the lock. CEMT class V locks have not been researched. Neither does it address locks in a tidal area with double sets of mitre gates per head. For these kinds of locks and for locks with intermediate heads (and possible cascading retention) please see chapter 7.

Situation 1 (B_{bu} higher than D)

Solution 3

B_{bu} , required for the outer gate, is also adhered to for the inner gate and for the capstone over the complete length of the lock. The gates are interchangeable and only one set of spare gates is required if the top of the lock floor is projected on one level across the complete length of the lock. The walls of the lock chamber and the inner head are too high for the functional requirements (water retaining and navigation) and therefore more expensive than strictly necessary. These (too) high walls and the earthing up in particular enlarge the bending moments in the floors, at least in reinforced concrete monolith constructions (that are always applied at the heads).

The lock terrain and the capstone are constructed on one level after all (with the exception of gradients), in order to prevent tripping and falling into the chamber.

At a centrally operated inland navigation lock, walking access next to the chamber it is not strictly necessary (as it is for a marine lock). It is theoretically conceivable to make the earthing up lower than the capstone height along the chamber in order to decrease bending moments. In practice, this has not been done (yet).

Solution 4

With regard to solution 3, the inner gate has been lowered. If desired, a raised walkway supported by stiles could be installed. Note that walkways on outer gates are very common, so that operating personnel can cross over the lock to reach the lift cylinders of the levelling gates. Solution 4 is not very viable as any saving in comparison to 3 relates to a limited number of square meters while the gates are not interchangeable and a second spare gate is required. Moreover, there is only one high water retaining gate, which increases the requirements related to reliability of closing.

Solution 5

All levels are equal to those that follow from the functional requirements. This means that a minimum of materials is incorporated in the concrete and steel constructions. Then again, the gates are not interchangeable, two spare gates are necessary and higher requirements have to be set for the reliability of the outer gate closing. The objection to two spare gates is smaller if there are several locks in the waterway that have gates of equal dimensions.

For ease of passage of the lock coping at marine locks, where flatmen operate, a gradual slope transition is made between the higher level next to the outer head and the lower level next to the chamber. The slope has a gradient of 1:12 for instance. For inland navigation locks, slope steps are sufficient.

Solution 6

This variation on solution 5 with a spare storm surge /floodgate on stand-by in the outer (upper) head has often been built in the past. Currently, this is hardly ever executed due to the costs of the two gates in the outer head and the larger length of the head as well as the current view on the safety philosophy. Besides, just like solution 5, a separate spare gate is required for the inner head. Yet, solution 6 is currently still being applied in cases of large differences between NHW en $Max.S$.

Two gates in one head, and this in the outer as well as the inner head, is sometimes used for more than just water retaining requirements (marine lock Terneuzen). The other considerations concern the availability of the lock for the lock operations and the image to the outside world that a large port complex is 'always' accessible, even if there is only one lock that can process the large vessels. The marine lock in Terneuzen is not a lock in the sense of solution 6 but of solution 3: both the gates in the outer head are identical to those in the intermediate head (1 gate) and in the inner head (2 gates).

Summary

Even though one thing and another depend on the specific conditions of the lock to be designed as well as the choice of the sill levels (see par 4.6.4.1), solutions 3 and 5 appear to be the most likely solutions and solution 6 to a lesser degree. Solution 4 is of little significance. The choice between 3 and 5 depends on the costs, which are largely determined by the height differences between the levels B_{bu} and B_{bi} . Solution 5 only becomes attractive if there are large differences in levels.

Situation 2 (B_{bu} lower than D)

Solution 7

The cladding is raised to level D for both gates and if necessary, walkways are fitted at this level. The gates are interchangeable and only one spare gate is required. In addition, it provides extra security against flooding.

Solution 8

The cladding of both doors is raised to level B_{bu} and above that, a walkway on level D. The exchangeability of gates is guaranteed while only one spare gate is required. Because there is not much difference between the costs related to 7 or 8, solution 8 is usually realized while solution 7 is executed sporadically.

Solution 9

The cladding of the head gate ends at level B_{bu} and that of the inner gate on B_{bi} . Necessary walkways for both gates are constructed at capstone level. The advantages of solutions 7 and 8 are no longer valid. This solution is only advisable at significant lift or, if there are several locks in the waterway with the same height dimensions and the two spare gates necessary can also be used for these locks.

4.6.4.3 Level selection of sill, capstone and gate cladding

There are no general applicable rules for the choices and solutions presented in par. 4.6.4.1 and 4.6.4.2. At the very most, it could be said that one should strive for minimal total costs (investment and exploitation). A choice at a certain lock is only possible after researching the combinations for the top (capstone, gate cladding) and the bottom (sills).

It can be ascertained that the uniformity of the gates is a weighty issue and that certainly during the past decade, many locks have been designed with the same gates in both heads; the solutions 3, 7 or 8 combined with solution 1 whereby it is noted once again that solution 7 is found only sporadically.

This does not need to result in an automatic choice for lock with 'one gate height'. Certainly in the case of substantial lift, the costs should be set off against the cost of locks with uneven gate heights. That is to say locks that, depending on the situation, contain the Solutions 5, 6, or 9.

For large lift, it could be attractive to include a raised upper head sill (solution 2), as it was done at Maasbracht. For lift in excess of 6 to 8 m, in which filling through gate openings becomes problematical, it is certainly worth investigating a stilling chamber with a raised upper head sill. Even at lift larger than 4 m, the designer should consider a raised sill, especially if there are different locks with the same dimensions, which would result in extra spare gate(s) being deducted from more than one lock.

4.7 Lock approach, horizontal dimensions and depth with a view to locking

4.7.1 Horizontal dimensions of the lock approach

4.7.1.1 Introduction

A lock approach should offer vessels the space to sail in and wait for locking. The following components are required to achieve this (see Figure 4.18).

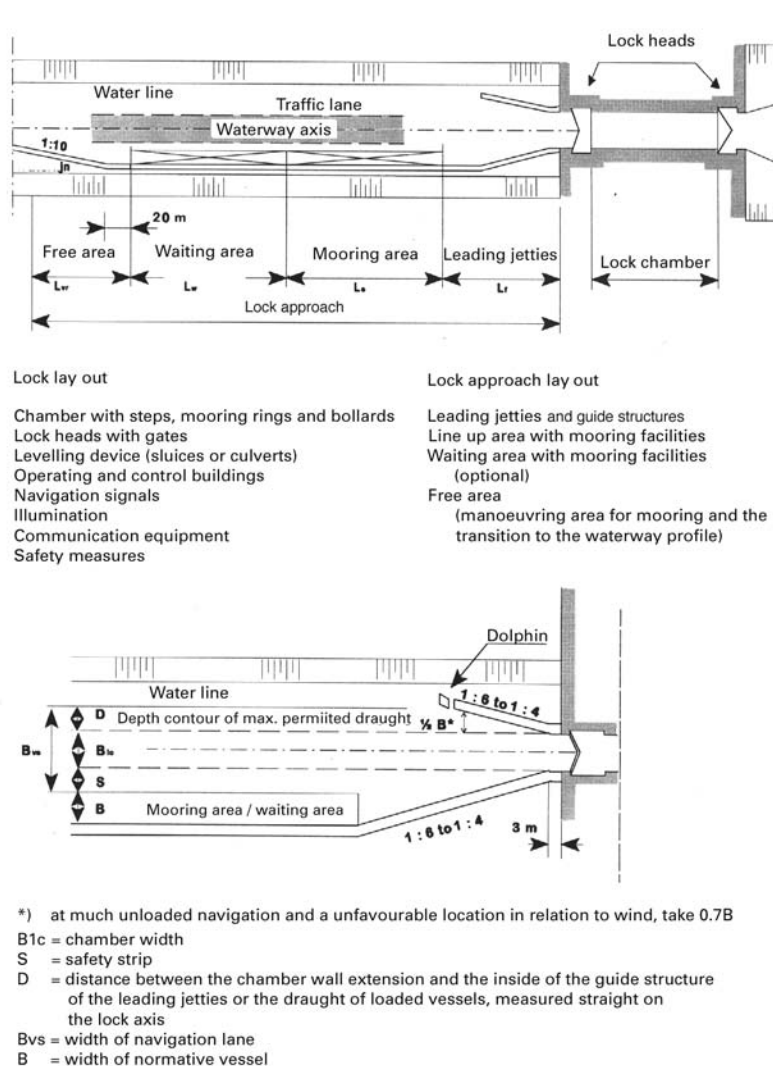


Figure 4.18 A diagram of a lock with lock approach and the lay out of a lock approach according to CVB (lit. [4.3])

For sailing:

- harbour mouth or free area, as connection between waterway and lock approach to decrease speed;
- navigation lane, for entering and leaving the lock;
- leading jetties, for guidance to the lock.

The navigation lane consists of:

- safety strip between the chamber wall extension and line up /mooring area for the protection of waiting vessels;
- strip in the chamber extension;
- strip between chamber wall extension and depth contour of maximum permitted draught along the slope to prevent bank suction.

For waiting:

- mooring area, to lock through at the next locking;
- (possible) waiting area, for vessels that have to wait even longer (demurrage);
- (possible) mooring area for vessels carrying dangerous goods that have to wait separately.

The necessary width of the lock approach is determined by the widths of the navigation lane and the mooring/waiting area. At two or more locks, it concerns several navigation lanes, mooring areas and a middle island. The required length of the lock approach is determined by the lengths of the leading jetties, the mooring area, the (possible) waiting area, the (possible) waiting area for vessels transporting dangerous goods and the free area. Areas with places for overnight stay/resting sometimes require extra length.

The cvb Guidelines Waterways (Lit. [4.3]) provide horizontal dimensions, for waterway classes I to V, for the stated parts of the lock approaches of inland navigation locks with relatively little navigation volume, for both locks with one chamber (minimum lock) as well as locks with two chambers. For more substantial navigation volume the breadth is quite sufficient; the length does not suffice because this is partly determined by the length of the waiting areas and therefore, by the navigation volume.



Photo 4.5 Lock approaches at the lock at Engelen

In this paragraph, the various parts of the lock approach are discussed whereby differentiation is made between marine navigation, inland navigation and recreational navigation. Extra length of the lock approach, for overnight stay or resting, is addressed in par 4.8. In chapter 5, (Lay out) the different parts are combined into a complete lock approach in which the possibilities and limitations of the surroundings are taken into account. The approach route to the lock approach is also addressed.

4.7.1.2 Harbour mouth / free area

At marine locks

Because sea-going vessels are relatively hard to manoeuvre, the arrival of the vessel in the lock approach is planned in consultation with the lock manager so that the vessel is able to sail directly into the lock. Waiting areas are therefore not created for these vessels. The lock approach serves as a manoeuvring area and there hardly is any differentiation between 'free area' (mouth area) and a navigation lane as is the case with inland navigation locks. Tugboats assist large vessels. Practice has shown that manoeuvring with marine vessels requires considerably more space than that required by inland navigation. There are no hard and fast rules for determining the correct dimensions; in most cases, thorough nautical research is required.

At inland navigation locks

If the lock links up with a canal reach, an approaching vessel from the canal will enter the free area. The free area serves as an area to decrease the speed of the vessel and it lies between the waiting area and the mouth of the lock approach.

In general, the stopping length required for decreasing speed is at least 2.5 times the length of the normative vessel (cvb Guideline) but this can differ from vessel to vessel and if necessary, it has to be determined by means of specific research. The designer has to take into account that the normative sailing in manoeuvre will probably occur and the feasibility of taking additional action (such as navigation measures). At a lock in a canal with very little navigation and a sheltered position, hardly any extra length is required for slowing down: the captain will do this on the last part of the canal.

Sometimes, insufficient length is available for realising the complete stopping length before reaching the mooring area. In this case, the lock approach should be extra wide so that the slowing down lane is partly next to the waiting area.

At minimum locks, the width of the free area is equal to the width of the lock approach at mooring area height.

At recreational navigation

The cvb guideline can be used for this and reads as follows: the length of the free area amounts to (in metres) 10 times the number of yachts that fit in the chamber, with a minimum of 60 m.

4.7.1.3 Navigation lane

For marine vessels

As described in the previous paragraph, separate navigation lanes are not distinguished for sea-going vessels. This fairway is part of the complete lock approach and the dimensions have to be determined by means of nautical research.

At inland navigation locks

The width of the fairway corresponds with the width of the lock. For the width of a minimum lock and the corresponding fairway, the cvb guidelines can be adhered to (also see Table 4.15 and Figure 4.18):

CEMT class	B _{lc} (m)	S (m)	D (m)	meaning:
I	6.0	3.0	5.0	B _{lc} = chamber width, S = safety strip next to mooring location, D = distance from the extended chamber wall to the bank opposite the mooring location. (at depth of vertical stabilizer of loaded vessel)
II	7.5	3.5	6.0	
IIa	8.0	4.0	6.5	
III	9.0	4.5	7.5	
IIIa	9.0	5.0	8.5	
IV	10.5	5.0	8.5	
Va	12.0	5.0	10.5	
Vb	12.5	7.0	11.5	

Table 4.15 Safety strip in lock approaches

The safety strip S between the mooring area and the entry and departure lanes are to prevent vessels sailing out from passing too close to the vessels in the waiting area. The length of the fairway ensues from the length that is required for mooring areas etc.

When drafting table 4.15 in 1995, the availability of bow propellers on vessels were hardly taken into account. In the meantime, most of the vessels (not the tug-pushed dumb barges) have been equipped with bow propellers. It is possible that smaller widths could be acceptable because of this but this reduction cannot, as yet, be quantified based on this research.

At recreational locks

The width of the navigation lane is equal to the chamber width, increased by a safety strip of 2 m wide on both sides (cvb Guideline, Lit. [4.3]).

4.7.1.4 Leading jetties (with guides)

The leading jetty serves to advance rapid and safe entry. For this reason the leading jetty is bordered by guide structures (see Figure 4.18). The mouth of the leading jetty receives its required width by means of providing both guide structures with sufficient length and a suitable angle with regard to the lock axis. For inland navigation locks and recreational navigation locks, it is recommended that the guide structures are continued right up to the berthing jetties at the mooring location. At a one-sided mooring location, the leading jetty has one long and one short 'leg'.

At marine locks

There are no actual guidelines for the shape and dimensions related to chamber access of a marine lock. In view of tugboat assistance, long guide structures (as used for inland navigation) are not positioned in front of the chamber, as this would severely limit the freedom of tugboat manoeuvrability. For the protection of both the vessel as well as the lock head, short guide structures could be positioned and/or lock heads could be equipped with roll fenders (see existing marine locks).

At inland navigation locks

The optimal angle of the guide structure, based on Dutch experience, is:

- for waterways in the classes I to IV: angle 1:4
- for waterways in the classes V and VI: angle 1:5 to 1:6, especially if there are many dumb barges (without bow propellers).

At narrow locks, it is particularly important that the leading jetty is symmetrical because of the view orientation of the captain and because of equal bank suction if the jetty is hydraulically closed.

The width of the leading jetty at the end of the shortest leg has to be at least 0.5 x B (width normative vessel) larger than the width of the chamber. The length of the leading jetty where this joins up with the guide structure of the mooring location, is determined by the chosen angle (and possible curve) and the width of the mooring location plus the safety strip (see Figure 4.18 and Table 4.15).

Between the lock head and the leading jetty, a straight guide structure of 3 m long is placed in line with the chamber wall. This serves to decrease the risk of an unloaded vessel with push prod protruding over the guide structure and colliding with the head.

For classes Va and Vb it is recommended that straight leading jetty legs are connected to the lock head with the curved part, in view of long formations getting stuck if the normative vessel arrives often. This recommendation does not apply to locks that are wider than the minimum lock.

At the locks of 24 m wide of class VI, intended for push-tow combinations of double width, the leading jetty slope is kept at 1:6 with an adjoining curved section with a radius of 600 m to prevent the combinations from getting stuck.

At recreational locks

The set-up of guide structures is the same as it is for inland navigation, with the exception of the angle; 1:3 is a suitable angle as recreational vessels are small and manoeuvrable.

4.7.1.5 Berths for mooring and waiting areas

Distinction is made between the mooring and waiting area. The mooring area has to offer sufficient space for the vessels in one chamber filling. If there are vessels that will not be passing through with the next lock (through demurrage), they must have access to a waiting area. Lock approaches are often used for vessels to moor and rest or to stay for the night (see par. 4.8 and Appendix 4.4).

Determining the necessary mooring and waiting area is not the same for marine navigation, inland navigation and recreational navigation. Vessels transporting dangerous goods receive separate treatment from other inland navigation vessels.

For marine vessels:

It is highly unusual that large sea-going vessels have to moor while waiting for a lock. For this reason, there are no facilities for waiting and mooring; at most, there are a few heavy dolphins. In the case of mixed use by marine vessels and inland navigation vessels, a mooring area could possibly be created for inland navigation vessels but the fairway will have to meet the requirements set for sea-going vessels (very wide).

For inland navigation vessels:

At a minimum lock and a capacity lock, the mooring area can be equipped according to the CVB guidelines (Lit. [4.3]). The width of the mooring area is equal to the width of the lock chamber. The length of the mooring area is 1.0 to 1.3 times the effective length of the chamber. The length of the mooring area is a bit longer than the chamber length in order to make berthing a bit easier and therefore smoother.

At minimum lock usually does not require waiting locations, whereas this could very well be the case at a capacity lock (larger navigation volume). If waiting places are needed, they are situated alongside the berthing locations if possible. The required waiting area length is determined by a navigation study, for instance by means of a SIVAK simulation (Appendix 4.2). For determining the required waiting area at an existing lock, the relatively easy VAT method could also be used (see Appendix 4.1). The exceedance frequency of a certain length of waiting row could be derived from SIVAK simulations. The question is which exceedance frequencies the lock authority finds acceptable. The following should be taken into account:

1. The probability of the simulated navigation volume occurring;
2. The objection (not safe) of a shortage of waiting row space for a short duration (e.g. 10 - 20 minutes).

ad 1.

It is usual to simulate a 'normative week' (see par. 4.3.5.). The occurrence probability depends on the division of navigation volume over time. In this, the probability that larger vessels have to wait is larger than the probability of this happening to smaller vessels (a large vessel does not fit into a small waiting location that has been vacated whereas a small vessel does find a mooring berth as soon as a large vessel departs).

ad 2.

Modern vessels can either be kept going for quite a while or remain stationary without actually mooring thanks to their bow propeller. In 1994, a survey was held among captains, which showed that at an expected waiting time in excess of 10 to 20 minutes, they would moor; in case of strong wind

(Bf 6 to 7) they would like to moor, in particular empty vessels and recreational navigation. VHF radio contact with the lock is a good aid in estimating expected waiting time. The demand for mooring is large if the lock approach offers little room for manoeuvring and/or if it is hard to keep the vessel going without mooring (vessel, wind, current).

A ready-made solution is not available for determining the waiting place length that is both nautically (safe) and well as economically (social/economic costs) acceptable. The study being undertaken in this is in pursuit of criteria in which both the length as well as the time (duration) is incorporated.

Vessels transporting dangerous goods

Generally, these vessels carrying a dangerous cargo require a separate 'dangerous goods waiting area' in the lock approaches of inland navigation locks (Lit. [4.6]) that are equipped according to the requirements stated in Table 4.16.

Number of vessels	Requirements for waiting areas at locks
1	in <i>crosswise</i> direction, keep a 10 m distance between the vessel with dangerous goods and other vessels
2	in <i>crosswise and lengthwise</i> direction a 50 m distance to other vessels; the same type of lead is permitted alongside; 100 m distance to structure or buildings
3	in <i>crosswise and lengthwise</i> direction a 100 m distance to other vessels; no other vessels permitted alongside; 500 m distance to structure or buildings

Table 4.16 Requirements for waiting areas for vessels transporting dangerous goods

Because other vessels cannot use the mooring places for vessels with dangerous goods, they are additional mooring places. The length corresponds with the normative vessel length plus at least 5 m for manoeuvring. For the width, one vessel width is used for calculation purposes.

For recreational vessels

For mooring areas at recreational navigation locks, the CVB recommends:

- The mooring area has to be spacious enough that a complete chamber filling of at most two deep can moor rapidly up to a joint width of a 7 m maximum.
- The length of the mooring place for locks up to 7 m is 1.2 times the effective chamber length and for locks of between 8 to 10 m wide, it is equal to 1.5 to 1.8 times the effective chamber length.
- At more than 2000 passengers per annum a two-sided mooring and waiting area is recommended; the disadvantage of crossing traffic is accepted.

The need for waiting places (with probability distribution) is ascertained by means of simulation, SIVAK for instance, just as is the case for an inland navigation lock. For recreational navigation, it is also of importance that a shortage of waiting places does not occur too often, because this rapidly results in what seems to be chaotic navigation and leads to a lot of irritation among water sport enthusiasts as to whose turn it is.

For inland navigation and recreational navigation together

In situating the mooring and waiting places for recreational navigation at locks with mixed navigation, special attention has to be paid to safety. The mooring places for recreational navigation preferably have to be separated from the mooring places for commercial navigation, for example in the manner as chosen at the Naviduct and the Oranjesluizen (old complex) in Amsterdam (Figure 4.19 and photo 5.5). If a more conventional solution is chosen with a waiting area for recreational navigation behind the commercial navigation, an intermediate distance of about 3 m is observed.

The need for mooring and waiting places for both inland navigation as well as recreational navigation can be determined by means of simulations. In choosing the criterion for an acceptable (incidental) shortage, the safety of smaller vessels plays an important part. It is only acceptable to keep larger inland navigation vessels going because there is too little waiting area available for these vessels if the waiting places for recreational navigation are well secured. Furthermore, it is quite inconvenient for inland navigation if smaller vessels keep sailing around in the lock approach due to a lack of mooring places.

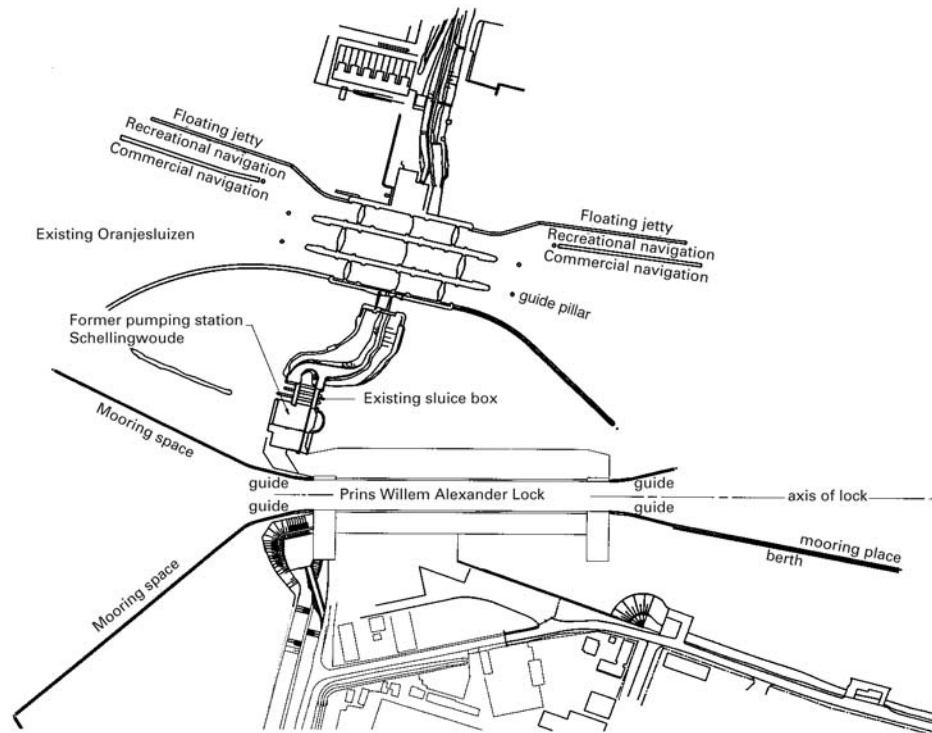


Figure 4.19 Lay out Oranjesluizen

4.7.1.6 Influence of current near and in lock approach

Flow in nearby fairways

At locks that are situated near a fairway where the water has a certain flow velocity, where the current passes the lock approach, special attention should be paid to the design and dimensioning of the lock approaches. Examples of this are a lock next to a canalized river where vessels have to enter the lock approach from a flowing river or a lock that is situated on tidal waters. The access to the lock approach should be spacious while there should also be sufficient length behind the entrance for incoming vessels to execute the given course directions and come to a stop.

Flush flow in the lock approach

In water transport via an open watercourse with a scouring sluice or via a culvert alongside the lock, attention must be paid to ensure that the points of water intake and water discharge are not on the same side as the mooring areas or at a large distance from the lock. The point of water discharge must be at least 15 m away from the mooring area, in a longitudinal direction. At the point of water intake in the fairway, the transverse current should not exceed 0.30 m/s. The longitudinal current in the fairway at the level of the line of water discharge should not exceed 0.50 m/s while the transverse current should not exceed 0.30 m/s. Also see cvb (Lit. [4.3]) and paragraph 5.3.5.

4.7.2 Depth of the lock approach

When choosing the depth of the lock approach the following needs to be considered:

- a deep harbour is usually expensive to construct (dredging work, guide structures, banks) and maintain (catches more sediment than a shallow harbour);
- a deep harbour is nautically more favourable.

The cvb recommends a lock approach equal to the depth of the fairway. A few aspects are addressed in more detail.

Depth with a view to sailing

In the 'free area' (the transition between fairway and lock approach) and in the whole navigation lane to the lock entrance, it is important that a reasonable speed can be maintained without causing too much flow and to facilitate easy steering. The flow has an influence on the vessels that are waiting at the berthing jetty structure as well as on the vessels that are lying in the open lock chamber. In view of this, a depth of 1.4 times the normative draught T is recommended. At a tight fairway profile, a factor of 1.3 could be used.

The required draught is naturally also closely connected to the height of the lock sill. If the lock sill and the lock approach are geared to the same normative vessel with $T = 3.5$ m, according to the above rule the lock approach lies at 4.90 m under the minimum lock level, and the sill at 4.20 m (if a keel draught of 0.7 m is assumed at a vessel lying idle). It is a good thing that the lock approach is much deeper than the lock sill, as it is more difficult for sediment to enter the lock chamber (where this could result in problems with the gates).

Depth with a view to manoeuvring

Manoeuvring in the lock approach (mooring, sailing out etc.) mainly takes place in the vicinity of the mooring berths and waiting area, but also at the leading jetty. In view of smooth manoeuvring, captains often indicate that large depth is desirable. However, there is no concrete evidence or research results available to substantiate this. Effective research is not easy. The impression is that a depth of 1.4 times the draught is sufficient for (steady) manoeuvring.

Depth with a view to propeller turbulence erosion

Everywhere in the lock approach, but in particular at the mooring places, significant propeller turbulence occurs every now and again. If the harbour is shallow, this causes an erosion hollow; this is problematic if it threatens the stability of a guide structure for instance. The eroded material causes an elevation elsewhere. This could result in unexpected (steering) problems and is therefore unsafe. Furthermore, propeller turbulence and return current can also erode the bed elevation of the lock entrance if there is no bed protection.

It is useless to prohibit the captains from using their screw propellers in this manner; in case of an imminent collision etc. they will do anything to prevent this without worrying about the bottom of the lock approach. There are two solutions to prevent erosion:

- make the lock approach deeper; the safe depth substantially depends on the type of bed material;
- deposit rubble layers in places where the bed of the lock approach is under threat; this does make maintenance dredging work more difficult in the lock approach.

Guidelines

The cvb Guidelines (Lit. [4.3]) recommend that the lock approach is made as deep as the connecting fairway. Besides this, the lock approach should be deeper than the lock sill to prevent sedimentation on the lock sill. These measures on erosions will have to be assessed from case to case.

4.8 Lock approach, horizontal dimensions with a view to other functions

4.8.1 The lock approach as stop over harbour

4.8.1.1 General

A lock approach with a lock could have a function as stop over harbour for vessels spending the night (Lit. [4.4] and [4.16]). A place for spending the night is defined as a mooring berth or a collection of mooring places where the vessels types permitted in the fairway concerned, loaded as well as unloaded, can be accommodated safely and be undisturbed.

In the lock approaches of locks for inland navigation or recreational navigation, the mooring places for the locking process are situated at burthing jetties or banks. These same mooring places could sometimes function as mooring berths for resting/spending the night provided that they are not required for both functions at the same time. The designer has to decide how many extra berthing jetties (or banks with mooring posts etc.) he has to include in the design for the purpose of resting/spending the night. This issue is addressed in the next paragraph.

4.8.1.2 Required mooring place length

Of all vessels that pass through the lock, only a small number will stay to rest or to spend the night. The next questions are of importance:

- which part of the total navigation volume will stay;
- how long are these vessels;
- during which part of the day will they lie there.

The answers to these questions are determined by a number of factors:

- the regulations in "Besluit Vaartijden en Bemanningssterkte Binnenvaart" (the Sailing Hours and Crew Act, see Appendix 4.4), influences the sailing pattern of vessels;
- operating times of the lock and of other locks and bridges along the connecting waterways as well as social issues (schools, boarding schools, especially in the weekends) have an influence on the sailing pattern;
- specific sailing patterns of local navigation streams (on the Maas for example, the sand and gravel navigation);
- the distance between the mooring places for spending the night. Given the rule of thumb that harbours for spending the night should not be more than 2 to 3 hours removed from each other, a distance of 30 km between harbours is often used. This distance is also stated for the Waal route.
- availability of other good resting places and places for spending the night in the vicinity;
- possible village or town in the neighbourhood of the lock (social reasons).

The "Vaartijdenwet, vtw" (the Sailing Hours and Crew Act) stipulates the resting times for various vessel categories. This results in certain patterns (in time and place) arising in relation to mooring places. This makes it difficult to estimate the vessels that could moor next to each other.

For a future situation, the method for determining the required length in mooring places for spending the night L_{ov} (all vessels behind each other), could consist of the following eight steps:

1. Execute a count of the existing situation, per class, of all vessels resting and spending the night.
2. Correlate this with the existing navigation volume through analysis and outline the behaviour related to spending the night.
3. Determine the future navigation volume.
4. Reduce the original count to the required number of mooring places in the future situation by corrections for all factors of importance.
5. Determine an exceedance value on which the design will be based (for instance 5% exceedance, that is about 18 nights per annum).

6. Use this to calculate the total required length of mooring places for spending the night L_{ov} (all vessels behind each other) for the future situation. Take into account and average space (of ± 5 m) in between the vessels.

In this calculation, the total length of vessels spending the night is determined. Because of the geography of lock approaches, vessels will not all be able to lie behind each other. In some places, they will moor in single file but in other places, they could moor 2 deep. For this reason, the following will have to be looked at per lock approach in order to obtain a division of the various mooring places.

7. What does the lock approach look like and where can mooring take place and at which depth?
 - Determine the maximum width of the mooring and waiting places (close to the lock) based on the CVB guidelines.
 - Further away from the lock, the maximum width will have to be determined per case (maximum 2 vessels wide ~ 25 m).
 - Determine which locks will not be operational during the night or will only be used for locking vessels in moving navigation.
 - Determine the nightly minimal requirement for mooring space for the whole lock complex.
8. Determine the required mooring place length by using the maximum degrees of occupancy. The maximum occupancy of single file mooring (~ 12 m) is 90% and for double file (~ 25 m) it is 160% (90% 1st row and 70% 2nd row). The mooring places can be executed as continuous burthing jetties or as posts.

Here is another calculation model for determining the length of mooring places in a lock approach:

The length in mooring places for spending the night $L_{ov} = 1000$ m.

In the lock approach, there is 500 m length for single file mooring (excluding mooring area) and the other mooring places can be used for double file mooring. The length of vessels at the single file mooring places is $500 \times 0.9 = 450$ m. This means that there should be $(1000 - 450) / 1.6 = 345$ m mooring place for double file mooring. In total, there should be $500 + 345 = 845$ m of burthing space, excluding the mooring area.

4.8.2 Lock approach as harbour of refuge

A harbour of refuge is understood to be a place where a vessel can have a safe place to lie during extreme conditions, until such time as the conditions have improved. (Lit. [4.16]). Very few extra facilities are required to turn many of the lock approaches into refuge harbours. Harbours of refuge are only of importance along the rivers and large lakes as it is not expected that other waterways (canals) will have such conditions that they would require refuge harbours. This paragraph describes harbours of refuge, insofar as they occur at locks, where there is a need for such harbours, the capacity and location requirements as well as other requirements that have to be met.

4.8.2.1 When are harbours of refuge required?

It is possible that a captain voluntarily seeks a harbour of refuge but it is also possible that the waterway authority issues a particular or general injunction forbidding use of the waterway. In both cases, the cause will lie in one of the following extreme conditions:

High water

In this connection, high water indicates a situation with a very large river discharge. This situation occurs gradually. Navigation can usually consider this well in advance. For the waterway user, the high water situation means:

1. usually more than sufficient water depth and navigation channel width;
2. high flow velocities;
3. orientation and place determination is more difficult.

In general, vessels will keep navigating for as long as possible. In increasing flow velocities, departure in particular becomes unsafe. At a certain stage, the motor capacity is no longer sufficient for sailing against

the current in order to rapidly respond to a local transverse flow for instance. It has transpired that in practice, captains only decide to seek refuge at flow velocities of around 3 m/s or leave the sailing area. Under these conditions, the weirs are lowered. Navigation takes place through lowered weirs. This is not perceived as risky but it is clear however, that the limited passage width requires extra concentration. If the authority decides to close the waterway, it is because he fears damages from navigation (wave action against the unprotected dike slopes etc.). In circumstances of high water in which the velocity flow is only just manageable, captains decide to only navigate in daylight due to visibility and orientation problems.

Low water

In small river discharge, the weirs usually ensure sufficient draught in the river. Even in dry periods, when the draught does not exactly meet the requirements, navigation is able to adjust extremely well and a harbour of refuge will not be sought rapidly. Extremely low water can occur however, if the weirs have to be lowered during small discharge. This could be the case with floating ice, to prevent the weirs from getting damaged or becoming stuck.

Thick floating ice

If there is substantial ice on the river, the river could become unnavigable for part of the fleet. This hardly ever happens on the Maas but on the Beneden-Rijn and Lek (and most canals) this does occur. Often, tugboats can assist navigation in finding a way through but for many vessels, navigation ends. In practice, most of the vessels find a place to moor, among others in the many public and private company harbours in our country.

Calamity

It is conceivable that a substantial water level decrease could occur due to a calamity, for instance if a weir had to sustain serious damage. The chances of this happening are very small but, if it happens, it will be sudden and unexpected. It could be that the water level decrease is not manifested rapidly which will give navigation the opportunity for a timely response. The general opinion is that there is no need to create extra refuge facilities for calamities.

4.8.2.2 Capacity and situation/location

The abovementioned conditions that create a need for harbours of refuge do not occur simultaneously. In essence, the mooring capacity has to be geared to the situation that would require the most mooring places. There are no accurate guidelines for the required number of mooring places in harbours of refuge. Case by case evaluation of the circumstances and fleet composition that could occur will have to take place. This determines how the captains are able to safely deal with deteriorating conditions and if necessary, seek refuge. The latter is an important measure of mooring capacity.

High water conditions occur gradually. Captains want to keep navigating as long as possible. Thanks to good reporting, they will hardly ever be 'caught unawares' by unacceptable conditions. This reduces the required capacity in harbours of refuge.

Low water conditions due to limited discharge occur very gradually and are not that extreme that vessels need a harbour of refuge. On the Maas, the regulations stipulate that when the water temperature drops to below 0.5 degrees Celsius, all weirs are lowered as large quantities of ground ice start forming. Navigation is informed but it often turns out that many vessels do not leave the Maas in good time and therefore still require a harbour of refuge that is still deep enough at (very) low water.

Thick floating ice also occurs bit by bit. Because of this, most captains are able to reach a safe mooring place, in a connecting canal for instance.

Calamities occur too seldom for this to be the base of required mooring capacity. The conditions mentioned above do not supply clear guidelines for determining the required capacity for harbours of refuge. Usually, estimates will have to be made based on experience. There will be little navigation during extreme conditions and the regular mooring and waiting berths at the locks will largely be open to function as refuge harbour. The available capacity of large lock approaches will completely meet the requirements or do so to a large extent in many cases, if the mooring places were calculated for extreme conditions. A harbour of refuge is only of use if it can be reached in time. The distances between these harbours should not be too large (about 40 to 50 km) but may require a few hours of navigation.

4.8.2.3 Specific requirements

In order to serve as a harbour of refuge, a lock approach will have to meet the following requirements:

At extreme high water:

- The mooring berths have to be accessible despite extreme flow velocities. Depending on the situation, it could be advisable to designate the top lock approach as harbour of refuge, because this has a downstream entry.
- The mooring berths have to provide shelter against the current and waves. It could be necessary to enclose the harbour with an extra high guide dam. In many cases, this would raise objections as it could limit the discharge capacity of the dam.
- The mooring facilities have to be sufficiently high, that is to say that the berthing jetties (possibly separate piles) including the bollards have to have sufficient height to keep the vessel(s) in her (their) place.
- From the vessel, shore must be reachable on foot.

At extreme low water

- During extreme low water, the harbour of refuge still has to be accessible and the mooring berths must contain sufficient water, even if the water level had to unexpectedly drop even further.
- Just like during high water, shore has to be reachable by foot. At low water, ladders and suchlike will have to be suitably placed so that footbridges can be reached.

At thick floating ice

- The mooring berth will have to be sheltered from the forces of current and from drifting/moving ice.
- The mooring berth should not be too isolated as the conditions are already far from conformable as it is.

4.8.3 Lock approach as a compulsory harbour

A compulsory harbour is understood to be place where a vessel can be forcibly moored or laid up by the authorities. This could be called for if a captain refuses to adhere to the rules and regulations, in the case of collision damages, too few crew, no documents with the cargo, occupying a prohibited mooring space etc. In these kinds of situations, the most extreme consequence could be a decision by the authority to tow the vessel to another designated mooring space. This rarely happens. There is no reason to provide special facilities for this. If and when this happens, a solution can be found in the existing facilities.

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Appendix 4.1 Nomograms/VAT methods

Nomograms method

Introduction

With the nomogram method (lit. [4.8]), the initial capacity of a lock is determined. In the method, the locking process is set as a series of successive time intervals. Time intervals are quantified based on observations and research. This can be used to investigate whether a lock of certain dimensions can process the navigation volume. By means of iteration, all required lock dimensions can be determined. The method allows insight but is laborious and does not provide results on costs and required waiting area.

Capacity

The capacity is the number of vessels that can maximally be processed per time unit (hour, week) by the lock complex under the given conditions, in the form of a formula:

$$C_s = 2 N_{\max} / (T_{d,o} + T_{d,a})$$

- of which: C_s = capacity (vessels/hour)
 of which: $N_{\max}$ = maximum number of vessels in the chamber
 $T_{d,o}$ = locking duration, locking up
 $T_{d,a}$ = locking duration, locking down

Lock cycle time

A number of time intervals can be distinguished in the locking process, namely the time intervals for sailing in, operation and sailing out. This concerns the locking up as well as the locking down. See Figure A4.1.

The locking duration T_d consists of three components:

$$T_d = T_i + T_b + T_u$$

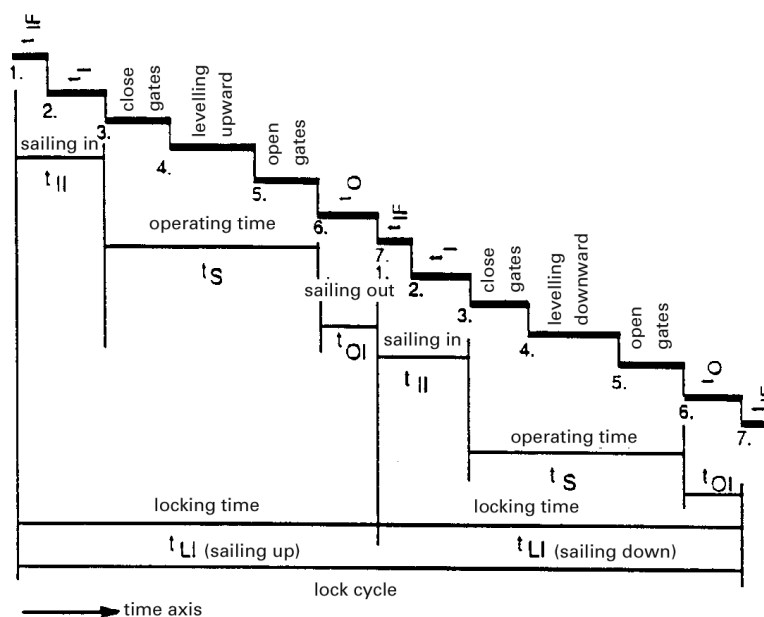
- of which: T_i = total sailing in time = $t_i + \sum t_i$
 t_i = alternation interval
 t_i = individual following time for sailing in
 T_b = operating time
 T_u = total sailing out time = $\sum t_u$
 t_u = individual following time for sailing out

The sailing in time T_i consists of an alternation interval t_i and the sum of the individual following times for sailing in $\sum t_i$. The alternation interval is the interval between the last vessel of the previous locking sailing out and the sailing in of the first vessel of the new lock load. An individual following time for sailing in is the time that is required per vessel for entering the lock, the following time is due to the fact that the vessel concerned will start sailing soon after the previous ship started. The sailing in time depends on the vessel type and size and on the geometry of the lock approach/lock.

The operating time T_b contains the time required for closing the gates, levelling and opening the gates. The sailing out time T_u is the sum of the following time for sailing out required by departing vessels. In general, sailing out requires less time than sailing in.

The complete lock cycle time T_c consists of the locking duration for locking up and the locking duration for locking down:

$$T_c = T_d (\text{locking up}) + T_d (\text{locking down})$$



LEGEND

Point in time

- 1 stern of the vessel of previous locking passes the gates
- 2 stern of the first vessel entering passes the gates
- 3 stern of the last vessel entering passes the gates
- 4 sailing in gates closed
- 5 sailing out gates open
- 6 sailing out gates open (first vessel departs)
- 7 stern of the last departing vessel passes the gates

Symbols

- t_{IF} Alternation interval
(interval between the last vessel of previous locking departing and first vessel of next locking entering)
- t_I following time for sailing in
(interval between successive vessels entering)
- t_O following times for sailing out
(interval between successive vessels departing)

Figure A4.1: Basic elements of the lock cycle

Nomograms and graphs

Based on observations and research, the following information was compiled on Dutch inland navigation locks:

- Tables with standard fleet compositions
A number of tonnage classifications can be distinguished. To indicate a fleet composition, a number of values of the average tonnages of the frequency distribution are provided over the tonnage classifications.
- Graphs for sailing in and sailing out times
The alternation interval and the individual sailing in and sailing out times are presented per tonnage classification of empty and loaded vessels and as a function of the wet chamber / vessel cross section.
- Graphs for the maximum number of vessels per locking
For a large number of lock widths, the maximum number of vessels permitted in a chamber per locking is provided as a function of the average tonnage and for several chamber lengths.

- Values for permitted intensity

Given the fact that one chamber filling is substantially more efficient than another, the point of departure for a lock cannot be the maximum capacity but should be the permitted intensity. Values have been established for the quotient of permitted intensity and the maximum capacity per lock per week, this is then relevant to the quantity of passed through load.

Calculation

The provided input: the chamber dimensions, the distance between the waiting area and the lock chamber, the operating time of the chamber, the percentage loaded and unloaded vessels for locking both up and down, the average tonnage of the fleet, the operating time per week and the percentage in a representative week with regard to annual transport.

From the graphs, the alternation intervals, the individual sailing in and sailing out times and the maximum number of vessels per chamber filling are determined for the average tonnage of the fleet. This is used to calculate the total sailing in and sailing out times. Together with the operating times of the chamber, the locking duration for locking up and locking down and the ensuing lock cycle time is established. The maximum capacity per hour and per week are derived from the number of vessels (or tonnage) and the lock cycle time of the average tonnage researched. With the quotient of permitted intensity and maximum capacity, the subsequent intensity per annum of the researched average tonnage is determined.

By means of iteration, the abovementioned method can be repeated to determine optimal chamber dimensions whereby the total quantity of load passing through corresponds with the permitted intensity.

Possible drawbacks of the method are that it is laborious, the fleet is too schematised and it does not provide insight into costs and required waiting area.

VAT method

The VAT method (lit. [4.17]) is used to investigate the required waiting area in the lock approach. This waiting area is intended for demurrage, in other words vessels that will not be locking through at the next lockage. This is not related to the mooring area. (Note: the mooring area is usually equal to the chamber dimensions).

The provided input required: the normative navigation supply on daily base, the navigation pattern in the number of vessels per hour (for instance 0-24 hours) and the locking capacity for the given fleet and lock. The locking capacity can be determined with the previously described Nomogram method or by means of SIVAK.

The method is simple but not very accurate. The method is an analogy of the liquid flow through of a barrel. This analogy is not completely accurate as locking is an intermittent process. Due to the presence of mooring berths at the locks, the influence of intermittency is sufficiently levelled off to be able to make a decision on the number of waiting spaces required. The method can be graphically reproduced, see Figure A4.2. First, the supply pattern is shown cumulatively. In the same figure, the capacity is set out in a straight (diagonally ascending) line. Where the curve of the supply pattern is larger than that of the capacity, vessels will be staying over. The shaded area is a measure of the sum of the waiting time of the vessels waiting that day. The figure also shows the maximum and average number of waiting vessels.

This method supplies the average and maximum number of vessels staying over (demurrage), the average waiting time of the vessels waiting and the required length for the waiting area. If the results are unacceptable, a new capacity will have to be determined for the adjusted chamber dimensions and the process will have to be completed again. Disadvantages of this method could be that the method does not provide insight into the passing through times and costs and that the method is relatively inaccurate due to the schematisation of the fleet.

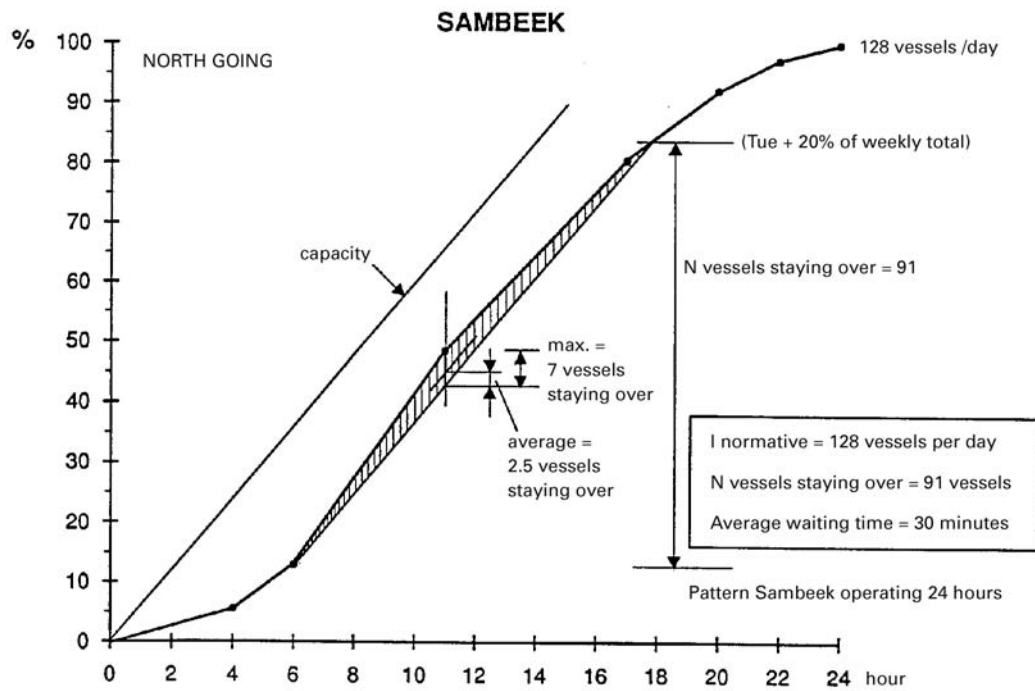


Figure A4.2: Determining the number of vessels staying over at lock Sambeek according to the VAT method

Appendix 4.2 SIVAK simulation model

Introduction

For the economic assessment of the lock capacity, the passing through time is the normative quantity. It is possible to determine reliable passing through times by simulating the navigation activity at locks by means of the SIVAK Simulation package (Simulatiemodel voor de Verkeers-Afwikkeling bij Kunstwerken, lit. [4.11]). In many cases, simulation is the obvious method: the model shows both the navigation volume as well as the locking process in detail.

SIVAK was developed by Rijkswaterstaat for dealing with navigation and road traffic volume at locks, constrictions and bridges situated in a network of waterways. It is intended as an advisory tool for waterway authorities in setting up plan studies and cost/yield analyses. The model can be used to express changes in the use and design of the structure and changes in the requirements for waiting areas for both navigation as well as road traffic (in the case of moveable bridges).

Passing through time

The passing through time can be defined as follows. The passing through time t_p of a vessel is equal to the total extra time required by locking, in comparison to the imaginary situation where there is no lock and the vessels are able to just keep sailing at normal speed. The passing through time consists of three components:

$$t_p = t_w + t_s + t_o$$

whereby:	t_p	=	passing through time
	t_w	=	waiting time
	t_s	=	locking time
	t_o	=	lock waiting time/demurrage

The waiting time is the time between arrival in a mooring area and arrival at the lock entrance decreased by the time it would have taken to complete the whole stretch at undisturbed sailing speed. The passing through time consists of the time required for entering the chamber, closing the gates, levelling, opening the gates and departing from the chamber. The waiting time is the extra waiting time required in the waiting area if a vessel is not able to lock through with the next lock operation. For a correct description of the definitions, see the SIVAK manual. As an example, the course of the vessel position as a function of time is visualized in the time/away diagram in Fig. A4.3 for the simple case of a lock with only one vessel per lock through. In broad strokes, SIVAK calculates the time and place of each individual vessel according to this set-up.

SIVAK model

The SIVAK package consists of a number of sub models:

- the vessel generator
- the actual simulation model
- the data processor for statistic processing and presentation of the results in a report
- a query model that can be used for obtaining very specific information from the database of a simulation
- two animation models.

In addition to the data files that the user completes in order to define the problem, library files are used to obtain vessel dimensions (including safety margins between vessels in the chamber, the width for wood fender), volume patterns, sailing in and sailing out times, sailing and lying costs. The vessel gene-

rator ensures that the stated number of vessels (of specified classifications and according to selected volume patterns) arrive at the lock and report for locking through according to an a-select draw.

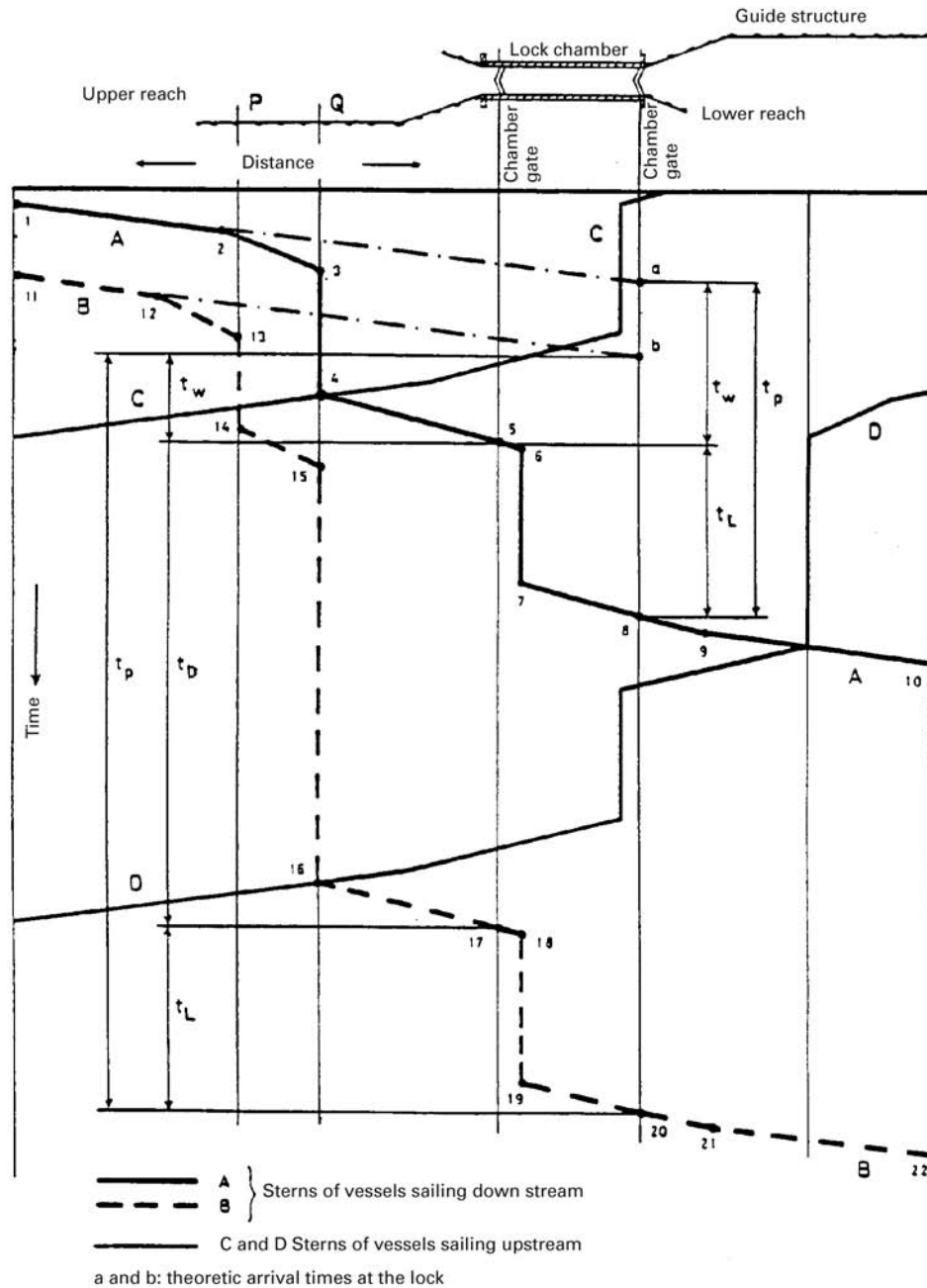


Figure A4.3: Time/away diagram of lock passages

Input

The data is entered:

- the number of lock chambers in the complex
- the horizontal and vertical dimensions of the chambers
- water levels, operating times (or process-), operational times
- navigation volume, per sailing direction,
 - number of vessels, tonnes of load,

- distribution of empty/loaded vessels,
- volume supply patterns (distribution of volume in time),
- vessel types, among others vessels transporting dangerous goods.

One can also indicate:

- possible preference for a certain chamber,
- mixed or separate locking (for instance recreational/commercial navigation) qualifying chamber arrangement,
- extra space for vessels transporting dangerous goods.

Simulation

- Select a normative navigation volume,
- Simulate the traffic flow of the volume at the lock as a function of chamber dimensions,
- For each of these simulations, calculate the passing through times and the costs that correspond with this flow of traffic (such as vessel costs related to passing through time and costs of building waiting facilities),
- Select the optimum of total costs, also taking factors into account that cannot be expressed in money; this also determines the optimal chamber dimension.

Results

The SIVAK simulation shows the passing through times of each individual vessel within the total completion of the navigation in the simulated week. The package also provides the costs/tariffs related to the sailing and lying of various vessel categories. This is used to calculate the passing through costs per vessel and subsequently, by means of summation, the total passing through costs of the passing fleet over a given simulation period are determined.

Usually, a period of a week is simulated. The total sum of time costs for passing through per (normative) week may not be linearly converted to costs per annum, because the passing through times (of the week considered) will not be proportional to the navigation volume (in that week).

There are two methods for obtaining annual figures:

- 1 'Accurate method':
This should actually be an integration in which total passing through times are separately calculated for every week after which the sum over the whole year is obtained. This can still be schematised by selecting various values of the navigation volume of a few representative weeks and simulating this as a whole. Summation of the now obtained week costs times the number of representative weeks supplies an answer that is a good estimation of the methods with complete integration of the 52 weeks.
- 2 'Short method':
Here we pretend that the weekly sum of the time costs for passing through and the navigation volume have a linear connection. If the navigation volume in the normative week is $p\%$ of the total annual volume, the sum of the time costs for passing through are calculated as:

$$\text{Passing through time}_{\text{week}} \times 100/p$$

The passing through times and the passing through costs are the significant quantities for deciding whether the capacity of the lock is sufficient or not. In the cost consideration, one will have to consider a much wider range of 'social economic costs'. If necessary, other chamber dimensions are chosen and the simulation is repeated. The simulations also show the requirements for waiting areas in the lock approaches.

The data processing module makes it possible to execute a large number of other parameters as well, which often provides better insight into the workings of various factors in the process. Animation can also play a role here. Besides, animation is also an important tool for conveying the insights obtained to other parties concerned, see Fig. A4.4.

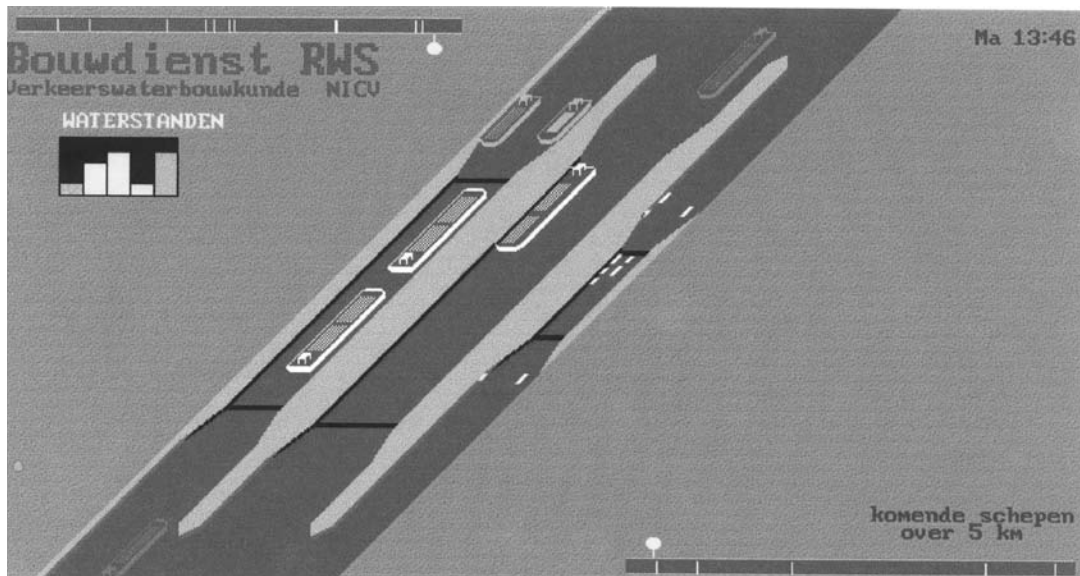


Figure A4.4: Animation with SIVAK

Differences in relation to Nomograms and VAT methods

This method has important differences from and advantages over the Nomograms and VAT methods (Appendix A4.1).

Nomograms/ VAT methods	SIVAK method
Assumes a continuous process; Vessels become uniform units	discrete, stochastic process; vessels are individual navigation participants with individual arrival times, sailing behaviour and dimensions
Usable for uniform fleet composition	Particularly useful for a large diversity in vessel dimensions and sailing behaviour
Less suitable for complexes with more than one chamber	Extremely suitable for complexes with more than one chamber

The advantages and disadvantages of both methods have to be viewed in light of the user's desire or the necessity to obtain an initial, global impression or to obtain detailed insight.

Appendix 4.3 WAROS Calculation model

Introduction

When a vessel enters or departs from a lock chamber the sailing speed and the vertical position of the vessel is adjusted. In addition, waves are created and the return current around the vessel changes. The WAROS calculation model computes the vertical movements of the vessel and intermittency of the water-way (lock, constriction, widening, sill, etc.) in sailing in, through or out of the corresponding water movements.

Formulating the problem

For safe passage through the lock, it is important to know the permitted vessel draught as a vessel is not permitted to touch the lock sill. The moving vessel itself causes the change in vertical position and therefore the keel clearance of the vessel. This change largely depends on the degree of blocking of the wet cross section of the lock and the forward speed.

Problems could also occur with vessels entering or departing from the lock. Vessels that sail in the lock generate waves. These waves cause hawser force and movement in vessels moored in the chamber. The waves also exert forces on the closed gates of the lock. The water level decrease along the sailing vessel exerts forces on the opened gates in the gate recesses. The return current and jet propeller speeds could affect bed protection just outside the lock or in the lock.

Physical phenomena

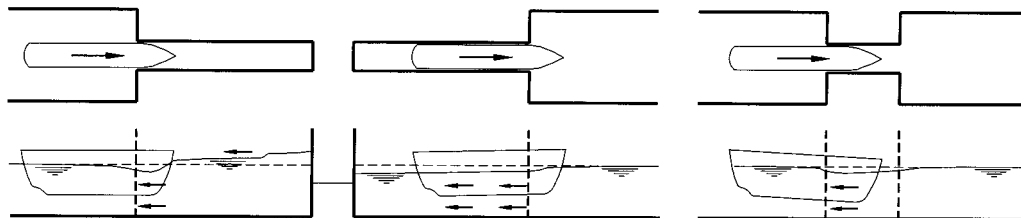


Figure A4.5: Wave phenomena during entry into, passage through and departure from a lock

When a vessel enters a lock with a closed end, a positive transitory wave is generated that precedes the vessel into the chamber. This wave reflects against the closed end and subsequently this wave partly reflects against the bow. In the meantime, the forward speed of the vessel is decreasing because of the increased water level under the bow.

The return current alongside the vessel is impeded in flowing through to the stern along the narrow cross section next to the vessel. The current velocities alongside the vessel are high due to the large water level difference between the bow and the lock approach. This results in a lowered water level next to the vessel, which subsequently changes the vertical position of the vessel. Energy losses occur due to the deceleration of water that flows into the lock approach.

Another situation occurs when departing from a lock with a closed end. The vessel accelerates in the narrow cross section of the chamber, which increases the return current velocity next to the vessel. The position of the vessel becomes lower due to the decrease in water level next to the vessel, which is generated by the vessel itself. The bow subsequently reaches the lock approach, which is at the original water level. The result is that the vessel dips backwards while the longitudinal acceleration decreases. During this time of departure, the keel clearance at the stern of the vessel decreases.

Passing through an open lock presents similar phenomena as previously described. The difference is that the generated waves reflect negatively against the open ends of the lock. This results in both the speed of the vessel as well as her keel clearance decreasing during the passage through a lock. The above-mentioned phenomena strongly depend on the vessel blocking the wet cross section, the initial sailing speed in combination with the applied motor capacity and the relation between the cross sections of the chamber and the lock approach.

WAROS Calculation model

The water is described with one-dimensional comparisons of water movements in a longitudinal direction on a large number of junctions in the waterway, while the vessel is described with comparisons of the vertical movement and the longitudinal movement. These comparisons are solved numerically through using a finite element method. The calculation model is validated by means of measurements from the model and prototype.

The input required: the detailed geometries of both the waterway with the intermittencies (lock) as well as the vessel, the activated motor capacity as a function of place and time and the initial water level and discharge (if necessary).

The output: as a function of time or place the sailing speed of the vessel, the minimal keel clearance and the pitch and heave of the vessel. At a number of indicated ranges, the water level and current velocities are executed as a function of time. Minimal keel clearance is used to check whether the sill will be hit, the water level progress to check whether other vessels are affected by the waves or whether the forces on the gates are becoming too large and the current velocities are used to assess bed protection.

Appendix 4.4 Influence of the sailing hours and crew act on moorings

Sailing hours and crew numbers act

The "Sailing hours and crew numbers act inland navigation", also called the "Vaartijdenwet" or VTW in short, came into effect in January 1995. This act regulates the limitation of working hours and undisturbed resting times in relation to the number of crew members. The VTW distinguishes between method of operation, that is to say day navigation, semi-continuous navigation and continuous navigation. The table below provides a summary of the act.

Resting times crew				
Method of operation	Number of hours:	Of which continuous:	Of which outside vessel sailing hours	In a 24 hour period, to calculate from:
Day navigation	8 per 24	8	8	last rest of at least 8 hours
Semi continuous	8 per 24	6	6	
Continuous	24 per 48	2 x 6	-	
Lying time of vessel				
Method of operation	Number of continuous hours:	If there is no tachograph:		In a 24 hour period, to calculate from:
Day navigation	8 per 24	22.00-06.00 hours		end of break of at least 8 resp. 6 hours
Semi continuous	6 per 24	23.00-05.00 hours		
Continuous	-			
Sailing time of vessel				
Method of operation	Number of hours:			
Day navigation	max 14 *) (16 with breaks)			
Semi continuous	14-18			
Continuous	min 18			

*) 16 hours uninterrupted is permitted once per week, if: equipped with tachograph and extensive crew

TableA4.1 Resting, lying and sailing times according to the Sailing hours and crew numbers act (VTW)

The definitions of day navigation, semi continuous navigation and continuous navigation follow from the table. The tachograph is the instrument that records when (and therefore how long) the propeller is working. This time is considered as the sailing time.

If the effective sailing time can be checked by means of the tachograph (on the screw propeller axle), the captain has more freedom to select his own sailing times (the duration of sailing times does remain limited). A vessel with a tachograph could sail through the night and comply with the compulsory resting period in the day. This means that mooring spaces should be available day and night for resting vessels. For this reason, it is sensible to not speak of areas for spending the night but of resting places. Characteristically, mooring takes place for several hours as opposed to mooring to wait for the next lock through.

Mooring places

Continuous navigation does not require mooring space other than those for locking. Semi-continuous navigation and day navigation have to observe rest periods and moor for a few hours, in accordance with the Sailing hours and crew numbers act (VTW). The times partly depend on the presence of a tachograph. Due to the various arrival and departure times of vessels in different methods of operation, this often results in mutual hindrance that is caused if one vessel has to moor next to or depart from alongside another vessel (mooring in double file). In order to save on the construction of berthing jetties/mooring berths is necessary to execute research into whether it is possible for groups of vessels to moor in double file in specific cases, without causing unacceptable hindrance to each other.

In the national Research into Mooring Problems Inland Navigation (Onderzoek Ligplaatsproblematiek Binnenvaart) (lit. [4. 19]) an expectation is expressed that because of the implementation of the VTW, some shift in methods of operation will occur: from continuous to semi continuous and, from semi continuous to day navigation. Furthermore, it is expected that most vessels from semi continuous navigation and day navigation will conform to night time resting hours, even if they do have a tachograph. This means that vessels in those groups could arrive at very different times through the night but that they will probably leave at about the same time in the morning (at 05.00 resp 06.00 hours). If this is the case, vessels with corresponding methods of operation could moor next to each other without causing too much hindrance. Consultations with KSV Schuttevaer has shown that captains are not in favour of appointed designation of mooring spaces by the lock personnel, they would rather decide this for themselves.

For creating tranquil mooring places, it is sometimes possible to make use of the fact that there are less vessels requiring locking at night; a lock with two chambers of which one chamber is non-operational through the night, the mooring berths in the waiting area could function as resting/overnight places. Also see Chapter 5, where various nautical requirements are integrated.

Appendix 4.5 Vessel classification

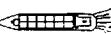
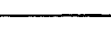
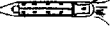
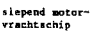
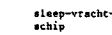
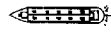
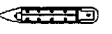
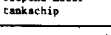
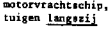
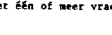
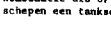
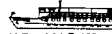
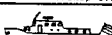
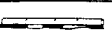
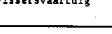
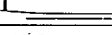
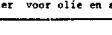
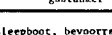
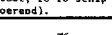
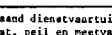
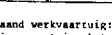
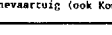
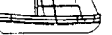
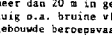
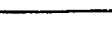
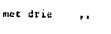
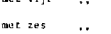
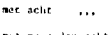
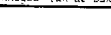
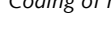
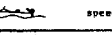
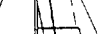
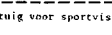
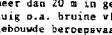
BINNENVAART			ZEEVAART
VRACHT- EN TANKEVAART	NIET UITSLUITEND VRACHTVERVOEREND		VRACHT- EN TANKEVAART
(00) Scheepstype niet te bepalen (b.v. bij mist) (01)  motorvrachtschip (03)  containerschip, ro-ro vrachtschip (02)  motortankschip (04)  gas-tankchip (05)  slepend motorvrachtschip (11)  slepend vrachtschip (06)  slepend motortankschip (12)  slepend tankchip (07)  motorvrachtschip, met één of meer vrachtautogruen langerij (08) combinatie als 07, waarbij tenminste één van de schepen een tankschip is. (09)  motorvrachtschip één of meer vrachtautogruen duwend (10) combinatie als 09, waarbij tenminste één van de schepen een tankschip is. (11) slepend vrachtschip (12) slepend tankschip (13)  gekoppelde sleepvrachtschepen (13)  sleepboot (14) combinatie als 13, waarbij tenminste één van de schepen een tankschip is. (15)  Vrachtduwbak (16)  Tankduwbak (17) Vrachtduwbak geladen met containers (18) Gas-tankduwbak	(40)  sleepboot losvarend (41) sleepboot behorend bij één of meer sleepschepen. De sleepboot kan ook langerij zijn vastgemaakt. Eventueel tweede sleepboot ook kode 41. (42) sleepboot assisterend bij duwact, zeeschip, werkvaartuig of ander drijvend object. (43)  duwboot losvarend (44)  passagierschip, veerboot, rondvaartboot, rode kruisschip e.d. (45)  dienstvaartuig Politie, Rijkswaterstaat (peil-, meet-, directievaartuig e.d.) Havendienst. Ook particulier directievaartuig. (46)  werkvaartuig bok zuiger baggermolen kabellegger bergingsvaartuig betonningsvaartuig (47)  gesleept object. anders dan de kode 1 t/m 16 (b.v. pijpleiding, brugdeel e.d.). (48)  visserijvaartuig (49) overige binnenvaartuigen en drijvende objecten, nog niet genoemd, inkl. bunkerboten en parlevinkers.		(50)  vrachtschip voor stukgoed (51)  containerschip, ro-ro vrachtschip, barge-carrier (52)  bulkcarrier (53)  tanker voor olie en andere vloeibare lading (54)  gastanker (60)  zeesleepboot, bevoorradingschip: losvarend (61)  zeesleepboot, bevoorradingschip: slepend (62)  visserijvaartuig (geen binnenvisser, geen mosselvisser) (63)  veerboot, ro-ro schip (niet uitsluitend vrachtvervoer). (64)  passagierschip (65)  zeegaand dienstvaartuig: patrouilleboot, loodsdienst, peil en meetvaartuig, andere tenders e.d. (66)  zeegaand werkvaartuig: bok, zuiger, kabellegger, bergingsvaartuig, betonningsvaartuig etc. (67)  gesleept zeegaand object: boor-, kraneland, dood schip e.d. (68)  marinevaartuig (ook Kon. landmacht). (69)  overige zeegaande vaartuigen en drijvende objecten: weerschip, opleidingsvaartuig e.d.
(21)  duwboot met één vrachtduwbak (22)  duwboot met twee vrachtduwbakken (23)  duwboot met drie vrachtduwbakken (24)  duwboot met vier vrachtduwbakken (25)  duwboot met vijf vrachtduwbakken (26)  duwboot met zes vrachtduwbakken (27)  duwboot met zeven vrachtduwbakken (28)  duwboot met acht vrachtduwbakken (29)  duwboot met meer dan acht vrachtduwbakken (31)  duwboot met één tankduwbak e.q. gas-tankduwbak (32)  duwboot met twee duwbakken w.v. tenminste één (gas) tankduwbak (33) duwboot met drie duwbakken w.v. tenminste één (gas) tankduwbak (34) duwboot met vier duwbakken w.v. tenminste één (gas) tankduwbak (35) duwboot met vijf duwbakken w.v. tenminste één (gas) tankduwbak (36) duwboot met zes duwbakken w.v. tenminste één (gas) tankduwbak (37) duwboot met zeven duwbakken w.v. tenminste één (gas) tankduwbak (38) duwboot met acht duwbakken w.v. tenminste één (gas) tankduwbak (39) duwboot met meer dan acht duwbakken w.v. tenminste één (gas) tankduwbak			(80)  motorjacht, ook snelvarend (81)  speedboot (82)  zeiljacht varend op (hulp) motor (83)  zeilend jacht (84)  vaartuig voor sportvissers (85)  zeil- e.q. motorschepen met een lengte van meer dan 20 m in gebruik als recreatievaartuig o.a. bruine vloot, charterschepen, omgebouwde beroepsvaartuigen e.d. (89)  overige recreatievaartuigen: roeilboot, kano, rubberboot, zeilplank e.d.

Table A4.2 Coding of navigation

Type des voies navigables Type of inland waterways		Classes de voies navigables Classes of navigable waterways	Automoteurs et chalands Motor vessels and barges					Convois poussés Pushed convoys					Hauteur minimale sous les ponts Minimum height under bridges	
			Type de bateaux: caractéristiques générales Type of vessel: générales characteristics					Type de convoi: Caractéristiques générales Type of convoy: Générales characteristics						
			Dénomination Designation	Longueur Length	Largeur Beam	Tirant d'eau Draught	Tonnage Tonnage		Longueur Length	Largeur Beam	Tirant d'eau Draught	Tonnage Tonnage		
D'INTÉRÊT RÉGIONAL OF REGIONAL IMPORTANCE	A l'Ouest de l'Elbe To west of Elbe			m	m	m	T		m	m	m	T	m	
		I	Péniche Barge	38-50	5.05	1.80-2.20	250-400						4.00	
		II	Kast-Campinois Campine Barge	50-55	6.60	2.50	400-650						4.00-5.00	
		III	Gustav Koenings	67-80	8.20	2.50	650-1000						4.00-5.00	
		I	Grosse Finow	41	4.70	1.40	180						3.00	
		II	Barka Motorowa 500	57	7.50-9.00	1.60	500-630						3.00	
		III		67-70	8.20-9.00	1.60-2.00	470-700		118-132	8.23-9.00	1.60-2.00	1000-1200	4.00	
	D'INTÉRÊT RÉGIONAL OF INTERNATIONAL IMPORTANCE		IV	Johann Welker	80-85	9.50	2.50	1000-1500		85	9.50	2.50-2.80	1250-1450	5.25 ou/or 7.00
			Va	Grands Rhénans Large Rhine Vessels	95-110	11.40	2.50-2.80	1500-3000		95-110	11.40	2.50-4.50	1600-3000	5.25 ou/or 7.00 ou/or 9.10
			Vb							172-185	11.40	2.50-4.50	3200-6000	
			VIa							95-110	22.80	2.50-4.50	3200-6000	7.00 ou/or 9.10
			VIb		140	15.00	3.90			185-195	22.80	2.50-4.50	6400-12000	7.00 ou/or 9.10
			VIc						 	270-280 193-200	22.80 33.00-34.20	2.50-4.50 2.50-4.50	9600-18000 9600-18000	9.10
			VII							285-195	33.00-34.20	2.50-4.50	14500-27000	9.10

Table A4.3 Information on CEMT classifications

Loading capacity class	CEMT-class	Class limitations Loading capacity	Engine power [pk]	Standard vessel							Surface cross section		tons/dm		
				Loading capacity [tons]	Length [m]	Width [m]	Loaded draught [m]		Water displacement [m]		[m²]				
							loaded	loaded 85%	loaded	loaded 85%	loaded	empty			
Motors vessels															
1	0	50 - 249	145	150	28	5.00	1.80	1.60	200	178	50	9.0	8.1	3.5	12
2	I	250 - 449	260	350	39	5.10	2.40	2.12	450	398	100	12.2	10.8	3.8	19
3	II	450 - 649	350	550	50	6.60	2.50	2.22	710	628	160	16.5	14.7	5.0	30
4	IIA	650 - 849	480	750	60	7.20	2.60	2.31	970	858	220	18.7	16.6	5.8	39
5	III	850 - 1049	615	950	67	8.20	2.60	2.31	1240	1098	290	21.3	18.9	7.0	49
6	IIIA	1050 - 1249	670	1150	80	8.20	2.60	2.31	1490	1318	340	21.3	18.9	7.0	59
7	IV	1250 - 1799	930	1550	85	9.50	2.80	2.48	1990	1758	440	26.6	23.6	9.5	73
8	V	1800 - 3199	1210	2250	95	11.40	3.00	2.65	2860	2523	610	34.2	30.2	12.5	97
9		3200 - 6500	1855	3600	110	11.40	3.90	3.42	4500	3960	900	44.5	39.0	13.7	113
Pusher barges															
9		3200 - 6500	2100	5400	180	11.40	3.90	3.41	6500	5740	1150	44.5	38.9	18.0	Per barge
10		> 6500		10800	188	22.80	3.90	3.41	12850	11230	2050	88.9	77.7	25.0	82 t

Table A4.4 Details on loading capacity classes in the navigation assignment model



Photo 4.6 Motor cargo vessel CEMT class I (Spits - Peniche)



Photo 4.7 Motor cargo vessel CEMT class II (Kempenaar - Campinois)



Photo 4.8 Sand/ballast barge CEMT class IIa



Photo 4.9 Cement tanker CEMT class IIa



Photo 4.10 Motor cargo vessel CEMT class III (Dortmund-Ems-Canal)



Photo 4.11 Container vessel CEMT class IIIa



Photo 4.12 Motor tanker CEMT class IIIa

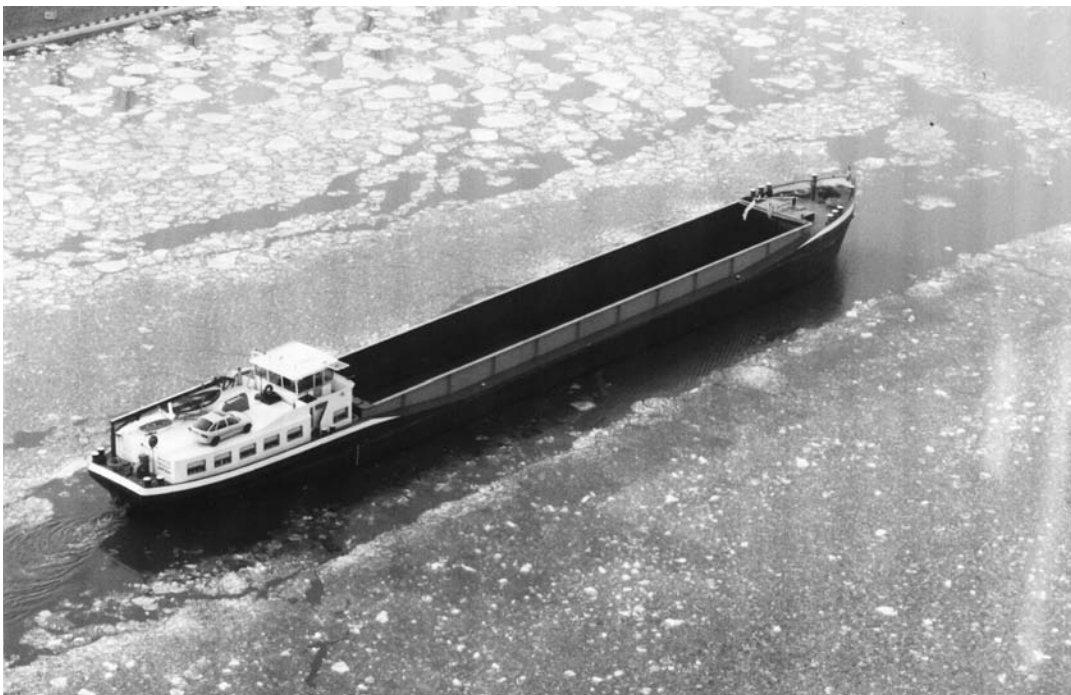


Photo 4.13 Motor cargo vessel CEMT class IV (Rhine-Herne-Canal)



Photo 4.14 Motor tanker CEMT class IV



Photo 4.15 Container vessel CEMT class Va (Big Rhine barge)



Photo 4.16 Pushed barge CEMT class Va



Photo 4.17 Pushed convoy CEMT class Vb



Photo 4.18 Breastedup formation CEMT class VIa



Photo 4.19 Breastedup formation CEMT class VIb



Photo 4.20 Low-profile coaster/ crawl-line coaster



Photo 5.1 Lay out of the lock complex at Terneuzen with (f.l.t.r.) large sea lock, Middensluis and inland navigation lock as link between the Westerschelde (above) with Canal from Gent to Terneuzen (below)

Chapter 5 Lay out of the lock complex

5.1 Introduction

A lock complex comprises of a lock with both lock approaches and the connecting fairway sections. The functional requirements and the use requirements of the lock complex are described in Chapter 2. In Chapter 4, the dimensions of various elements are addressed. This chapter describes how the different elements of the lock complex fit together in an effective lay out.

Design details of lock approaches are addressed in Chapter 16, the guide and berthing structures in Chapter 15.

The lock has a simple, rectangular shape with a head on either side. The lock approach is more complex as it has to contain diverse elements such as the leading jetty, the waiting areas and other mooring places, the sailing space and the safety strips. The lock approach provides safe and rapid sailing access to the lock and it provides sheltered mooring places. The connection between the lock approaches and the rest of the fairway mainly depends on the local situation. In essence, we can distinguish two levels of conformity:

1. dimensioning and equipping the lock approaches, which results in the lay out of the lock complex;
2. connecting the lock approaches to the fairway, which results in the overall conformity of the lock complex.

The lay out and the overall conformity substantially qualify the speed and safety of dealing with navigation. In practice, the two levels of conformity cannot be separated. Difficulties in the overall conformity often lead to adapting parts of the lay out. Creating the lay out in cohesion with the surroundings is therefore an iterative process with input from experts in different disciplines.

If the design is made for a *completely new lock*, in a situation without spatial limitations, the requirements with regard to dimensions, nautical science, morphology, drainage etc. will preferentially be approved without curtailment.

If a lock complex is being adapted by means of constructing a *new lock chamber* the total lay out will have to be redesigned as an integrated whole. This does not mean that everything will have to be renewed but it does mean that the performance of the old and new parts of the complex cannot be separately assessed.

In the designs for *adaptation of the lock approaches* at existing locks, the current guide structures, jetties etc. often no longer fit the new navigation definition. A traffic study is often required to determine a new prognosis on navigation volume in order to establish the length of guide structures.

At a low *navigation load*, it is often sufficient to adhere to lower requirements with regard to nautical factors such as safety, speed and comfort. This is due to the fact that these limitations are hardly felt by low navigation numbers and does not lead to feelings of being unsafe. Besides, the economic interest is not large enough to justify costly interventions.

This chapter is set out as follows. First, a number of contradictory requirements are described that are part of a selection process and make the lay out and conformity with the surroundings more difficult (par.5.2).

Building the lay out of the lock approach is addressed in par 5.3. Fairly concrete guidelines are available for regular inland navigation locks but the guidelines for marine locks and recreational locks remain broad outlines. A few possibilities are addressed to adapt the lay out if the available space for the lock complex is too small. Furthermore, it states how flushing means should be integrated in the lay out. In the overall conformity (par. 5.4), in addition to the required space, the connections between the lock approaches

and the fairway are particularly modified. Lastly, par 5.5. provides some practical examples in which the integration of various requirements and levels of conforming are brought to the fore.

5.2 Contradictions in requirements

In the program of requirements concerning the lay out and the overall conformity of the lock complex, there will be requirements that are in contradiction to each other. The importance and the influence of each of these requirements will have to be weighed up against each other. This paragraph describes a few of these contradictory requirements. Solutions are not provided only the comparative assessment is addressed.

Morphology < > manoeuvring

In lock approaches along sediment bearing rivers sedimentation can occur due to low current velocity in the lock approaches. This is problematic for two reasons: maintenance dredging is costly and during the execution of the dredging activities, the suction dredgers hamper navigation. In order to limit sedimentation, a narrow lock approach mouth is desired, in particular if there is an impeding current.

Safety < > pumping/flushing along the lock

It could be necessary to transport water alongside the lock for the benefit of the water management or to compensate for lockage water losses. Due to flushing or pumping, a transverse current could occur either above and/or below the lock that could be a hindrance to navigation. A solution with a bypass channel requires more space but it also requires less effort to limit hindrance to navigation than the solution of a flush culvert that is integrated into the lock.

Wave penetration < > manoeuvring

Lock approaches of locks along open water are sometimes penetrated by inconvenient wind waves while lock approaches along very busy waterways often have to deal with the arrival of navigation waves. The lock approach mouth will be made as small as possible and/or be given such orientation that the waves are hardly able to penetrate. This often results in the navigation route having one or more curves while the optimal width and orientation of the lock approach mouth will have to be determined by means of a separate nautical/hydraulic study.

Wave generation < > manoeuvring

There is an inclination towards fast sailing in large lock approaches. This can result in waves being generated in the lock approach such as navigation waves or wind waves that cause disruption to moored vessels.

Swiftiness < > water shortage

To limit lockage water loss in periods of water shortages, it could be decided that measures are taken to lock through as many vessels as possible per lockage. The numbers of lock through decrease, as does the water usage. Due to these measures, the average passing through time and the costs for navigation increases. As periods of water shortage are generally of a short duration, the average drawbacks for navigation throughout the year will not be large. It will however, require an increase in (simple) waiting berths in the lock approach.

Furthermore, it is possible to limit lockage water loss by pumping the water back. Here we need to consider the costs of pumping, the energy and the possible extra waiting time for navigation due to pumping. Storage lakes could also be used, as is the case at the old lock at Panheel (photo 5.2) where there is also a pumping station.

Swiftiness < > limiting salt intrusion

Lock systems with the intended result of limiting salt intrusion generally have a decelerating effect on locking as the objective of these systems is to have as little contamination as possible between the fresh and the salt water (Chapter 21). For this reason, the water movement due to filling and emptying flow, sailing vessels and propeller turbulence should be as calm as possible. This requirement slows down the sailing as well as the levelling. In order to achieve the required lock capacity, a larger lock will be required which will, in turn, increase the salt drawback.

Monopolized space < > limiting salt intrusion

Some desalination systems such as a pneumatic barrier for instance, hardly require extra space and therefore have little influence on the lay out. They are not very effective however. More effective systems require more space and therefore are a substantial determining factor in the lay out and sometimes even in the choice of location (photo 5.3, Kreekraksluizen, system not operational).

Nautical optimum < > finances available

Usually, the designer is forced to seek possible savings because of financial reasons while maintaining the swiftness and safety of navigation. Sometimes a non-optimal nautical solution can be acceptable, if for instance, the difficulties only occur incidentally.

Availability of land < > optimal required space

If the ground required for the lock complex is not available or obtainable in its entirety, the design will have to be adapted to the possibilities within the available space (see par 5.5).

When purchasing land, one could be faced with polluted soil and subsequently with higher costs. This could be sufficient reason to not execute an otherwise favourable solution.

When fitting in a lock complex it could happen that requirements are set in relation to the distance to existing construction with a view to safety, sound, vibrations and such like.

5.3 Dimensioning and lay out of lock approaches

5.3.1 Introduction

As an introduction, the formulated requirements for the lay out of lock approaches are summarised here:

- the lock complex has to create conditions for swift and safe passage, including navigation processing in the lock approaches;
- for this purpose, the entrance to the lock approach and the lock approach itself need to be sufficiently spacious and well oriented;
- the lock approach has to offer mooring berths for locking as well as for possible other functions;
- the mooring berths have to be safe given passing navigation, waves, currents and possibly ice.

The lay out requirements concern the lock approach in particular; in front of the chamber the lay out naturally is a rectangle with gates on both sides (and possibly an intermediate head). The lock approach should preferably be in line with the lock axis and, if possible, be straight across the complete length. If the latter is not possible, the incoming and outgoing navigation lanes (see further on) should be widened in the curves.

The lay out of the lock approach can be systematically developed by (for instance) first drafting a lay out across the width and subsequently drafting the lay out for the required length. The sluiceways alongside the lock require separate attention. Distinction is made between the three well-known categories of locks, namely inland navigation, marine navigation and recreational navigation. For inland navigation locks and recreational navigation locks guidelines were drafted by the cvb (lit. [5.2]), which are summarised below and supplemented or provided with more details in some instances.

5.3.2 Width lay out for inland navigation locks

Lock approach with one lock chamber

In making a lay out for the width of the lock approach, the strip lay out (or navigation lanes) is worked out according to the cvb Guidelines for a minimum lock (see fig. 4.18).

The waiting area and waiting berths are situated on the starboard side of vessels sailing in. This corresponds with the usual navigation picture (sheer away to starboard) so that the situation does not lead to unwanted crossing of courses.

The width of the line-up area is at least equal to the width of the normative vessel. In many cases, the width of the chamber is used for this. The line-up area is wide (and long) enough for one chamber filling. The navigation lanes consist of the width of the lock chamber (at the minimum lock this is hardly wider than the normative vessel) plus safety strips on both sides. These safety strips are reserved to prevent vessels from sailing too close to the vessels in the mooring berths or too close to the bank. The cvb recommends concrete values for the various strips as a function of the navigation class (see table in par 4.7.1.3).

The width of the lock approach ensues from the summation of the width of the mooring berths, the navigation lanes for entering and departing and the safety strips.

A capacity lock is often wide enough for the chamber to accommodate two smaller vessels or the normative vessel with one smaller vessel next to each other. If the line-up area then has the same dimensions as the lock chamber, the vessels will have to moor next to each other in the line-up area. Captains would rather avoid this situation. If the lock approach is sufficiently long, the mooring berths could be longer and smaller but it is also an option to create mooring berths at the opposite guide structure if there is a lack of available length in the lock approach.

If mooring berths as well as waiting berths are required at a lock, these could also be situated on the other side, opposite the mooring area. However, it is less desirable to situate mooring or waiting berths on the wrong side of a lock with one chamber as this causes crossing courses with vessels that are sailing out of the lock.

Lock approach with two chambers

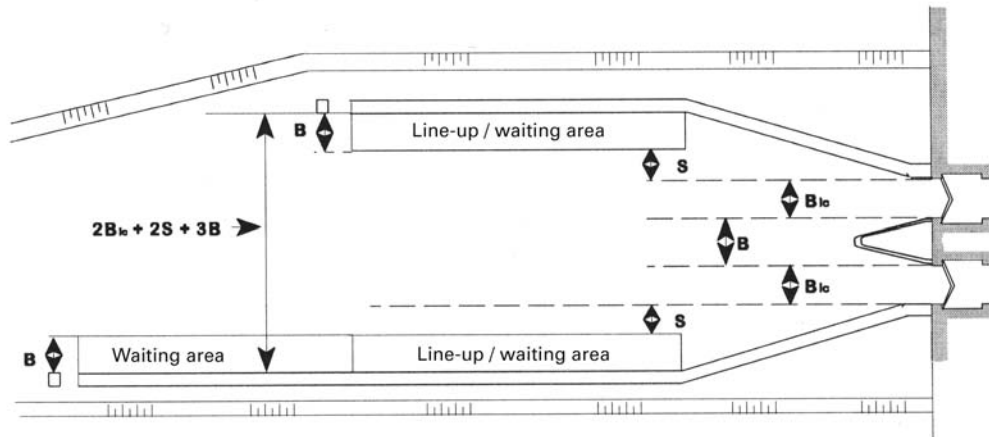


Figure 5.1 Lock approach of a lock complex with two identical locks (Source: CVB, Lit. [5.2])

The CVB Guidelines contain a lay out for a lock complex with two chambers (see fig 5.1). This is an example of both sides having line-up (and possible waiting areas). The principle of all mooring berths on starboard side has been deviated from, which results in crossing navigation. Also see photo 5.2 (Schutsluizen Panheel).



Photo 5.2 Lay out of lock complex at Panheel with new lock with stilling chamber (left) and the old lock with storage reservoirs (right) as connection to the Kanaal Wessem-Nederweert on the Maas

The lock island plays a role in the lay out of the lock approach. If the lock island is wide, for instance more than twice the chamber width and the lock approach is actually too short for the required waiting and mooring areas, it is an option to create a guide structure/ berthing jetty in line with the axis of the island that could serve as a mooring area on both sides.

If the lock island is narrow – for whatever reason – and both lock chambers are open on the same side, it is possible that vessels end up in each others territory when sailing in and out. There is no safety strip between their navigation lanes. Navigation technically, both chambers become dependent, which decreases the capacity. The question of whether this is a serious drawback will depend on the navigation volume, fleet composition and the dimensions of vessels (possible tugboat use) in relation to the chamber dimensions. The diagram below provides an overview of the degrees of dependence:

Vessels sailing into the same lock approach from different chambers			
	2 large vessels	large and small vessel	2 small vessels
Chambers at small distance	very dependent	moderately dependent	non dependent
Chambers at large distance	moderately dependent	non dependent	non dependent

An example of a very narrow lock island is found at the Krabbersgatsluizen at Enkhuizen (Paragraph 5.5.3). In order to limit the costs of the lock/tunnel combination, both chambers were situated at the minimal (constructional) distance from each other.

To avoid dependence, the lock island should certainly not be narrower than the width of the normative vessel.

Lock approach with tapering width

If space allows, it is attractive to make the start of the lock approach (at the mouth) extra wide and subsequently converging both banks towards the lock at an angle of 1:10 with regard to the lock axis, until the width of the leading jetty is reached according to cvb Guidelines (Photo 5.3, Kreekraksluizen). An advantage is that vessels that are moored at some distance from the lock experience less disturbance from the water movement of passing vessels. This is important as, at a larger distance from the lock, both entering and departing vessels have a higher average speed than they do closer to the lock. Widening of the harbour decreases hindrance. The extra width is not necessary close to the lock. This is also an attractive solution in situations where sailing into the lock approach is more difficult due to currents or waves as the extra width in the free area also offers the opportunity for adjusting and correcting the sailing course after a mediocre entry.



Photo 5.3 Lay out of Kreekraksluizen in the Schelde-Rijnverbinding

5.3.3 Length lay out for inland navigation locks

Starting from the outside of the lock head, the lay out is made by successively situating (see fig. 4.18 and par. 4.7.1): the leading jetty, the mooring and waiting area, the free area.

- **Leading jetty**
The length of the leading jetty with guide structures is determined by the angle with regard to the lock axis and the width of the mooring area with the adjoining safety strip. Usually the angle amounts to 1:6 but it can also be 1:4 if the use of the bow propeller is general rule. It is recommended that a straight guide structure of about 3 m is constructed between the lock head and the leading jetty if the guide structure is lower than the lock head. For CEMT class Va, a leading jetty with curved section on the lock head is recommended for a minimum lock while for class Vb, this preference always applies. (see par. 4.7.1.4).
- **Line-up area**
The length of the line-up area depends on the length and width of the lock chamber. The cvb recommends that the line-up should be 30% longer than the effective length of the lock chamber. This is favourable for the swiftness of mooring and unmooring because if the line-up area is longer than the lock chamber, vessels in the line-up area have more widely spaced mooring available (see par. 4.7.1.5).
- **Waiting area**
If waiting berths are required, these are preferably situated adjoining to the line-up area. The required length for the waiting berths is determined by means of a navigation volume study (see par. 4.7.1.5).
- **Free area**
The free area (length) is defined in the cvb Guidelines as the space required by the captain as transition between regular navigation on a fairway and manoeuvring in the lock approach. This transition entails: decreasing speed (slowing down) and if necessary, correcting the entry manoeuvre. The free area is situated between the waiting area and the mouth of the lock approach. The dimensions of the free space depend on various factors (see par 4.7.1.2).

The length of the lock approach is determined by summation of the four stated lengths. The above is based on locks with only one category of vessels (regular commercial navigation). Extra facilities often have to be created due to a combination with recreational navigation (see par. 5.3.6).

Separate mooring facilities have to be created for vessels transporting dangerous substances, as specific distances to other vessels have to be adhered to (see par 4.7.1.5). As these vessels are relatively few, it usually is sufficient to have one mooring berth that can function as a mooring and waiting berth. It is acceptable to situate this berth at a larger distance from the lock.

5.3.4 Lay out of discharge sluices along inland navigation locks

The lay out of the lock complex is influenced by the size of the flushing discharge within the time that navigation is permitted. The solutions are presented in order of increasing discharge. Please note however that, as a rule, a hydraulic and a nautical expert are generally consulted for a correct design.

Discharge through the lock

Flushing through gate openings (or culverts) of a lock can take place outside the operating times of a lock or when there is very little navigation. Discharging is only possible if flush disruption does not cause problems. Flushing is done through the upper gates (or upper culverts) whereby the lock serves as a dissipating chamber while the lower gates are open. The flow from the chamber will meander through the lower lock approach through the large width of the lock approach and will make contact with the banks further down. If there regularly are vessels in the lower lock approach during flushing, it is recommended that the line-up and waiting areas concerned are situated lower down from the lock than usual.

One-sided means of discharge

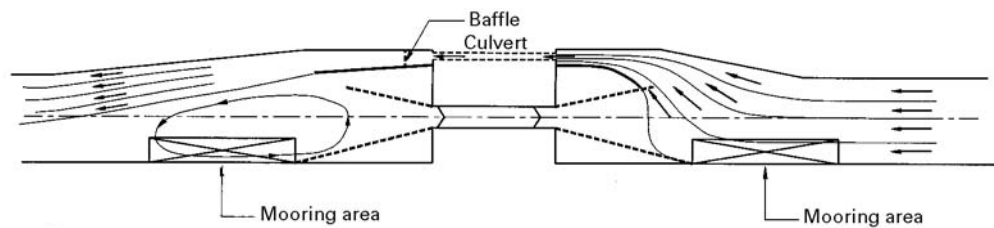


Figure 5.2 One-sided means of discharge with open leading jetties

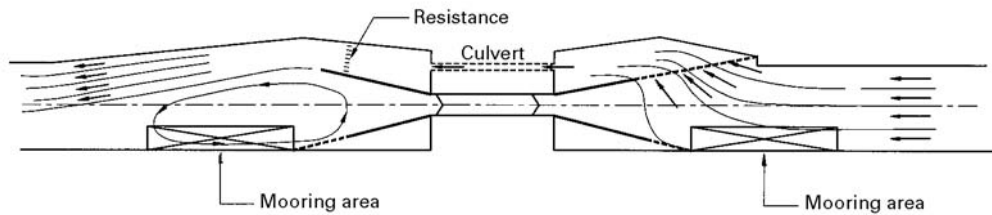


Figure 5.3 One-sided means of discharge with closed leading jetties

Given a limited discharge in a waterway with a lock able to flush independent of navigation, one or more one-sided culverts are often placed next to the lock. The intake and discharge of the culvert (or culverts) has to be kept as far as possible away from the navigation lane, the line-up and the waiting areas. There should not be any flow in front of the lock entrance. The water flows through the culvert by means of natural head or by means of pumping.

The line-up/waiting berths are placed at both the intake as well as the discharge sides of the canal banks that are opposite the culvert. The culvert mouths are positioned as deep and as close as possible to the canal banks, in the abutment wall of the lock and as far as possible away from the navigation lane. The prerequisite is that there is not much flow left over at the line-up and waiting area.

Measured over a year, flushing (or inlet) discharges vary greatly: in the incidentally occurring wet (or dry) periods, the discharges are high while discharges are smaller at other times. If the requirement is for navigation to continue during times of greater discharges, a lock culvert without additional facilities is not sufficient. The culvert mouths have to be expanded with separate, open inlet and discharge canals along the canal bank (see fig 5.2 and 5.3). These inlet and discharge canals are created by means of connecting a freestanding sheet piling screen to the abutment wall.

The point of inflow into the intake canal is at a distance of at least one half up to a whole vessel length from the lock entrance. The freestanding sheet piling screen can be constructed in a bent form that converges towards the culvert mouth and is situated outside the area frequented by vessels. The guidance structures of the leading jetty are completely open (fig 5.2). An alternative is that the freestanding sheet piling screens are part of the leg of the leading jetty, whereby the leg is extended to the canal bank and where this extension is only open at the bottom (fig 5.3). (Remark: This extension could be executed as an open guide structure with aprons sticking into the water and below that a bottom gap. The other leg of the leading jetty has the same length but is completely closed.

The water that flows from the intake pond to the point of intake flows universally, so therefore almost transversely across the navigation lane. Close to the intake point, the canal has a transverse current that is almost equal to that of the longitudinal current in the supply pond. If the latter is higher than the permitted transverse velocity (for instance 0.30 m/s), this results in problems from a nautical point of view. Just before the point where the water reaches the point of inflow, the flow velocities increase. This has to remain outside the area of the fairway.

The discharge point is also at a distance of at least one half up to a whole vessel length from the lock entrance, against the canal bank. The structure consists of a freestanding sheet piling screen. This screen could be close to the bank wall in combination with an open leading jetty construction (fig. 5.2) or it could be part of a leading jetty leg (fig. 5.3), whereby the other leg of the leading jetty is identically constructed. By using a discharge dispersing construction (diffuser, pile screen, baffle, sill and such like) behind the mouth of the culvert, the flow velocity at the point of discharge can be reduced to less than 0.9 m/s.

The efflux water is guided along the canal bank. By creating the lowest fluctuation possible, it ensures that the flow follows the canal bank for as long as possible. In a downstream direction, the flow velocities further decrease to a point where the velocities are so low that the flow disengages from the bank and goes further into the canal. Just past the point of discharge, an eddy occurs that circulates in the lock approach and provides flow velocities of about 1/3 of the main current.

At a main current of 1 m/s this results in a speed in the eddy of about 0.30 m/s. As a transverse flow velocity in front of the lock entrance and at the mooring spaces, this is slightly higher than acceptable.

Double-sided means of discharge

At larger discharge, both sides of the lock will require a means of discharge in the form of one or several culverts. The intake and discharge canals are now equally constructed on both sides of the canal banks in completely the same manner, as is the case in one-sided means of discharge (fig. 5.2 and 5.3). By continually striving for the most symmetric flow situation possible with identical means of discharge on each side, large transverse flow velocities are prevented. The mooring /waiting areas of both lock approaches are positioned diagonally across from each other as in a situation without flow. The line-up and waiting area on the side of the discharge canal will have to be placed further back, for instance at a distance of two vessel lengths from the lock entrance due to direct hindrance from the discharge flow.

Open bypass canal

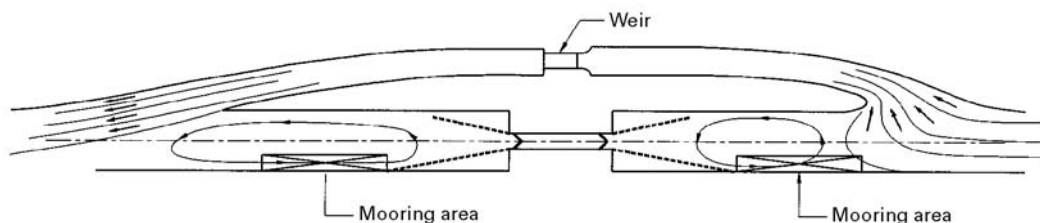


Figure 5.4 Open bypass canal at a lock

If the discharge is so large that sufficiently low flow velocities cannot be obtained, it requires an open bypass canal so that the flowing water can be directed around the lock (fig. 5.4). The bypass canal will have a scouring sluice, weir or pumping station. The intake and discharge points of water are well past the ends of the line-up area and possible waiting berths. Both the line-up and waiting areas in the lock approaches are situated on one side and this would be the side opposite the open bypass.

The angle between the fairway and the supply canal is between 20° and 45° for instance. A sufficiently large radius of curvature for the bends (in particular the convex bank at the middle island) has to be ensured in order to obtain an increasing flow velocity in the bypass canal and to prevent a too large transverse current on the fairway.

The angle between the discharge canal and the fairway should not be too large (for instance less than 20°) while the radius of curvature of the bend following on from the canal should be such that the discharge flow remains close to the corresponding bank of the canal. The discharge channel has a slightly divergent passage for the decrease of flow velocity.

Navigation diversion

If there is an even more substantial discharge (for instance the Haringvlietsluizen, sluizen Afsluitdijk) navigation is re-routed around the means of discharge, just like at a lock next to a weir in a river. The lock is in the diversion of navigation (see photo 5.4 Nieuwe Statenzijl). The branching of the navigation

route takes place in gentle curves for safe entry and departure despite transverse current. The radius of curvature at the upstream side of the middle island has to be sufficiently large to assist in proper influx to the drainage sluice. The line-up and waiting areas have to be inside the navigation diversion.



Photo 5.4 Lay out of the lock complex at Nieuwe Statenzijl with navigation lock (left) and drainage lock (right)

5.3.5 Lay out for recreational navigation

The CVB Guidelines (lit. [5.2]) can be followed for this. The dimensions of the various parts are addressed in part 4.7.1. In essence, the lay out is the same as for inland navigation, but the angle of the leading jetty legs is now 1:3. At a busy lock (for instance for the 2,000 passages per annum) a double-sided line-up and waiting area is recommended, which can alternatively function as line-up and waiting area.

5.3.6 Lay out for a combination of commercial and recreational navigation

At locks with both recreational navigation and commercial navigation, it is recommended that the recreational navigation vessels have separate mooring facilities. Local conditions generally determine how recreation vessels can be offered safe mooring facilities. Sometimes use can be made of the fact that the draught of recreational navigation is slight, so that the mooring facilities for recreational navigation can be situated close to a slope. However, do take into account the wave movement caused by commercial navigation by means of keel clearance. Commercial navigation first enters the lock, followed by the recreation vessels. The following solutions can be distinguished for line-up and waiting areas for recreational navigation (see fig. 5.5):

- 1 in line with and at some distance from the mooring/waiting berths of commercial navigation (e.g. locks at Heel, par. 5.5.2);
- 2 placed slightly back and at some distance from the mooring/waiting berths of commercial navigation (e.g. locks at Lith, par. 5.5.3);
- 3 behind the mooring/waiting berths of commercial navigation in a separate box (e.g. Krabbersgatsluizen, par. 5.5.4, Old Oranjesluizen, photo 5.5);
- 4 at the opposite side of the line-up area of commercial navigation.

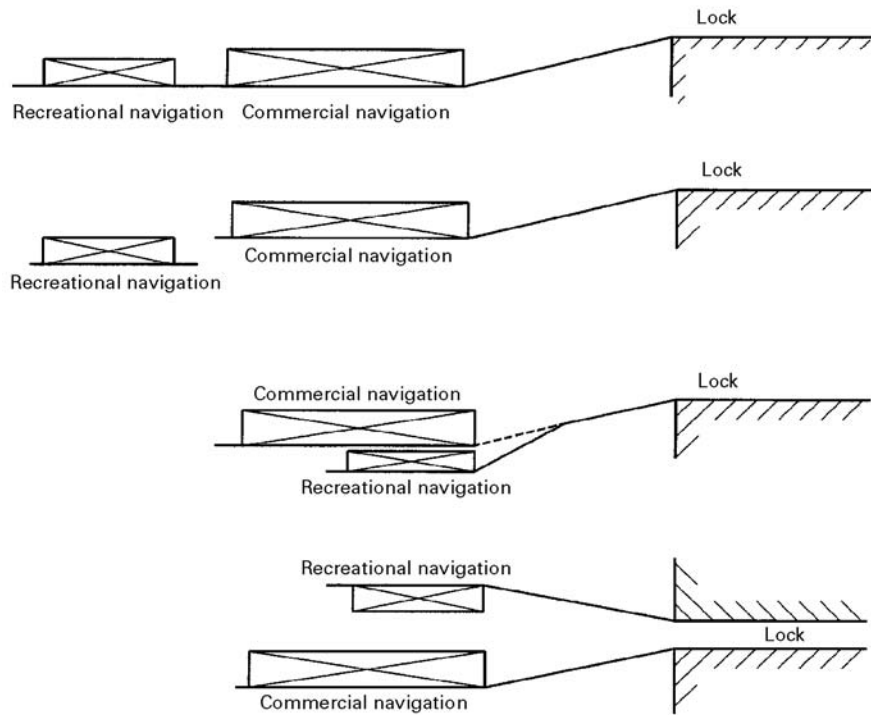


Figure 5.5 Line-up/waiting area at a combination of commercial and recreational navigation



Photo 5.5 Lay out of Oranjesluiscomplex in Amsterdam with (f.l.t.r.) 3 navigation locks, discharge locks and a push-tow lock

The dimensions of the line-up area for recreational navigation correspond with the horizontal dimensions of the chamber or is smaller if recreational navigation is only a part of the number of passing vessels. Solutions 1 and 2 have the disadvantage that the mooring berths are situated far from the lock. This could have a negative influence on the lock capacity. Solution 3 and to a lesser degree solution 2 have

the advantage that commercial navigation cannot access the mooring berths for recreational navigation. The motorboats and yachts are safe. Solution 4 has the disadvantage that recreation vessels could cross the path of departing vessels even though recreation vessels are only supposed to depart after commercial navigation has entered the lock. Technically, the third solution is the best solution, with separate boxes if there is substantial recreational navigation and sufficient space. Naturally, cost should also be taken into consideration in making the choice.

5.3.7 Lay out for marine navigation

At large marine locks, the lock approach only serves as an area for manoeuvring as mooring berths are not required (see par. 4.7.1). The lay out and dimensions are almost exclusively determined by the requirement that there should be sufficient space available for entry from open water with currents, wind and/or waves, reducing speed and manoeuvring, whether or not with tugboat assistance. In almost all cases nautical research is recommended.

5.3.8 Possible measures for lack of space

Spatial limitations could be the result of existing structures or important natural environments. If the surroundings dictate many spatial limitations, these could have a substantial influence on the lay out. Below are a few examples of possible measures.

Adaptations due to lack of length for the lock approaches

When there is too little space to provide the lock approach with its nautical optimal length, sailing in becomes more difficult (one has to enter slower or stop faster).

It is possible to make the lock approach a bit longer by equipping the lock with a type of gate that would keep the lock head short. The costs of a different type of gate will have to be weighed up against the length gained for the lock approach. Lift gates, rolling gates and a few pivot gates at the head of the lock result in shorter heads – and therefore shorter locks – than mitre gates and a single pivot gates with gate recesses.

If the lock is too long because a bridge is situated over one of the heads, one could consider moving the road junction to outside the lock approaches.

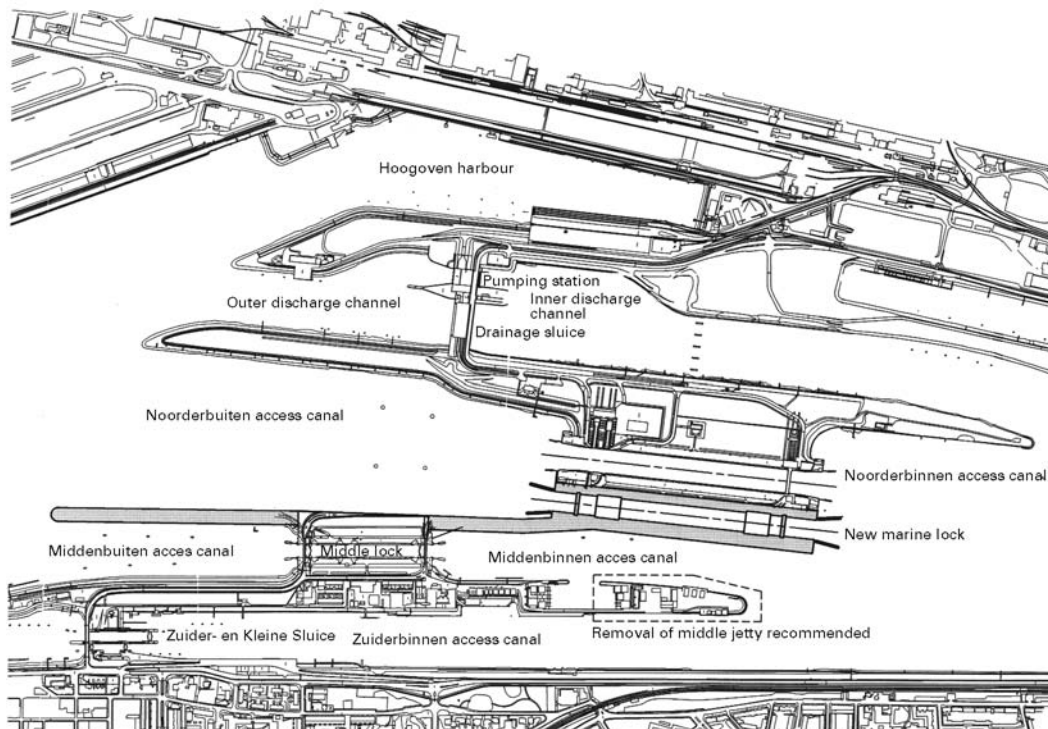


Figure 5.6 Outer lock approach IJmuiden with one of the possible locations of the new marine lock

If there is too little length available for waiting berths, consider making the lock wider as this increases lock capacity and decreases waiting area requirements. This was done at 2nd Lock Lith. Lack of space resulted in a larger lock.

Adaptations due to lack of width for the lock approaches

If the space is too narrow for a nautically optimal lock approach, a smaller (less safe) lock approach could be acceptable if extra safety precautions or a navigation regulation is imposed.

If a new lock is to be built in an existing lock complex, the new chamber will be placed close to the other chamber if there is a lack of width. An example is one of the variations for the new marine lock at IJmuiden next to the existing Noordersluis where the available total width is narrow (see fig. 5.6). Instead of the usual rolling gate for a lock like this, a different type of gate has to be chosen. Furthermore, the mutual distance between the chambers becomes so small that, in view of safety and the required physical space, large vessels (vessel and tugboats) will have to wait for each other when sailing in and out. The navigation situation in the chambers then becomes dependent, which can result in a capacity decrease per chamber (par 5.3.2).

5.3.9 Influence of other functions on the lay out

Lock approaches are often used to rest or to spend the night and sometimes, they also serve as a harbour of refuge or a compulsory harbour (see par. 4.8).

Resting /spending the night

The most important requirement for a place to rest or spend the night is that vessels should be able to rest there safely and – in essence - be undisturbed.

A place to spend the night must at least have a connection with the bank (passable on foot). (See photo 5.6, locks at Hansweert and photo 5.8, Volkeraksluizen).

Par. 4.8.1. explains how the required length for mooring places for resting/spending the night can be determined. Even though resting places are also a requirement during the day due to the Sailing hours and Crew numbers Act, resting places are generally used more often at night. For this reason, they can be used as line-up and waiting places in the day while they are reserved as resting / overnight places at night. For the lay out, this means that the resting places are usually situated in line with the line-up and/or resting places. Attention must be paid to passing vessels to ensure that they do not cause too many bothersome water movements in this area. Especially if the harbour is narrow, the lock personnel will have to oversee sailing speed and passing distance.



Photo 5.6 Lay out of two push-tow navigation locks in Kanaal door Zuid Beveland

Refuge places

A harbour of refuge and refuge places in lock approaches also have to offer safety under extreme conditions (par. 4.8.2). The safety requirements place special demands on the location of mooring places: they have to be accessible under extreme conditions and they have to be sheltered. For refuge places in the lock approach, these requirements will often not have the highest priority at the lay out. Yet, by means of adapting the design of the complex, including dams etc. one will have to endeavour to create safe hydraulic conditions. If, for instance, hindrance is expected because of wind waves, the harbour mouth and the mooring places will have to be adapted for this.

In par. 4.8.2, the considerations are given in relation to the necessary mooring place capacity. The regular line-up and waiting places can generally be used for refuge if, in extreme conditions, they meet the requirements for accessibility and shelter. Usually it comes down to the fact that no extra mooring spaces are required. Basically, it boils down to no extra mooring berths being required and therefore the influence on the lay out is nil.

5.4 Connection of the lock approaches

The overall conformity concerns the connection of the lock and lock approaches to both sides of the fairway. Particularly in relation to the connection of the lock approach, it matters whether the mouth will be connected to still waters or moving waters or possibly even open waters. The different cases are described below.

5.4.1 Connection to still water

Lock between two canal reaches

In the connection of a lock to a canal reach, captains are able to use the last part of the canal to reduce speed and manoeuvre to the line-up /waiting places. Separate free space is not required, apart from the transition length used to bridge the width difference of less than 1:10 between the canal and the lock approach, so that vessels from the canal are also able to easily reach the first mooring berth (furthest from the lock).

Furthermore, the canal parts connecting to the lock approach should not contain narrow bends. If the canal itself is not straight, one will at least have to try to keep the complete lock complex including the lock approaches straight.

To reduce hindrance caused by translation waves at the lock entrance and in the lock, the lock approach does not converge but is kept wide right up to the lock. The leading jetties should be open structures instead of closed sheet piling.

Lock as a lateral branch of the through fairway

In this case the lock approach and lock should be viewed as secondary fairway with regard to the through fairway. Sailing in and out is sometimes rendered more difficult by the fact that navigation on the through fairway has right of way. The optimal angle of connection depends on the local situation and on the issue of how important navigation streams that utilize the lock run. At sailing in and out of the lock approach, view can sometimes be limited while a (sharp) bend has to be sailed. The waves generated by navigation in the main canal can cause much hindrance in the lock approach, particularly in the case of an unfavourable angle of connection to the lock approach.

Waves are understood to include the long, primary wave (bow wave, water level decrease next to the sailing vessel and stern wave) as well as the short, secondary waves. At a converging shape and steep banks of the lock approach or leading jetty, provided with closed (sheet) piling, the waves will become higher towards the lock. Unfavourable nautical conditions have to be overcome the best way possible by the most suitable design of a lock approach. A few possibilities are:

- Waves are kept outside the lock approach as much as possible by making the entrance as narrow as is nautically acceptable, with regard to both water width and water depth at the entrance. The lock approach right behind the entrance does have to be wide so that safe entry and departure can take place despite the narrow mouth.
- The lock approach to the lock is kept wide and deep in order to limit the primary wave movement from the main fairway, which is noticeable as 'suction' in the lock approach (open leading jetties).
- The lock approach is connected to the main fairway at a right angle to limit the penetration of diagonal, short waves into lock approach. Furthermore, if possible, the lock approach is equipped with wave damping banks to damp the short waves.
- Ensure unobstructed views (visibility lines according to CVB).
- Situate line-up and waiting areas as such that they have least hindrance from waves entering diagonally.

5.4.2 Connection to moving water

The connection of lock approaches to moving water (a river) has far-reaching requirements for the lock approach design.

Connection of a lock next to a weir in the river

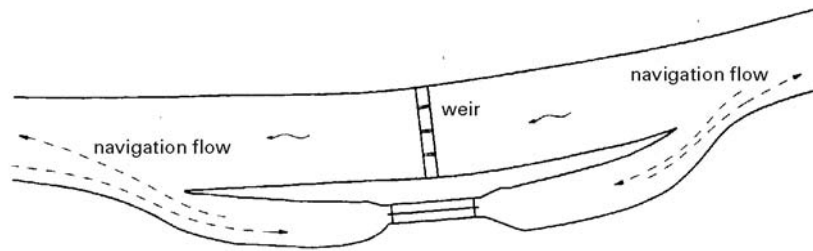


Figure 5.7 Lock complex in Lith

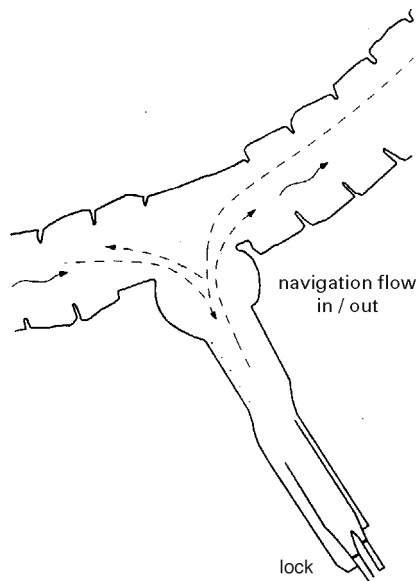
The connection with a sharp angle usually concerns a navigation lock next to a weir in the river. Examples are the locks in the Maas (fig. 5.7, locks in Lith and photo 5.7, locks at Sambeek) and the Rhine. The lock approaches are entered from one direction. The upper lock approach has to be longer than the lower lock approach as vessels sailing into the upper lock approach are sailing downstream into the lock approach and therefore have a higher entry speed.



Photo 5.7 Lay out of lock complex at Sambeek on the Maas with weir (left) and 3 navigation locks

There are also examples of sharp connection angles at locks that are part of a connexion between a river and a canal, for instance lock St. Andries and lock Engelen at Den Bosch. Here, the right angle approach was not used because a diagonal entry would be too difficult due to currents. The connection was designed to only sail in from a downstream direction (against the current). Vessels approaching from the upstream direction (with the current) have to first go around the river (turn up) before they can sail in. This solution is only a viable solution if the river is wide enough and navigation volume is not too high.

Connection oriented diagonally on the river



This connection to a canal reach on a river is intended for entering from both sailing downstream (that is to say from the upstream side) as sailing upstream. Examples are locks at Tiel (Amsterdam-Rijnkanaal, fig. 5.8), Zwolle (Zwolle-IJsselkanaal) and Eefde (Twenthekanaal). In these examples, the mouth is wide and half-circle shaped widening has been introduced behind the mouth. Thanks to this shape, just behind the mouth in the lock approach, a large eddy turns that is driven by the current in the river. To ensure safe entry and departure, the flow velocity in the river in front of the harbour mouth should not be too high. If the flow velocity in the river is very high (more than 2 m/s for instance) and the harbour has a width of less than the length of a vessel, a diagonal connection cannot be entered safely even if the approach is from the downstream side. The solution would be to choose a sharp angle (see above).

Figure 5.8 Connection oriented diagonally on the river

Sedimentation versus nautical requirements

If a lock approach connects to moving water that contains sediment, there is a large chance that the sediment will precipitate in the harbour. A narrow lock approach mouth is required to combat sediment penetration. The geometry of the connection, including the mouth, is very sensitive to detail: small changes in the mouth can have a large influence on sedimentation.

A narrow mouth is unfavourable to navigation however, certainly if there are currents that render entry even more difficult. The impeding current could be: strong flow velocity with the current, strong transverse flow (or another unfavourable angle), a flow pattern that changes in time, sudden changes in transverse flow (gradient, along the path of the vessel). For permitted transverse flow and transverse flow gradient at the mouth of a lock approach there are no generally applicable quantitative standards. A good estimate is obtained by comparing the design situation to existing situations with regard to lay out, current and normative vessel.

The combination of a narrow harbour mouth with passing current requires relatively high sailing speeds. However, this is only permissible if there is sufficient room available inside the mouth of the lock approach (width and length) to safely decrease speed and correct the manoeuvre if necessary. If there is not enough room, the harbour mouth will have to be made wider which in turn means that there will be more sedimentation.

The optimization of the lock approach design for the nautical morphological situation outlined above requires a combined nautical/hydraulic/morphological study (example Tweede Sluis Lith, lit. [5.3]).

Nautical recommendations

From nautical considerations, concrete guidelines cannot be derived for dimensions and design of the lock approach as these are determined by a large number of factors: flow conditions, manoeuvrability characteristics of the fleet, regulation of navigation, width of the mouth/canal etc. Recommendations can be supplied. It is favourable for navigation if:

- sailing in can take place in a flowing line, that is to say without sharp bends; an entrance with a bend and counter bend is highly inconvenient;
- the transverse current is not too high in front of the mouth of the lock approach and the current gradient is not too strong;

- the lock approach is wide so that a mediocre manoeuvre can be corrected, even if there are moored vessels and so that oncoming vessels can be safely met while slowing down;
- the lock approach is long so that speed can be reduced safely;
- the situation can be overseen from both the river as well as the lock approach, both by day and by night.
- the slopes of the banks and dam heads at the mouth of the lock approach are steep or vertical, so that one can sail close by and they are visible both by day and by night;
- the lock approach is deep as this results in less hindrance due to ship waves and it enlarges manoeuvrability;
- the lock approach has gentle, riprap slopes because this dampens both ship and wind waves.

Remark:

The nautically desired steep banks in the harbour mouth are exposed to strong hydraulic loads if the vessels pass close by. This has to be taken into account in the design of the bank protection concerned.

View

With a view to the visibility at the mouth of the lock approach, the guidelines drafted by the CVB on right angle connections of side harbours to a fairway with no or little current can be used (see fig. 5.9). In case of strong current, one will have to set more stringent requirements for visibility on the upstream side, for both entering and departing vessels, than this guideline provides for. This is because the current increases the speed of vessels from an upstream direction. For this purpose, an incoming vessel should oversee a large part of the lock approach as she enters at relatively high speed. There are no quantitative guidelines for the situation of a diagonal connection. A qualitative guideline is, every captain must be able to oversee the fairway over such a distance that he is able to steer away or stop in time. It is clear that this requirement has to be dealt with thorough practical knowledge and expertise.

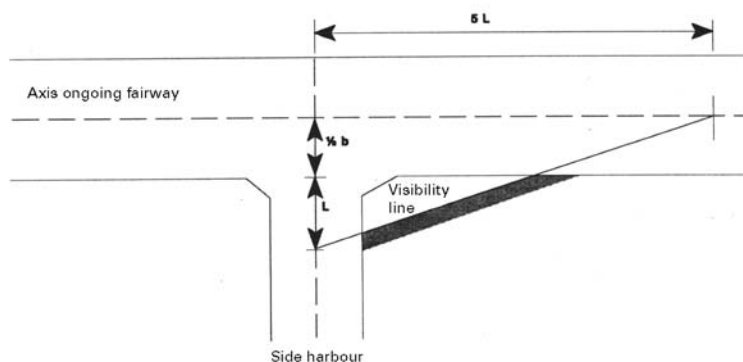


Figure 5.9 Visibility line (Source: CVB, Lit. [5.2])

5.4.3 Connection to water with wave hindrance

Waves in a lock approach can be caused by other navigation (lock approach on a busy fairway) or by wind (lock approach on open water). Both entering and moored vessels could experience hinder from this.

If a vessel is experiencing wave problems before, during or after entering a lock approach, the captain will often try to solve this by sailing faster. This requires a large lock approach with a wide lock approach mouth. This wide lock approach mouth could be the cause of much wave penetration.

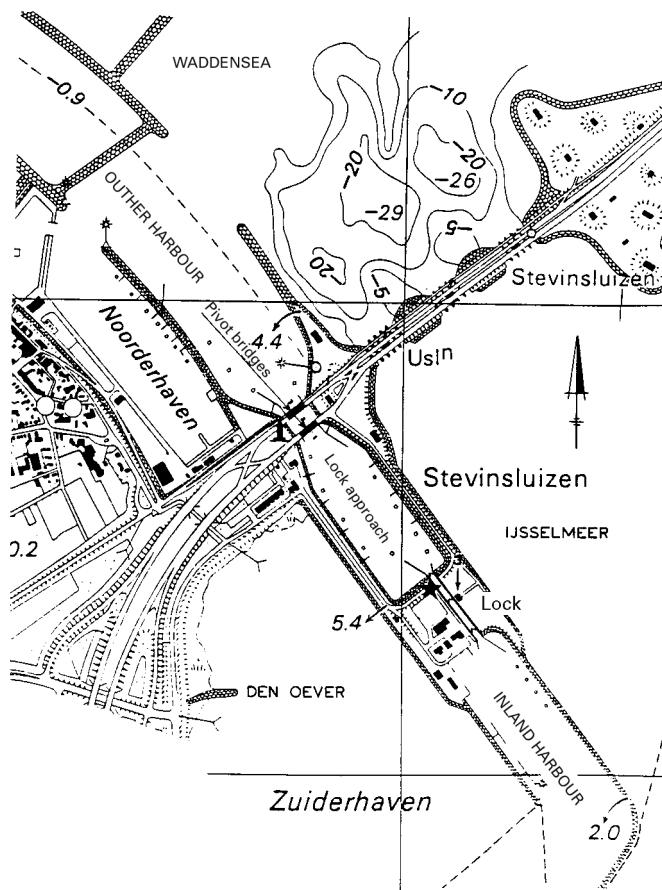


Figure 5.10 Lock approaches Kornwerderzand

Waves from outside penetrating in the lock approach can often be combated successfully by not only making the harbour mouth smaller but also by orienting it differently (if space allows) or by constructing a wave abatement training wall in front of the mouth.

An example of a different orientation is the southern lock approach of the Kornwerderzand (fig. 5.10) that is oriented on the southeast and from that direction; the fetch (wind, waves) is much smaller than it is from the direction that most vessels approach from namely the south-southwest. This does result in the navigation route having more bends and curves. In such cases, the optimal width and orientation of the harbour mouth will have to be determined in a separate nautical-hydraulic study.

At the Volkeraksluizen (photo 5.8), guide dams have been created for both the push-tow locks as well as the yacht locks in order to limit wave penetration in the lock approaches. Wave hinder is increased, especially line-up areas, if a lock approach becomes increasingly narrow towards the lock entrance because the incoming waves become increasingly higher as it becomes narrower. If wave penetration cannot be sufficiently prevented, the hinder can be reduced by using wave abatement slopes in the harbour. These are particularly effective against relatively short waves and are therefore recommended in all harbours where navigation generates hampering waves.



Photo 5.8 Lay out of lock complex Volkerak with (f.l.t.r.) yacht lock, drainage sluice and three push-tow locks as connection of Volkerak (below) with Haringvliet (above)

5.5 Examples

5.5.1 Introduction

The previous chapters and paragraphs contain guidelines and methods for determining the main dimensions of a lock and lock approaches and for the lay out, given the various functions of the complex.

The design of the lay out of the lock with lock approaches is a process of consultation and interaction between various experts. The most important disciplines in the design team are:

- transport studies
- nautical science
- hydraulics, morphology
- hydraulic engineering
- steel and mechanical engineering
- electrical engineering
- environmental management
- cost calculation
- planning expertise

To provide a picture of where such a design for the lock approaches leads in practice, the following paragraphs explain the lay outs and the overall conformity of the lock approaches of three lock complexes. The first example in par. 5.5.2 concerns the existing lock complex at Heel in the Maasroute whereby the guide and mooring structures were renewed and adapted to the changes in navigation and adjusted to forecasts for the future, without changing the shape of the lock approach. The second example is the lock complex at Lith (par. 5.5.3) where the construction of a second lock leads to the lay out and expansion of the lock approaches, including new connections. The third example is the new Krabbersgatsluizen (par. 5.5.4) where completely new lock approaches were realized.

5.5.2 Lock complex in Heel



Photo 5.9 Lay out of lock complex in Heel (left) and Linne (right) on the Maas

At the existing lock complex in Heel the lock approaches were equipped with new guide and mooring structures (lit. [5.4] and [5.5]). The lock complex consists of two chambers (Westsluis and Oostsluis) and is considered high load. In the lay out, this is expressed in the presence of much waiting area for the waiting vessels (vessels that are unable to lock through with the next lock activity). The lock island is narrow and therefore does not provide room for mooring places. The lock island has been extended on both sides with a small cofferdam for separating the navigation of both the locks. The mooring places are situated in front of the upper lock approach (connection Maas) and the lower lock approach (connection Lateraal Kanaal) on the west side and on the east side of the lock approaches. Fig. 5.11 shows the lay out of the old and the new, renovated situation whereby the old lay out is shown in thin outlines and the new lay out is shown in thicker outlines. The new situation (photo 5.9) is based on future need. The following information is provided as explanation:

Width of lock approach

The available width of the lock approaches is enlarged by situating the new berthing jetties closer to the (unchanged) banks. The lower lock approach has a constant width and at the upper lock approach, the width increases towards the river (divergent shape).

Leading jetties

At the lower lock approach the leading jetty is 110 m long (code G) and made 1:6. Because of the divergent shape of the upper lock approach the line-up area is at some distance from the lock and is relatively wide so that the 1:6 leading jetty on this side only has to be 90 m long (code E).

Mooring places

The two locks each have a mooring area in the upper and lower lock approach. The four mooring areas for commercial navigation (code D) are each 170 m long. This is 1.3 x the chamber length of 132 m. On the west side of the upper lock approach, adjoining to the leading jetty, there is 245 m of waiting area for regular commercial navigation (code C). In the lower lock approach there is such little demand for waiting places that separate waiting places have not been created.

Vessels carrying dangerous goods

Separate mooring places of 110 m long (Code A) have been equipped for vessels carrying dangerous goods on the west side of both the upper and lower lock approaches, and at a distance of 100 m from the closest mooring berths of other vessels.

Recreational line-up and waiting areas

For recreational navigation there are two line-up /waiting areas with a length of 50 m (code F). These are found at 30 m distance from the line-up area for commercial navigation on the east side of the upper lock approach and on the west side of the lower lock approach. These waiting/ line-up places are at a considerable distance from the lock. The bollards are dimensioned for commercial navigation as in practice, these waiting areas are frequently used as stop over place for loaded cargo vessels spending the night.

Places for spending the night

The places for spending the night largely correspond to the line-up area on the east side (an example of dual function). The intention was that the east chamber would be non-operational at night so that the places for spending the night would be quiet. In practice however, it has proven that both locks have to operate by day and night.

Tachograph users who should be able to rest in the day as well, have been given a place for spending the night at a larger distance from the lock. On the eastern side of the lower lock approach a 75 m long (code B) mooring place for spending the night has been positioned at a distance of 60 m from the closest mooring berths of other vessels. Furthermore there is a 80 m long mooring place for day navigation spending the night on the west side of the lower lock approach, in combination with the recreational waiting/line-up area (dual function) thus at a large distance from the Westsluis. The berthing structure is dimensioned on commercial navigation.

Refuge mooring places

No special facilities are required for this; after renovation, the lock approaches meet all the set requirements.

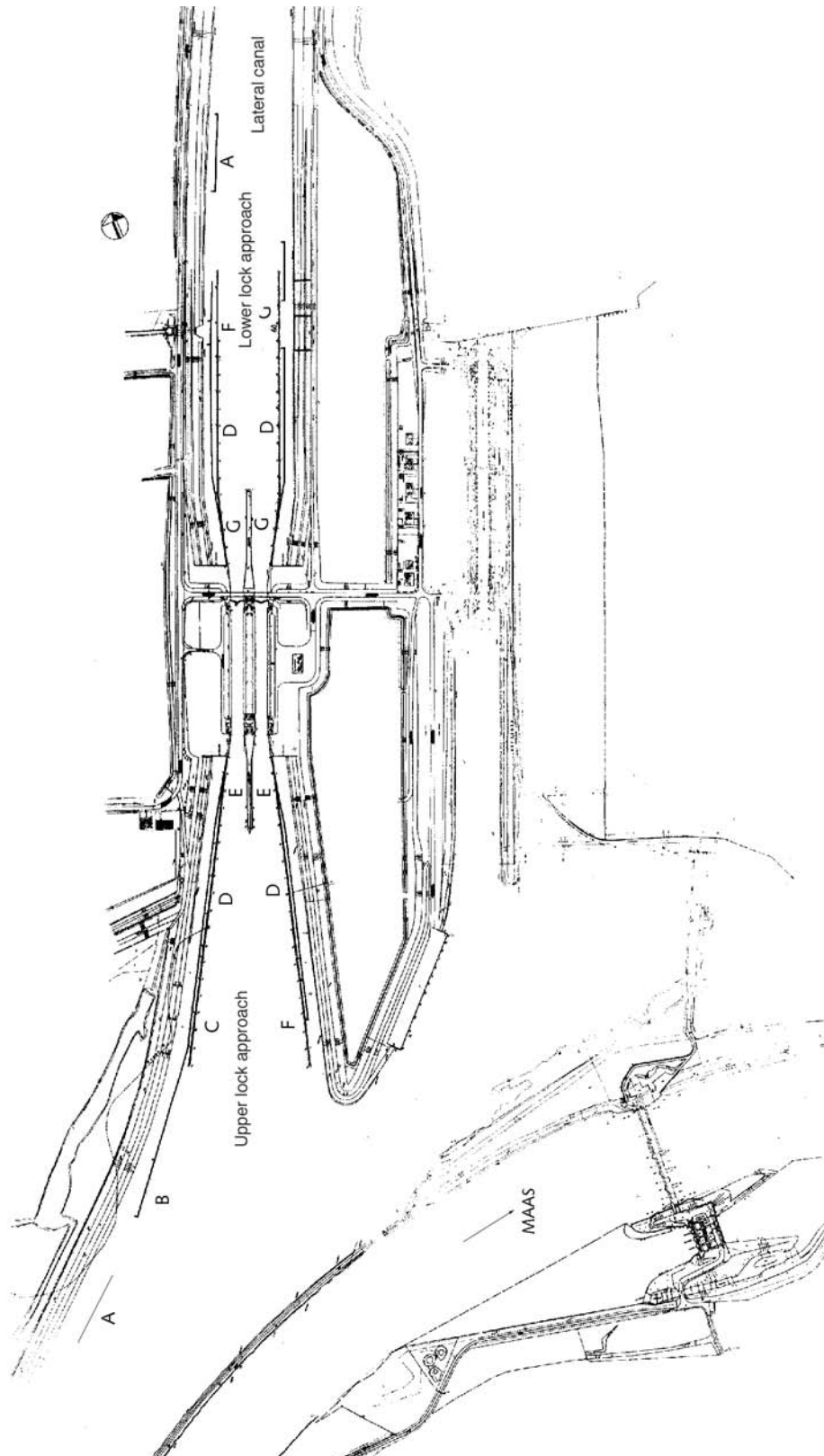


Figure 5.11 Lock approaches with waiting areas at lock complex Heel

5.5.3 Lock complex in Lith

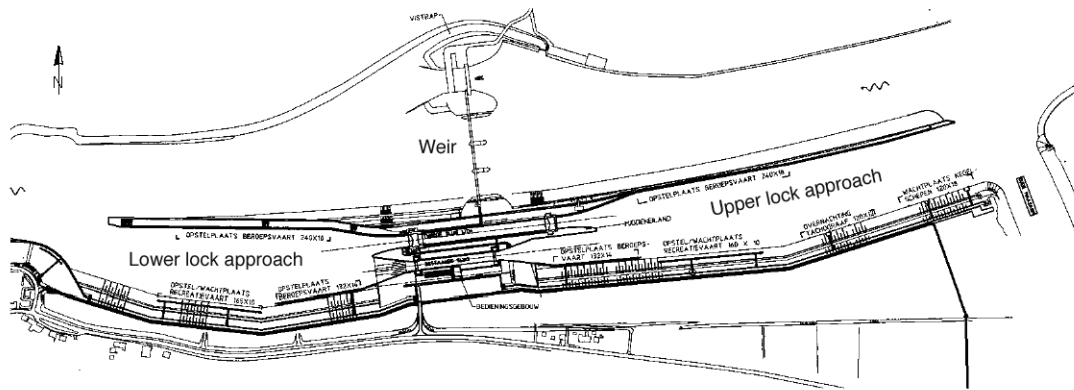


Figure 5.12 Lock approaches at lock complex in Lith

General

As part of the improvements to the Maasroute, the lock capacity of the lock complex and weir site Lith was enlarged by the construction of a second lock (lit. [5.6]). This new lock is suitable for a side-by-side formation and has effective chamber dimensions of 18 x 200 m², a minimal sill depth of 4.70 m and is placed between the weir and the old lock. The space in between the old and the new navigation lock is only about 30 m. The lock approaches were enlarged and re-equipped and the connections between the lock approaches to the Maas have been adapted.

Lay out of lock approaches

The point of departure for the new lock approaches is that the existing length of the lock approaches could not be extended due to previously existing claims on those terrains. The upper lock approach (east side) with a length of about 800 m is larger than the lower lock approach (west side), which has a length of 500 m. The upper lock approach is longer because the stop length of vessels sailing downstream is larger due to a higher sailing speed than vessels sailing upstream.

The lock approaches were widened on the north side by removing the larger part of the old separation dam between the Maas and the lock approaches on the lock approach side and replacing this with sheet pile instead of slopes. The south side of both lock approaches was widened by moving back the bank contour with slopes (see fig. 5.12).

In order to realise as much length as possible for the line-up and waiting areas in the lower lock approach, the leading jetties taper at 1:4. These angles are the same on the upstream side. The leading jetties are constructed as closed (sheet pile) structures. The middle island between the old and the new lock has rounded heads.

The new, second lock is solely for commercial navigation use. For the second lock, mooring berths with a length of 240 m (1.2 times chamber length) and 18 m wide (equal to the chamber width) were positioned on northern banks of the lock approach. The vessels are moored against lined sheet pile. The bottom has local riprap protection. Behind the upstream mooring area, there is still some space to establish a waiting area. This solution was decided against partly due to the difficult accessibility for vessels entering from the upstream side. On the downstream side, all available space was used for mooring berths.

The old lock is destined for both commercial as well as recreational navigation. Mooring areas with floating guide and berthing structures were positioned on the southern banks of the lock approaches. Next to the leading jetty, there are mooring berths for commercial navigation with a length of 132 m (1.2 x effective chamber length of 110 m) and a width of 14 m (chamber width). On a (longitudinal) distance of 30 m from the mooring berths for commercial navigation and approximately 10 m closer to the bank, mooring berths with a length of 160 m were made for recreational navigation. In the

upstream lock approach, at some distance from the waiting berths for recreational navigation there are mooring facilities of 120 x 12 m² for tachograph vessels spending the night and a waiting area of 120 x 18 m² for vessels transporting dangerous goods.

Should there be a shortage of waiting area in the future, a waiting area for commercial navigation could replace tachograph/spending the night berth in the upstream lock approach. In the downstream lock approach, a mooring berth for recreational navigation can be created behind the mooring/waiting area. The downstream lock approach did not have space available for a waiting berth for vessels transporting dangerous goods. For this reason, this waiting place was positioned outside the harbour on the northern bank of the Maas.

Overall conformity

A combined model research on hydraulic, morphological and nautical issues was executed for the mouths of the lock approaches. This was with a view to limiting the sedimentation in the lock approach and the safe and rapid sailing from the lock approaches to the Maas and the other way around.

For the mouth of the upstream lock approach, use was made of sheet piling for both sides of the mouth as this provides navigation with better orientation and requires less safety width than slopes do. The width and orientation of the mouth is such that vessels can sail safely and rapidly from the Maas to the lock approach and the other way around. Sediment flow to the lock approach is counteracted by keeping the length across which the exchange of flowing, sediment containing water in the river with the slow circulating water in the lock approach small, and by limiting the speed differences on this boundary. To this end, the width of the mouth (or the length of the exchange boundary) is decreased to about 130 m. The southern Maas bank just above stream from the mouth of the lock approach is directed in a special way. Because of this, the current in the Maas leaves the southern the bank before it reaches the mouth of the lock approach and then holds course near the head of the intermediate island, which keeps the current from entering the mouth of the lock approach.

The mouth of the lower lock approach is also equipped with sheet pile structures, has a smallest width of about 90 m and is very accessible to vessels due to its orientation. The current on the southern bank of the Maas leaves the intermediate island near the head to subsequently hold course again just downstream from the mouth of the lock approach. The sediment supply to this mouth also remains limited due to the short boundary between the river and the lock approach and the limited speed differences on this boundary.

5.5.4 Krabbersgatsluizen in Enkhuizen

General

The lock complex in Enkhuizen forms a connection from the Markermeer to the IJsselmeer in the dike Enkhuizen/Lelystad. There is a navigation lock of 115 x 12 m² and an adjoining scouring sluice that can only be sailed through during low flow velocities. The two new navigation locks are situated about 800 m further on in an artificial polder against the dike. Road traffic passes underneath the locks. The new locks have effective dimensions of 125 x 12.5 m² with an intermediate distance of (only) 4.5 m. The locks are mainly intended for recreational navigation even though commercial vessels up to and including CEMT class Va with superstructures should be able to pass through the locks (lit. [5.7]).

Lay out of lock approaches

The mooring places for both locks are situated only on the western side and in both lock approaches, these consist of a line-up area for commercial navigation with behind that a line-up/waiting box that is the size of the chamber for recreational navigation (see fig. 5.13). Due to the large capacity of the locks, there are no mooring areas in front of the eastern lock. The fact that the line-up area and the box in front of the southern lock approach is situated on the port side before sailing in has to do with a logical sailing route towards the lock. Recreation vessels leave the boxes just in front of the leading jetty, before sailing into one of the two locks. To avoid crossing traffic, sometimes it will be necessary to wait a while before sailing out of the western lock to facilitate sailing into the eastern lock or the other way around.

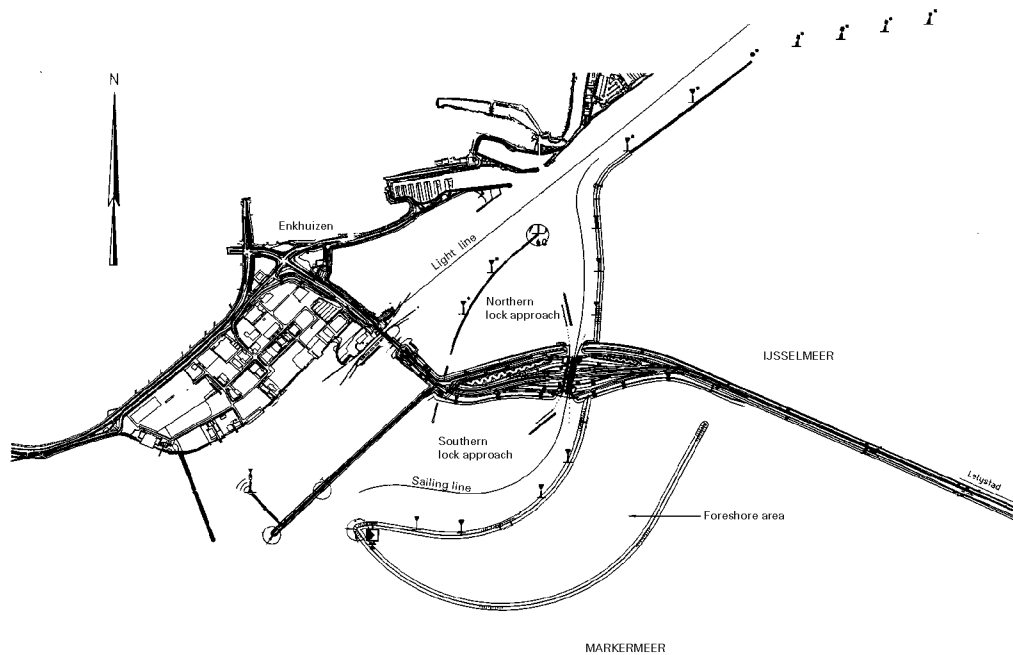


Figure 5.13 Lock approaches Krabbersgatsluizen in Enkhuizen

Leading jetty legs are positioned on the western side of the western lock and on the eastern side of the eastern lock. From a cost perspective, a joint middle lock-chamber wall was constructed which also does not continue into the lock approach as a mooring structure. The consequence of this is that the vessels from both locks can pass and meet each other at short distance. For recreational navigation, this is not a problem. Where it concerns commercial navigation, they will have to wait for each other.

Overall conformity

The lock approaches of the new locks are of very large dimensions and are separated from those of the old locks by existing separation dams.

The new southern lock approach now has a separation dam with the Markermeer in a curved shape in order to combat wave penetration from the Markermeer. The new mouth of the lock approach is approximately 200 m wide and is separately situated from the mouth of old the lock. The vessels sail through the mouth of the lock approach in a substantial bend to the mooring areas of the new locks. In the case of southwesterly winds, some hindrance could occur in front of the lock entrance from the wind waves that are generated in the lock approach area itself (wind fetch of 1 km maximum).

The 250 m wide mouth of the new, northern lock approach was created by making an opening in the existing Krabbersgatdam. This lock approach is separated from the IJsselmeer on the east side by an almost straight separation dam. On this side, the vessels also sail to the mooring areas of the new lock in a spacious bend. Given the orientation of the lock complex, hinder due to wind waves in front of this lock entrance will only occur during northerly winds.

Literature

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- [5.2] Commissie Vaarweg Beheerders (CVB), 'Richtlijnen vaarwegen, CEMT-klassen I t/m V', Rotterdam, juni 1996.
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Photo 6.1 Flow pattern during the filling of the yacht lock in the Volkerak

Chapter 6 Intake and discharge systems

6.1 Introduction

The filling and emptying system serves to level the water in the chamber, containing one or more vessels, to correspond with the water level in the lock approach. This has to take place in such a manner that the water forces experienced by the vessels moored in the chamber are limited and the levelling times are of short duration.

During the filling of the chamber (levelling upward), the lockage water volume (a product of the length of the chamber inside the gates, width of the chamber and initial water level difference) enters the chamber. In this, the energy of the flow – originating from changing the potential energy into kinetic energy from the difference in water level – is disrupted in the chamber there where the vessels are moored. The non-permanent character of the filling flow generates transitory waves. Because of the flow and the waves in the chamber, the vessel experiences horizontal hydraulic forces during vertical displacement. During the emptying of the chamber (levelling downward), whereby the lockage water and the corresponding energy flow end up in the lock approach, mainly transitory waves are generated in the chamber. This goes hand in hand with the exertion of forces on the vessels.

Many types of filling and emptying systems are possible for the method in which levelling takes place in the chamber. In all of these types, the lockable openings play an essential role. The different types of filling and emptying systems are related to the way in which water is brought into or the way it leaves the chamber. This could be as simple as gate openings (that is to say openings in the gate itself) to as complicated as filling by means of bypass lock culverts and a stilling chamber.

The objective of this chapter is to reach a preliminary design of an intake and discharge system. It first provides a summary of the system types so that the most suitable type can be determined for the situation that is being researched (par. 6.2). Then, information is presented on the hydraulic phenomena during filling and emptying a lock (par. 6.3). This is followed by a presentation of the calculation method for the tentative dimensions and lifting speed of the intake and discharge system (par. 6.4). A calculation programme (LOCKDIM) can be used for this. An overview of the requirements for the geometry of the systems is provided in par. 6.5. Lastly, in par. 6.6 the LOCKFILL calculation programme is presented that, on the basis of the selected dimensions and lifting speeds of the filling and emptying system, makes further calculations on this system. The chapter is restricted to the intake and discharge systems according to the type of gate openings and lock culverts/stilling chambers as these are most likely in the Dutch situation. Filling and emptying systems for special locks such as the large marine locks, high lift/drop locks and locks with side ponds are briefly discussed in par. 6.2. Locks with fresh/salt water separation systems are dealt with in chapter 21. In complicated intake and discharge systems (high lift/drop, density differences in the water, very short levelling times) an expert has to be consulted and/or a model study has to be completed (for instance) by Delft Hydraulics.

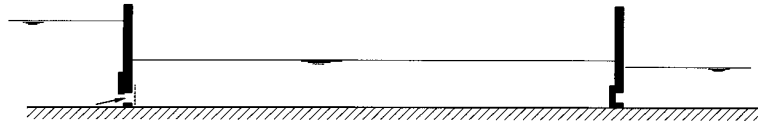
For the preliminary design of a filling and emptying system for a new lock, the following working method is recommended:

- a choice is made for the type of system (par. 6.2, gate openings or culverts/stilling chamber);
- the dimensions of the chosen type of filling and emptying system are calculated (par. 6.4 or the LOCKDIM calculation programme);
- the hydraulic design is determined (par. 6.5);
- the chosen preliminary design is checked by using the LOCKFILL calculation programme (par. 6.6).

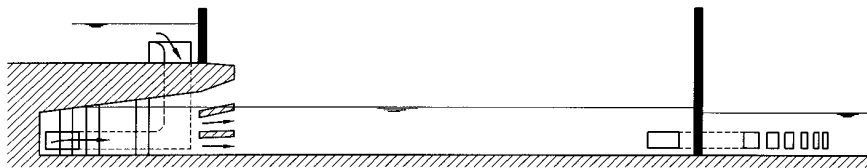
6.2 Type of filling and emptying systems

6.2.1 Overview of types

6.2.1.1 Normal types



Type gate openings



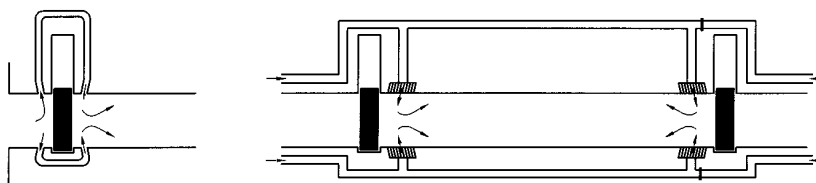
Type lock culverts/chamber

Figure 6.1 Normal types of filling and emptying systems

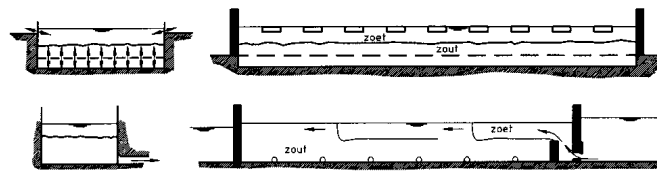
At present, the most used filling and emptying systems for locks in the Netherlands are the gate opening type or the type with lock culverts with a chamber (fig. 6.1) (lit. [6.9]):

- Gate openings**
 The gate opening type is the most prevalent and the simplest type. It consists of a number of openings in the bottom of the gates with movable sluice gates on the upstream side. Usually, energydissipating barriers are placed on the downstream side of the openings in order to disperse the flow directly behind the gates and break down the energy. In many cases, the openings are of rectangular shape and the slide speed is constant. The upper and lower gates are often identical and therefore interchangeable.
- Lock culverts with stilling chamber**
 The type with lock culverts and a stilling chamber usually has lock culverts with valves at the upper head that discharge into a stilling chamber. The stilling chamber is fitted with energy dissipating barriers, baffle vanes and the like to break down the energy of the water and to dissipate the water to the chamber according to longitudinal flow. For emptying, gate openings or lock culverts are installed at the lower head. The gates of the upper and lower head differ as the high upper gates are low and the lower gates are high. This type is used at a lift/drop of 5 m or more for a one-directional retaining structure.

6.2.1.2 Special types



Examples of culvert systems for marine locks (Noordersluis IJmuiden and Zeesluis Baalhoek)



Examples of systems with salt/fresh water separation (Duinkerken and Bergsediepsluis)

Figure 6.2 Special types filling and emptying systems

Special types of filling and emptying systems that are also used in the Netherlands for newly designed locks, are systems with culverts for large marine locks with salt/fresh water separation systems (fig. 6.2 and Lit. [6.3], [6.4], [6.7], [6.9]).

- **Culvert systems for large marine locks**

Culvert systems for large marine locks have been applied in culverts in both heads (Noordersluis IJmuiden) as well as with special outlets (Belgium: Kallo, Berendrecht), two longitudinal culverts with two transverse culverts and special outlets in both heads (Baalhoek, not built) and a longitudinal culvert with two transverse culverts in the chamber and bottom grids (Zeesluis Terneuzen). The marine lock at Zeebrugge has openings with butterfly valves in the rolling gates.

- **Salt/freshwater separation**

In a filling and emptying system that includes salt/freshwater separation, the water is levelled and exchanged in the chamber.

In the salt/freshwater separation system called Duinkerken (Kreekrak- en Krammersluizen), salt water is taken in and discharged in a vertical direction via a perforated floor and freshwater is taken in and discharged in a transverse direction via wall openings at a higher level. There is minimal mixing of salt and fresh water in the chamber. The perforated floor is connected to the culverts and the outer water while the wall openings are connected to the surrounding freshwater.

In the system of Bergsediepsluis, (desalination only) the salt water is discharged in a transverse direction to an adjoining cellar via low-lying tubes and the fresh water is taken in on top in a longitudinal direction over a sill via gate openings. Also see Lit. [6.4].

Remarks:

- The desalination system Terneuzen, in which the complete (salt) chamber volume flows into a salt pit in the lock approach after which this is discharged into the sea via a culvert, concerns desalination after levelling.
- A pneumatic barrier ensures temporary separation of salt and fresh water after gate opening. The pneumatic barrier does not obstruct the lockage water.
- For a more detailed description of salt /freshwater separations systems, please see Chapter 21.

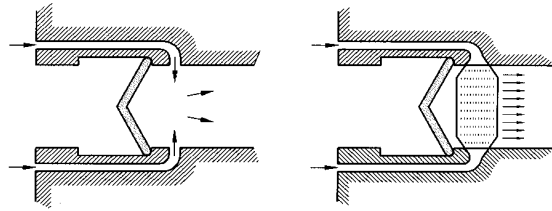
6.2.1.3 Types seldom or not used in the Netherlands

There are a few filling and emptying systems that are hardly ever used or will not be used at all in new designs for inland navigation locks (see fig. 6.3, and Lit. [6.1], [6.3], [6.7], [6.8]).

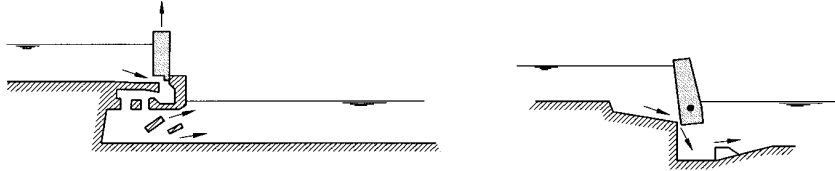
- **Lock culverts for inland navigation locks with limited lift/drop**

The bypass culvert discharges are preferably situated in opposite walls so that the water jets collide with each other and lose their energy. The culvert system is an expensive system that was often applied in the Netherlands in the past so as not to weaken the gates with openings.

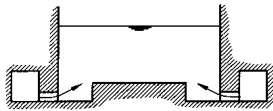
The system is still applied in the Netherlands for emptying a lock with large lift/drop. In Germany, the bypass culverts are situated extra deep at locks with large lift/drop and the discharge is executed as a floor grid in the head concerned.



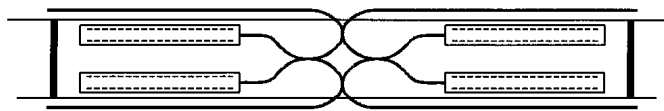
Lock culverts (as colliding flow and with floor grid)



Moving gate (lift/drop gate and tumble gate)



Wall filling system



Floor filling system

Figure 6.3 Examples of types of filling and emptying systems that are not used or no longer used in the Netherlands

- **Moving gate for large lift/drop**

Filling takes place by means of slowly raising a gate or opening a sector gate or tumble gate (pivoting on a horizontal axis). This results in a gap opening right across the complete width of the lock. (Remark: mitre, pivot or rolling gates are not suitable).

The water pours into a concrete stilling chamber with refraction bars and blocks in the front of the chamber. Much attention has to be paid to the design in order to prevent unfavourable flow patterns in the front of the chamber and the gate movement has to be very slow in order to prevent large translatory waves. The system with a moving lift/drop gate has been applied many times in the Netherlands (among others the Twente-kanaal, old locks Maasroute).

- **Floor or wall filling system**

In a wall filling system the water is supplied via longitudinal culverts and a large number of transverse culverts. The transverse culverts often discharge in a stilling chamber in the chamber floor. In a floor filling system, the water is supplied to one or more places by means of culverts under the chamber floor and from there, brought into the chamber via floor grids. These systems are intended for high lift/drop locks and are extremely costly but they do provide rapid levelling times. The extra costs have to be weighed up against the time gain. In the past, a few wall filling systems were applied in the Netherlands (Middensluis IJmuiden, old lock Weurt).

6.2.2 Type selection

The selection of the type of filling and emptying system depends on the following issues to be discussed, namely:

- *Initial lift/drop over the lock (for inland navigation locks)*
 - For inland navigation locks, the type of filling and emptying system depends on the initial lift/drop and it hardly depends on the width of the lock (waterway classification).
 - For locks with a lift/drop of up to about 6 m, filling and emptying systems by means of the gate openings type is recommended.

- With extra adjustments, the gate openings type is also applicable to filling lifts of 6 to 8 m. These adjustments consist of a special (model research) design of the openings (for instance extra resistance grids or a large number of smaller openings) and an adjusted lifting programme of the sluice gates. Gate openings with such a large lift require high gates because the gate openings always have to remain under water.
 - With extra adjustments, the gate opening type is also applicable to a limited lift/drop in the opposite direction of what the openings were designed for. This requires openings of a special design, researched in a model.
 - The lock culvert type with a stilling chamber is used for lift/drop from 5 m. For lift between 8 and 12.5 m, this type is a necessity. This type is only suitable for water retaining in one direction.
 - For emptying at large lift/drop between 8 and 12.5 m, lock culverts and (under special conditions) gate openings can be used. A lot of attention has to be paid to the manner in which the water flow gets rid of its energy outside the lock, as the water depth remains limited here. In the case of culverts, the flows have to collide with each other to lose their energy and in the case of gate openings, the flow has to lose its energy in a stilling chamber.
- *Inland navigation lock or marine navigation lock*
 - For inland navigation locks and recreational navigation locks – depending on the size of the lift/drop – either the gate opening type or the lock culvert type with stilling chamber is appropriate.
 - Because the draught of sea-going vessels can be much larger than the draught of inland barges, the sill and the lock bottom at marine locks are much lower than they are at inland locks. The fall at marine locks changes rapidly (tides and possible seiches), at river locks the fall changes slowly (flood wave). At marine locks, the density differences between salt and fresh water results in extra forces on the vessels while the permissible forces on large marine vessels are smaller (relatively seen) due to the limited mooring equipment.
 - At a small marine lock (suitable for supply vessels for instance), gate openings can be used as the type of filling and emptying system.
 - At a large marine lock (width above 30 m), the first appropriate type of filling and emptying system is with culverts (bypass culverts or longitudinal culverts with transverse culverts at both heads) combined with special discharge openings to create an even flow pattern in the chamber. The gate opening type is also possible if no high requirements have been set for the levelling times and if much attention is paid to the spread of the filling jets from the openings.
- *Levelling time*
 - For most Dutch inland locks and small marine locks that have gate openings and lift/drop between 2 and 6 m, the levelling time is 8 to 10 minutes. For extra long locks or large lift/drop, this can increase to 12 minutes. Smaller lift requires less than 8 minutes. At bypass culverts with stilling chambers, the filling time is not more than 10 minutes. In large marine locks with lift of between 1.5 and 5 m, levelling times will amount to between 11 and 15 minutes. In general, a desalination system doubles the levelling time because of the exchange of chamber contents.
 - If the levelling time is unimportant, gate openings can also be applied at large lift/drop if high gates are installed in the upper head and the openings are always submerged in water.
 - If short levelling times are required at large lift/drop, a wall or floor filling system and longitudinal culverts is required. The levelling times can almost be halved provided that this does not result in problems for the canal reach (translatory waves).
- *Salt/fresh water separation*
 - A special system is needed for salt/fresh water separation during the filling and emptying, for instance the system Duinkerken (whether simplified or not) or the system as applied in the Bergsediepsluis. See Chapter 21 and Lit. [6.4].
- *Water saving*
 - For the purpose of saving water, one or more side ponds can be created or adjoining locks can be each other's side ponds.

- *Costs (construction, operation and maintenance)*
 - At low lift, a system with gate openings is the least expensive and has the most favourable maintenance aspects.
 - At larger lift/drop and the application of bypass culverts with a stilling chamber the concrete structure and the fitting in of the closing gates are costly indeed, but the upper gates are low and less expensive than would be the case without a stilling chamber, whereby high upper gates are required.
 - Special filling systems are usually expensive and can only be justified because of their objective (e.g. shorter levelling times, salt/fresh water separation or water saving).

Depending on which factors are important, the above-mentioned can help to make a first selection in the type of filling and emptying system.

6.3 Phenomena during chamber reversal

6.3.1 Flow through the openings and average chamber water level

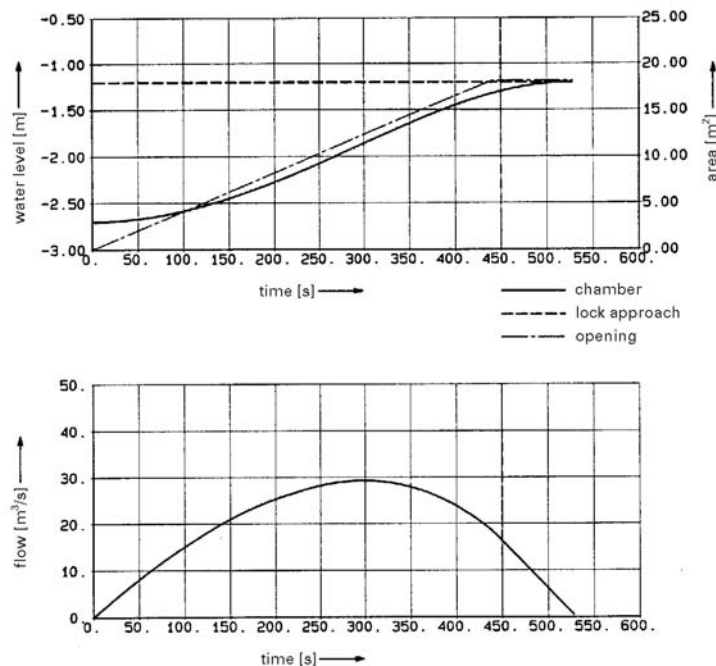


Figure 6.4 Example of water levels & effective opening and filling flow as function of time during the filling of a lock with gate openings

See (Lit. [6.5], [6.10], [6.12]).

The discharge through the openings (filling or emptying discharge) is a function of the current lift over the gate and the dimensions and design of the gate openings. (Fig. 6.4).

The levelling starts with pulling open the sluice gates whereby the area of the openings increase gradually. Furthermore, the lift/drop over the gate is large and the area of the opening is limited. Thereafter, the head (water level difference) decreases through the incoming (or out flowing) water while the size of the openings increase. At the end of the levelling process, the remaining head is limited and, as a rule, the dimensions of the openings are at maximum. This results in a filling or emptying discharge through the openings that starts slowly, reaches a maximum and subsequently slowly reduces to zero.

The (average) water level in the chamber corresponds with this discharge: during filling the level of the chamber water initially rises slowly, at maximum discharge it rises the fastest, while at the end of the process the water level in the chamber increases slowly until the water level of the lock approach is reached. Emptying takes place in a similar manner but now, the water level falls instead of rises. (Remark: At density differences between the water of the lock approach and the chamber after completion of the levelling process, a small difference in level remains – for instance 0.15 m – between the lock approach and the chamber).

In order to ensure uneventful lying of the vessels during levelling whereby the hawsers can be changed to higher or lower bollard recesses in good time, the rising velocity of the water level is limited to a maximum (for instance for inland navigation 1 m per minute at fixed mooring bollards).

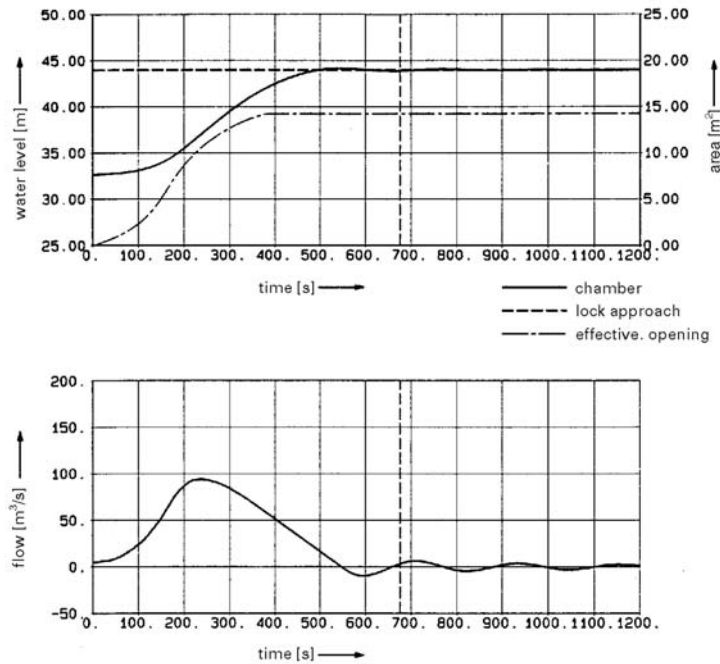


Figure 6.5 Example of water levels & effective openings and flow as a function of time during the filling of a lock with bypass culverts/stilling chamber

If lock culverts are used, the inertia effects of the water column in the culverts at the end of the levelling process are important (fig. 6.5). At the end of this process, the discharge in the culverts reduces to zero to subsequently change direction, by which the average chamber water level during filling rises above the level in the lock approach. The water level in the chamber subsequently decreases to below the level of the lock approach and fills up slowly to the same level as the lock approach. This oscillating movement (in vertical sense) of the average water level in the chamber toward the upper or lower water level (over travel effect) has to be taken into account during the design as this would otherwise lead to problems during the opening and closing of the gates. A similar effect occurs during emptying. Shortening the length of the culvert or keeping the culvert diameter as wide as possible can reduce this effect.

During levelling, particular moments can be distinguished. These are the moment of maximum discharge, the moment that the openings are completely open (for the first time), the moment that the difference in level over the gate is reduced to about 0.10 m (gates may be opened) and the moment that the chamber is completely level (at gate opening discharge is zero). For the designer, the only moment of importance is the moment that the head over the gate is at 0.10 m.

6.3.2 Wave and flow phenomena in the chamber

The discharge through the openings is accompanied by wave and flow phenomena in the chamber. Because the discharge flows in or out at a chamber end (upper head during filling, lower head during emptying) these phenomena mainly occur in a longitudinal direction of the chamber. The vessel in the chamber, which has her bow near the filling or emptying gate, is subject to wave and flow phenomena and has an influence on these as well. These phenomena are accompanied by water level differences in the longitudinal direction of the chamber that, in turn, exert forces on the moored vessels (see fig. 6.6 and 6.7). Because of the non-permanent character of the discharge through the openings, transitory waves are generated at these openings, which propagate in the chamber (fig 6.6a and 6.7a). The waves reflect completely against the gates of both chamber ends and partly against the bow and the stern of the vessel. Due to the blockage of the transverse section by the vessel, the speed of the transitory wave next to the vessel decreases in comparison to the transverse section without a vessel, where the wave height next to the vessel increases. Because of the transitory waves in a longitudinal direction of the

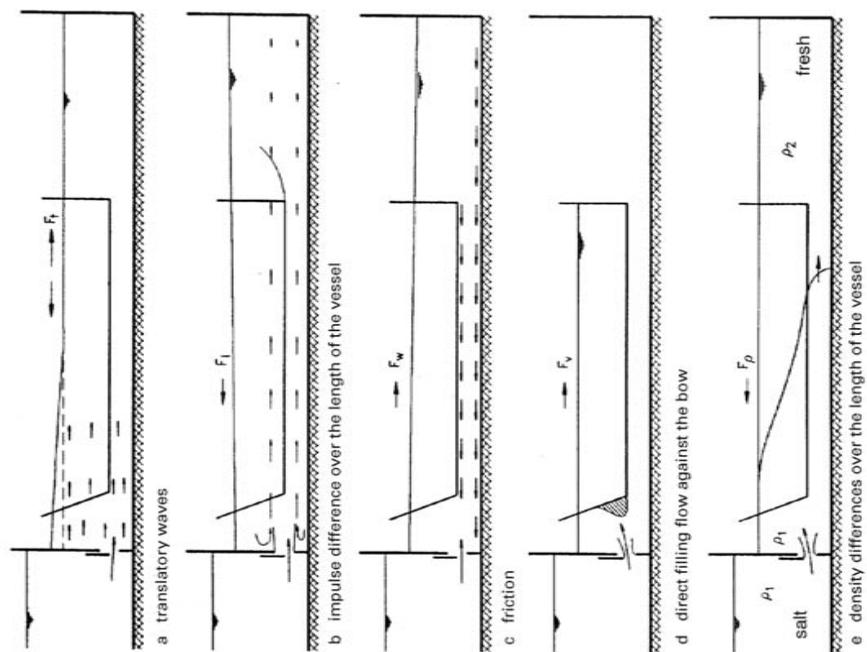


Figure 6.6 Components of the longitudinal force during filling

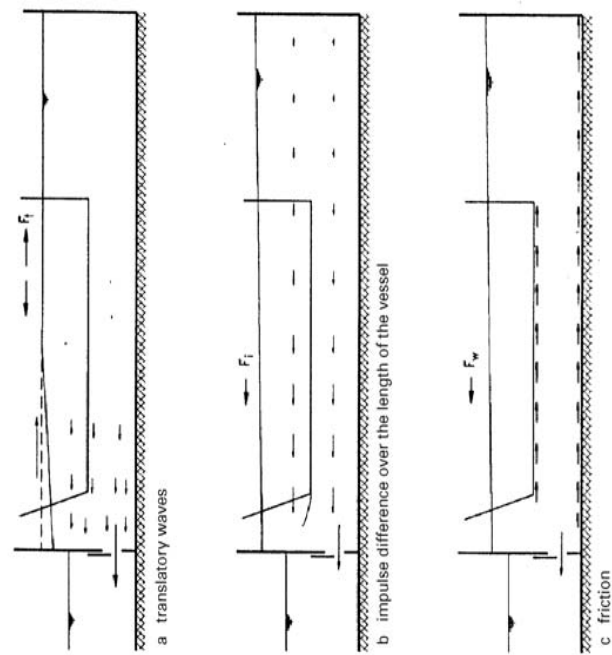


Figure 6.7 Components of the longitudinal force during emptying

chamber, an oscillating movement is created in the water level corresponding with the own frequency of oscillation of the chamber. This oscillation period is the time that a disruption requires to travel up and down through the chamber.

In filling by means of gate openings, there are concentrated intake jets with high flow velocity behind the gate openings (fig. 6.6b). These high flow velocities decrease in longitudinal direction of the chamber (from the filling gate to closed chamber end) through turbulent exchange with the surrounding water. Close to the vessel, this flow pattern changes substantially due to partial blocking of the cross section by the vessel (fig 6.6b and 6.6d). At the bow of the vessel the concentrated filling flow is less able to break down rapidly because of the limited surrounding water available, at the stern of the vessel the flow detaches and only starts spreading and breaking down further on.

A section line in the chamber decreases the average discharge through subsequent cross sections in longitudinal direction because a shorter part of the chamber behind this cross section has to be filled. Previously mentioned effects result in a flow impulse (momentum is equal to the product of flow velocity and discharge) that decreases in longitudinal direction of the chamber, which corresponds with water level differences in longitudinal direction of the chamber.

In filling with a stilling chamber, something similar occurs, aside from the fact that there is substantially less concentrated flow directly behind the stilling chamber.

When emptying a lock the energy is not broken down in the chamber but outside the lock. In emptying a chamber, the discharge per cross section decreases (in absolute value) in longitudinal direction (from emptying gate to closed chamber end), which is also accompanied by water level differences in the longitudinal direction of the chamber (fig. 6.7b).

Friction between the water and the chamber floor, the chamber walls and the skin of the vessel result in a water level difference in the longitudinal direction of the chamber (fig. 6.6c and fig. 6.7).

If there are density differences between the water of the lock approach and the chamber, internal (density) waves are generated when filling the chamber (fig. 6.6e). These waves propagate at low speed in the chamber and reflect against the vessel and the gates. These waves are accompanied by water level differences in the longitudinal direction of the chamber.

This chapter does not address wave and flow phenomena outside the chamber (in the lock approach) caused by levelling.

6.3.3 Hawser force criteria

Normally, an inland barge in the chamber is moored to a bow and stern spring rope (see fig 6.8) that, during vertical movement of about 2 m, needs to be moved during levelling to mooring bollards that are situated higher or lower. In locks with high lift/drop, floating bollards are used whereby moving the hawsers becomes unnecessary. The hawsers have to be kept taut during levelling in order to combat large horizontal movement with accompanying dynamic effects; the vessel should not 'fall' in the hawser. Marine vessels are moored with at least 4 hawsers (fig. 6.8).

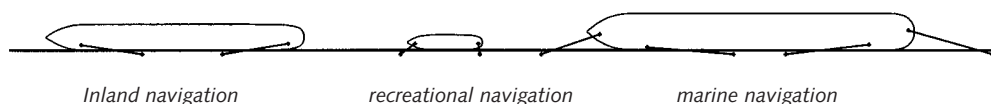


Figure 6.8 Example of moored vessels in a lock chamber

For practical reasons, the quality of the filling and emptying system is not tested against the actually occurring hawser forces or horizontal movements of the vessel during levelling. Use is made of the hawser force criteria defined as a permissible longitudinal force on a -in horizontal sense- fixed vessel.

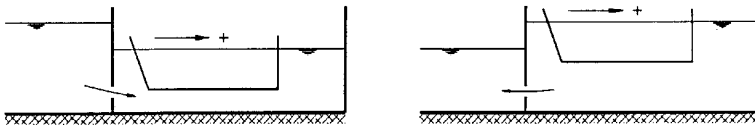


Figure 6.9 Definition of longitudinal force

The longitudinal force exerted on a vessel for both filling and emptying is defined as follows (fig. 6.9): the longitudinal force is positive in the direction of the closed chamber end and negative in the direction of the chamber end with levelling openings. The longitudinal force is expressed as a relative value in the ‰ of the weight of the water displacement of the vessel.

The hawser force criteria for inland navigation vessels are as follows (Lit. [6.13]):

vessel class	hawser force criteria (‰ of total water displacement)	
	in filling	at emptying or filling with floating bollards
CEMT class III	1.50	2.00
CEMT class IV	1.10	1.50
CEMT class Va	0.85	1.15

For loaded '4+1' or '6+1' push-tows, the (absolute) longitudinal force may not exceed 100 kN. The longitudinal force should preferably not change direction more than once. The water displacement in recreational navigation is small; the permitted (relative) longitudinal force is approx. 3 ‰.

Large ocean going vessels are moored with at least 4 hawsers. Because the capacity of the mooring equipment is weaker (relatively seen) than it is with inland barges, the permitted (relative) longitudinal forces are much lower than 1 ‰: for example 0.25 ‰ at DWT 50.000.

(Remark: Capacity of the mooring equipment means the permitted forces in the hawsers and the winches).

6.3.4 Occurring longitudinal forces

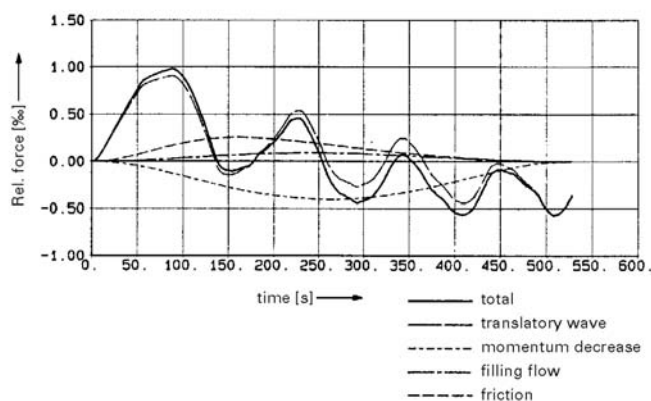


Figure 6.10 Example of longitudinal force as function of time during the filling of a lock with gate openings

The longitudinal force acting on the vessel is determined by the water level differences over the bow and the stern of the vessel and by flow velocity and friction on the vessel (fig. 6.10). The longitudinal force during the filling of the lock through gate openings can be seen as being built up out of five components:

a *Translatory waves* (fig. 6.6a)

The water level differences because of translatory waves result in a contribution in the longitudinal

force that varies in time. Distinction can be made between an average and a harmonic contribution. The average contribution can be traced back to the course of discharge in time: before the point in time of the maximum discharge the average contribution is mainly positive (increasing discharge), thereafter it is mainly negative (decreasing discharge). The harmonic contribution follows from the reflections against the gates and the vessel and is strengthened by the discontinuities in the course of discharge. These discontinuities can occur if the gate openings reach their maximum opening position before the maximum discharge is reached.

b *Momentum decrease in longitudinal direction of the chamber (fig. 6.6b)*

The water level differences due to the momentum decrease of the flow in the longitudinal direction of the chamber cause a negative longitudinal force; the water level difference only results in a positive longitudinal force for short vessels that are not too close to the filling gate. The contribution in the longitudinal force is at its peak, just before the moment in time of maximum discharge when the momentum of the flow (proportional to product of flow and discharge) is at its maximum.

c *Friction (fig. 6.6c)*

The friction leads to a water level difference over the length of the vessel while the friction also directly seizes at the skin of the vessel. This results in a positive contribution in the longitudinal force with a peak just before the maximum discharge.

d *Flow action (fig. 6.6d)*

The concentrated filling flow crashes into the bow of the vessel in the beginning of the filling process. Initially, this supplies a positive contribution to the longitudinal force. After some time, the vessel has risen so much that the filling flow does not touch the bow any longer and the result of this is that the contribution disappears.

e *Density differences (fig. 6.6e)*

The differences in water levels and density of the water between the bow and the stern cause a negative contribution to the longitudinal force at a chamber that initially contains fresh water, which is filled with water from a lock approach with salt water. The contribution is positive in the opposite density situation (chamber with salt water, lock approach with fresh water).

Usually, components a and b provide the largest contribution to the longitudinal force.

The situation where filling takes place by means of bypass culverts with a stilling chamber shows a similar picture as described above. The contribution in longitudinal force of component a (translatory waves) is identical, the contribution of component b (momentum decrease) is smaller and that of component d (filling flow) is absent because of better discharge spread at the bow, component c (friction) is identical and component e (density differences) is lacking (no stilling chamber in tidal areas).

Like in the previous case in this situation, the components a (translatory waves) and b (momentum decrease) provide the largest contribution to longitudinal force.

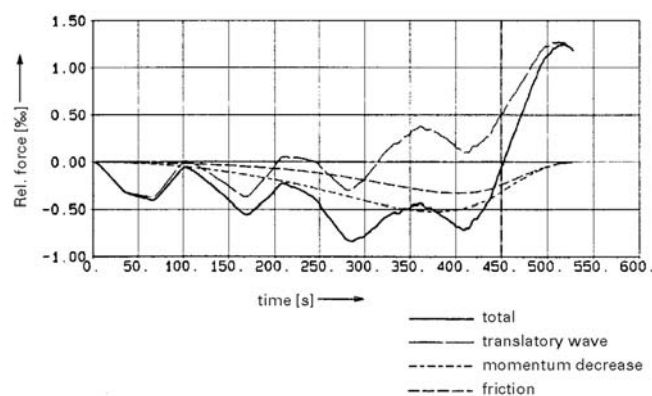


Figure 6.11 Example of longitudinal force as a function of time during the emptying of a lock with gate openings

When emptying locks (fig. 6.11) the contribution in the longitudinal force of component a (translatory waves) is also present. Before the maximum discharge, this is negative and thereafter mainly positive with a maximum at the end of the emptying process because of low water levels with large blockages

of the chamber profile caused by the vessel. In contrast to filling, in emptying, the end of the emptying process is normative. The contribution of component b (momentum decrease) is negative in the longitudinal force and limited by the absence of concentrated flow (fig. 6.7b). The contribution of component c (friction) is also limited and negative (fig. 6.7c). Components d and e (filling flow and density differences) are absent during emptying. In emptying, component a (translatory waves) is dominant. This picture is not different for emptying with gate openings or with culverts.

In all cases, there is longitudinal force on vessels. In the longitudinal filling system presented here, the transverse force on vessels is limited. This need not always be the case. If the chamber is asymmetricaly filled or emptied because a part of the gate openings or a culvert is out of use, a significant asymmetric flow pattern with transverse flow is created in the chamber. Transverse forces also appear if vessels are lying in front of culvert outlets or wall openings.

6.4 Dimensioning

6.4.1 Procedure

Before a preliminary intake and discharge system can be designed, the type of system, the normative situation and further details have to be known. The various types of systems are dealt with in par. 6.2 and par. 6.2 addresses the normative situation and further details (see Lit.[6.12]).

Subsequently, this paragraph includes presented calculations that will have to be worked out for the preliminary design. This could be in accordance with par. 6.4.3 (via filling openings), par. 6.4.4 (filling via culverts/stilling chamber), par. 6.4.5 (emptying via gate openings) or par. 6.4.6 (emptying via culverts) or with the PC programme LOCKDIM. Point of departure for the calculations is that the most important components of the longitudinal force on the vessel may not exceed the stipulated maximum longitudinal force. The calculations supply dimensions of the filling and emptying system, the opening speed of sluice gates and the levelling times, all in temporary sense. It is important to state that the calculations implicitly assume that the requirements for the hydraulic design of the system, to be researched, are met as stated in par. 6.5.

In order to check the preliminary design or to finalize the design for limited lift/drop, the temporary dimensions and lift rate are entered in the LOCKFILL calculation programme, after which the final values can be established. As a function of time, LOCKFILL calculates the discharges, water levels and longitudinal forces during levelling in the locks whereby all contributions to longitudinal force are processed. This programme is described in par. 6.6 (in brief) and dealt with in Lit. [6.13]. Note that LOCKFILL is a menu guided PC programme.

6.4.2 Normative situation and further information

For the preliminary design of a filling and emptying system, the point of departure is the normative situation in the chamber. This situation can be described with the water level in the chamber/the initial lift/drop and with the cross section of the vessel:

- the maximum occurring initial water level difference (lift) over the lock with the corresponding lowest water level in the chamber or the lowest occurring water level in the chamber with the corresponding maximum lift over the lock;
- the vessel with the largest cross section (usually this is the largest loaded vessel) with her bow at the stop stripe; for push-tows, both single and double barge lengths are calculated through.

Because it cannot be established in advance whether the maximum occurring lift or the lowest water level in the chamber is normative, both situations will have to be calculated.

The preliminary design is based on rectangular gate openings or bypass culverts. In addition, a constant lifting rate of the sluice gates is assumed. Not taken into account are possible requirements in relation to maximum discharge in the lock approach for the prevention of annoying transitory waves.

Further refinement of above mentioned points are only addressed when the design is further elaborated on. In this respect for instance, we could mention limiting the discharge in the beginning or the end of the levelling process by means of openings which are partly blocked at the bottom or at the top, round openings, sluice gates with a triangular bottom edge or non-constant lift rates.

In addition to the above-mentioned information, the following is required:

- type of filling system;
- lock dimensions (length and width of chamber, level of chamber floor, position of stop stripe);
- other vessel information (length and mass);
- discharge coefficient of gate openings (estimated as average value) or ξ value of culvert valves;
- permissible longitudinal forces and vertical velocity of the water surface.

6.4.3 Filling with gate openings with a view to dimension setting

The longitudinal force on a vessel during the filling process with gate openings (this means openings in the gate itself) is determined by 5 components as stated in par 6.4. Two components, namely a (translatory waves) and b (momentum decrease in longitudinal direction of the chamber) are dominant at different times of the filling process. With the aid of these two components the dimensioning of the openings is derived. The other components c, d and e (friction, direct filling flow and density differences) are not taken into consideration.

As stated, component a (translatory waves) consist of an average and harmonic contribution. Component a is large at the beginning of the filling process because the blockage, caused by the vessel in the cross section of the chamber, is the largest at that time. With this, the component only consists of the average contribution because of the slowly increasing discharge.

The harmonic contribution in component a can become large when discontinuities are present in the course of discharge. This occurs when the gate openings reach their maximum size before the maximum discharge has been reached. It is important that this is prevented so that the discharge takes place as smoothly as possible.

Component b (momentum decrease in longitudinal direction of the chamber) is at maximum just before the moment of maximum discharge, when the product of filling discharge and velocity flow (proportional to the momentum of current) through the gate openings reaches its maximum.

Requirements to be set for hydraulic design (par. 6.5) show, among others, that for a good spread of flow the total width of the gate openings should be as large as possible. A practical assumption is that this width is between 0.5 to 0.67 times the lock width. In Lit. [6.6], recommendations are made for the width of a rectangular gate opening: 1.40, 2.15 or 2.60 m.

Four conditions are developed from the preceding:

- 1 The separate contribution in the longitudinal force of component a (translatory waves) in the beginning of the filling process may not exceed the permitted longitudinal force.
- 2 The separate contribution in the longitudinal force of component b (momentum decrease), just before the moment of maximum discharge may not exceed the permitted longitudinal force.
- 3 The course of the discharge should be smooth by having the moment of maximum gate opening occur slightly later than the moment of maximum discharge.
- 4 The total width of the gate openings amounts to 0.5 to 0.67 times the lock width. Note however that inland navigation locks are usually shallower than marine locks. Inland navigation locks therefore have openings that are a bit wider and lower than those found in marine locks.

At a total width of the filling openings chosen under condition 4, the maximum lift rate of the sluice gate follows from conditions from 1 and 2. The lower of the two has to be applied. The conditions of 3 provide the lift height of the sluice gates.

In the calculation, the permitted longitudinal force is set lower (for instance 0.8 ‰) than the actual permitted longitudinal force. This is done because it is a schematic calculation that only includes part of the components of longitudinal force.

The first maximum lift rate follows from condition 1:

$$v_{h0} = \frac{F'_p \cdot g \cdot A_{ks0}}{1000 \cdot \mu \cdot b_h \cdot v_0} \quad (6.1)$$

in which:	v_{h0}	= lift rate in view of translatory wave influence	(m/s)
	F'_p	= positive longitudinal force (e.g. +0.80 ‰)	(‰)
	A_{ks0}	= wet cross section next to the vessel at = t_0	
		= $((h_{ben} - z_k) \cdot b_k - A_s)$	(m ²)
	h_{ben}	= downstream water level (= init. chamber water level) (m Ref. level NAP)	

z_k	= level lock bottom	(m Ref. level NAP)
b_k	= width of lock	(m)
A_s	= cross section of vessel = $b_s d_s$	(m ²)
b_s	= width of vessel	(m ²)
d_s	= draught of vessel	(m ²)
μ	= discharge coefficient (e.g. between 0.65 and 0.75)	(-)
b_h	= width of filling openings (e.g. between 0.5 and 0.67 of the lock width, condition 4)	(m)
v_0	= $\sqrt{(2 g \Delta h_0)}$	(m/s)
Δh_0	= initial water level difference = $h_{bov} - h_{ben}$	(m)
h_{bov}	= upstream water level	(m Ref. level NAP)
g	= 9,81 = acceleration gravity	(m/s ²)

The second maximum lift rate follows from condition 2:

$$v_{hm} = \frac{-F'_n A_{ksm} c_b g l_s}{16000/27 \mu b_h v_0 V (c_{l1} / A_{str} - c_{l2} / A_{ksm})} \quad (6.2)$$

in which:	v_{hm}	= lift rate in view of influence of filling flow	(m/s)
	F'_n	= negative longitudinal force (e.g. -0.80 ‰)	(‰)
	A_{ksm}	= wet cross section of the vessel at max. discharge = $(h_{ben} + 5/9 \Delta h_0 - z_k) b_k - A_s$	(m ²)
	c_b	= blocking coefficient vessel (e.g. 0.90)	(-)
	l_s	= length of vessel	(m)
	V	= $b_k l_k \Delta h_0$	(m ³)
	l_k	= length of lock chamber	(m)
	A_{str}	= $1,5 b_h d_2 (h_{ben} - z_k)$	(m ²)
	d_2	= coefficient for cross section jet (recommended 0.25)	(-)
	c_{l1}	= $((l_k - x_b) / l_k)^2$	(-)
	c_{l2}	= $((l_k - l_s - x_b) / l_k)^2$	(-)
	x_b	= distance bow/filling gate	(m)

The normative lift rate follows from equations (6.1) and (6.2):

$$v_h = v_{h0} \text{ als } v_{h0} < v_{hm} \quad (6.3a)$$

$$v_h = v_{hm} \text{ als } v_{h0} > v_{hm} \quad (6.3b)$$

in which:	v_h	= normative lift rate	(m/s)

The lift rate of the sluice gates follows from condition 3:

$$t_h = d_3 \sqrt{\frac{2 b_k l_k v_0}{3 g \mu v_h b_h}} \quad (6.4)$$

in which:	t_h	= lift rate sluice gates	(s)
	d_3	= relation between end of lift and max. discharge with $1 < d_3 < \sqrt{3}$ (recommended $d_3 = 1.35$)	(-)

The maximum area and lift rate of the gate filling openings follows from comparisons between (6.3a,b) and (6.4):

$$A_h = b_h v_h t_h \quad (6.5a)$$

$$h_h = v_h t_h \quad (6.5b)$$

in which: A_h = area filling openings (m²)
 h_h = lift height sluices (m)

The filling time of the chamber (lift 0) is:

$$t_{ev} = 1/2 t_h + \frac{b_k l_k v_0}{g \mu A_h} \quad (6.6)$$

in which: t_{ev} = filling time chamber (s)

6.4.4 Filling with culverts/stilling chamber with a view to dimension setting

In essence, the dimension setting of the preliminary design for filling with bypass culverts and a stilling chamber takes place in a similar way to filling with gate openings. Because the hydraulic phenomena can be fierce, in particular at high head locks in which other matters also play a part (air suction, cavitation, geometry, see par. 6.5.2) it is strongly recommended that experts are consulted in the preliminary design phase.

The effects of inertia of the culverts are not yet included in the preliminary design. The bypass culverts with sluices are treated as gate openings with sluices and the stilling chamber ensures a well spread flow throughout the chamber. This is incorporated into the calculation as follows:

- the total width (b_h) and the maximum area (A_h) of the gate openings is replaced by the total width (b_r) and the maximum area (A_r) of the culverts;
- condition 4 for a minimal, total width of the gate openings does not apply because the stilling chamber takes care of the dispersion; the total width of the culverts is set at, for instance, $b_r = 0.33 b_k$ (b_k = width chamber);
- usually, when calculating the discharge through the culverts, a row of ξ values is used for the total culvert resistance (inflow, bend, friction, sluice and exit loss). The ξ values are brought into the kinetic head of the velocity of the complete culvert cross section and are a function of the sluice distance. For the preliminary design, the row of ξ values is replaced by a μ value (discharge coefficient) brought into the sluice openings as in the case of gate openings, for instance between 0.70 and 0.80.
- because the stilling chamber distributes the filling discharge over the complete discharge area of the stilling chamber, a A_{str} is defined in a different way:

$$A_{str} = b_k (h_w - z_w)$$

with: b_k = width chamber (m)
 h_w = top discharge opening of stilling chamber (m Ref. level NAP)
 z_w = bottom discharge opening of stilling chamber (m Ref. level NAP)

If the water level has not reached the top of the stilling chamber at the maximum flow rate, h_w should be replaced by $(h_{ben} + 5/9 \Delta h_0)$.

The rest of the calculation developments are completely analogue to the filling with gate openings (par. 6.4.3) via the equations (6.1 up to and including 6.6).

Please note however that in the application of the type stilling chamber/lock culverts with a high lift/drop, a non-constant lift rate of the sluices is often applied to limit the filling time of the chamber. This is not included in the set-up as described above.

6.4.5 Emptying with gate openings with a view to dimension setting

The longitudinal force on a vessel during the emptying with gate openings is determined by three components, as stated in par. 6.3. One component, a (translatory waves) is dominant and this is at two moments in the emptying process. The dimensions of the gate openings are derived with the help of this component. Component b (momentum decrease in longitudinal direction of the chamber) can sometimes not be completely ignored but is only used to check. Component c (friction) is ignored.

From the above mentioned, four conditions are developed:

- 1 The separate contribution in the longitudinal force of component a (translatory waves) at the end of the emptying process may not exceed the permitted longitudinal force.
- 2 Likewise at the beginning of the emptying process.
- 3 The course of the discharge should be smooth by having the moment of maximum gate opening occur slightly later than the moment of maximum discharge.
- 4 The separate contribution in the longitudinal force of component b (momentum decrease) slightly prior to the moment of maximum discharge may not exceed the permitted longitudinal force.

The total width of the gate openings at emptying is of less importance to the flow in the chamber. Due to the damage to the bottom outside the lock chamber, the same width as the width for filling is recommended.

The maximum area of the gate openings follows from condition 1. The maximum lift rate of the sluice gates follows from 2 and 3, the lower of the two should be applied. Condition 4 is used to check the negative longitudinal force.

The maximum area of the gate openings follows from condition 1:

$$A_h = \sqrt{\left(\frac{F'_p A_{kse} b_k l_k}{1000 \mu^2} \right)} \quad (6.7)$$

in which:	A_h	= total discharge opening	(m ²)
	F'_p	= supply of positive longitudinal force (e.g. +0.80 ‰)	(‰)
	A_{kse}	= wet cross section next to the vessel on $t = t_e$	
		= $(h_{ben} - z_k) b_k - A_s$	(m ²)
	h_{ben}	= downstream water level	(m Ref. level NAP)
	z_k	= level lock bottom	(m Ref. level NAP)
	b_k	= lock width	(m)
	A_s	= cross section vessel = $b_s d_s$	(m ²)
	l_k	= length lock chamber	(m)
	μ	= discharge coefficient (depending on design opening, e.g. between 0.65 and 0.75)	(-)

The first maximum lift rate follows from condition 2:

$$v_{h0} = \frac{-F'_n g A_{ks0}}{1000 \mu b_h v_0} \quad (6.8)$$

in which:	v_{h0}	= lift rate i.c.o. start translatory wave influence	(m/s)
	F'_n	= supply negative longitudinal force (e.g. -0.80 ‰)	(‰)
	A_{ks0}	= $(h_{bov} - z_k) b_k - A_s$	(m ²)
	h_{bov}	= upstream water level (= init. chamber water level)	(m Ref. level NAP)
	b_h	= width discharge openings (for instance between 0.5 and 0.67 of the lock width)	(m)
	v_0	= $\sqrt{2 g \Delta h_0}$	(m/s)
	Δh_0	= initial lift	(m)

The second maximum lift rate follows from condition 3:

$$v_{hh} = \frac{3 \mu A_h^2 v_0}{4 d_3^2 b_h V} \quad (6.9)$$

in which:	v_{hh}	= lift rate i.c.o. smooth discharge progress	(m/s)
	A_h	= total emptying opening, from equation (6.7)	(m ²)
	v_0	= $\sqrt{2 g \Delta h_0}$	(m/s)
	d_3	= relation moment end of lift and max. discharge with $1 < d_3 < \sqrt{3}$ (recommended $d_3 = 1.10$)	(-)
	V	= $b_k l_k \Delta h_0$	(m ³)

The normative lift rate follows from equations (6.8) and (6.9):

$$v_h = v_{h0} \text{ als } v_{h0} < v_{hh} \quad (6.10a)$$

$$v_h = v_{hh} \text{ als } v_{h0} > v_{hh} \quad (6.10b)$$

in which:	v_h	= normative lift rate	(m/s)

The lift rate and the maximum lift height of gate openings follows from equation (6.4):

$$t_h = A_h / (v_h b_h) \quad (6.11a)$$

$$h_h = v_h t_h \quad (6.11b)$$

in which:	t_h	= lift time sluices	(s)
	A_h	= total discharge opening, from equation (6.7)	(m ²)
	h_h	= lift height sluice gates	(m)

The emptying time is:

$$t_{el} = 1/2 t_h + \frac{b_k l_k v_0}{g \mu A_h} \quad (6.12)$$

in which:	t_{el}	= emptying time chamber	(s)

Condition 4 is used to check the negative longitudinal force:

$$F'_m = \frac{-16000/27 \mu b_h v_h v_0 V (c_{l1} / A_{ksm} - c_{l2} / A_{km})}{g l_s c_b A_{km}} \quad (6.13)$$

in which:	F'_m	= negative longitudinal force during maximum discharge = for instance a maximum of -0.8 ‰	(‰)
	v_h	= normative lift rate from equation (6.10a/b)	(m/s)
	c_{l1}	= $((l_k - x_b) / l_k)^2$	(-)
	x_b	= distance bow/emptying gate	(m)
	A_{ksm}	= wet cross section next to the vessel during max. discharge = $(h_{bov} - 5/9 \Delta h_0 - z_k) b_k - A_s$	(m ²)
	c_{l2}	= $((l_k - l_s - x_b) / l_k)^2$	(-)
	l_s	= length vessel	(m)
	A_{km}	= wet cross section behind the vessel during max. discharge = $(h_{bov} - 5/9 \Delta h_0 - z_k) b_k$	(m ²)
	c_b	= block coefficient vessel	(-)

If the calculated negative longitudinal force F'_m is too high, the area of the openings A_h or de lift rate v_h should be reduced.

6.4.6 Emptying with culverts with a view to dimension setting

Due to the high construction costs, culverts for emptying are avoided. Instead, gate openings are applied unless this is impossible from a hydraulic point of view. The dimensioning for the preliminary design of lock culverts for emptying is done in the same way as it is done for gate openings. The effect of the inertia of the culverts is not taken into consideration and the culverts with sluices are treated as gate openings with sluices. The latter is processed in the calculation as follows:

- The total width (b_h) and the maximum area (A_h) of the gate openings is replaced by the total width (b_r) and the maximum area (A_r) of the culverts. The total width of the culverts is, for instance, $b_r = 0.33 b_k$ (b_k = width chamber).
- For the preliminary design, the ξ values for the resistance of the culverts is replaced by a μ value (discharge coefficient) brought into the sluice opening such as for gate openings, for instance $\mu = 0.70$ to 0.80 .

The rest of the calculation developments are completely analogue to the filling with gate openings (par. 6.4.5) via the equations (6.7 up to and including 6.13).

6.5 Hydraulic design

In addition to the size of the openings and the sluice programme, the hydraulic design also determines the quality of the filling and emptying system. It concerns the question of whether the forces on vessels are acceptable at relatively short levelling times (see lit. [6.12]).

6.5.1 Filling with gate openings in view of the design

6.5.1.1 General

The requirements set for the design of gate openings primarily result from limiting the forces on vessels during the levelling process. The requirements are:

- *Even flow distribution*
The design has to be such that the filling stream with its high flow velocities is distributed as evenly as possible across the complete wet cross section from as close as possible behind the openings.
- *Flow direction*
The flow direction has to be directed along the longitudinal axis of the lock.
(Note: If rip-rap is used as bed protection in the chamber, this requirement is also relevant.)

To meet these requirements, the following hydraulic principles are the points of departure:

- *Spreading the flow*
Several small discharges that do not work together break down much faster than a single, large discharge. The multiple smaller discharges are divided across the wet cross section.
- *Generating turbulence*
The energy from the filling streams is broken down by the generation of significant turbulence. This can take place by creating resistance on the downstream side of the openings.
- *Directing the flow*
The discharge eventually has to be directed along the longitudinal axis of the lock axis in order to prevent the flow from joining together or with the walls. The flow velocities also have to be directed horizontally in order to prevent turbulence on the surface.

The design of the filling openings has to meet the previously stated requirements and hydraulic principles as much as possible. Paying attention to the points mentioned in par. 6.5.1.2 up to and including 6.5.1.5 can achieve this.

Photos 6.1 up to and including 6.6 provide an overview of possible flow patterns. The water can be rather turbulent at a filling system when the gates are lifted at large lift/drop locks (photo 6.2 and 6.3). Filling through gate openings without energy dissipating barriers (fig. 6.4) could result in turbulent water behind the filling gate. Photos 6.1, 6.5 and 6.6 show flow patterns behind gate openings with energy dissipating barriers that are less turbulent.



Photo 6.2 Flow pattern during filling by means of lifting the upper gate of the old lock in Born



Photo 6.3 Flow pattern during filling by means of lifting the upper gate at the lock in Eefde



Photo 6.4 Flow pattern during filling by means of gate openings of the lock in the Noord Willemkanaal



Photo 6.5 Flow pattern during filling by means of gate openings of the push-tow locks in the Volkerak



Photo 6.6 Flow pattern during emptying by means of gate openings of Kleine Sluis in IJmuiden

6.5.1.2 Location of sluices and energy dissipating barriers

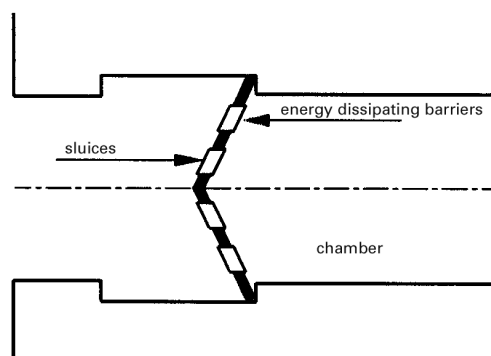


Figure 6.12 Location of sluice gates and dissipating barriers (horizontal cross section)

Position the sluice gates on the outside of the gate (upstream side), the highest flow velocity then occurs in the gate (fig. 6.12).

The flow resistance (for instance energy dissipating barriers) are positioned on the chamber side (down-stream side) so that the highest flow velocities are broken down before entering the chamber.

6.5.1.3 Place, number and shape of the openings

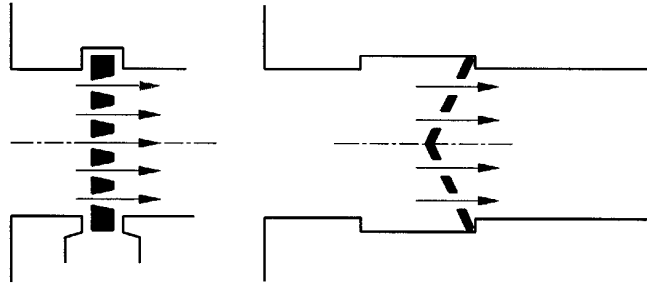


Figure 6.13 Width partition in the openings

Divide the openings as evenly as possible over the width of the chamber and make the openings equal in size. This brings about an even discharge distribution over the width of the chamber (fig. 6.13).

Use as many openings as possible. Several smaller discharges break down faster than a few large discharges.



Figure 6.14 Broad, low and low-lying openings (front view gate)

For an even distribution of the discharge in the width and for proper dissipation of the flow velocities over the complete water depth, use has to be made of low, wide openings (fig. 6.14).

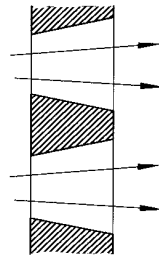
Install the openings in the bottom half of the lowest water depth. This limits the flow action against the bow during maximum inflow and keeps the water surface from becoming very turbulent.

At the lowest water level, inland navigation locks are generally shallower than marine locks. For this reason, inland navigation locks generally require somewhat broader and lower openings than marine locks. In the application of rectangular openings a total width of filling openings of about 0.67 x the width of the lock is recommended for inland navigation locks and more than 0.5 x the width of the lock is recommended for marine locks.

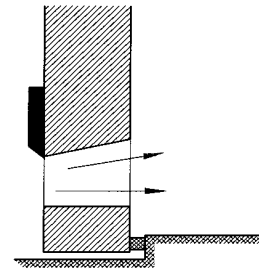
Lit. [6.6] recommends standard widths for gate openings of 2.60 m, 2.15 m and 1.40 m. This is often deviated from, as the sluices are not interchangeable anyway. The standard widths do result in the following at different lock widths:

Lock width [m]	Width of opening [m] (inland navigation lock)	Width of opening [m] (marine lock)
24	6 x 2.60	6 x 2.15
16	5 x 2.15 of 4 x 2.60	4 x 2.15
12.5	6 x 1.40	5 x 1.40 of 6 x 1.40
10.5	5 x 1.40 of 2 x 2.15 + 2 x 1.40	4 x 1.40
8.5	4 x 1.40	

Remark: An even number of openings on mitre gates, even and uneven on single pivot gate, roller gate and lift gate.



Horizontal divergence (horizontal cross section)



Vertical divergence (vertical cross section)

Figure 6.15 Divergence openings

Make the openings divergent (fig. 6.15). Horizontal divergence is intended to advance the width spread and vertical divergence is intended to advance the height spread. The latter is realized by having the ceiling of the opening running up.

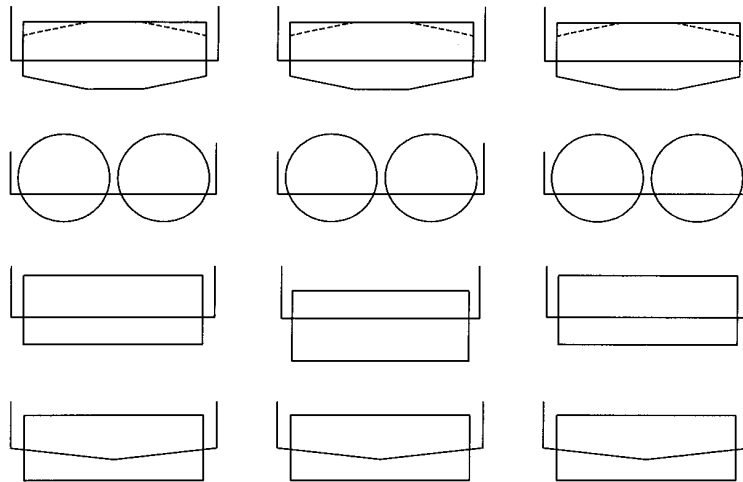


Figure 6.16 Influencing area gate openings in the time.

It could be favourable to not allow the area of the openings to increase linear in time and in doing so, limit the amplitude of the forces on vessels due to transitory waves (fig. 6.16). This can be done by having the flow rate run as smoothly as possible in the initial stage of the filling process and at the moment that the openings are completely open. This can be achieved by a non-linear sluice lift (varying lift rate with soft-start and stop) with rectangular openings or through a linear sluice lift (constant lift rate) with specially shaped openings. These special shapes could be: openings with triangular blocking pieces at the bottom (and possibly at the top), round openings, openings with different levels at the bottom (and possibly at the top) or equal, rectangular openings with adapted bottom edges.

Photos 6.7 to 6.13 show examples of gate openings with sluice gates and energy dissipating barriers.

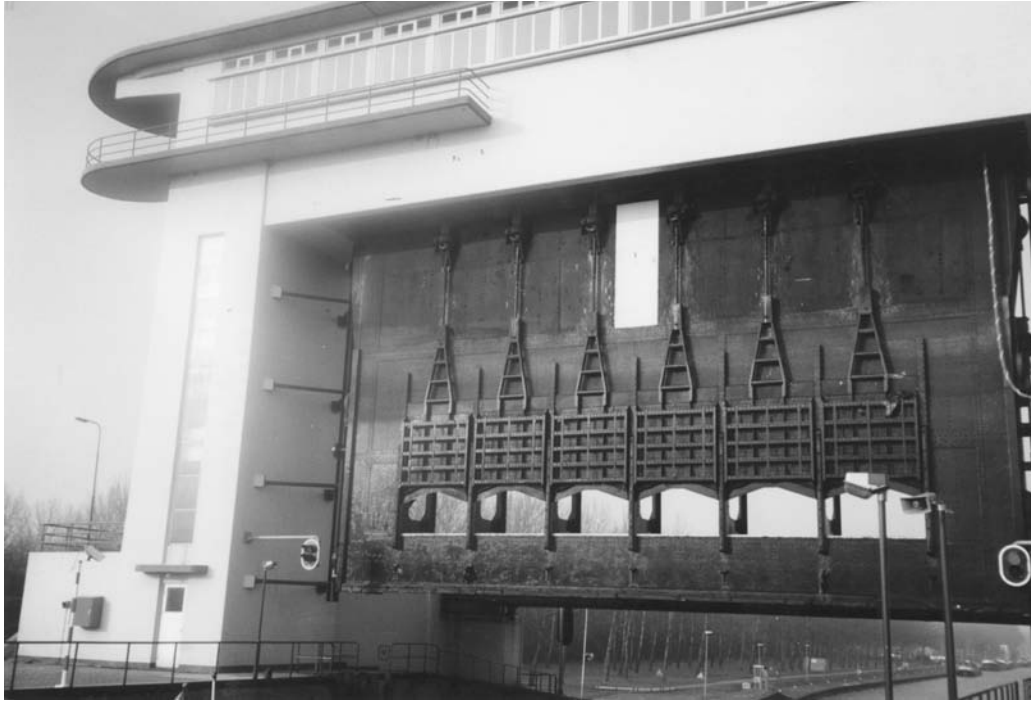


Photo 6.7 Gate openings in the lift gates of the Princess Beatrix locks in Nieuwegein

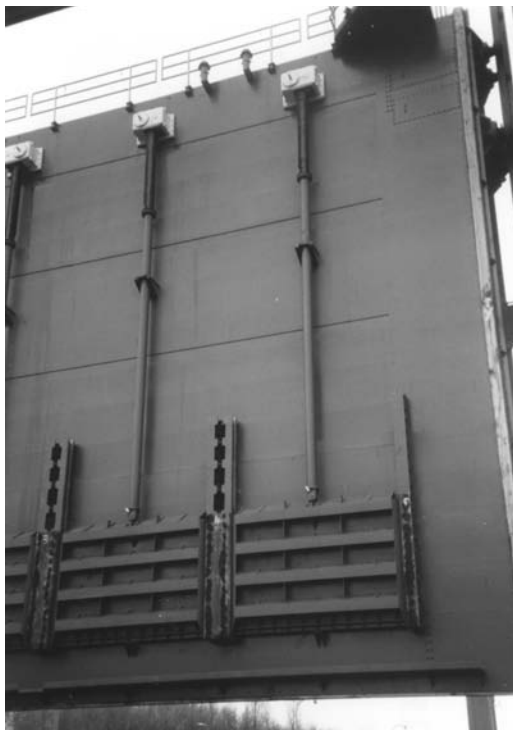


Photo 6.8 Sluice gates over the rectangular openings in the lift gate of the new lock in Weurt



Photo 6.9 Energy dissipating bars behind the rectangular openings in the lift gates of the new locks in Weurt



Photo 6.10 Lock paddles for the rectangular openings of the mitre gates of the Kleine Sluis in IJmuiden



Photo 6.11 Energy dissipating bars behind the rectangular openings of the mitre gates of Kleine Sluis in IJmuiden



Photo 6.12 Sluice gates in front of the round openings of the sliding gate of Nieuwe Oranje lock in Amsterdam



Photo 6.13 Energy dissipating bars behind the round openings of the sliding gate of Nieuwe Oranje lock in Amsterdam

6.5.1.4 Downstream resistance



Vertical energy dissipating bars (horizontal cross section) Vertical energy dissipating bars (horizontal cross section)

Figure 6.17 Downstream resistance with vertical bars

Application of the vertical barriers is intended to evenly distribute the flow between the energy dissipating barriers (fig. 6.17). The energy dissipating bars function as a resistance grid, whereby the discharge coefficient of the openings is decreased. The blocking by the energy dissipating barrier has to amount to at least 50% of the downstream area of the openings without energy dissipating barriers. One alternative is the application of energy dissipating bars right behind the openings.



Horizontal bars (vertical cross section)

Horizontal baffle vane (vertical cross section)

Figure 6.18 Downstream resistance with horizontal bars

If vertical energy dissipating bars cannot be applied, one or more horizontal bars could be placed on the downstream side of the openings (fig. 6.18). These horizontal bars could have a rectangular or triangular cross section (top corner upstream). The bars are intended to split the flow in two separate flows above each other and/or for directing the flow.

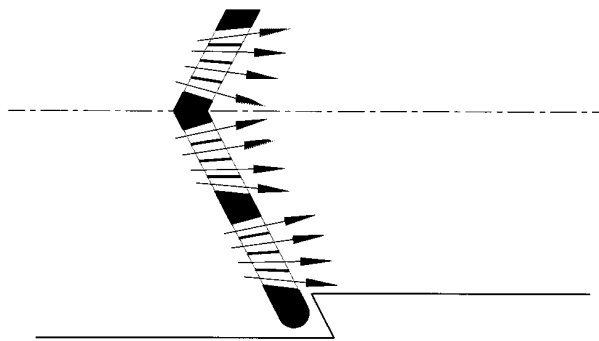


Figure 6.19 Vertical baffle vane at mitre gates (horizontal cross section)

At mitre gates, vertical standing baffle vanes could be positioned in the openings (fig. 6.19) in combination with horizontal energy dissipating barriers. Without provisions, the flow will be at right angles to the mitre gate, whereby a central flow occurs in the lock axis. Vertically standing, straight baffle vanes in the openings could force the flow in the longitudinal direction of the lock axis.

The total downstream opening (that is to say between the energy dissipating bars) has to be larger than the total upstream opening. The largest flow velocity has to occur in the gate and not outside the gate.

The smallest opening between the energy dissipating bars has to be at least 0.30 m. Floating waste gets trapped in gaps that are too narrow.

6.5.1.5 Lower edge of sluice

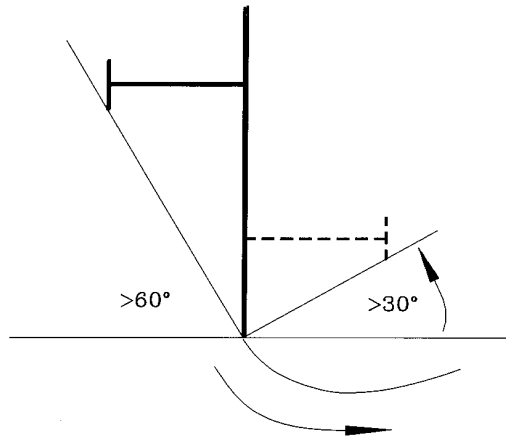


Figure 6.20 Lower edge of sluice gate

In order to avoid vibration in the sluice, a flow separation point has to be created under the sluice gate (fig. 6.20). For this purpose, the lower edge of the sluice gate has to be as sharp as possible. The angle between the connecting line of the horizontal stiffening girder and the lower edge of the horizontal has to be at least 60° on the upstream side and 30° on the downstream side.

In fig. 6.21 to 6.24 four examples are provided of possible designs of the openings. It concerns inland navigation locks (fig. 6.21 and 6.22) and small marine locks (fig. 6.23 and 6.24) of 16 m wide. Fig. 6.21 and 6.23 indicate a solution with vertical energy dissipating bars at flat gates. Fig. 6.22 is a baffle vane solution and fig. 6.24 a solution with vertical energy dissipating bars at mitre gates.

6.5.2 Filling with culverts and stilling chamber with a view to shaping

Lock culverts with a stilling chamber are generally applied at high lift/drop. The occurring hydraulic phenomena are quite fierce and very sensitive to the dimensions and shape of the lock culverts and the stilling chamber. The computation of a preliminary design has to be executed by an expert and if possible, be based on either existing stilling chambers or model investigation.

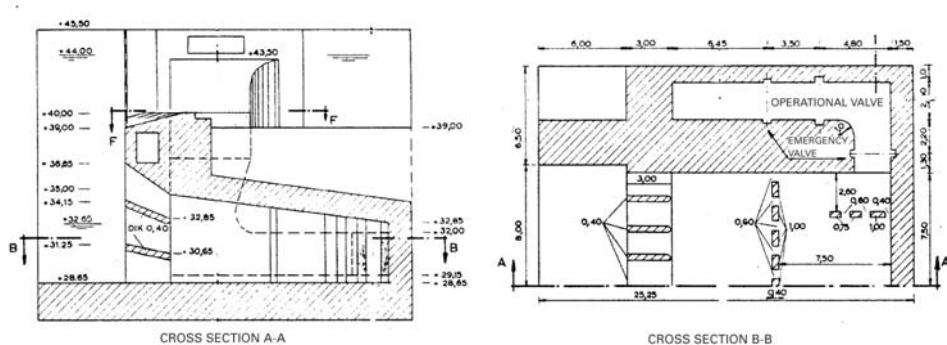


Figure 6.25 Design of lock culverts with stilling chamber Born

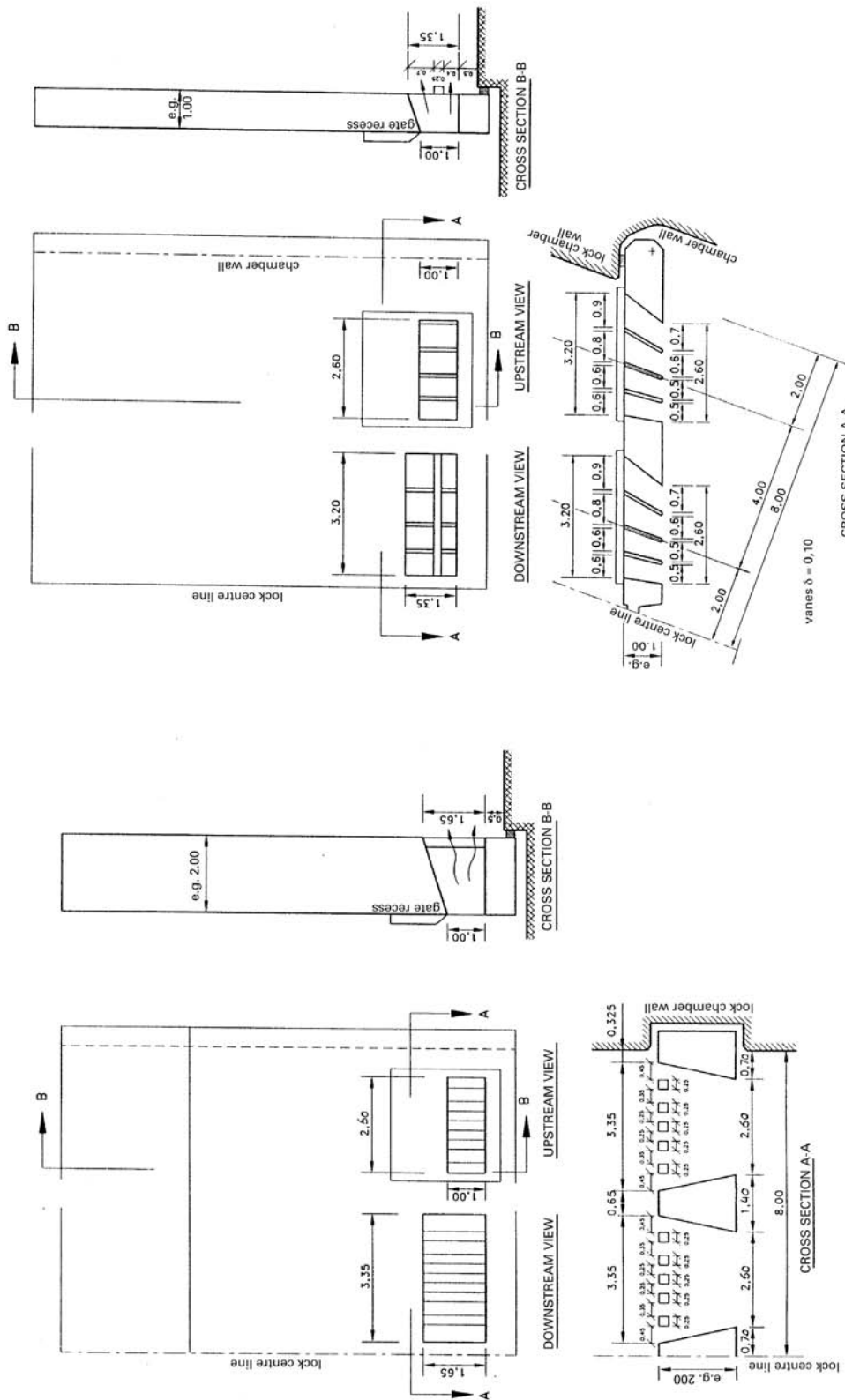


Figure 6.21 Design example of filling openings for 16 m inland navigation lock with flat gate and vertical energy dissipating bars

Figure 6.22 Design example of filling openings for 16 m inland navigation lock with mitre gates and vertical baffle vanes

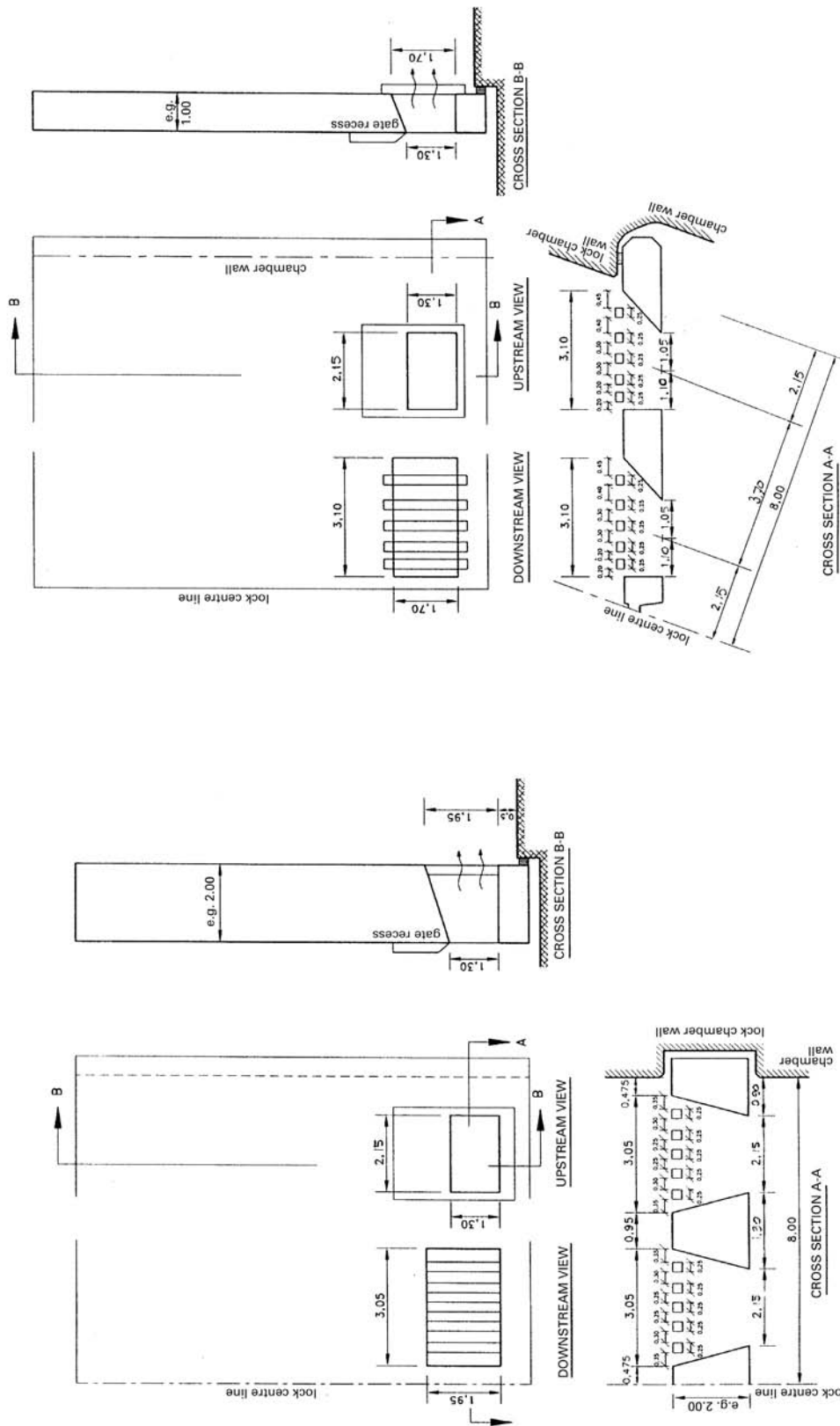


Figure 6.24 Design example of filling openings for 16 m marine lock with mitre gates and vertical energy dissipating bars

Figure 6.23 Design example of filling openings for 16 m marine lock with flat gate and vertical energy dissipating bars

6.5.2.1 Bypass culverts

In bypass culverts, in combination with a stilling chamber, flow is let in on the upstream side through the inflow opening situated in the wall of the gate recess of the upper head (fig 6.25) just above the level of the upstream bottom. The flow can also be let in on an abutment wall that is at a right angle to the chamber wall. The water falls into a vertical shaft and is guided into a horizontal culvert part, parallel to the chamber wall at the level of the chamber floor. In this horizontal part, the regulating and emergency valves as well as possible valve shafts are found. The water is subsequently introduced straight down from the chamber wall into the stilling chamber.

A possible problem with lock culverts is air.

When the water in the culvert takes along too much air in the form of air bubbles, this air is unable to escape due to the short period it spends in the stilling chamber and it ends up as a water/air mixture in the chamber. The result of this is a very restless water level surface and the air/water mixture could increase the draught of a small loaded vessel that can be washed over and be subjected to substantial forces.

If water bubbles collect somewhere in the culvert system, unclear inertia phenomena occur in the culvert and the flow distribution starts deviating in a manner that is difficult to predict. At a certain point, the air can escape through a sluice shaft and the water collides with the ceiling with a bang, resulting in very high local pressures.

The risk of transporting air occurs at two places: the culvert inlet where air can enter via vortexes, and downstream of the valve, where the pressure is low due to high momentum in the flow.

At the inlet, this problem of transporting air can only be solved by positioning the inlet openings sufficiently deep and ensuring a proper rounding off so that the intake occurs at low velocities. The inlet has to have a vortex free design.

To prevent the problem at the valves, these should preferably be the closed type (for instance butterfly valves or sliding valves). If a valve shaft is used that is open on top, the ceiling of the culvert should be sufficiently low: air suction is only prevented when the ceiling behind the valve is positioned sufficiently deep and therefore at a level of once the 'lift/drop height' under the downstream water level. The latter can generally not be realised in practice so that air suction can usually not be prevented.

In order to counteract contraction of the flow in the culvert and in doing so, decrease the cross section of the culvert, the outer corners of the lock culvert should always be rounded off.

The outflow of the culvert should take place as square to the lock wall as possible to make the filling flow collide with columns or a wall. This can be boosted by shaping the culvert through as shown in figure 6.26.

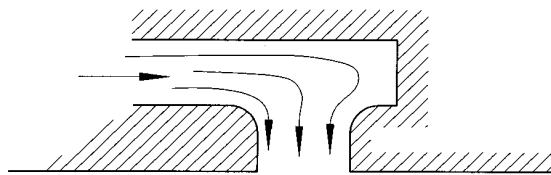


Figure 6.26 Continuation of the culvert past the outlet

If there are doubts about sufficient width spread of the flow through the stilling chamber, each bypass culvert could be executed in duplicate.

Cavitation occurs at lift/drop larger than 10 m if there is not sufficient pressure head. This means that culvert valves should be positioned sufficiently deep. Damage to the structure occurs due to cavitation. The normative situation for the system is a situation in which one lock culvert is out of use and the other culvert has to deal with everything. The flow pattern is no longer symmetric in this case.

6.5.2.2 Stilling chamber

The water is introduced into the stilling chamber via a perpendicular culvert outlet. In the stilling chamber, this flow collides with the columns or against the wall that is parallel to the lock axis, whereby the flow loses part of the energy and bends in the direction that is parallel to the lock axis. The flow, now directed parallel to the lock axis, subsequently collides with a grid of vertical columns that are perpendicular to the lock axis with a large blocking effect (for instance 60%). This grid ensures that the water is well distributed in height and width when entering the chamber. If necessary, more vertical and tilted baffle vanes could be positioned behind the grid that direct the water in longitudinal and horizontal direction of the chamber.

The ceiling of the stilling chamber is slanted in order to decrease the change over of cross section of lock to the chamber/stilling chamber (fig. 6.25). Sometimes, holes are used in the ceiling of the stilling chamber. The objective of these measures is to prevent extra transitory waves from being generated when the chamber water level reaches the ceiling of the stilling chamber.

The level of the top of the stilling chamber generally corresponds with the upstream bed level; the top of the ceiling of the stilling chamber at the outlet is just below this.

The same normative system situation applies to the stilling chamber, where one culvert is in use and the other culvert is out of use.

Photos 6.14 to 6.17 show pictures of bypass culverts with stilling chamber.



Photo 6.14 Inlet opening in upper head of the locks at Maasbracht

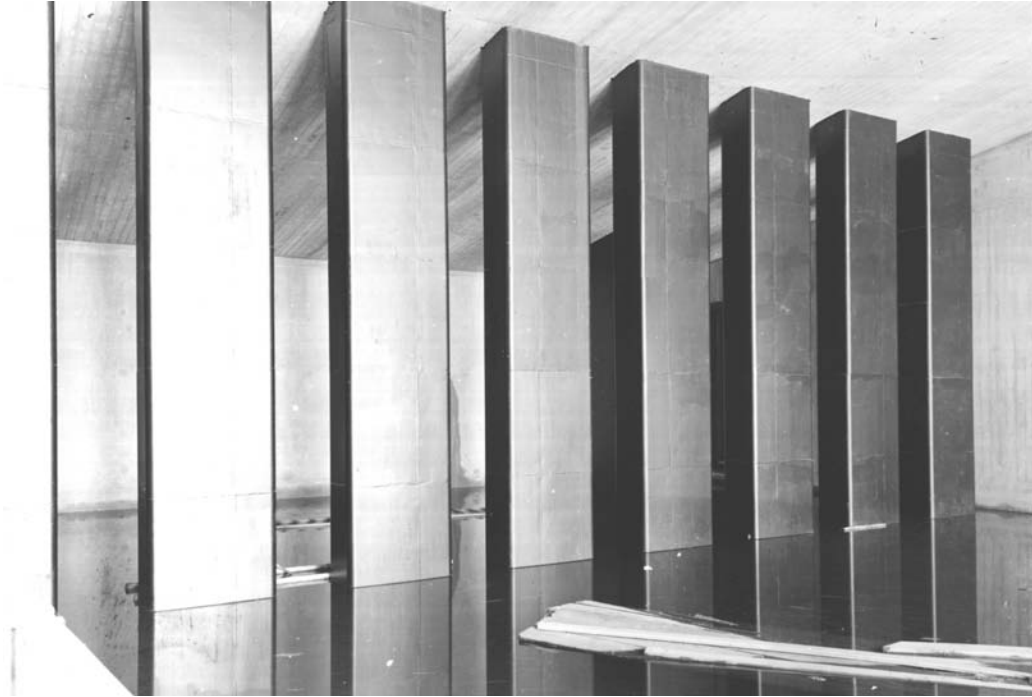


Photo 6.15 Columns in the stilling chamber of upper head of the locks in Maasbracht



Photo 6.16 Upper head with stilling chamber of locks in Maasbracht



Photo 6.17 Stilling chamber of navigation lock in Almere

6.5.3 Emptying with gate openings with regard to shaping

There is an acceleration area of flow in the chamber during emptying whereby high velocities only occur close to the gate openings. These flow velocities hardly have any effect on vessels moored in the chamber.

To prevent damage to the bed right outside the gates and in the flow deceleration area of the lock approach and in order to limit bed protection, shape requirements are generally set for the outlet openings. Keep in mind however that the flow discharges into the lock approach with a downstream water level is permanently low. The flow velocities are therefore considerable.

The requirements set for the emptying outlets to prevent damage to the bottom of the lock approach are similar to the requirements at gate intake openings and concern the flow distribution (evenly spread flow velocities across the cross section downstream of the gate) and the flow direction (direction lock axis). This results in the following rules:

- position the sliding gates on the chamber side of the gate (highest flow velocities inside, not outside the gate);
- use as many openings as possible and divide the openings as best as possible across the width of the chamber. Provide wide, low and deep lying openings. Make the openings divergent in horizontal and vertical sense;

- provide the lock approach side with resistance, preferably energy dissipating bars or, if necessary in the case of mitre gates, place vertically positioned vane blades in the openings for a flow direction according to the lock axis.

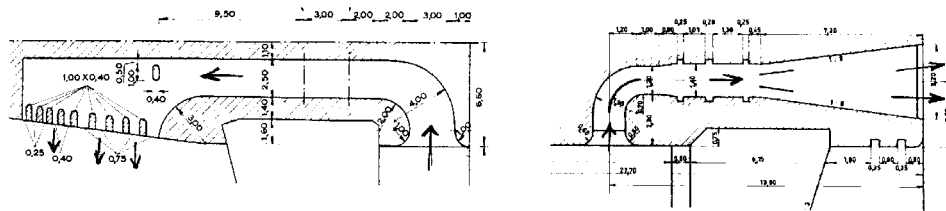
Instead of spreading directly behind the openings across the complete wet cross section, there are possible alternatives:

- direct the flow via the emptying outlets down into a stilling basin behind the lock head. The stilling basin takes care of the spread height of the flow. This alternative is recommended at large lift/drop;
- install low sills in the floor behind the emptying openings in a V shape or as a zigzag spillway. These sills only have sufficient effect when they have a height of at least 0.25 times the water depth.

6.5.4 Emptying with bypass culverts with a view to shaping

Culverts bypassing the tail gates for emptying the chamber are usually applied at large lift/drop. Lock culverts with valves are fitted at both lock walls and the culverts should preferably be symmetrical.

The same as with bypass culverts in an upper head, it is important that the level of the culvert and its intake is as low as possible in order to prevent air suction with the inflow and behind the valves. The inflow at the chamber wall should be rounded with a large radius to prevent high flow velocities at the chamber wall. The bends in the culvert should be rounded off wherever possible.



Outflow at the extended lock walls (Born)

Outflow at the abutment walls (Oostvaardersdiep)

Figure 6.27 Outflow of bypass culverts

The outflow can take place at extensions of the lock walls or at the abutment walls; as far as possible, the flow has to be perpendicular to the wall of discharge (fig. 6.27). If the flow discharges from the extended chamber walls, the discharging jets will collide with each other square on thus losing part of their energy. If the flow discharges from the abutment walls, it can be kept outside the navigation lane. Perpendicular discharge can be achieved by fitting a grid with uneven resistance distribution or by fitting baffle vanes.

Photos 6.18 and 6.19 show the design of the culvert inflow and discharge openings of a lower head.



Photo 6.18 Inflow opening of the bypass culvert of the lower head of the locks at Maasbracht



Photo 6.19 Outflow opening of the bypass culvert of the lower head of the locks at Maasbracht

6.6 LOCKFILL

6.6.1 Objective and possibilities of LOCKFILL

The LOCKFILL calculation programme (Lit. [6.13]) calculates the filling or emptying process of a lock based on a given filling or emptying system and lift programme.

The programme input consists of the initial water levels, the dimensions of the lock chamber, the filling and emptying system as well as the vessel, the sluice gate programme and a number of coefficients. The programme calculates the average water levels and discharges in the chamber as a function of time and the corresponding filling or emptying time. These water levels and discharges are subsequently used to calculate the longitudinal forces on the vessel moored in the chamber. The LOCKFILL results are presented by means of three plots (water level with area of openings, discharge and longitudinal force as functions of time).

Based on the calculated filling or emptying time and the maximum longitudinal force, assessments can be made on whether the chosen filling or emptying system meets the requirements or whether another lift programme or another dimension of the filling or emptying system of the lock should be entered.

The LOCKFILL calculation programme is based on model investigations, desktop studies and previously developed calculation programmes (Lit. [6.10] and [6.11]). Appendix 6.1 provides an overview of the basics of the calculations. To a limited degree, LOCKFILL has been validated by equations with existing model investigations; further validation is planned.

With LOCKFILL, a filling or emptying system with gate openings and slides can be calculated. A filling or emptying system, consisting of bypass culverts with a stilling chamber for filling and lock culverts or gate openings for emptying, is possible under certain conditions. For applying either one of the systems, it is implicitly assumed that the hydraulic design meets certain specific requirements: during filling, for instance, the outflow into the chamber must be evenly spread across the width of the chamber and occur in longitudinal direction of the chamber. Furthermore, the lock chamber must have a rectangular cross section, a constant width and a horizontal bottom. The influences of density differences are optional in the programme. For a system with bypass culverts/stilling chamber, for special systems or under unfavourable hydraulic conditions (for instance lift/drop of more than 4 m, the vessel close to the opening or very small keel clearance) the use of LOCKFILL alone is usually not sufficient. In these cases, additional hydraulic research is required, by means of a physical scale model for instance. However, even if this is the case, LOCKFILL remains a necessary tool in the design process.

In the application of LOCKFILL, it is important to know that the calculation results strongly depend on a number of coefficients that have to be entered, for instance such as the discharge coefficients of the openings. This discharge coefficient can best be determined in a physical scale model. If there is a lack of time and resources, the coefficients could be estimated from existing measurements with similar openings. For openings with unmeasured discharge coefficients, a number of calculations with different discharge coefficients will have to be executed.

LOCKFILL is a menu driven calculation programme for PC use. Firstly, an input file has to be made via the menu structure. LOCKFILL has 6 input blocks namely:

- general data (calculation time step, end time);
- lock approach (water level, density);
- filling system (gate openings or culverts, cross sectional area, lift rate, discharge or loss coefficients, length of culvert);
- chamber (initial water level, density, dimensions, floor, filling jet);
- vessel (dimensions, geometry, distance bow/gate);
- other coefficients (for the dispersal and density differences).

The calculation is executed. Lastly, the results could be presented as a plot on the screen or be saved for a plotter or a printer.

6.6.2 Working with LOCKFILL

Fig. 6.28 provides an example of the plot version.

The top plot contains graphs of the water level of the lock approach and the chamber as well as the total, gross flow-through area under the sluice gates. The middle plot contains the discharge through the levelling openings. The bottom plot provides the various components from the longitudinal force and the total longitudinal force on the vessel.

In the top graph of the water level, the time with a rest drop/lift of 0.10 m can be determined (gates can be opened because the longitudinal force exerted by this on a vessel is limited). In addition, the levelling time can be read. The maximum rising velocity of the water in the chamber can be deduced as well as the oscillation effects in the culverts. The graph for the gross flow-through area can be adjusted by means of the input.

The maximum discharge can be read from the middle plot. This can be used to assess whether the course of the discharge flow is sufficiently smooth: bends in this course cause large amplitudes of the longitudinal force due to transitory waves.

The bottom plot provides various components of the longitudinal force and the total longitudinal force in % of the vessel weight. The maximum longitudinal force can be read, and the number of times that the longitudinal force sign (direction) changes. Based on the separate components, assessments can be made on whether or not certain components are too dominant in the process.

If the filling or emptying time, the total longitudinal force and/or any component hereof does not comply, suitable measures can be taken. This is illustrated as follows:

- If the filling time is long and the longitudinal force is small, the lift/drop rate and/or the maximum area of the openings can be enlarged for instance.
- If the amplitude of the component of the transitory waves is substantial, it could be worth considering making the course in time of the area of the opening more smooth or decreasing the lift/drop rate.
- If the component of the momentum decrease is substantial, it is worth considering better dispersion of the filling jet or decreasing the maximum area of the openings.
- If the component of the jet action against the bow is considerable, the filling jet requires better dispersion or should be directed downward.
- The component of the density differences can hardly be influenced by the filling system.
- If the total longitudinal force does not comply (is too large) while this is not due to the separate components, a decrease in the lift/drop rate of the sluice gates is a possibility.
- If, despite all measures, the total longitudinal force remains too large and the filling or emptying time remains too long, lowering of the chamber bottom should be considered.

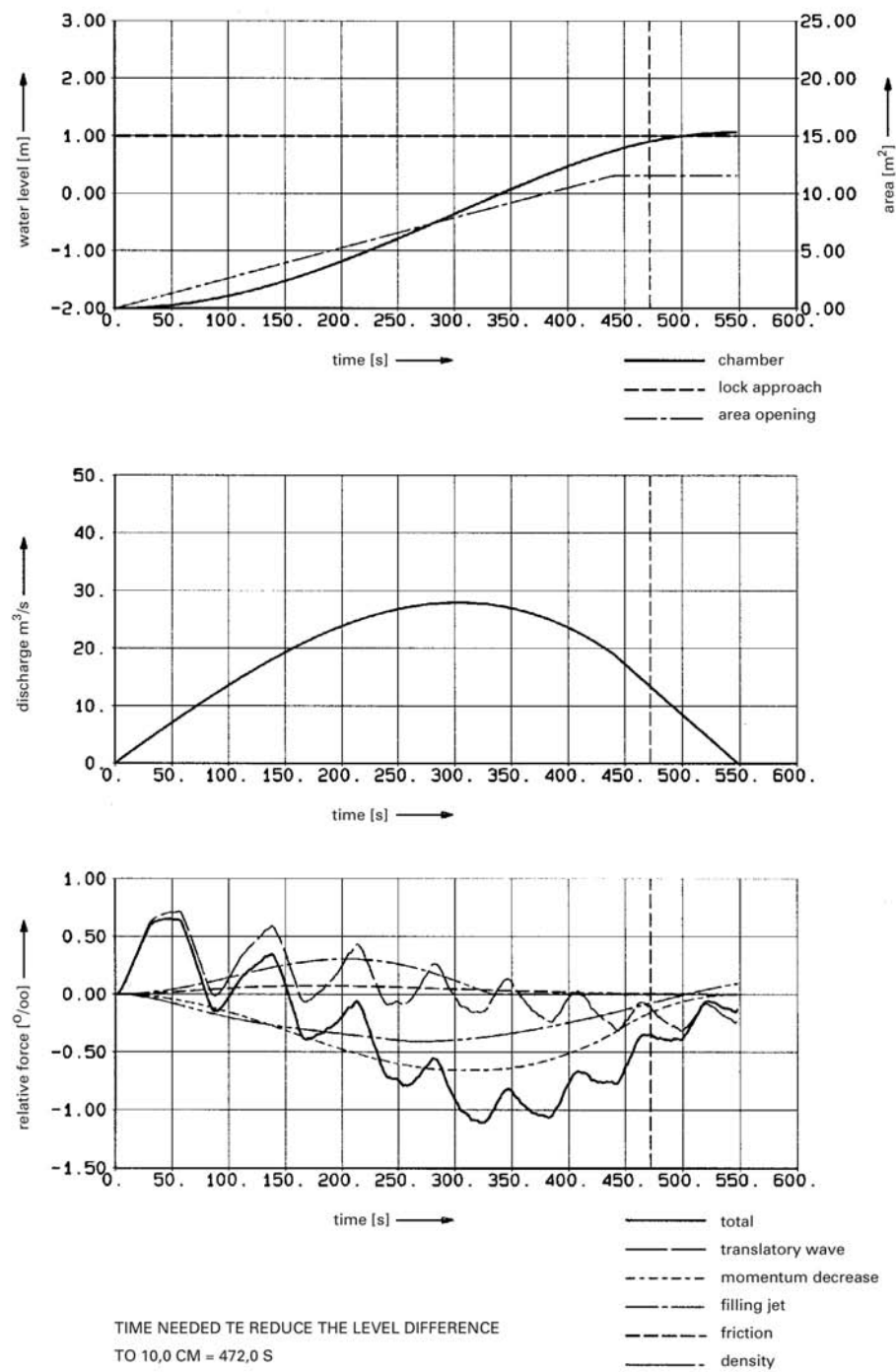


Figure 6.28 Water level/area of opening, discharge and longitudinal force

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- [6.13] Vrijburcht, A., 'Troskrachtcriteria van schutsluizen', Waterloopkundig Laboratorium, Delft, Q1443, november 1994.

Appendix 6.1 Calculation basics of LOCKFILL

In the first part of the LOCKFILL calculation module (Lit. [6.2]), the discharge and the average water level are calculated. This is used in the second part to derive the longitudinal forces on the moored vessel.

In the first part, LOCKFILL starts from a water storage calculation for the discharge and the average water level. The lock chamber and the lock approach have horizontal water levels. The chamber and the lock approach are linked by means of gate openings or culverts that open gradually by means of sluice gates.

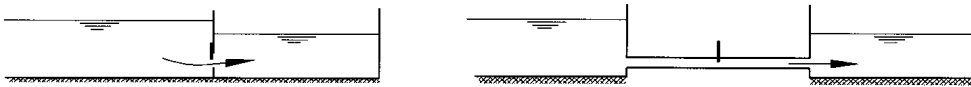


Figure 6.29 Water storage calculation

The discharge through the gate openings is calculated by means of the instantaneous drop/lift over these openings as well as the cross sectional area and discharge coefficient of these openings. At bypass culverts, the discharge is also determined by the inertia of the culverts and the discharge coefficient is replaced by energy loss coefficients. In the case of density differences between the water of the chamber and the water of the lock approach, the influence of this on the discharge is taken into consideration.

The discharge and the horizontal surface area of the chamber are used to derive the (average) water level in the chamber. The filling or emptying times of the lock are established from the development of the water levels.

In the second part, the 5 components of longitudinal force, namely translatory waves (a), momentum decrease in longitudinal direction of the chamber (b), friction (c), jet action (d) and density differences (e) are calculated in a one-dimensional method.

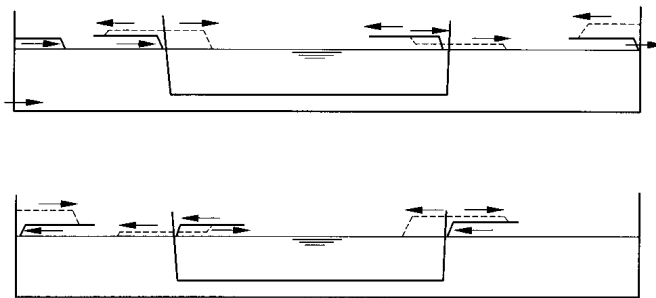


Figure 6.30 Reflection of translatory waves

First, the influence of the translatory waves (a) is calculated (fig. 6.30). From the discharge at the gate openings or culverts, the primary translatory wave that propagates through the chamber is derived. At the reflection points (bow and stern of the vessel and at both the chamber ends), these and other incoming waves are split into outgoing waves, namely reflecting and/or continuing waves. At some stage, an outgoing wave at a certain reflection point becomes an incoming wave for the next reflection point. This is calculated in time. The sum is found of all waves at the reflection points and is converted into water level differences over the vessel and to component (a) of the longitudinal force.

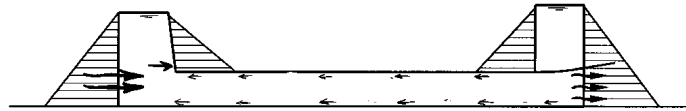


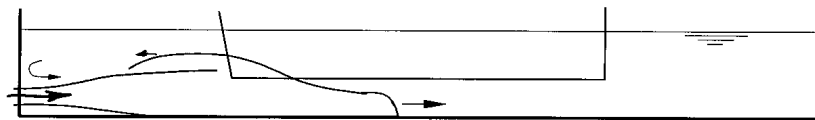
Figure 6.31 Applying momentum equations between bow and stern

The momentum equation for the water is subsequently applied to the area between the cross section just in front of the bow and the cross section just behind the stern, with the vessel and the lock bottom as further contours (fig. 6.31).

The momentum of the flow at the boundaries of this area is calculated for component b. With the aid of formulas from the literature, the dispersion of concentrated inflow jets to the bow of the vessel are calculated; this is used to determine the flow momentum at the bow. In addition, the flow momentum at the stern is calculated, under the assumption that the flow is released at the stern. With the aid of Chezy's formulations, the friction of the water in the region is calculated. This concerns the friction of the water with the chamber bottom, chamber walls and the skin of the vessel (component c).

With the formulas of the flow pressure exerted on a plate standing at an angle to the flow, the force of the concentrated filling jets on the bow is calculated (component d).

The momentum equation, applied on the stated region, yields the water level differences between the



bow and the stern and the components b, c, and d of the longitudinal force.

Figure 6.32 Density differences

Subsequently, the influence of the density differences (component e) during the filling of the chamber are calculated (optional, fig 6.32). The filling jets mix with the surrounding water and this is calculated by means of a mixing coefficient or according to a mixing chamber between gate and bow. This gives rise to an internal wave that propagates with an internal wave speed, which is calculated with formulas from literature. The reflection of the internal wave against the bow and the gates is calculated according to certain schematisations. From the flow and density situation at the bow and the stern, momentum equations are used to calculate the influence of density differences on the longitudinal force. Lastly, the total longitudinal force is obtained by the sum of the components of longitudinal force that are relevant to the examined situation. Fig. 6.33 provides the flow chart of LOCKFILL.

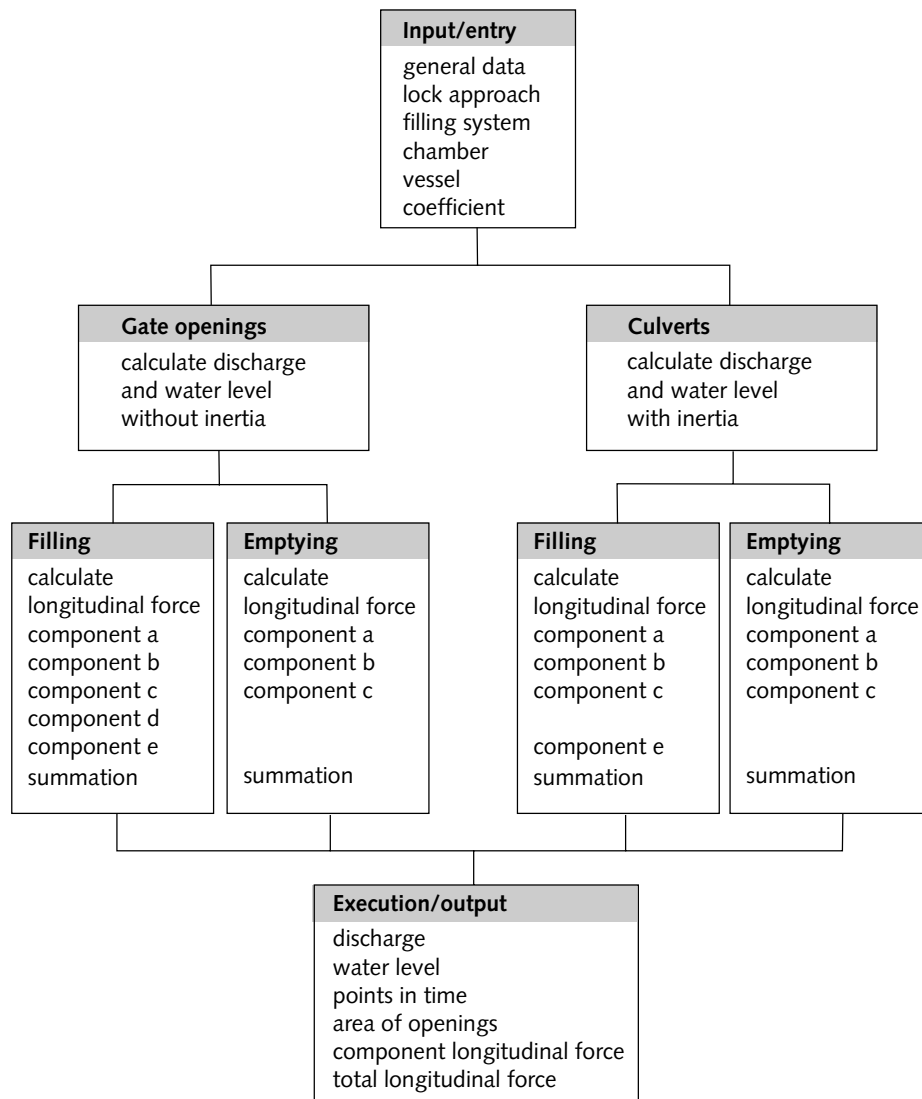


Figure 6.33 LOCKFILL flow chart



Photo 7.1 Mitre Gates at Tweede Sluis Lith during installation (1998)

Chapter 7 Gates, operating mechanisms and sluices

7.1 Introduction

Lock gates are an essential part of a navigation lock. They are movable elements that retain water for the lift of the lock when closed and allow vessels to pass when open. If the lock gates are closed in both the upper and lower head, the water level for the vessels can be gradually brought from the level of the one reach to the level of the other reach (levelling). To facilitate movement of the lock gates, gate operating mechanisms are used. Levelling requires sluice gates in the gates or culverts. These sluice gates are equipped with sluice operating mechanisms.

Functional requirements are set for lock gates, operating mechanisms and sluice gates. These are used to reach the objectives, namely the retaining of water and the locking of vessels to a higher or lower level. The requirements are:

- the gates have to move from a closed to an open position and provide unimpeded passage to vessels entering or leaving, in a length of time that is in relation with the required duration of the lock cycle;
- the gates have to move from an open to a closed position and then be able to absorb the subsequent difference in water level;
- if so required, the gates have to be equipped with lockable openings for the filling or emptying of a lock chamber. The speed with which the sluice gates move have to, in conjunction with the size of the openings, bring the vessels to the required water level in a responsible manner (with regard to safety and duration).

There are several types of lock gates but in the Netherlands, the choice is currently made between four types: mitre gates, single pivot gates, rolling gates and lift gates. On the one hand, the choice is determined by the preconditions and the program of requirements, whereby the lift over the gate, one or two sided retention, the conditions in which the gate should be able to move and the passage width and overhead clearance have to be kept in mind. On the other hand, the costs of similar solutions are an important choice argument. Both electro-mechanical and electro-hydraulic operating mechanisms are applied, each type in diverse variations. It is possible to choose an operating mechanism for each gate type that is not only tailored to the requirements during movement but is also tailored to the gates in both opened as well as closed condition.

This chapter deals with the lock gates (lock gates types: par. 7.2 and lock gate selection: par. 7.3), gate operating mechanisms (par. 7.4) and sliding mechanisms and lock paddle operating mechanisms (par. 7.5) for the normal Dutch design situation. Extraordinary or specific foreign conditions are not addressed. This chapter should enable the designer to select a type of lock gate and gate operating mechanism. For further elaboration on the selected type to an actual preliminary design, we refer to chapter 12 where the load/stress and the steel and mechanical engineering aspects of the gates, operating mechanisms and sluice gates are addressed.

The figures in this chapter and those in chapter 12 are found at the end of the chapter, from page 7-69. The tables follow on page 7-146.

7.2 Types of lock gates

7.2.1 Overview of the lock gates

An overview of the most important types of gates for navigation locks with their distinguishing features and characteristics is dealt with in this paragraph (also see Lit. [7.10] to [7.13]):

Gates rotating on a vertical axis

- *Mitre gates (fig. 7.1 to 7.4, photos 7.2 and 7.3)*



Photo 7.2 Wooden mitre gate of lock at Dalem during positioning (1998)

Mitre gates are flat gates that, when closed, lean against each other and form an obtuse angle. The gates rotate on a vertical axis in the gate recesses. The lift load is transferred to both chamber walls whereby forces are not only created in the direction of the chamber wall but also in the direction of the axis of the gates (horizontal forces or thrust). Basically, the gates are intended for a one-sided retaining structure. With extra facilities, a (limited) negative retaining structure can be realized. In opened condition, the gates are in shallow gate chambers in both chamber walls. The advantages of mitre gates are the economic use of materials, its function as a three pivot girder, the shallow gate recess and the simple operating mechanism; disadvantages are the exact dimensions, the sensitivity to waste and ice and the possibility of collisions (being pushed open by a vessel colliding with the gates) in the direction of the point. In the Netherlands, this is the gate used most often.



Photo 7.3 Iron mitre gates of Kleine Sluis in IJmuiden (1999)



Photo 7.4 Single pivot leaf gate of Lock in Gorinchem (1987)

- *Single pivot leaf gate (fig. 7.5, photo 7.4)*
The single pivot gate is a flat gate that, when closed, closes of the passage perpendicularly. Via the rotation point and the gate tip, the lift load is transferred to both the chamber walls and exerts forces, parallel to the chamber walls. The gate can be provided with a bolt lock for bilateral retention. When open, the gate disappears into a shallow, long gate chamber. In the opposite wall a gate recess is left open where the gate is supported when closed. The possibility for two-sided turning is an advantage; a disadvantage is the long gate chamber, the heavy operating mechanism, heavy rotation points, the large water movement during the beginning and the end of opening and closing as well as the sensitivity to waste and ice. In the Netherlands, single pivot gates are only used in locks with narrow width of passage.
- *Standing tainter gates (fig. 7.6)*
A standing tainter gate is a gate that is bowed in the horizontal surface (part of a circumference) with arms (radius of the circle) through the rotation axis (centre of the circle). The gate and arms form a sector of a circle (wedge). Both chamber walls have a gate with rotation points on the chamber wall (compare the Maeslandkering). Tainter gates can retain bilaterally and be moved under water pressure. The lift force is transferred to the rotation points. When open, the gates are stored in sector shaped gate chambers in the chamber walls. Advantages of standing tainter gates are the light operating mechanisms and the movement under water pressure (if required); disadvantages are the expensive gates, pivoting points and gate chambers and the large construction area for the gate chambers. The only sensible case in which to apply double tainter gates is if the lock is also used as a sluice(way). In the Netherlands, this gate is hardly ever used.
- *Wing gates (fig. 7.7)*
Wing gates are mitre gates equipped with an extra gate plate that is at an angle to the mitre gate. The gates are positioned on both sides of the lock. The gate plate turns in quarter circle shaped gate chambers. Two lock culverts, one of which is connected to the outer water and the other to the inner water, regulate the water level in the gate chamber behind the plate. Because the surface of the plate is larger than the surface of the gate, the gates can retain positively as well as negatively and be opened and closed under lift. Wing gates were used in the Netherlands to prevent calamities (for instance still being able to close off if mitre gates were damaged due to collision) or in combination with draining or sluiceways. The gates can be moved by playing with the height of the gate openings.

Gates rotating on a horizontal axis

- *Tainter gate with counterweight (fig. 7.8)*
A tainter gate is a gate that, viewed from a vertical surface, has a circle segment (cut off half circle) as cross section. On the sides of the gates at the chamber walls, short arms are positioned that go through pivoting points that coincide with the centre of the circle. The extended arms have counterweights on the opposite sides of the gates (compare Thames barrier). The rotation points (centre of the circle) are positioned about halfway in the water depth. The gate can retain bilaterally. Even though the lift load over the gate is guided toward the rotation points and the gate is balanced, a relatively heavy operating mechanism has to be used due to the difference in upward force in various positions. To open, the tainter gate turns downwards into a slot in the bottom or into a stilling chamber or it turns up, but this results in limited clearance (fig. 7.8). Advantages are the light operating mechanism and the short, shallow gate chambers. Disadvantages are the considerable forces on the pivoting points and the sensitivity to waste and silt in the cunet and the construction depth of the cunet (for example 15% of the span), if the gate is positioned in the bottom when open (in view of clearance, this is the common solution). In the Netherlands, this application is sensible if there is limited space for construction in combination with the requirement for unlimited clearance.
- *Tainter gate without counterweight (or sector gate)*
This tainter gate does not have a counterweight and the gate has longer arms than the previous. The gate with arms forms a circle segment. For an open position, the gate drops into a deep

chamber in the bottom or is pulled up (compare the drainage sluice in Haringvliet). The gate is mostly applied in the upper head of locks with a very high lift, in combination with an energy dissipating chamber and therefore not in the Netherlands.

- *Tumble gate (fig. 7.9)*

A tumble gate is a flat gate with a rotation axis at the bottom. When in closed position the lift load rests against the rabbet in the chamber walls, when in open position the gate turns down to a cunet in the bottom. The gate is suitable for one-sided turning but with a bolt lock, it is also suitable for bilateral retention. Disadvantages are the turning points below water, sensitivity to waste and silt and large water movement during opening and closing as well as the fact that it is difficult to inspect and execute maintenance. For Dutch conditions, this gate is not an attractive option. The gate is mainly applied in the upper head of high lift locks abroad. Tumble gates with a rotation axis at the top or as overhead gate (garage door) under a bridge (fig. 7.10) were built in the past.

Gates with horizontal movement

- *Rolling gate (fig. 7.11, photo 7.5)*



Photo 7.5 Rolling gate at Krammersluizen during installation (1985)

The rolling gate is a flat gate that, when closed, perpendicularly closes the passage and the lift load is directly transferred to the chamber walls. The gate can retain bilaterally. There is a deep gate chamber in one chamber wall where the gate is stored when it is open. The other chamber wall has a gate recess. The gate rests on two roller carriages, each fitted with four wheels. The carriages are guided along rails by either flanges on the wheels or by means of roller guides or guide blocks; the choice made in this depends on the size of the indirect loads. The gate is guided along the rails with sliding guides while the horizontal guiding wheels at the top keep the gate in vertical position during movement. Usually the gate is equipped with float control chambers, which result in decreased load on the roller carriages. Yet, resistance in water during movement can increase, which could have consequences for the operating mechanism. Advantages of the gate are the possibility for two-sided turning and the light operating mechanism. Disadvantages are the expensive, deep gate chamber and the expensive gate guiding system.

As variation to the rolling gate, the roller carriages can be replaced by hydrostatic slide bearings ("sliding gate") (photo 7.6).



Photo 7.6 Sliding gate at Nieuwe Oranjesluis in Amsterdam during installation (1994)

A disadvantage could be that due to the minor overweight required, the gate could be sensitive to waves during movement or it could possibly careen due to the force of the operating mechanism. The rolling gate could also be made in bowed shape (including gate chamber) in order to reduce the construction width. In the Netherlands, the gates are mainly used for bilateral retention in locks with large width of passage. In smaller locks with large lift, double leaf gates are also used; the rolling gate is then divided into two and hangs from the upper rails.

Gates with vertical movement

- *Lift gate (fig. 7.12, photo 7.7)*

The lift gate is a flat gate that in closed position, just like the rolling gate, perpendicularly closes the passage and transfers the lift load to the rabbet in the chamber walls. The gate is suitable for unilateral or bilateral retention whereby the construction is almost identical. The open position is achieved by moving the gate up vertically, along guiding sleeves in the control portal that are positioned on both sides of the chamber walls. The gate is balanced by means of counterweights although these are lacking at some locks.

Advantages of a lift gate are the short heads, the possibility of bilateral retention, good inspection and maintenance possibilities and little sensitivity to waste and ice. Disadvantages are the limited clearance (does not always need to be a disadvantage), the complicated gate guides and operating mechanisms and the expensive super structures. This gate was used in the past in the Netherlands for locks with large lift where the gate is lifted as a whole for emptying or filling and the gate is guided with guide wheels. At present, this gate is used for reasons related to limited building space.



Photo 7.7 Lift gate at Prins Bernardsluis in Tiel

- *Drop gates (fig. 7.13)*
The drop gate is also a flat gate that, when closed, transfers the lift load to the chamber walls. For an open position, the gate drops down a shaft in the bottom. This type of gate is applied in the upper head of a high lift lock in combination with a energy dissipating chamber; disadvantages are the bottom seal, difficult accessibility and sensitivity to waste and silt. Locks with a smaller lift require a deep shaft in the bottom and for this reason, this gate is not used in the Netherlands.
- *Double leaf lift gate*
The double plate lift gate is a lift gate that consists of two parts that are placed either next to each other or above each other. The gate is mainly used in the upper head where extremely large water level variations occur. Disadvantages are the deep rabbets and complicated gate guidance and operating mechanisms. This gate is of no importance in Dutch locks.

The Netherlands has locks with very small to very large lift (from a few decimetres to about 14 m) while the horizontal dimensions can be very small to very large (passage width from 4 m to 50 m). From the overview provided above, four gate types have been selected that are important to the Dutch situation and which will frequently be selected in the future. These are mitre gates, the single pivot leaf gate, the lift gate and the rolling gate (including sliding gate). These are dealt with in paragraphs 7.2.2 up to and including 7.2.5.

This is not to say that in future, the selection of other types of gates is out of the question. In situations with limited space and very high clearance for instance, the tainter gate with horizontal pivot point is an alternative.

7.2.2 Mitre gates

7.2.2.1 General

Mitre gates are called mitre gates because, in closed condition, the points lean against each other. Nevertheless, they are flat gates as shown in fig. 7.1 and 7.2. In closed condition, the gates each lean against each other at gradient of 1:3. The gates turn on vertical axels present in both gate chambers. In opened condition the gates are inside the gate chambers completely.

Positive lift load over the gates is absorbed as pressure and bend on the gates. The gates in turn, transfer the generated forces to the chamber walls via the gate axis and bearing surface parallel and perpendicular to the gate chambers. Fig. 7.14 provides a schematic diagram of the reactive force and moments for the gate. The reactive force perpendicular to the gate axis is equal to half the lift load over the gate length. The reactive force parallel to the gate axis (also the normal force in the gate) is 1.5 times the force of lift load over the gate length and is called the thrust. Due to the short gate length with regard to the lock width and the applicable gate gradient of 1:3, the required thickness of each mitre gate is small. This results in favourable material use for the gate.

For the civil construction of the lock, the resulting reactive force on the gate chamber wall is dispersed in parallel and perpendicular directions to the lock axis. What is dispersed parallel to the lock axis is equal to the lift load over half the lock width and this is taken into account in the stability of the complete lock head. What is dispersed perpendicular to the lock axis is equal to the lift load of $2/3$ of the lock width and this is the force that is taken into account in the concrete construction of the gate chamber wall.

In the case of negative lift load, the forces and moments of coupling the gate points to each other are just the other way around. Holding the gate points in position by means of the gate operating mechanism results in other forces and moments on the gate during a negative lift load.

7.2.2.2 Turning points



Photo 7.8 Bottom pivot of the mitre gates at Middensluis IJmuiden

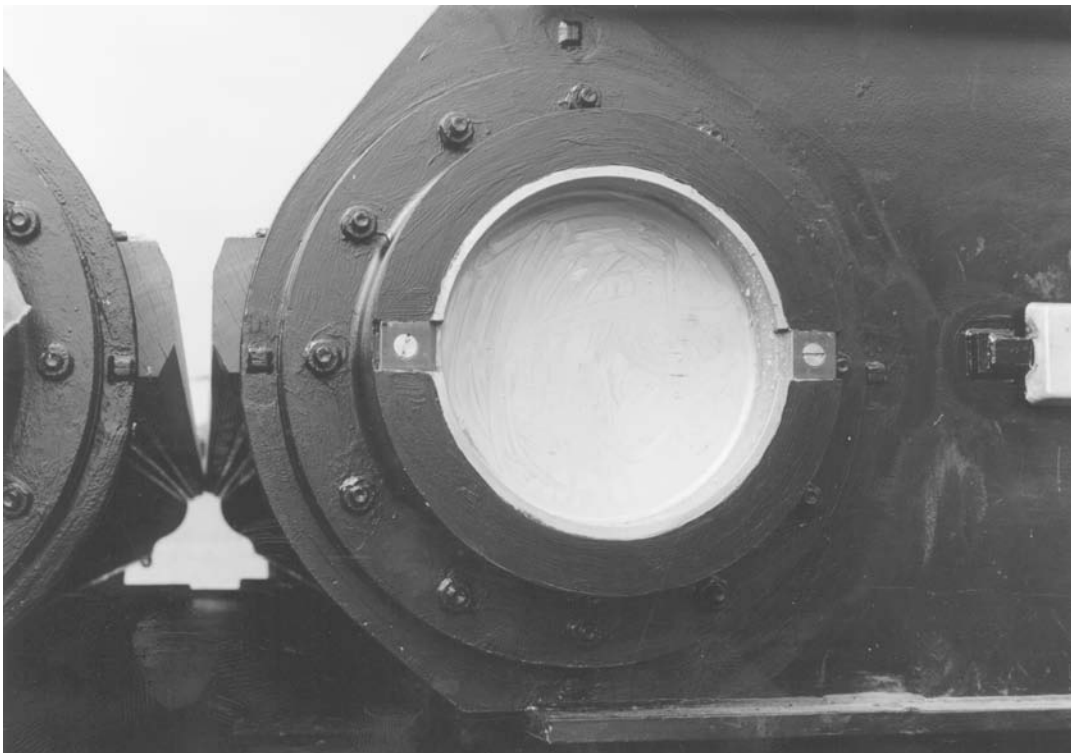


Photo 7.9 Pivot basin of the mitre gates at Middensluis IJmuiden



Photo 7.10 Collar of the mitre gate Tweede Sluis in Lith



Photo 7.11 Pintle rod of the mitre gate at Middensluis IJmuiden

The pivot points of the axes are in the gate chambers. These are recesses in the walls of the lock head. The bottom turning point consists of a pivot (photo 7.8) and a pivot basin (photo 7.9); the pivot is anchored in the bottom, the pivot basin to the gate (fig. 7.19). The upper turning point consists of a collar (fig. 7.10) and a pintle rod (fig. 7.11). The rod is attached to the gate and the collar is anchored to the wall of the gate chamber (fig. 7.17).

When completely open, the weight of the gates is placed on the turning points decreased by the buoyant force. During movement, the force in the turning points is larger due to the load resulting from differences in water level over the gate (residual lift, upward force, wind waves and the like) and the operating mechanism (fig. 7.15).

In general, clearance has been left between the pivot and pivot basin and between the pintle rod and collar. In a closed position with a positive difference in level over the gates, the gates topple slightly and lean on the gate chamber along the full height (fig. 7.20). For this reason, each gate has been provided with a vertical support beam in the direction of the longitudinal axis of the gate and one perpendicular to that (fig 7.1). This results in relief of the pivot points. In cases of extreme thrust, the wooden support beam is replaced by a number of steel bearings, divided over the height of the gate. The gate chamber will then have steel chairs that transfer the thrust to the walls of the gate chamber. If the gate load is variable due to high wind waves that make the pintle rod jitter in the collar, the upper turning point should be without clearance. When a negative difference in level must be retained, the upper turning point should be without clearance in order to avoid substantial leakage. In a closed condition, such a turning point together with the pivot has to absorb the complete load of the water level to be retained. Usually, these turning points have to be substantial as they experience considerable load (fig. 7.18).

7.2.2.3 Parts

Mitre gates are generally control gates. A control gate consists of a framework of horizontal girders that are placed on a front and a back post. Between the girders, there are vertical posts. Cladding is placed on this framework of girders and posts. The cladded fields themselves could still be braced with horizontal or vertical plate bracers. The water pressure is transferred via the (possibly braced) cladded areas to the posts and girders that in turn, transfer the pressure to the front and back posts.

Mitre gates have the following functional parts:

- A *cladding* that absorbs the water pressure and creates a separation between water on both sides of the gate. Horizontal girders and vertical posts support the cladding. The cladding is placed on the low water side to prevent the pressure on the pivot from becoming less than 30% of the dry weight due to upward force.
- *Horizontal girders* that transfer the load from the cladding via the vertical posts to the front and back posts.
The number of girders depends on the height of the gates and the lift load. The height of the girders (thickness of the gate) depends on the width of the gate and the lift load. The height of the girders varies between 5% and 6% of the clear width of the lock head. The place of the upper horizontal girder is determined in the height direction by the upper turning point and the point of action of the gate operating mechanism. The bottom girder is usually in the centre of the bottom seal. If the gate is equipped with levelling openings, the second last girder is positioned above the openings.
- *Vertical posts* between the horizontal girders.
The vertical posts transfer the load on the cladding to the horizontal girders. At levelling openings the distance between the bottom and the second last girder is sometimes so large that the vertical posts between these two girders are higher than the posts used between the girders above this. The construction is then also used to support the levelling sluices and to attach the guides for this.
- The *front post*, the vertical post that transfers the force with which the gates support one another to the parts of the gate concerned.
- The *back post*, also a vertical post, transfers the thrust from the gate to the wall of the gate chamber, or to a turning point if these were executed 'without clearance'.

- A provision to improve the *gate torsion strength*. This could be either by means of a chamber construction in the gate or by means of transverse bracing to the non-cladded side. During movement the gate load is on torsion because the centre of gravity of the external load does not correspond with the position of the push-pull rod either due to the load of an obstacle in front of the gate or due to a negative lift load. For an example of such a chamber construction, see fig. 7.1.
- Wooden or steel *support* along the back post to transfer forces in the direction of the axis of the gate to the wall.
- Wooden or flexible *sealing* along the bottom girder and on the back post, perpendicular to the axis of the gate. The wooden support on the front post also functions as sealing.
- Wooden *guiding beams* on the cladding side to prevent damage from vessels sailing past.
- Supports on the uncladded side to support the gate against vessel impact and to prevent the operating mechanism from becoming overloaded due to gate deformation.

Besides this, there are turning points that are the point of action for the operating mechanism and in general, there are levelling sluices with slide guides and energy dissipating bars.

Sometimes when the gates are low in comparison to the width, only vertical posts are applied without horizontal girders in between. These posts reach from the bottom to the top horizontal girder. This kind of structure is found at small lift.

7.2.2.4 Sealing

The position and the kind of sealing depends on the turning points:

- *Turning point with clearance*
Gates that have turning points with clearance and a 'free' or 'unrestricted' turning point (fig. 7.21) are provided with wooden supports along the back post (one in the gate axis for thrust and one perpendicular to the gate axis) (photo 7.11) and along the front post (in the gate axis). The sealing takes place via the perpendicular axis support of the back post, along the bottom girder and along the front post in the gate axis.
- *Turning points without clearance*
Gates provided with turning points without clearance (fixed turning points) require one flexible (rubber) seal, positioned perpendicular to the gate axis at the back post, that rests against the sealing face with sufficient pre-stress. Using a wooden seal instead of a rubber seal is not possible because this becomes jammed before the gate is closed. The same applies to a seal along the bottom girder.
The support on the front post could, at small load, also function as the seal and is made of wood. At larger load the gates lean against each other on steel supports and flexible seals are required along the complete height of the support.

A watertight mitre gate construction requires a high level of accuracy, both from the gate as well as from the civil work. The following measures are taken for this:

- the sill is poured with the aid of an accurate set mould so that the position of the gates, in regard to each other, is guaranteed;
- the pivots are adjusted in the recesses in the bottom of the gate chambers with respect to the sill and the collar and are then poured in (fig. 7.13);
- the collars and upper turning points are subsequently adjusted with regard to the concreted pivot and are then filled with concrete;
- the vertical support areas for the sealing can then be accurately adjusted;
- tolerances are provided for the gate dimensions.



Photo 7.12 Support areas of the mitre gate at Tweede Sluis in Lith



Photo 7.13 Adjusting the pivot of a single pivot gate of the lock in Gorinchem (1987)

Despite these measures, it is possible that operational leakage occurs due to deflection of the chamber walls or due to damage to the seals because of floating waste. During movement, this can easily get jammed between the gates, in the gate chamber or on the sill. When gates are exchanged, the supports or where appropriate the seals sometimes have to be adjusted so that spare gates can be used in both heads. The dimensions of both heads will not always be identical. For this reason, please take into account that mitre gates are never guaranteed to be watertight.

7.2.2.5 Levelling

Navigation locks with mitre gates level up to a lift of 5 or 6 m with the aid of lockable openings in the gates. Because of the gates in the lower head of canal locks, a lift of about 8 m can be levelled. Chapter 6 extensively deals with the hydraulic aspects of levelling and the design of the openings.

The sluice gates in the gates are situated on the high tide side. These sluice gates close very well as they experience pressure from the difference in level. Behind the sluice gates, the thickness of the gate is available for the guide logs that divide the water as much as possible over the width of the lock. On the low tide side of the gate, where the opening can be the largest, energy dissipating bars are placed that decrease the energy of the water pouring into the lock. The levelling openings are kept as low as possible in the gates so that vessels experience the least inconvenience from the water flow. In a vertical sense the flow is guided upward; the effect of the division is not large at the start of lifting the sluice gates.

For constructional reasons, the total width of the levelling openings directly behind the sluice gates is no larger than 60% of the passage width of the lock head. Each set of gates has at least four sluice openings so that, should one of the four cease to function, the remaining openings can still divide the water stream over the width of the lock in an acceptable manner.

The levelling openings can be standardized in width, which makes sluice gate design easier. By using the widths 1.40, 2.15 and 2.60 m, the deviation from the standard of 60% of the width of passage of the lock head is relatively small (< 3%). Yet, it is not always done like this. The height of the levelling openings varies between 0.60 and 1.75 m; the speed of the sluice gates is between 2 and 10 mm/sec. Both parameters are dependent on the lift over the gate and on the length of the lock chamber. However, the degree of lock blockage because of the vessels and the distance from the bow to the lock gate are also of importance.

7.2.2.6 Sensitivity to waste

Mitre gates are sensitive to waste. During the opening of a gate, floating and drifting waste could get caught between the gates and the gate chamber and block the movement to such an extent that the desired end position cannot be reached. During closing, the floating or sunken waste could get caught between the gate and the sill with the same results as just described. Lock problems mainly occur with mitre gates that have not been used for a long time, such as the intermediate gates (silting). When it blocks, the force on the turning point due to the supplied force of movement can run up quite high and become normative for the gate construction and the operating mechanism.

Gate chambers can best be kept free of floating or drifting waste by using an air bubble installation. By blowing air from the bottom, waste is removed from the gates. On the coastal side of locks, where a pneumatic barrier is already in use for combating the exchange of fresh and salt water, it is possible to make simple adjustments that so that air bubbles are also blown from the bottom of the gate chambers. It is impossible to prevent the gates or the gate and the sill from being blocked by an obstacle unless previous inspection takes place if the lock gates have not been in use for a while.

7.2.2.7 Sensitivity to ice and ice forming

Mitre gates are sensitive to floating ice in front of the gates and in the gate chambers as well as ice growing on the front post and around the back post. Ice blocks in front of the gates could also be the cause of the gates not being able to open completely. If the ice on the front post becomes too thick, the gates are unable to close completely. Ice on the back post could cause jamming and damage to the structure as well as the turning points. In addition, the operating mechanisms could be too weak to move the

gates. Operating mechanisms already yield a lower return in cold periods and because of that, a lower capacity for pulling or pushing. Furthermore, sliding levelling gates could become frozen. These problems mainly occur outside the chamber in the upper or inner head.

Ice forming in front of and on the gates can be prevented for a substantial period of time by, just like with waste, blowing air bubbles from the bottom of the gate chambers and possibly in front of the gates. Ice blocks are also kept away from the gates. Furthermore, moored tugboats or gauging-vessels with rotating propellers are positioned in front of the gates. Ice forming in the lock chamber can hardly be prevented.

In locks with large lift, where it is impossible to keep ice blocks away from the gates by simple means, ice logs are sometimes used. The ice that enters the chamber together with the vessels is kept away from the gates and the gate recesses by this. The ice log drifts with the decreasing water level and stops the ice during levelling. The air bubbles blowing in the gate chambers are enough to prevent further inconvenience. Behind the ice log the gates are able to move freely in the water. As long as the blocks of ice leave the chamber together with the vessels, the lock can remain operational. The ice log has to be hoisted up to allow vessels to pass. General measures for decreasing ice problems are unrelated to mitre gates. In chapter 10 of the Delft Hydraulics report Q1442 (Lit. [7.15]) and in the memorandum 'Knelpunten door vorstproblemen' (lit.[7.8]) this subject is addressed in more detail.

7.2.2.8 Gate chambers

When open, mitre gates are positioned in the longitudinal direction of the lock. A gate chamber protects the gate from catastrophic collisions. Vessel impact from the side is absorbed by the supports on the chamber wall and to a large degree, by the turning points. The heads of the gates are enclosed by the gate chamber in such a manner that it is impossible for a vessel to sail in between the gate chamber and the gate.

The space around the gate in the gate chamber should not be too narrow so that the water can easily flow towards and away from the gates at the beginning of closing, the end of opening or when the gate is open and the vessels are passing. This prevents the operating mechanism from excessive load.

Fig. 7.22 provides a schematic outline of what a gate chamber should look like with respect to the gate shape. Dimension L1 is about 0.8 times the gate thickness, dimension b1 at least 0.4 times the gate thickness. The gate thickness is usually 1/16 to 1/20 of the width of passage of the lock.

7.2.2.9 Foot or bicycle bridges

For accessibility of both chamber walls, lock gates are usually provided with a foot bridge. Maintenance or repairs to the operating mechanisms of the gate sluices requires good accessibility. The foot bridges have at least one handrail.

If there is no linking bridge nearby, sometimes a public road has to be present over the navigation lock for pedestrians and cyclists. The tapered shape and the thickness of the gates limit the possibilities of a passable bicycle path. Both sides of the path must have a railing.

7.2.2.10 Mitre gates in wood or in steel

Most of the mitre gates are made of steel, see examples in fig. 7.1 and 7.2. There are hardly any drawbacks in the use of steel gates with regard to required dimensions or absorption of load.

For small and medium-sized navigation locks, mitre gates are sometimes made of wood. This is due to economic considerations (construction and maintenance costs, life span) or historical considerations (lock as monument). Wooden gates are largely gates that absorb a light load during movement, such as sheltered locks and/or locks where large wind waves do not occur. For medium-sized locks, an additional requirement is that the lift load cannot be large. The required hardwood beams are often not available or cannot be used due to environmental considerations (felling tropical forests). Wooden gates are unable to absorb large local forces or only do so with difficulty. Extra facilities are therefore required for attaching the gates to the turning points and the operating mechanism. Fig. 7.4 and photo 7.2 show

examples of a wooden mitre gate. It is possible that in the future, synthetic mitre gates or gates in stainless steel could be used in small locks (chapter 22).

7.2.2.11 Maintenance and exchange

Major repairs and repairs to the mitre gates usually take place by exchanging the gates with a (set of) spare gate(s). To do this, navigation in the lock has to be blocked. To keep this disruption as short as possible, the spare gates are kept available in fully operational condition, which means complete with sluice gates and operating mechanisms, with fixtures for push-pull rods, pivot basins and pintle rods. The term of major, periodic maintenance depends on the material (steel requires more frequent maintenance than wood does), the preservation used, how intensively the lock is used and the chances of damage due to collisions.

The exchange of gates takes place with mobile lifting devices, floating derricks or special facilities, depending on the dimensions and weight of the gates or the accessibility of the lock complex. During installation and transportation, the gate hangs in a hoisting yoke that is specially designed for that type of gate.

Mitre gates that have turning points with clearance are fairly simple to hang. The gate is positioned above the pivot pin, slightly out of plumb. The gate is guided by the supports on the gate. When the gate is resting on the pivot it is moved in the direction of the collar after which the collar encloses the pintle rod.

The gates with fixed (clearance free) turning points have more parts that need to be disassembled and reassembled for the exchange. These activities are labour intensive, also because of the more accurate dimensions.

7.2.2.12 Unilateral and bilateral retaining structures

Unilateral and bilateral retention

Mitre gates are extremely suitable for unilateral retaining locks with a width of passage between 6 to 24 m. This one-sided turning occurs at locks in canals or rivers next to a weir, or at locks on a river or basin.

In locks that have to retain a lift on both sides, mitre gates are also used. The two-sided turning occurs at locks that are subject to tides, locks that are subject to river levels as well as at locks between two basins. For locks with a width of passage of between 6 and 24 m, these are extremely suitable.

Single set of gates at bilateral retention

In a one-sided turning structure, one set of mitre gates carry positive load for a certain period and negative load during other periods. The negative lift load causes tensile forces in the mitre gates that can only be absorbed by the gate chamber wall via the turning points. During negative lift load of consequence, the turning points are under such load that fixed, clearance free turning points are required (fig. 7.18) with a roller bearing as upper turning point. The application of clearance free bearings also means that positive lift load has to be absorbed by the turning points.

Without additional provisions, mitre gates that must be able to retain negative load will not seal well. The gates will have to be bolt locked due to the negative lift load, either to each other or via the operating mechanisms. In the first case, leakage occurs between the front posts and this can only be solved by a complicated construction. In the second case, the gates have the tendency to start bending and leaking at the bottom. To limit this, the gates have to be made extra stiff thus heavy. If the operating mechanisms are to absorb the negative load the gates will have to be (partly) heavier than would be necessary for movement.

Double set of gates in the tidal area

Navigation locks in areas where there could be differences in lift are often provided with two sets of gates per lock head. One set for positive retention to the one side, the other set for positive retention to the other side. On closer inspection, it will become apparent that one set of gates, depending on the direction of rise, will experience (albeit) limited negative load.

During locking in the tidal area, often all four gates of the lock head concerned are closed out of safety considerations (square lock). Sudden increases or decreases in water level then cannot surprise the lock manager. In lock approaches along the Dutch coastline it is locally possible for surges to occur with a rising velocity of 0.1 m per minute and with a maximum amplitude of 1.5 m. Always using the square locking gates results in a substantial reduction of the effective length of the lock chamber (fig 7.23, top figure).

Square locking also has consequences for the levelling system through the gates. During the levelling process with squarely locked gates, the gate sluices in both sets of gates have to be opened. Because a difference in level occurs between the gates, it causes a negative load on one of the two sets of gates and this has to be absorbed by the operating mechanism. The negative load can be decreased by immediately opening the downstream sluice completely while opening the upstream sluice more gradually (fig. 7.24).

To increase the effective chamber length it is possible to use only one set of gates per head, the positive retaining gates, around the time of high tide or low tide. If the gates are also able to retain negatively, even to a limited degree, the outer gates sets can be used to increase the chamber length even further during periods when the water is more or less equal on both sides of the lock (fig.7.23, lower figure).

Double set of gates at rivers

At locks where it is only the influence of the river level that necessitates bilateral retention, square locking is not necessary. The increase in river level is very gradual and therefore the sets of gates can be used unilaterally.

7.2.3 Single leaf pivot gate

7.2.3.1 General

A single leaf pivot gate, hereafter called a pivot gate, closes off the complete sluice opening when closed and stands at a right angle (90°) to the lock axis. In this, the gate is a girder on two supporting points that is only under strain of bending due to the lift load over the gate. The reactive forces are transferred to the chamber walls via the front and back posts. The thickness of the gate is 12 to 16 % of the clear width of the lock. This is about twice the thickness of mitre gates.

The gate turns on a vertical axle in the gate chamber. When open, the gate stands in the gate chamber, outside the clear width of the width of passage. In the chamber wall opposite the gate chamber, there is a gate recess in which the front post rests against the chamber wall when closed. If the gate is positioned against the head of the lock head, a gate chamber and gate recess is not necessary and this results in a relatively short construction time of the lock. Fig. 7.57 provides a schematic overview.

Pivot gates are also suitable for retaining bilateral lift. The negative lift load is absorbed by the turning points on the one side and by a (sometimes) complicated bolting system on the other side (fig.7.56 and 7.58).

Disadvantages of the pivot gate are the relatively long motion time and the relatively large force of movement required. When it closes, the gate pushes out a large quantity of water when compared to the lock content. In almost closed condition, it is difficult for this water to flow around the gate tip and results in waves in the chamber where moored vessels could experience inconvenience. The speed of the gate has to be kept low. On the other side of these disadvantages, we find the advantages: only one operating mechanism is required as opposed to two mechanisms for mitre gates and the operating mechanism is placed completely outside the lock profile and therefore, it cannot be damaged by collisions.

Pivot gates belong to a gate type that has been used in locks for a very long time. They were generally made of wood for unilateral retention. As the need for larger locks grew and the required wooden beams

were not available, wooden mitre gates became the solution. At present, the gates are mostly made of steel as steel has hardly any limitations in the gate dimensions for which the pivot gates are now regularly used.

In the past decade, steel gates and very occasionally wooden pivot gates were used in locks. In unilateral water retention the pivot gates are particularly suitable for very small locks, which are mostly (short) recreational navigation locks to 6 m wide. Small locks (to 10 m wide) that have to retain bilaterally, are also fitted with pivot gates. It is more economical to equip medium-sized and large locks with other types of gates.

7.2.3.2 Parts

The parts and the design of wooden pivot gates for unilateral load are, in broad strokes, the same as the parts for mitre gates. The structures face different strains however (strain of bending). The mitre gate of fig 7.4 can also be used as a pivot gate. The collar has to be set-up differently because the direction of load of the end positions differs from that of mitre gates (fig. 7.25).

A bilaterally loaded gate is usually made of steel because it is difficult for wooden gates to absorb large local forces. Fig. 7.5 provides an example of a steel pivot gate. During both positive and negative lift load, the reactive force at the back post is absorbed by two turning points and at the front post, it is absorbed by two saddles (positive load) or a bolt lock (negative load). The operating mechanism is mounted on the jib of another horizontal girder.

7.2.3.3 Sealing

Wooden gates close off against the vertical supports on the sides and against the sill at the bottom. Given large load, the sealing at the bottom has to be a flexible (rubber) support as the bearer is unable to sufficiently follow the deformation under load.

In the case of steel gates with bilateral load, all supports are flexible and to achieve proper sealing, there should be sufficient pre-stress from the gate operating mechanism or the bolt lock.

In general, the most flexible supports with high elasticity should be selected in order to have the least pre-stress force possible. Take into account the deviations from the dimensions of the concrete work, the gate and the bolting installation as well as the locking method.

7.2.3.4 Levelling

The levelling through openings in the pivot gate in a unilateral retaining structure is better than it is with mitre gates. It is easier to realise an even dispersion of incoming water across the lock by positioning the pivot gate perpendicular to the lock axis.

In bilateral retention, it is often not even possible to realise the same level of flow distribution in both directions. If the intake is normative, this determines the place of the dissipating bars. In this case, the gates are not the same and therefore, not interchangeable. The levelling sluices for a bilateral retaining structure, that should close watertight, require a specially adapted construction (fig. 7.123). The solution to a bilateral retaining structure with identical pivot gates in accordance with fig. 7.57 always has good intake conditions.

7.2.3.5 Sensitivity to waste and ice

A pivot gate is sensitive to floating waste and is particularly sensitive to ice at the gate chamber and gate recess. This is because these gates cover a large area when turning, even more than is the case with mitre gates. In front of the opening, waste collection takes place in the gate chamber and for closing, in the gate recess. The consequence for the strength of the gate is not that large as the gate operating movement at the front post causes less large forces. The gate chamber can be kept clear of waste and

ice reasonably well by blowing air from the bottom. Gates getting stuck due to waste on the bottom cannot be prevented unless a deeper floor is constructed in front of the sill.

The solution of a pivot gate that turns outside the lock, therefore without gate chamber and gate recess (fig. 7.57), prevents a large number of the previously described problems. The gates can then move the waste and the ice away in front of the gates.

7.2.3.6 Gate chambers and gate recesses

For the shape and the dimensions of the gate chamber, the same considerations apply as apply at the mitre gates (fig. 7.22).

The gate chamber is positioned on the side of the rotation axis. Due to the thickness of the gates, the depth of the chamber is larger than that of mitre gates. A pivot gate is about twice as thick as a mitre gate for the same clear width of a lock.

The gate recess is the recess in the lock head that is not on the turning point (or gate tip) side. The depth of the gate recess is usually made as large as the gate chamber. The water is then able to flow around the tip of the gate as long as possible. In the case of bilaterally retaining gates, the recess has to be deeper due to the bolt locking construction (fig. 7.26), which should be able to turn to the wall sufficiently so that the pivot gate is able to pass.

7.2.4 Rolling gates

7.2.4.1 General

A roller bearing gate is a gate construction that moves diagonally across the lock axis to open or to close (fig. 7.11). From an open position, the gate rolls (or slides) from the gate chamber to the opposite gate recess. The gate moves through a cunet in the bottom of the lock chamber. The roller bearing gate rests on two roller carriages that serve to guide the weight of the gate while rolling. The gate can hinge around the roller carriages and move sideways in relation to the roller carriages. The gate can tip towards the top roller guide that is positioned in the beginning of the gate chamber. In closed position, the gate horizontally leans against both chamber walls and is pressed onto the supports by the water pressure.

The rolling gate is bilaterally retaining. This means that with regard to construction, the gate must have cladding on both sides. A single cladding for both retaining directions is not feasible. The cladding on the low tide side retains the highest outer water level, while the cladding on the high tide side retains the highest inner water level. Usually, the cladding is not the same in height. It is not advisable to use rolling gates for unilateral retention, as mitre gates are more economical in this case.

Rolling gates are only used for bilateral retention. Very large locks, marine locks, usually have rolling gates. Large navigation locks for inland navigation that have to retain bilaterally, could be equipped with rolling gates. Smaller rolling gates are hardly ever used.

7.2.4.2 Parts

The component parts of a roller bearing gate are also determined by the manner in which the parts are transported and mounted in the lock chamber. Rolling gates up to 24 m clearance are transported on a pontoon and with a floating derrick or (if possible) a mobile lifting device on rails in the chamber. For gates up to these dimensions and weights, the required hoisting equipment is present to a satisfactory degree. This does not apply for the much larger rolling gates. Hoisting equipment for this purpose is not generally available or unobtainable in the short term. Therefore, these gates are executed as self-supporting gates.

Rolling gates that can be positioned by means of a derrick are composed as follows (fig. 7.11 and 7.12):

- a *cladding* on both the high and low tide side of the gate;
- the cladding transfers the load from the inside, across a number of vertical posts that are divided across the length of the gate. The girders are part of a vertical portal or other compound open

- constructions;
- various horizontal girders that absorb the load from the portals;
- the horizontal girders transfer the load to the end portals that, in turn, transfer the load to the gate chamber and gate recess. The gate derives its torsion rigidity from the previously mentioned construction parts;
- the end portals and the bottom of the cladding have been provided with wooden or synthetic supports;
- two bearings on which the gate rests on the bottom roller carriage and that take the gate along in the direction it should go;
- if desired, a relief tank in the gate which decreases the overweight on the roller carriages;
- one or two attachment points for the steel cable(s) that pull the gate open and closed;
- protective beams against collision over the cladding;

The thickness of the gate is not so much determined by strength but by the required width of the roller carriages. It is important that the gate has good flow through in the longitudinal direction. During movement the gate pushes aside a quantity of water. This is seen most clearly when pulling back the gate into a narrow chamber. There should be as little obstruction as possible between the walls of the gate.

Rolling gates rest on the roller carriages with a certain overweight in order to be stable under all conditions, also at the highest water level and waves. The tensile forces determine the required overweight on the carriages. On the front carriage through the force of opening, on the back carriage through the force of closing. The maintenance method often determines the maximum load on roller carriages. Silt on the gate increases the weight in 'dry position' to a large degree.

Very large rolling gates, for which there is no hoisting equipment in the shape of a floating derrick available at the time required, have additional accessories that make the gate self supporting:

- a water chamber with which the gate can be transported over the waterway concerned with sufficient freeboard;
- equipment to float the gate down on to the roller carriage; for this purpose, the water chamber is divided into a number of sections that can be separately filled or emptied (fig. 7.28);
- accessories with which the gate can be lifted for maintenance (air pipes, control valves etc.).

7.2.4.3 Assembly and maintenance and the constructional consequences

Positioning in the lock

A rolling gate with its own floating system is manoeuvred to above the cunet in the bottom. The roller carriages were previously positioned on the rails. The gate chamber and gate recess are used as guides while the gate is floated down. Provision was made in the cunet at the bottom to place the roller carriages on and between the rails and to fix them in place. During the positioning, the placing of the gate releases the gate rollers. Because the roller carriages are not fixed to the gate, in essence it is possible to change the roller carriages by lifting the gate slightly.

At the first assembly of the gates, the gates can usually be placed at inner water level. This determines the position of the gate on the water chamber. The gate should have sufficient floating space above the bottom roller carriages (fig. 7.30). In the exchange of gates, there is probably a low water level on the tidal side of the gate. If the position of the water chamber is based on the low water, this is usually so low in the gate that it will prove to be unstable if floating without guidance.

Positioning in the chamber

During the exchange of rolling gates, obstruction of the lock can be reduced if the floating down takes place in the gate chamber. The gate chamber will have to be provided with additional guidance facilities for longitudinal and cross direction. In fig. 7.29 this is indicated in the view from above. Naturally, the facilities for placing the roller carriages in the gate chamber have to be present.

Floating positioning of a gate in the chamber requires a wider end log at the end of the chamber. Fig. 7.31 shows the consequences in front of the entrance of the gate recess. The underside of the wider end log

has to connect with the supports (sealing) at the underside of the gate. The underside of the end log tapers down for this purpose (fig. 7.32).

A constant water level can be maintained in the gate chamber by closing this off with partitions or stop logs after the gate has floated in. The positioning of stop logs can take place as indicated in fig. 7.33. In this manner extra obstruction caused by a floating derrick is prevented. The water level can be maintained by the pumping installation for pumping out the chamber. Normally the chamber has to be pumped out for exchanging the rails or for maintenance to the gate that has to take place in situ.

Floating down

There are ballast tanks, trim tanks, diving tanks, sink tanks and relief tanks that together, make up a water chamber that is situated across the complete width of the gate (fig. 7.28). The floating down of a gate takes place by allowing water in certain tanks. The arrangement and capacity of every tank is determined by its function. The level of the underside of the water chamber depends on the available water level and the required stability of the gate, the top of the required freeboard.

At the beginning of floating down, the ballast tanks are filled with water to the extent that the top of the water chamber tallies with the waterline. The filling of the separate trim tanks sets the gate horizontally. Further floating takes place by means of filling the diving tanks, whereby the content has to be sufficient to float the gate down onto the carriages.

If the top of the water chamber sinks through the water line, the gate starts to float on the above lying sink tanks. The gate takes its stability from this in longitudinal direction. In cross direction, the stability will be almost nil, which is why gate guidance is required during floating down.

When the gate is resting on the roller carriages, the ballast tanks are filled some more. The volume of the tanks is adjusted to the required overweight of the gate on the carriages. This can differ per carriage. The centre of gravity could be outside the middle but also, the tensile force on the gate is larger for opening than for closing (fig. 7.34).

Maintenance

Maintaining the gate and executing major repairs requires extensive provisions made in relation to the environment. There are very few existing facilities for large and heavy gates with their own floating systems. The maintenance can best be executed in the gate chamber, which will have to be equipped as a gate dock. If that affects the reserve lock too severely, an extra dock will have to be built there.

Rolling gate without a floating system

Positioning a rolling gate without its own floating system takes place with a floating derrick in the lock chamber. The gate is manoeuvred above the chamber and the recess. When lowering the gate, it is guided between the supports of the chamber and the recess. The roller carriages are flexibly attached to the gate. The flanges of the wheels (or otherwise) seek the rails that are mounted on the cunet in the bottom of the lock. It is clear that positioning a gate with the aid of a floating derrick is much simpler than placing a 'self-supporting system'. This makes the maintenance (conservation) much simpler because the gate can be placed on the bank and maintenance is executed in the own workshop for instance.

7.2.4.4 Sealing

Rolling gates seal against the vertical supports on the sides and against the sill at the bottom. The material of the supports depends on the manner in which the gate is guided. If it is a rolling guide with push-off design, the wooden gate rests on concrete in closed position. The wood could be provided with a rubber slab and the vertical sealing then becomes optimal.

The horizontal sealing, along the bottom of the gate, has to withstand deflection. The concrete sill (or the poured profile) is in a straight line. To provide the bottom middle of the gate the possibility of bending, and thus bending back, a spring suspension is applied. Due to the lift over the gate, the suspension could bend out too far on the inside. The suspension is stopped by the supports that are placed at the ends of the vertical beams (fig. 7.35). The bottom support also has a rubber slab for proper sealing.

If the gate has sluice gate guides, rubber cannot be applied. The gate does not seal well. Local inaccuracies or damage in the supports or in the dimensions of the structure then cause some leakage.

7.2.4.5 Gate guides

During movement, rolling gates are exposed to load perpendicular to the gate surface due to differences in water level and water density. With a rolling gate, the load is absorbed by three support points, two at the bottom in the cunet and one at the top of the gate in the gate chamber.

If the load is small, the gate is able to move while it is indirectly being stopped by the supports. At the bottom, there are two support points and these are positioned at the end portals. At the top, there is one support point that is a bearing on the gate, which slides along the wall of the gate chamber or, with a bearing on the wall of the gate chamber that slides along a track on the gate. The choice for a track along the gate or along the gate chamber depends on the design of the entrance of the chamber but also on the height of the vertical supports.

If the loads are very large, as is the case at marine locks, wheels are used to guide the gates. To prevent the wheels from having to absorb the lift load in closed condition, the wheels are relieved in that position. This usually requires complicated constructions that are difficult to maintain.

7.2.4.6 Levelling

Levelling through openings in the rolling gates can be found in locks with a width of for instance 24 m. At larger locks levelling usually takes place by means of separate culverts as these exert lower forces on the vessels and larger sea-going vessels have mooring systems that, relatively seen, can absorb less than the mooring systems on inland navigation vessels absorb.

Levelling through rolling gates is structurally less simple. There are three possibilities:

- 1 In both claddings an opening with sluice gates on the downstream side (fig. 7.36, right picture). The sluice gates are negative turning gates. This negative turning requires pre-tension in the guide, which increases the lifting power of the sluice gates.
- 2 A chamber is installed between the claddings so that one two-sided turning sluice gate is sufficient (fig. 7.36, middle picture).
- 3 In both claddings, an opening with a sluice gate on the upstream side (fig. 7.36, left picture). The sluice gates are positive turning gates but cut across the bracings present in the gate. The guide and the operating mechanism are difficult to reach.

A good dispersion of the water flow in the chamber cannot be achieved with solutions 1 and 3. It is possible with solution 2 and this is the preferable solution.

7.2.4.7 Gate chamber and gate recess

The gate chamber for a rolling gate that can be lifted from the water by means of hoisting (thus without own floating ability) requires few facilities. The width and the length have to be sufficient to limit head-water in front of and behind the moving gate. It must be possible to lay open the chamber to inspect the rails and guides. The gate must be pulled far enough out of the clear width of the lock to prevent collisions with vessels sailing by.

The gate chamber for larger gates (very large marine locks) where the gate is floated in and subsequently sunk in requires a large number of facilities:

- the gate chamber has to be long enough that the roller carriages can be hoisted away behind a gate laid open;
- it must be possible to exchange the roller carriages under a floating gate;
- the chamber should be sufficiently wide for the execution of simple repairs;
- the chamber has facilities for floating a gate into the chamber;
- guides should be placed in the chamber for floating up or sinking down the gate;
- the chamber is provided with supports against which a gate should run up if the stop switch fails;
- if required, the chamber should connect to a road over the gate.

If the gate chamber is also used as a dock, the following is also required:

- it should be possible to lay open the chamber without obstructing the lock;
- there should be facilities to support the gate;
- the bottom of the chamber should be easy and safe to reach;
- a mobile lifting device should be able to drive over the chamber in order to supply and remove spare parts while the chamber remains accessible.

A gate recess is equipped with a guide to guide the gate into the recess free of interference. During the movement the gate is twisted by load perpendicular to the gate surface. If these loads are substantial, rollers with push-off direction are used. Against the wall of the recess there are flexible supports in case the stop switch fails.

7.2.4.8 Road traffic over a rolling gate

Rolling gates can be made suitable for the traffic on lock level. Depending on the thickness of the gate, one or more traffic lanes are possible. The capacity is smaller than that of a separate, movable bridge of the same dimensions because of the bends in the road (fig. 7.37). This could be better but it requires (1) a top roller carriage that moves with the gate and makes the chamber longer or (2) an expensive bridge over the gate chamber.

7.2.4.9 Sensitivity to waste and ice

Rolling gates are sensitive to silt and floating waste. It is sucked into the gate chamber during the closing of the gate, sinks behind the gate and collects against the back wall of the gate chamber. There should be sufficient space there to contain this waste. The waste is periodically removed with a grab dredger or something similar. The gate and the roller carriages are equipped with track clearers to prevent them from getting stuck. In addition, a waste grid is positioned at the bottom of the gate in front of the roller carriages.

Problems hardly occur in the gate recess because waste can easily pass through into either the chamber or the lock. It is possible for the gate to get stuck due to floating wood or the like.

A rolling gate is also sensitive to ice. The gate could get stuck during movement due to floating ice in the gate chamber and recess. This is mainly the case in a gate chamber where floating ice can collect due to the suction action of the gate. Ice can grow on the gate supports. This can lead to the gate getting stuck or even becoming icebound.

Blowing air bubbles from the bottom can combat ice forming in the gate chamber. Should the chamber become too filled with ice despite of this, the lock will become obstructed. The ice can be kept from the chambers by blowing air bubbles from the bottom. The ice inside the lock chamber does not cause any problems in relation to the gate other than damage to the preservative layer.

7.2.4.10 From rolling gate to sliding gate

A rolling gate has one substantial disadvantage. It has many moving and rotating parts that are under water. This results in high maintenance costs and lock obstructions. It is very difficult to inspect the moving parts as they are all positioned under the gate. For inspections, the gates with the roller carriages or the roller carriages themselves have to be exchanged.

For the rolling gates of the Nieuwe Oranjesluis, a system was developed in which the roller carriages that require high maintenance were replaced by two hydro-bearings that carry the overweight of the gate. Hydro-bearings are level, round bearings that can be pushed up slightly in height with the aid of water pressure. The profile of the bearing repels water. The bearing is carried on a water film, which results in a sideways movement that hardly requires force. This enables the gate to move, or even better 'to glide'. See par. 7.4.4.3.3 for further information.

7.2.5 Lift gates

7.2.5.1 General

A lift gate is a flat gate that opens and closes by means of a vertical movement. In the highest position, the gate hangs between two towers. The gate moves between two recesses that were made in the walls of the lock head and that continue into the towers where they are usually made of a steel construction. Lift gates are usually partly balanced. Still, the tensile force during hoisting is rather substantial and, in comparison to other types of gates, it requires large operating mechanisms.

In a closed position, under pressure from the level difference, the gate is pushed against the supports in the recesses. Lift gates are used as one-sided and two-sided retaining gates. There is very little difference in construction. A lift gate for two-sided retaining only requires one cladding and this makes it simpler and lighter than, for instance, a rolling gate that has two claddings. Fig. 7.40 provides a diagram of a two-sided retaining lift gate while a one-sided retaining lift gate looks almost the same.

Lift gates are only used when the headroom can be limited. Given the economic considerations, a higher application than required for Rhine navigation height (Rijnvaarhoogte) is hardly ever sensible. It is used at locks with one-sided and two-sided retaining with a maximum passage width of 24 m. Lift gates are usually selected in cases where there is no space for other types of gates. Lift gates require little room in relation to width as well as length.

7.2.5.2 Parts

The lift gate is a simple construction that contains the following functional parts (see fig. 7.12):

- a single cladding and a bottom support on which the gate rests and seals in closed position;
- a number of horizontal girders that transfer the load from the cladding;
- vertical end logs (or end girders), one on each side of the gate, that transfer the load to the horizontal girders. The end girders with the supports rest on the rollers in the recesses in the lock heads;
- vertical posts between the horizontal girders that make the cladding areas smaller;
- wooden supports on both sides of the end girders; at very high load this is a different kind of material;
- sluice gates or rollers with axel support in the gate. The axel support takes place by means of the end girders and the adjoining vertical girder.

Fig. 7.40 shows a diagram of a two-sided retaining lift gate. The one-sided retaining lift gate looks almost the same, only the supports on the high tide side can be left out. The gate can be torsion slack and if the vertical supports are not in the same area the gate must be able to twist slightly.

7.2.5.3 Gate guides

Lift gates are guided by means of rollers or sliding guides while going up or coming down. The sliding guides are mounted on the gate. The tracks for the guides are positioned in the recesses and on the towers. At the same time, the tracks function as the supports for the end position and as the sealing. Sliding guides are simple but require extra tensile force in the hoisting direction because of the load against the lift gate during movement. During load, extra overweight is also required to drop the gate.

Rollers move along rails that are positioned in the recesses and in the towers. The rails and the sealing are positioned next to each other (see fig. 7.41). Rolling guides require less tensile force. However, the rotating parts under water do require much attention and maintenance. The rollers and axels are considerably more expensive and heavier than sliding guides; the weight to be balanced is therefore also heavier and deeper recesses are required.

Selection of a system (sliding or rolling) depends on the size of the load on the gate during lifting on the one hand and on the other, on the cost of both solutions, including the hoisting devices. At large lift in which lifting or turning are about the same, a roller guide is a requirement.

A gate could start running out of true while being lifted. A roller guide or a slide guide on both sides of the gate ensures that the roller wheels do not start running next to the rails. The roller for side guidance is placed in a vertical direction in the middle of the rollers. The sideways swerve of the rollers then becomes minimal at permitted position out of true.

7.2.5.4 Sealing

In closed position, the lift gates lean against the vertical supports in the recesses. These supports also seal. One-sided turning gates with roller guides that rest on the gates when in a turning position seal by means of steel spring suspension on the end log (fig. 7.42). In two-sided turning gates the end logs on both sides are provided with supports (see fig. 7.40).

Due to large load, sometimes two-sided turning gates with roller guides cannot keep resting on the rollers. The rollers are then relieved in closed position by turning the axels over about 90° (see fig. 7.119). For this purpose, the axel in the wheel is positioned eccentrically, outside of centre, with respect to the part of the axel in the support points. Because of the construction and the water pressure, the gate is then able to move, independent of the direction of load, until it reaches the bearing saddles. Sealing takes place by means of a hollow rubber profile.

The bottom of the gate rests on the bottom of the lock, both under the cladding and under the end logs; in fig. 7.40, those are supports B and C. Given sufficient overweight, these bottom supports also seal. The overweight required depends on the lift to be retained and on the supports (width and material).

7.2.5.5 Levelling

Levelling by means of openings in the lift gates is very possible just as it is in a single pivot gate. With regard to construction, the total width of the opening can be about 60% of the passage clearance. On lift gates, the cladding is usually on the high tide side, the sluice gate guides are on the same side. Behind the cladding are the guide bars for width dispersion. If necessary, the sluice gate is designed to seal well in both directions where it concerns two-sided turning.

Levelling by means of lifting the gate is not possible without additional features as this results in a gap opening up over the full width of the gate with the rather large lifting velocity of the gate. In fig. 7.43, a strip has been placed at the bottom of the gate that ensures that the opening that opens up is smaller than the lift height of the gate.

7.2.5.6 Sensitivity to waste, ice and ice forming

Lift gates are sensitive to floating waste. Waste drifts into the gate on the open side if a waste grid is lacking; in open position, the waste can fall onto a vessel passing by underneath. A lift gate guided by rollers could become stuck if wood drifts into the roller recess. To prevent this, track cleaners have to be installed. Silt will sink onto the horizontal girders; this must be taken into account when determining the overweight of the gates above water. Floating ice has the same effect on the gates as floating waste. Ice collection in the gate has to be avoided. Grids in front of the open part of the gate are recommended, even though this could result in extra frozen water.

Ice could form in the gate chambers around the guides and sealing areas. Usually, rails and bearing surfaces of rubber seals are heated. The profiles for this are hollow.

7.2.5.7 Assembly and disassembly of lift gates

At initial assembly, the lift gate is hoisted to above lock level with the aid of a floating derrick. Subsequently, the gate is lowered to the bottom of the lock head via the recesses. Beforehand, part of the guidance has to be disassembled on one or both sides. The hoisting cables with hoisting devices are let down to the points of suspension. Once the gate is balanced, the balance weight rests on hydraulic jacks when in the highest position. When the cables of the balance weight are connected, the weight is

pushed up and the cables are connected to the gate. The jacks are then relieved and the weight hangs from the gate. Once the second weight hangs from the gate, the gate can be lifted. Before this is done, the disassembled parts of the guide have to be put back in place.

For disassembly, when a gate needs to be exchanged, the hoisting devices lift the gate to above lock level. Underneath the gate, a steel beam is placed across each recess. The gate is let down onto the beams. The balance weight has to be kept in this position by jacks. After the removal of part of one guide, the gate can be positioned on a floating derrick and turned outward, as shown in fig. 7.44. Either the hoisting equipment or facilities for equipment required for the installation or removal of parts is available in the tower. Disassembly is rather time consuming. Other activities can be executed in the chamber at the same time.

7.2.5.8 Maintenance

Minor repairs to the lift gates can take place on the spot, if the lock may be obstructed. In the past, one of the stated advantages of lift gates was on the spot maintenance without gate exchange. The current environmental requirements are such that the exchange of gates is often more economical. A third party can subsequently execute preservation.

7.2.5.9 Road traffic over a lift gate

Fig. 7.45 shows how a traffic road can be constructed with lift gate. This cannot be done over the gate because the lifting towers are in the way. A traffic lane is constructed in front of the gates and it rests on the gate supports. When the gate is lifted, the 'bridge' also goes up. The road can best be constructed outside the lock chamber. Situating this inside the chamber yields a larger collision possibility and a larger chamber length. The traffic strip results in a disadvantageous load on the gate and the gate guides. For lift gates, the road link is generally only used for accessing the chamber walls for operational purposes and for maintenance purposes. One traffic lane is sufficient for this.

7.3 Selection of lock gates

This paragraph is intended for selecting a type of lock gate. After addressing the specific characteristics of the four types of lock gates in par. 7.2, a division is made in par. 7.3.1 into one and two-sided turning gates and in size. The various locks to be distinguished are linked to gate types in par. 7.3.2 and 7.3.3. When linking a lock type to a gate type, attention is paid to technical possibilities, construction, exploitation and maintenance costs, reliability and durability, locking capacity, environment, monopolized space etc. In addition, attention is paid to situating the gates in the lock. An example of a gate selection procedure follows in par. 7.3.4. Please note that in the design process during the assessment of the variants, the operating mechanism of the gate (par. 7.4) and the lock head (Chapter 8) have to be taken into consideration when making a gate selection.

7.3.1 Lock lay out

One-sided turning lock/retaining structure (fig. 7.46)

The one-sided turning lock is usually a lock in a canal, a lock in a canalized river next to a weir or a lock where a canal links up with a river, a basin, a storage basin or another canal. The lift over the lock can vary in time due to river discharge, weir and storage basin management, increase and decrease of the water level due to wind action but the lift is always in one direction. With the exception of the rise and fall of the water level due to wind action, the lift changes either slowly in time or does not change at all. With a view to the lock gates to be used, the locks can be subdivided into the following lock dimensions:

- very small locks, width of passage 4 - 6 m;
- small locks, width of passage 6 - 10 m;
- medium size locks, width of passage 10 - 16 m;
- large locks, width of passage 16 - 24 m.

The very small locks are exclusively intended for recreational navigation. The small, medium and large locks are primarily intended for inland navigation but are also accessible to recreation vessels and small seagoing vessels. According to the CVB guidelines, locks with a width of passage of 9 m are accessible to vessels up to waterway classification III (Dortmund/Emskanaal-vessel), 10.5 m to waterway classification IV (Rijn/Hernekanaal-vessel), 12.5 m to waterway classification Va (Big Rhine barge) or Vb (two-barge push-tows in long formation) and 24 m to waterway classification VI (four-barge push-tows).

Two-sided tuning lock /retaining structure (fig. 7.47)

Locks in tidal areas such as at the sea, sea arms or at rivers with an open connection to the sea experience the influence of changing sea levels on the outside due to tides, storm surges and seiches. The inland water level is usually a more or less fixed canal or basin level though the influence of the sea, a river water level increase or decrease due to wind action at a basin is often present. The lift can change around within a few hours.

Locks that are connected to rivers can also be bilaterally retaining. The discharge and possible weir management determine the water levels in the rivers. In a canal between two rivers, differing water levels rule over the lock depending on the river discharges concerned. A lock in the place where a canal links up with a river experiences the influences of the changing water levels in the river at the outer head. The turning lift can take days due to the duration of a flood wave.

A lock between two basins or in the place where a canal links up with a basin can also be bilaterally retaining due to an increase or decrease in water levels due to wind action on the basin or due to other water level management. The change in water level could take place over several hours. For two-sided turning locks the same lay out is adhered to as applies to one-sided turning locks, with the additional extras:

- very large locks, width of passage > 24 m.

Recreational navigation is generally dealt with in very small, small and medium sized locks. Inland navigation uses small, medium sized and large locks while sea-going and marine vessels use small,

medium sized, large and very large locks. Locks in tidal areas are often marine locks that, due to the large draught of marine vessels, are often deeper than the locks for inland navigation and are much wider and longer due to the dimensions of the sea-going vessels. Combinations of inland with sea-going navigation respectively with recreational navigation are acceptable provided that the safety is guaranteed. A combination of marine navigation with recreational navigation should be avoided.

Table 7.1

Table 7.1 indicates which kind of gate is used for which kind of lock. The main categories for lock types are (1) two-sided turning marine locks (2) two-sided turning inland navigation locks and (3) one-sided turning inland navigation locks with a subdivision in lock size. Recreational navigation is not taken into account in this classification as this is classed under very small or small inland navigation or marine locks. The classification of the lock gate types is (a) mitre gate (one-sided turning or two-sided turning because of double set or bolt lock closing, (b) pivot gate (one-sided turning or two-sided turning due to bolt lock closing) or (c) rolling gate (two-sided turning) and (d) lift gate (one-sided turning and two-sided turning). The table is explained in the following paragraphs.

7.3.2 Lock gate type for one-sided turning

At relatively small lift over the lock (to a few metres), the upper and lower head have the same sill depth and therefore the gates can be identical. At larger lift over the lock, the sill in the upper head is higher than the sill in the lower head; the upper head gate is larger than the lower head gate.

Very small locks

In very small, one-sided turning locks, pivot gates are used almost exclusively because this provides the simplest solution. Technically speaking, mitre gates are also possible but not viable because the double quantity of gates and operating mechanisms required and the costs of the investment, management and maintenance are higher. Given the dimensions, there is hardly any difference in sensitivity to waste, ice or collision between pivot and mitre gates. The placing of the gates according to fig. 7.50 with equal upper and lower heads is preferable to the positioning in fig. 7.51 with a shorter upper head but different gate operating mechanisms.

Small locks

Small one-sided turning locks are equipped with both mitre gates and pivot gates (see fig. 7.48 and 7.50). The simplicity of the pivot gate is lost against other aspects. The advantages of the mitre gates over the pivot gates are mainly that the monopolized space is smaller (shorter lock), the gates are smaller and lighter, the duration of movement is shorter and the required investment is usually lower. On the other hand, the pivot gates seal better and only require one operating mechanism per head. The result generally is that the mitre gates are selected.

The difference in operating movements of the upper gates and the tail gates is due to the wet gate height during gate movement. In canal locks with a lift of several meters, the sills in both heads are at the same height. The gate in the lower head must be able to turn in canal level while the gate in the upper head turns in canal water level plus the lift.

At larger lift, the sill in the upper head is positioned higher. The head gate is then lower than the tail gate. However, both gates then turn in about the same depth of water.

Medium and large locks

For the reasons mentioned above, generally speaking mitre gates are chosen almost exclusively while pivot gates are never selected for medium sized and large one-sided turning locks. Given the lock dimensions, pivot gates will be very heavy and difficult to handle. Due to lack of space, lift gates can be selected at locks with large lift. Because of the simple levelling system related to the slow lifting of the gate, lift gates were often chosen at high lift in the past. Because this type of levelling system is of lesser quality (opening a wide gap) than for instance an energy dissipating chamber, it is no longer in use. Anyway, at a large lift over the lock the gate in the lower head is usually higher than the gate in the upper head.

7.3.3 Lock gate type for two-sided turning

Very small locks

In very small locks, bolt lock pivot gates are usually applied for two-sided turning. Fig. 7.56 provides the gate positioning whereby the gate and the operating movement of both heads are identical. This positioning is used at large positive lift and a smaller negative lift and it requires considerable lock length. If the positive lift over the lock is said to be much higher than the retaining level of the lock or the maximum locking level and the negative lift over the lock is limited, it is possible to limit the lock length by placing the gates at the head of the lock, according to fig. 7.57. The forces in the hook bolts remain limited. The gates serve partly as guide structure and the lock is not sensitive to waste and ice.

If the positive lift is almost equal to the negative lift over the lock, it would be better to apply the arrangement of fig. 7.58. The lock length is large with respect to the effective lock chamber. All three set-ups have identical gates, bolt locks and operating mechanisms, which is a clear positive point. Management and maintenance show very few differences. The sensitivity to waste and ice and the monopolized space are the most favourable in fig. 7.57. The collision sensitivity is most favourable in fig. 7.56. The final choice in the gate selection therefore depends on the water level combinations, previously stated arguments and the investment costs.

Small locks

Small locks can be equipped with mitre or pivot gates, in the set-up according to fig. 7.52 to 7.58. The choice for selecting the pivot gates can be made as described above. Cost estimates should be used to compare the set-ups for mitre gates to reach a final decision.

The set-up for fig. 7.52 with double mitre gates was often used in the past but is hardly ever considered now. The disadvantages to be mentioned are very high costs due to the very long lock length with respect to the effective length of the lock chamber and the large number of gates, sluices and operating mechanisms, the large monopolized space and locking with square closed gates in a lock in a tidal area. The advantages to be mentioned are the small sensitivity to collision, hardly any limitations in lift and no leakage.

Fig. 7.53, 7.54 and 7.55 show the set-ups with single, bolt locked mitre gates, which result in favourable proportions of effective chamber length and total lock length. The retaining of negative lift has to be limited. For aspects such as cost of investment, management and maintenance, the three set-ups are equal. The solution in fig. 7.53 is most sensitive to ice and the one in fig. 7.55 is the least sensitive. Sensitivity to collision is the largest for fig. 7.55 and the smallest for fig. 7.53. Experience has taught us that for small locks, the set-up with single, bolt lock mitre gates is the most attractive option financially if there is a limited negative lift over the lock. At large negative lift, the set-up with a single pivot gate is more attractive.

Medium locks

Medium sized locks generally have mitre gates. The considerations as described above for mitre gate set-ups also apply here. A choice is made between the set-ups of fig. 7.53, 7.54 and 7.55. Single pivot gates are not used here, mainly due to the long duration of movement.

Closer study of this could promote the utilization in the end.

Large locks

Large, two-sided turning locks do not only have mitre gates but also have rolling gates or lift gates. The set-up with double sets of mitre gates (fig. 7.52) is certainly possible for large locks, as already stated at small locks, but not an attractive option due to the costs (long lock, many gates and operating mechanisms, maintenance etc.) monopolized space and the square locking in tidal areas. One set of mitre gates per head (fig. 7.53, 7.54 and 7.55) is a more economical solution with regard to monopolized space, the investment and the maintenance costs, provided that the bolting of the gates for negative load does not require a sizeable extra investment. The choice in the position of the gates determines the sensitivity to collision. Just like with small locks, the set-up according to fig. 7.55 is the most sensitive and according

to fig 7.53 the least sensitive. The consequential loss at collision is often a weighty argument for the selection of the gate set-up.

Large locks in tidal areas mainly have rolling gates (fig. 7.59). Because of the double cladding, these are two-sided turning, robust and therefore well able to withstand collisions. Rolling gates require a large construction width because of the gate chamber and the machine room behind that. The maintenance costs are high in relation to the maintenance cost of mitre gates, due to the many rotating parts under water but the exploitation costs are slightly lower.

Lift gates (fig. 7.60) are used when the monopolized space has to be small and because they can easily be made suitable for movement at an initial lift over the gate. This type of gate is unsuitable at a marine lock because of the limitations in clearance and the relatively deep lock. The lift gate is suitable for an inland navigation lock. Esthetical issues related to the surroundings could limit the choice for a lift gate. Once a lift gate has been selected, high aesthetic requirements will be set for the design and colour of the tower and gate. The cost of investment, exploitation and maintenance are high. Sensitivity to collision, ice and waste is small. It is the only gate type to cause inconvenience to vessels sailing through underneath.

Very large locks

Very large locks with a lock width of more than 24 m are only found in marine locks. Rolling gates are virtually the only gates that are used in these locks. Rolling gates can be realized in nearly all widths and heights. They are robust which makes them resistant to collisions. At a collision resulting in large deformation of the gate, the rails and the lower roller carriage are weak links. (Leaking floating tanks are the weakest links as the gate can generally not be moved). In opened position the gates are pulled into the gate chamber to the extent that they cannot be damaged by passing vessels. The maintenance of rolling gates in large tidal locks is expensive and time consuming. Very large gates have to be self-supporting due to their weight. This means that they are floated in and independently sunk onto the roller carriages. The lock and the gate chambers accommodate this. A gate dock is present for the maintenance. Very large marine locks are usually found once per lock complex and obstruction has to be avoided as much as possible. In general, two gates are present for each head and they are each other's replacement.

The use of other types of gates (mitre gates, sector gates) is not impossible but generally not economically viable.

7.3.4 Choice of gate

Choosing a gate type to be used in a navigation lock takes place during the preliminary design. Based on experience, a limited number of gate types are selected. The main dimensions for preliminary designs are determined for each type of gate with operating mechanisms, after consultations with a specialist in the field of levelling processes and in consultation with all disciplines involved. Subsequently, preliminary designs for each of the lock heads are made and included in the lay outs of the lock complex concerned. The lock complex design is then checked against the Programme of Requirements. From an economic-financial perspective a comparative assessment of the various solutions is made and recommendations are reported to the principal.

In general, it could be said that the choice of the type of gate mainly depends on the width of passage of the lock head, the requirements set for the gate(s) as retaining structure and the requirements with regard to gate movement.

Table 7.1 indicates what type of gate is suitable for which width of passage of the locks. This is mainly determined by the lock width, whether a lock is unilaterally or bilaterally retaining and, in the case of bilateral retention, how large the negative lift is. This usually yields a number of gate types.

Table 7.1 can be summarised in words as follows

For one-sided turning locks, mitre gates are generally used. Pivot gates are only used for very small locks (width of passage 4 – 6 m). For medium and large locks (10 – 24 m), one-sided turning lift gates are also possible.

For two-sided turning locks, there is more choice. For very small locks (4 – 6 m) irrespective of the conditions that they have to retain, this is a bolted pivot gate. For small locks (6 – 10 m), the choice can be made between bolt-locked pivot gates (allow a large negative lift) and bolt-locked mitre gates (allow limited negative lift). For medium sized locks (10 – 16 m), the suitable gates are bolt-locked mitre gates (limited negative lift) and double sets of mitre gates or two-sided turning gates (allow large negative lift). For large locks (16 – 24 m), mitre gates are used for small negative lift and at large negative lift either rolling gates are used (marine and inland navigation) or lift gates are used (only inland navigation). Very large locks (> 24 m) for sea-going vessels are equipped with rolling gates.

If the applicable gate types have been selected via table 7.1, the most favourable type of gate can be selected in the preliminary design phase via a selection matrix (see tables 7.2 to 7.5). These selection matrixes contain a number of variants (gate types) positioned against a number of aspects. These aspects are construction costs, maintenance, operational safety, durability, locking capacity, environment, ease of use and water resistance. Each variant is given a report mark or a number of points for each one of the aspects. The aspects themselves are provided with a weight factor that expresses the mutual importance. Multiplying the grade or points by the weight factor yields a score. All the scores of the aspects added together supply a total score. The highest score has to be the best variant.

Please note that the figures, points and weight factors can never be determined completely objectively. The highest total score indicates which variant or gate type is preferable, though due to possible subjectivity, a critical attitude should be adopted. The principal's preference for a particular gate could play an additional role in this.

As described above, each variant combination (that is to say gate type) has an aspect score. This could be the allocation of a report mark between 0 and 10 whereby it should be noted that the number 0 is not given because this would be a senseless variant and number 10 is also not given because no variant is perfect. It can also be done by entering the scoring by means of a figure between 1 and the number of variants, for instance at three variants a 3 for the best, 1 for the worst and 2 for the intervening area.

The aspects that determine the choice are stated below in descending order of importance and are provided with a weight factor such as could be used in a design and a brief explanation. (Remark: naturally, other weight factors are also possible!):

- *Operational safety, weight factor 0.25*
Operational safety is the most important aspect. The focus of operational safety is how predictable the functional performance is, not the life span: a gate that has to be replaced after 10 years for instance, can be operationally safe provided that the replacement was planned in advance.
- *Maintenance, weight factor 0.20*
Simplicity, intensity and maintenance costs are just as important. Maintenance costs mainly concern the steel construction and the mechanical and electrical part.
- *User-friendly, weight factor 0.15*
Ease of use is understood to include easy operation, good processing of navigation, convenient arrangement, control measures at maintenance, negative load, calamities etc. and sensitivity to ice, waste and collisions.
- *Construction costs, weight factor 0.15*
The development and building costs include not only the costs of the gates but also the costs of the civil part of the heads, the operating mechanisms of the gates and the electrical costs.
- *Locking capacity, weight factor 0.10*
Locking capacity is strongly determined by the time required for opening and closing the gate.
- *Water resistance, weight factor 0.05*
Depending on the location, leakage loss is more important or less important and this changes the weight factor.
- *Durability, weight factor 0.05*
Durability concerns the length of time that a gate can fulfil its function without major repairs and the total life span of the gate.
- *Environment, weight factor 0.05*
This concerns the environmental load due to extraction of materials, manufacturing process, construction activities and maintenance methods.

Tables 7.2 and 7.3 concern the example of a bilateral, medium-sized inland navigation lock (width of passage 10 – 16 m). 3 variants are selected, the gate type mitre gates, single pivot gates and lift gates, even though the single pivot gate is not specified in table 7.1 as a selection possibility. Table 7.2 concerns the report marks of 0 to 10, table 7.3 concerns the scoring of 1, 2 and 3. Table 7.2 shows that the best variant is the mitre gates and in table 7.3, mitre gates and some pivot gates have equal scores. In both tables, lift gates prove to be the worst variant. It is remarkable that a few pivot gates score so well next to mitre gates because up to now, mitre gates were mostly utilized for this type of lock.

Tables 7.4 and 7.5 concern the example of a bilaterally retaining, medium-sized inland navigation lock (width of passage 10 – 16 m). 3 variants are selected, the gate type mitre gates, a few pivot gates and rolling gates, even though rolling gates are not specified in table 7.1 as a selection possibility.

Table 7.4 contains report marks from 1 to 10, table 7.5 concerns the scoring of 1, 2 and 3. Table 7.5 shows that the best variant is a single pivot gate and table 7.5 furthermore shows that the variant rolling gates ends on the second place.

The tables 7.2 and 7.3 for one-sided turning and tables 7.4 and 7.5 for a two-sided turning show that the total scores for the different variants do not differ all that much from each other. In order to curb the subjectivity somewhat, it is usual that weight factors, figures and points for such multi-criteria matrixes are completed by several people, independently of each other. Discussions on the scores and such like can lead to a better balance in the end result. In fact, all stated variants are possible and the results mainly depend on which aspects are emphasised (the choice of the weight factors) and the principal's preference for a certain gate.

7.3.5 Level of top of gate cladding

In chapter 4, the turning levels of the gates and the level of the capstone were extensively addressed. In this paragraph a few aspects are discussed that are of importance to the gate.

One-sided turning / unilateral retention

In locks for one-sided turning (such as locks in canals) that are generally equipped with mitre gates, the levels of the top of the gate cladding in the upper and lower head are usually the same height. This level is determined by the highest upper water level increased by an allowance for rise in the water level due to wind action, transitory waves and the like. The level of the capstone over the length of the lock follows from the maximum locking level increased by an allowance for navigation. This level is at least equal to that of the gate cladding but could also be slightly higher, at least for locks in canals.

The gates of the upper and lower head, at equal level of the top of the cladding, need not always be equally high (see fig. 7.62). At locks with large lift it could be more economical to position the sill of the gates in the upper head slightly higher than the sill in the lower head. This choice partly depends on the required draught of the lock.

At locks positioned on rivers, it could happen that the highest water level on the river side is much higher than the maximum locking level. If this is the case, it is worth considering whether to adjust the top of the cladding of the tail gate and the capstone in the chamber to the maximum locking level (thus not to the highest upper water level).

The top of the cladding and the capstone at navigation locks positioned in a canalized river next to a weir could sometimes have levels that are lower than the highest river level, whereby the gates and the lock complex are flooded at very high discharge.

Two-sided turning / bilateral retention

The point of departure is a lock equipped with rolling gates in a tidal area with a canal on the inside. Rolling gates have cladding whereby the cladding that retains the outside water is found on the inside of the gate (so called inner cladding) and that which retains the inner water is found on the outside of the gate (so called outer cladding).

The following can be said about the minimum levels of the top of the *gate cladding* (see fig. 7.63).

The minimum level of the top of the inner cladding of the gate of the outer head is determined by the highest outer water level (NHW). This is increased by an allowance for the influence of a rise in the sea level, local rises in water level due to wind action, seiches, wind waves, retaining height and such like (par. 4.5).

The minimum level of the top of the inner gate cladding of the inner head is determined by the maximum locking level increased by an allowance for wind waves or transitory waves of 0.5 m for instance. This minimum level could in essence be even higher because the inner gate also has to function as spare gate, see par. 7.3.6. The minimum levels of the top of the outer cladding of the gates of the outer and inner heads is determined by the maximum canal level (CL) on the inside increased by an allowance for wind waves or transitory waves of 0.5 m for instance.

The following can be said about the minimum levels of the capstone.

The minimum level of the capstone at the outer head is equal to the level of the top of the inner cladding of the gate in the outer head. For the lock chamber and the inner head the minimum level of the capstone lies at the maximum locking level increased by an allowance for dealing with navigation.

If the difference between the highest outer water level and the maximum locking level is small, it stands to reason that the inner gate cladding of the outer and inner head are positioned at the same height and the gates kept equal. The level of the capstone is then also kept the same over the length of the lock and is at least equal to the level of the top of the inner cladding.

If the difference between maximum locking level and maximum canal level is small, it stands to reason that the top of the outer cladding of the gate in the outer head and the outer and inner cladding of the gate in the inner head are kept the same.

Instead of rolling gates, the previous can also be applied to one-sided turning, double mitre gates. For the inner cladding of the rolling gate one reads flood gates and for the outer cladding of the rolling gate one reads tail gates. For the top levels of the cladding of two-sided turning mitre gates, the levels of the inner cladding of the rolling gates is used.

7.3.6 Reserve barrier, intermediate head and guard gates

Reserve barrier

We understand the reserve barrier or second retaining structure to be the retaining structure that sufficiently replaces the main water retaining structure should the latter fail. The main water retaining structure of a navigation lock is usually provided with a reserve barrier or second retaining structure in the shape of tail or inner gates.

At unilateral retention, the reserve barrier is present in the shape of tail gate(s) and the top of the cladding is usually just as high as that of the head gate (fig. 7.62).

At bilateral retention, the reserve barrier is the inner gate and the top of the cladding that can be lower than that of the outer gate (fig. 7.61). Suppose that the retaining height of the outer head is higher than the retaining height of the chamber (capstone level, chamber walls) and the inner head. In the case of a failing outer gate and an outer water level higher than the retaining height of the inner gate, the water cannot be retained and it flows over the lock terrain and the inner gate into the canal. As long as the storage capacity of the canal is sufficient during the high water and no damage ensues, this does not pose a problem and the levels of the gate cladding and capstone can remain the same. If it is a problem, then the failure probability of the outer gate must be decreased. Nowadays, a second outer gate is generally not the solution unless the difference between NHW and maximum locking levels is large.

Retaining in series

In retaining high water levels in series, a water level between the outer and inner water level is maintained in the chamber. This limits the load on the heads and gates.

Intermediate head

Locks with a highly varying vessel complement are provided with an intermediate head if this is

financially sound. In general, intermediate heads are only used in very long locks. The length of the short chamber section should be sufficient to at least lock through the normative vessel. Advantages of using an intermediate head are: limiting water loss, decreasing the fresh/salt burden (if present), decreasing the levelling time, larger availability of the lock, (always a reserve head available) and the possibility of retaining flood water in step series over three gates.

Because there is a third gate, there are always two other gates for retention should one of the gates fail. Fig. 7.65 shows three different situations for a lock with three equal rolling gates whereby one gate fails per situation and the outer water reaches the level of the top of the cladding of the outer gate. Because of the construction of substantial overflow cavities in the intermediate and inner gate, the water resulting from overtopping (wind waves) and possibly also overflow can be discharged into the inner water. The opening of overflow cavities can take place by, for instance, removing the emergency stop logs or by opening sluices by means of operating mechanisms. In a similar manner, this is also possible with double sets of mitre gates (fig. 7.66).

Guard gates

In case of maintenance or calamity, every gate in the lock must be replaceable by a spare gate. However, it is not necessary for several gates to be replaced at the same time. If the gates differ from each other then either as many spare gates are required or a tall reserve gate should be made that can be utilized in both heads. If the gates are kept equal, only one spare gate or (for mitre gates) one set of spare gates is required, which is cheaper than several spare gates.

7.4 Gate operating mechanisms

7.4.1 Introduction

For each type of gate, a selection can be made from different operating mechanism designs. The choice is determined in the main by the preconditions, the programme requirements for the retaining and moving gate and the costs (investment, management and maintenance). Operating mechanisms are always provided with electric drive, controls and operation. (Manual drive is not used anymore: an emergency power supply and/or manual emergency operating mechanism is always present).

In general, the requirement for a gate operating mechanism is that the gate is moved with control and is independent of the hydraulic load that could occur in the gate during movement. The hydraulic load concerns wind waves or transitory waves and the pressure differences over the gate due to its own movement. Furthermore, the gate operating mechanism must be able to keep the gate in an open position, also when a vessel sails past. It likewise applies to the closed position that the gate is not allowed to bang with the waves if there is no lift over the gate. In an intermediate (emergency) stop, the gates must be held in position by the operating mechanism.

The movement time of the gate depends on the type of gate and the width of passage. This is the result of the gate mass to be moved and of the water that is brought into motion by the gate movement as well as the load that is exerted on the gate itself and the moored vessels. For lift gates, the movement time depends on how high the gate has to be lifted. Movement time for mure gates amounts to (roughly) 30 - 60 s for small locks (6 - 10 m), 60 - 75 s for medium sized locks (10 - 16 m) and 75 - 120 s for large locks (16 - 24 m). These times are exclusive of acceleration and delay times. For single pivot gates in small locks, this is 60 - 120 s, which is clearly longer than it is for mitre gates. For rolling gates, the movement time does not really depend on the width of passage; for large and very large locks (> 24 m) this is not longer than 120 sec. Lift gates are usually moved at a speed of 0.20 m/s. The movement time for opening the gate increases in the presence of push-off designs and bolt locks.

In this paragraph, the operating mechanisms of mitre, pivot, rolling and lift gates are sequentially dealt with. Furthermore, it deals with the bolt locks of mitre and pivot gates and the guides of rolling and lift gates.

7.4.2 Operating mechanisms for mitre gates

For mitre gates, three types of operating mechanisms are used namely the Panama wheel, the rack bar and the hydraulic cylinder. These types are described below and followed by an overview of provisions for negative retaining and a description of how a selection is made between the types.

7.4.2.1 Mechanical operation by Panama wheel

Set-up

The operating mechanism consists of a large, horizontally positioned gear wheel that is connected to the lock gate via a push-pull rod and is driven by a pinion. The pinion is connected to the electric motor via the gear wheel (see fig. 7.67 and photo 7.14). The mechanical operation unit is positioned in the basement next to the gate chamber, the push-pull rod sticks through an opening in the wall.

The set-up according to fig. 7.67 is suitable for use in locks where the water does not enter the basement chamber through an opening in the wall. If the highest water level is above the level of the opening, a set-up will have to be selected according to fig. 7.68 in which the electrical equipment is set-up in a dry room above the Panama wheel. If the water level drops after the area of the Panama wheel has been filled up, all operating mechanisms will have to be thoroughly cleaned.

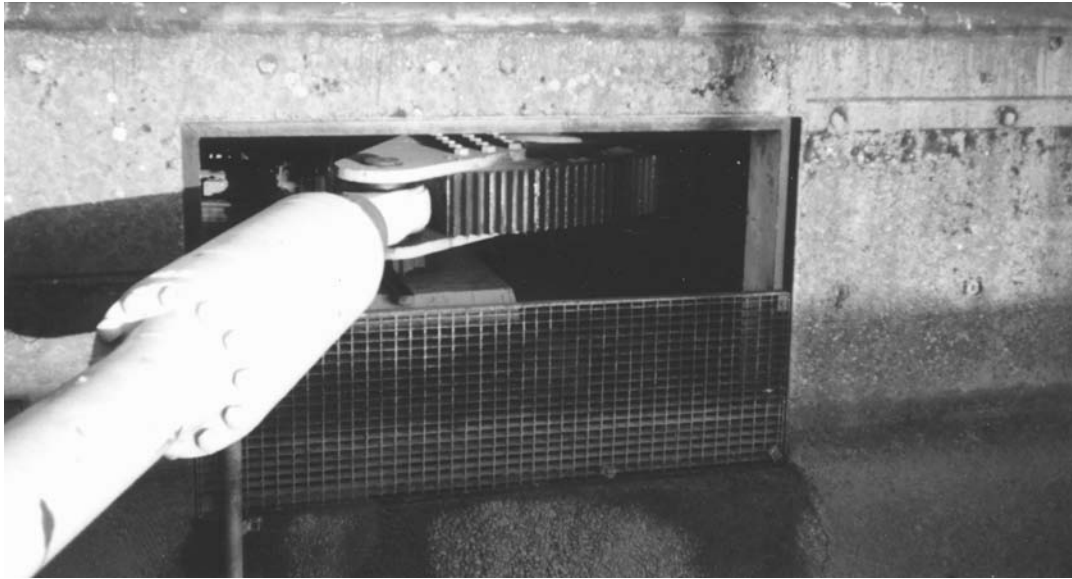


Photo 7.14 Panama wheel operating mechanism, lock at Oosterhout

Activity of force

The magnitude of the force in the push-pull rod does not only depend on the power of the driving source but it certainly also depends on the position of the push-pull rod with regard to the axis of the gear wheel.

The most usual solution is shown in fig. 7.69. The force in the push-pull rod in the ultimate positions (completely opened and totally closed gate) is about three times as large as it is at the halfway mark. This corresponds with the relation between the size a (a is the distance from M to AR , with M as pivot point of Panama wheel, A = point of action push-pull rod at the gate and R = point of action push-pull rod to Panama wheel and the length of the swivelling arm MR . The distance from D (pivot point gate) to point A (point of action push-pull rod is about $1/3$ of the gate length. Near the ultimate positions, the angular velocity of the gate is much larger than it is half way (see fig. 7.70). The force to be delivered in the ultimate positions can further be enlarged by decreasing the distance but this is not recommended because the operating mechanisms then becomes sensitive to every obstacle, which could easily lead to overload.

In the push-pull rod, a pre-stressed buffer spring is built in to help the operating movement to keep on turning when the gate has already reached a standing position. The operating movement pulls or pushes the spring in to the extent that the required pre-tension is achieved and movement can be eliminated. The spring makes it possible to bring the gates back to the final position if there is an obstacle no matter how small.

Advantages and disadvantages

The advantages are:

- a robust construction with little inspection and maintenance required;
- insensitive to foundation settings or measurement deviations in gates, therefore also to the exchange of gates;
- the push-pull rod can be locked, if necessary, resulting in a (limited) negative retaining structure. The other parts of the operating mechanism are not placed under load.

Disadvantages are:

- the construction is expensive due to the gear wheels, the wide chamber and the complicated assembly;
- the operating mechanism cannot move under water due the danger of waste between the gears;
- the chamber requires a wide lock terrain;
- the initial assembly is time consuming due to the adjustment of loose parts in respect of each other. Placement moulds are required for positioning the attachments in concrete in the foundations.

Utilization

Mechanical operation with a Panama wheel was used quite often in the past in medium and large locks. Nowadays, it is rarely used. In small locks, the chambers monopolize a disproportionately large area.

7.4.2.2 Mechanical operation by rack bar



Photo 7.15 Direct rack bar for gate and sluice movement of Koopvaardersschutsluis in Den Helder



Photo 7.16 Direct rack bar for gate movement of Koopvaardersschutsluis in Den Helder

Set-up

The operating mechanism consists of a horizontally positioned, direct rack bar, being a push-pull rod that is connected to the lock gate and is driven by a pinion. The rod is pushed against the pinion by a pressure roller. The pinion is connected to an electro motor via the gear case (fig. 7.75). The operating mechanism is placed in a basement chamber next to the gate chamber, the rack bar sticks through an opening in the wall.

The set-up according to fig. 7.75 is suitable for use in locks where the water should not run into the basement chamber through an opening in the wall. In the set-up according to fig. 7.78 there is part of a basement chamber that, in principle, could be inundated and a section that is situated higher and is a dry part of the basement chamber, the axis of the rack pinion is watertight.

Activity of force

The force that is exerted on the gate through the rack bar is constant in every gate position. The distance from the rack bar to the axis of rotation of the gate multiplied by the force in the rack bar yields the gate moment. Fig. 7.76 provides this for both of the ultimate positions. The rack propulsion has an electrical speed regulator to prevent end speeds from becoming too high. In this way, it is also prevented that the suction force from the gate chamber at the start of closing becomes normative.

In order to limit the force on the rack bar and pinion, the connection point on the gate is positioned about halfway down the length of the gate. The rack bar is provided with a buffer spring in order to realize the pre-tension created between the gates and chamber. This can also be done by attaching the springy unit to the chamber wall (see fig 7.75).

Advantages and disadvantages

The advantages are:

- a simple construction made up of one unit that is easy to install;
- cheaper than a Panama wheel operating mechanism for instance;
- with a blocking behind the rack bar, it is easy to adapt it for negative retaining.

The disadvantages are:

- the position of the rack is sensitive to deviations from the horizontal field and therefore requires regular inspections;
- the operating mechanism cannot move under water, as it will get stuck due to dirt;
- the rack is susceptible to collisions.

Utilization

Direct rack drive for mitre gates is applied in small (6 - 10 m) and medium sized (10- 16 m) locks. They can also function in large locks (16 - 24 m), but the collision sensitivity becomes so large that the racks then have to be protected from this.

7.4.2.3 Mechanical operation by hydraulic cylinder

Set-up

The operating mechanism consists of a horizontally positioned hydraulic cylinder with a piston rod whereby the cylinder is hinge-mounted to the basement chamber wall and the piston rod is hinge-mounted to the gate. The piston rod is moved by changing the oil pressure in front of and behind the piston rod. The oil pressure is supplied by a hydraulic unit (oil pump, electro motor, valve control and the like). By executing the hinges differentially, the operating mechanism is insensitive to dimensional deviations in the foundation or the gate (fig. 7.79).

The basement chamber for the cylinder is small. The cylinder can be positioned high and just under capstone level so that the piston remains dry even at high water levels. For that matter though, the hydraulic cylinder can function under water without problems and for that the hydraulic unit is positioned in a separate, dry area. The wires and piping to the cylinder are made watertight when brought from the dry area through the wall to the cylinder chamber.



Photo 7.17 Hydraulic cylinder operating mechanism of mitre gates and sluices at Rozenburgse lock



Photo 7.18 Hydraulic cylinder gate operating movement at Rozenburgse lock

The dry area can be randomly positioned in the lock complex whereby it is even possible to use one area and drive all the gates from there.

Activity of force

The cylinder can supply a constant force against the gate on the spot of the connection point. As can be seen in fig. 7.79, the connection point of the piston on the gate is closer to the turning point of the gate than is the case with other operating mechanisms. Therefore, the required force on the gate is larger but the distance to be covered is smaller, which is favourable for hydraulics ('large force / small stroke'). The distance from the connection point to the turning point is about 1/5 of the gate length.

The speed, with which the gate leaves and enters the gate chamber and closes in the end, can be controlled by reducing the capacity of the pumps in these positions. The course of the piston speed is shown in fig. 7.80. With hydraulic drive, it is usual to have the gates wait for each other just before closing. The intention is to prevent one gate from being ahead of the other gate due to unequal pump capacities. After this brief stop, the gates are slowly pushed together against each other.

It is not necessary to have a buffer spring between that gate and the cylinder. In the ultimate positions, the cylinder can be put under pressure and kept under pressure by a pump and a battery. The pump switches off once there is sufficient pressure in the cylinder.

Advantages and disadvantages

The advantages are:

- the operating mechanism is compact and requires a small chamber space;
- the operating mechanism is hardly affected by dimensional deviations and settings;
- the cylinder can function under water without problems, also with regard to environmental requirements and it is not sensitive to floating waste;
- the drive unit can be positioned in any available location;
- installation is inexpensive when compared to mechanical operating mechanisms;
- the cylinder is easy to exchange.

The disadvantages are:

- the initial installation is time consuming due to the piping and wiring required as is the initial testing of the installation;
- the total installation is much more complicated than an electro mechanical installation;
- the concrete space for the cylinder and the drive unit has to be conditioned against oil leakage;
- the standing time of hydraulic equipment is shorter than that of mechanical equipment while inspection and preventative maintenance is required more often;
- the maintenance requires qualified personnel;
- the return of the installation is low, the required motor capacity is therefore high;
- more susceptible to malfunction due to the large number of (electro mechanical) components.

Utilization

Hydraulic cylinder drive of mitre gates is used in small (6 -10 m), medium sized (10 - 16 m) and large (16 - 24 m) locks. The drive is especially suitable where there is large load on the gate during movement, when there is not enough space for large chambers or when the gates have to keep moving at very high water levels that require the operating mechanisms to function under water.

7.4.2.4 Revetments for negative retention

Mitre gates are very suitable for a positive load direction. If the gates also have to turn and retain negatively, usually extra provisions are required for the gates and operating mechanisms that stop the gates. A few solutions are possible and depend on the size of the negative lift that needs to be retained.



Photo 7.19 Hydraulic cylinder gate operating mechanism and direct rack bar and lock paddle operating mechanism of push-tow locks in the Volkerak



Photo 7.20 Hydraulic cylinder gate operating mechanisms of Tweede Sluis at Lith

Small negative load

If the negative load is small and not larger than the maximum load on which the strength of the operating mechanism was determined, the three previously mentioned operating mechanisms could be used without major adjustments. Consider lifts between 0.20 to 0.75 m.

Propulsion with a Panama wheel or with a direct rack bar has to be provided with a heavier buffer spring because the gates would leak under normal circumstances. In the end, the brake stops the load and this does not require further strengthening.

The operating mechanism with hydraulic cylinder is suitable, without any additional provisions, whereby the pressure in the battery is increased to the maximum work pressure.

A disadvantage of these systems is that the gates can open from inside in the case of a collision. If the opening through which water leaks away is not very large, the gates in the other head can still be closed. If this is not the case, much water will run out of the canal to the sea or river side during negative turning. At negative retention to the canal, this could result in floods in the hinterland.

Large negative load

If the load due to negative lift is larger than the strength of the operating mechanism, the operating mechanism will have to be adapted or completely reinforced.

In case of propulsion with a Panama wheel, the push-pull rod will have to be strengthened and a locking device installed on the wheel, right behind the connection to the push-pull rod to relieve the rest of the operating mechanism (fig. 7.73).

In the direct rack operating mechanism, after closing and pre-stressing, a beam drops in behind the rack so that the gate cannot push it back. The clearance between the beam and the rack, necessary for positioning, is subsequently reduced by lifting the brake from the operating mechanism. Fig. 7.77 and 7.78 show examples of this solution.

The hydraulic cylinder operating mechanism has to be completely adapted for the larger load. In addition, provision has to be made to prevent leakage if there is an electrical power failure.

A disadvantage of the locking operating mechanisms is the damage that they could incur due to a collision. Deformation occurs which seriously weakens them and they open further than they did before the collision. This applies to the hydraulic cylinder to a lesser degree, as it is better able to follow the overload at a lower speed.

Another solution for absorbing negative load through the mitre gates is to fit a locking device to lock the gates together. Fig. 7.83 shows mitre gates that have been equipped with eyes that a pen can fit through. The pen has room in the hole, which enables the gates to open a little and to leak. Disadvantage of this solution is that at a collision, not only the gates but also the turning points (pivot and anchor and collar) incur more serious damage.

7.4.2.5 Selecting a type of operating mechanism

An opening mechanism with a Panama wheel is complex and expensive and is therefore hardly ever used nowadays. It is a very reliable system that requires very little inspection and maintenance.

An operating system with a direct rack rod is the most obvious solution when the gates are under light load during movement and the collision risk of the gates is small.

An operating system with a hydraulic cylinder is the most used and is mainly suitable in one of the following cases:

- during movement the gates are under relatively high load due to wind waves and transitory waves;
- the collision risk on the gates is fairly substantial;
- there is a probability that the gates need to move while the water level has risen to the extent that

- the operating mechanism is under water;
- in limited space for operating mechanism chambers, which mainly occurs at small and/or short locks;
- the principal prefers hydraulics due to uniformity of maintenance or because of hydraulic operating mechanisms on sliding gates.

If economic factors are not part of the consideration, the type selection in operating mechanism can take place according to a decision outline (see fig. 7.144). This decision outline can also be summarised in words, based on a number of aspects:

• insufficient space:	no, Panama wheel or rack	yes, → cylinder
• high reliability:	no, rack	yes, → Panama wheel or cylinder
• under water:	no, Panama wheel or rack	yes, → cylinder
• overloaded:	no, Panama wheel or rack	yes, → cylinder

Instead of a decision outline, a selection matrix can be drafted for selecting the gate operating mechanisms as is the case for choosing a gate. The gate operating mechanisms under consideration are supplied with various aspects and these aspects are compared with each other and weighed with a weighing factor. Table 7.6 provides an example of such a selection matrix for the operating mechanisms of the Krabbersgatsluizen.

Comparing an electro mechanical operating mechanism with an electro hydraulic operating mechanism yielded a higher positive score for the latter, which was subsequently selected. The mentioned weighing factors are not valid for general use and can clearly be different in another situation.

7.4.3 Operating mechanisms and locking devices for pivot gates

7.4.3.1 Propulsion with hydraulic cylinder

Hydraulic cylinder option

The single pivot gate is found in very small (4 – 6 m) and small (6 – 10m) locks. During the turning action, the exterior load on the pivot gates has to be absorbed by the operating mechanism. Due to the relatively large length of the pivot gate, the load on the propulsion is so large that an hydraulic cylinder is preferable to a Panama wheel or direct rack.

The preference for a hydraulic cylinder could also stem from the fact that there is a large probability of collision with the long push-pull rod of a direct rack. However, for recreational navigation, a Panama wheel could initially be considered as propulsion (fig. 7.7.4).

Set-up

The best place for the hydraulic cylinder is outside the profile of passage. For this purpose, the gate is equipped with a short lever on the upper girder that turns inside the operating mechanism chamber. Because of the short lever, the forces within the cylinder are extremely large and therefore very suitable for hydraulic propulsion.

The hydraulic cylinder is set-up outside the passage profile, usually in the longitudinal axis of the lock. Depending on the available space, the cylinder is either placed in front of the turning point (fig. 7.82) or behind the turning point (fig. 7.81), the first set-up being preferential. In this situation, the cylinder is smaller in diameter than it is in the other set-up as the piston side is on the correct side. This side can provide the larger force which is necessary for opening the gate, as the gate experiences greater external load during opening than it does during closing. The set-up of fig. 7.81 is applied if there is insufficient space due to the position of the culvert valve.

Just like with mitre gates, the hydraulic system for a pivot gate has to be able to maintain the stated forces in the ultimate positions. The reduction of the angular velocity of the pivot gate corresponds with the angular velocity of mitre gates, apart from the fact that during opening and closing, timely permitted speed adjustments have to be made to prevent undesirable transitory waves in the chamber.

The cylinder pulls and pushes on the lever as extension of the upper horizontal girder. Because of the position of the extension with regard to the axis of the gate, the foundation is cut through at the position of the collar. The design has to take this into account.

7.4.3.2 Facilities for negative retention

Kinds of locking devices

The reasoning for choosing a hydraulic cylinder as propulsion for a pivot gate also applies to the pivot gate for two-sided turning.

The two-sided turning pivot gate has to be locked against negative load. The kind of locking device depends on the size of the load and the permitted water loss. There are three possible solutions:

- *Original operating mechanism*
The operating mechanism that was designed for the gate movement is strong enough to absorb the negative load. However, provisions will have to be made for power failure. The pressure on the batteries can otherwise drop back so much that the gate is pushed open by the negative load.
- *Reinforced operating mechanism*
The negative load is too substantial for the operating mechanism and has to be adjusted to the larger load.
- *Separate locking device*
The negative load is so large that a separate locking device is required at the gate tip. How this separate locking device is executed depends on whether the pivot gates turn inside or outside the lock head.

Separate locking device at lock head with gate chambers and recesses

If the gates are placed in a lock head with complete gate chambers and recesses (gates turn inside the lock, see fig. 7.56), there is sufficient space in the gate recess for a locking device that turns in front of the gate after closing. An example of a frame shaped locking device is found in fig. 7.85 and in photos 7.21 and 7.22. After the gate has been closed, the frame shaped locking device with a hydraulic cylinder (1) is turned in front of the gate with a second hydraulic cylinder (3) and pre-tensioned against the flexible supports. The locking frame has two supports positioned above each other that also push against the bottom of the gate and results in hardly any leakage. The locking frame is made as such that it can be dismantled above water. An alternative to this solution is drawn in fig. 7.84, where the locking frame is pre-tensioned by an electro motor on an eccentric axis. Both options are provided with mechanical locking devices that prevent the locking devices from twisting due to juddering which otherwise results in the gate not being pushed against the supports any longer.

Separate locking device at lock head without gate chambers and recesses

Pivot gates that turn outside the lock head (fig. 7.57) do not have a gate recess for support. Locking is done by means of a hooked locking device that is pulled over the support after the gate has closed (fig. 7.27 and 7.86). At the same time, the gate is pre-tensioned against its supports. Only one locking device is used and it is above water. For this reason, the gate needs extra bracing to prevent substantial leakage at the bottom of the gate. The hooked locking device is compact, easy to access and inspect, without obstructing the gate. The construction is heavy though.

A simpler solution for locking a pivot gate that turns outside the lock, are sliding locks (fig. 7.87). From the front post (tip of gate) of the closed pivot gate that is pushed closed by the operating mechanism, two hydraulic cylinders are used to push two pens, positioned above each other, that rest on the bearings in the camber of the recess. The pens are secured with rods. These sliding locks cannot pre-tension the gate, the pre-tension has to come from the operating mechanism. This construction does have the advantage that the maintenance can take place at the same time as the gate maintenance. The disadvantage is that inspection can only take place when the gate is exchanged.



Photo 7.21 Frame shaped locking device for single pivot gate of the lock at Nieuwe Statenzijl



Photo 7.22 Detail of the locking device for single pivot gate of the lock at Nieuwe Statenzijl

7.4.4 Operating mechanisms and guides for rolling gates

7.4.4.1 General

Operating mechanisms

Rolling gates have operating mechanisms in the shape of cable winch gear that opens and shuts the gate. In the past, locks were equipped with rolling gates that were moved by means of rack bars or with a locomotive. With a locomotive on rails with drive wheels, the own weight has to be very substantial or a gear wheel is required to supply the necessary tensile force to the gate. The use of cables has so many advantages over rack bars or a locomotive, that these are no longer used.

Compared to other types of gates, operating mechanisms for rolling gates have to deliver relatively small forces. This is because the perpendicular external load during movement is absorbed by the gate supports on the gate surface. The tensile force is a derivative of this. The tensile force is strongly influenced by the type of guide: a rolling or a sliding guide. The selection of the guide is an economic consideration in relation to the size of the corresponding winch gear.

Gates with a roller guide, both vertical for the overweight as well as horizontal for the loads, require a relatively light winch unit. The tensile force then largely depends on the speed with which the gate moves and the manner in which the water displaced by the gate can be pushed away. The gate has to allow flow through for this. The tensile force of a gate with sliding guide could be a factor 10 larger than the tensile force at a rolling guide.

There are various cable winch units available. It could be a two-sided drive wheel with a cable drum on each side (fig. 7.88), a one-sided drive wheel with one cable drum (fig. 7.93) or a two-sided drive wheel with one drum (fig. 7.94). The choice depends on the volume of the tensile force, the kind of guide and the available space.

In opened position, the gate is pre-tensioned against the supports to prevent the gate from being sucked out of the chamber. In closed position, the level in the gate chamber must be able to follow the water level outside. The gap between the gate and chamber and between the gate and recess should be sufficiently large.

Gate guides

In vertical sense, a rolling gate is supported by two lower roller carriages, equipped with wheels that run on rail tracks in a slot on the bottom. A rolling gate pivots on these roller carriages and during its movement it has to be indirectly supported. In a horizontal sense the gate is guided on both sides by the horizontal guide wheels, by sliding guides or a combination of both. This results in two points of suspension at the bottom and one point of suspension at the top of the gate.

The horizontal wheels run on rails while the sliding guides run in tracks. The choice depends on the volume of the perpendicular load on the gate during movement because the friction caused by the operating mechanism of the gate has to be overcome. Rails are only applied as a guide while tracks are also used for support and sealing.

In order to have the gate move freely from its supports, the gate has to be centred by a push on and off system that pushes the horizontal guide wheels to almost against their rails.

7.4.4.2 Operating mechanisms

7.4.4.2.1 Two-sided drive wheel with a cable drum on each side

The schematic progress of cables of a two-sided drive wheel with a cable drum on each side can be seen in fig. 7.89. Two identical systems have been installed on both sides of the gate chamber. They consist of a drive wheel cable drum, a cable wheel and a bottom and top cable. The top cables are connected to the rolling gate at the connection points. All of this is positioned above the highest water level in order to prevent internal rust formation.

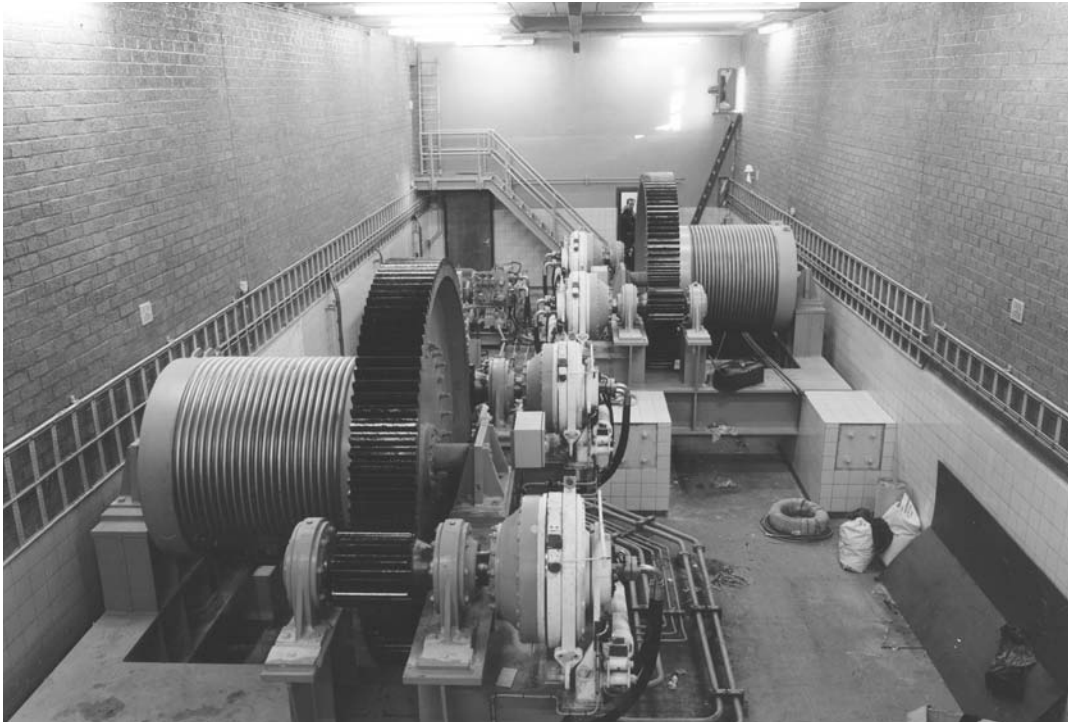


Photo 7.23 Cable drums for the drive wheel of the rolling gate of Noordersluis in IJmuiden

The gate is opened by synchronic movement of both cable drums whereby the top cables are pulling on the connection point of the gate. A cable tension control device, which is installed on every top cable, ensures that the bottom cable remains tight. If the cable drums turn the other way, the bottom cables pull the gate closed by means of the cable wheel. Once again, the cable tension control device ensures tight upper cables.

Fig. 7.90 shows the cable tension control device of the rolling gate in the marine lock of Terneuzen. The twist that the spring of the cable tension control device has to be able to make depends on the tensile force, the thickness of the cable and the length over which it is pulled. If one cable is overloaded and the other cable is underloaded, an extra group of springs ensures that the overload in the one cable is signalled and adjustments can be made with a stretching screw.

The cables that drive the gate are found on both sides of the gate, each one in its own channel. The cable drums are positioned in a chamber behind the gate chamber and the cable wheels in the cable channels next to the chamber.

In opened position, a block brake keeps the gate in pre-tension against the supports in the gate chamber. The cable drums are centrally driven (fig. 7.88), which has the disadvantage that the load in both cables are never equal due to differences in elasticity, certainly at low load on the cables. A better solution is each drum having its own drive and the same engaging and disengaging gear so that both cables are pulled equally hard.

The speed of the gate during movement is not constant (fig. 7.91 and 7.92). The gate speeds up gradually to a speed considered higher than the speed of the gate type and it slowly decreases speed towards the end. This is intended to prevent high transitory waves in the gate chamber.

The result of the longitudinal resistance of the gate through the water coincides with the gate axis if the gate has a symmetrical shape. The resistance of the horizontal gate guides coincide with the gate cladding and therefore not with the gate axis. This resistance is a result of the hydraulic load directly on the gate (wind waves, seiches, surges, density differences, rest lift and the like).

The hydraulic resistance of the guides is much smaller for a roller guide than for a sliding guide. If the longitudinal resistance of the water is large with respect to the (incidentally occurring) resistance of horizontal guides such as is the case with roller guides, then the moment on the horizontal surface is not large. Two cables per side is a solid solution in this case.

7.4.4.2.2 One-sided drive

Rolling gates for medium sized (10 - 16 m) locks are sometimes driven by one cable along one side of the gate (fig. 7.11 and 7.93). The gates are narrow in comparison to large gates, whereby the eccentricity of the driving cable can be small.

The cable can best be situated on the side where the largest resistance of the horizontal guides on the gates usually occurs. Despite this, the horizontal guides are exposed to larger forces due to the asymmetric pulling than they would be with two-sided cable drive. A rolling guide is therefore preferable at one-sided drive.

One-sided cable drive does result in a financial saving on the civil construction work and in the monopolized space in the longitudinal direction of the lock, but not on the drive. The cable is thicker, the drum and the cable wheel are therefore larger and the cunet deeper while the gate requires a rolling guide. Moving a rolling gate by means of cables on one side of the gate is therefore not recommended.

7.4.4.2.3 Two-sided drive with one drum

The construction consists of an operating cable drum, two cables with weights, a top roller carriage with guide wheels and a central rod (fig. 7.94 and 7.95 and photos 7.24, 7.25 and 7.26). The cables form the connection between the operating cable drum and the top roller carriage, the rod is the connection between the top roller carriage and the rolling gate. The top cable on the operating cable drum has the function of opening the gate and runs via two horizontal guide wheels on the corner points of the top roller carriage and a vertical guide wheel in the gate chamber to a counterweight for keeping the cable pulled tight. The cable is provided with a cam that runs against a cable stop. The gate can only start moving after that. In exactly the same manner, a bottom cable is applied for closing the gate.

The construction of both cables with horizontal guide wheels on both corner points of the top roller carriage and the vertical guide wheel to a counterweight ensure that both sides of the top roller carriage are pulled with equal force. The top roller carriage moves straight ahead, together with the central rod of the rolling gate and the top roller carriage.

The top roller carriage rolls on wheels with flanges on elevated rails along the length of the gate chamber. The tie rod between the top roller carriage and the gate is movable as the gate must be able to move sideways. During gate exchange, the cables do not need to be disassembled; only the tie rod needs to be disengaged.

The drive of the cable drum of fig. 7.94 is situated in a watertight chamber behind the gate chamber.

7.4.4.3 Gate guides

7.4.4.3.1 Rolling bottom guide

A rolling gate is supported by two lower roller carriages that transfer the overweight of the gates to the bottom and that also guide the gate sideways at the bottom at large load perpendicular to the gate area (photo 7.27). The rolling gate is roller guided to prevent large tensile force during the movement of the gate. The reason for the use of separate lower roller carriages is caused by having to be able to change the wheels in the wet, separate from the gate and the gate being able to move sideways.

Every lower roller guide is provided with four vertically positioned runners and if these also guide the gate sideways, they are provided with horizontally positioned guide rollers (fig. 7.100). On top of the lower roller carriage there is a centrally hinged and flexible gate bearing point so that the gate can tip over slightly (fig. 7.98 and 7.101). The vertical guide wheels are level if horizontal guide wheels are present; otherwise these are provided with flanges.

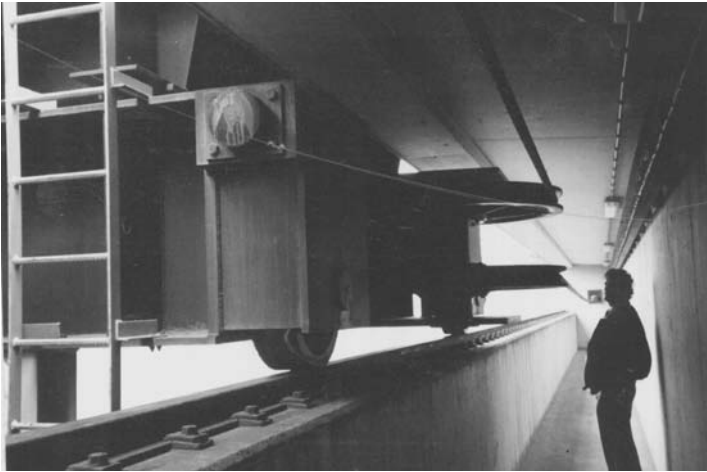


Photo 7.24 Top roller carriage of rolling gate drive of locks at Hansweert

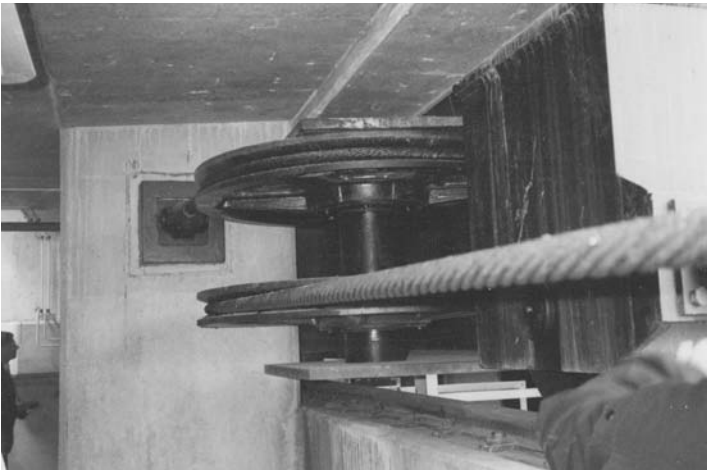


Photo 7.25 Cable wheel of rolling gate drive of locks at Hansweert

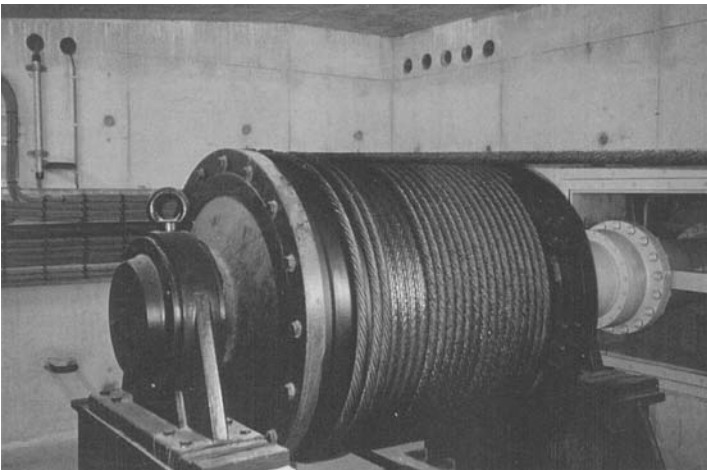


Photo 7.26 Operating cable drum of rolling gate drive of locks at Hansweert



Photo 7.27 Lower roller carriage of the rolling gate at Middensluis in Terneuzen

In the cunet in the bottom, there are two rails for the vertical guide wheels and also two rails for the horizontal guide wheels (if present). The guide wheels are bearing-mounted in synthetic bushes or on roller bearings.

Fig. 7.105 provides an example of a lower roller carriage with vertical and horizontal wheels. This roller carriage is provided with four vertical guide wheels and four horizontal guide wheels as well as a hinged gate bearing point on the top. The roller carriage is quite long due to the position and place of the push off device (see below). The gate thickness depends on the dimensions of the roller carriage. The roller carriage drives under the level of the sill and because of this, a deep slot construction is required.

Fig. 7.100 shows a far more compact roller carriage that only requires one shallow cunet. The gate does have to be thicker while the roller carriage is substantially heavier because of the projecting wheels and axels. The lower roller carriage in fig. 7.99 has the advantages of the previous solutions such as a shallow cunet in the bottom, a lighter construction of the roller carriage and a thinner gate. The roller carriage has four vertical and two horizontal wheels. A disadvantage is that this lower roller carriage has a tendency to tip over and this has to be prevented by enlarging the bearing force of the gate.

The rails for the lower roller carriage have to be mounted extremely accurately with regard to each other in order for the load to be well-divided over the wheels. Every roller carriage drives on four wheels. A small deviation from the horizontal area results in twisting of the roller carriage and increased load on two of the four wheels. The horizontal rails also have to be accurate with respect to the vertical rails. Joints in the concrete floor between the gate head and the gate chamber are bridged by the rails and not by the foundations, which can only absorb transverse forces here. The rails do not have good protection against dragging anchors.

In order to allow the gate to move free of its supports and to execute a rolling guide, a push-off device centres the gate during movement. This push-off device, which is a part of the gate, pushes out the horizontal guide wheels in the lower roller carriage to the extent that there is very little clearance left between the horizontal guide wheels and the rails (see fig. 7.105). If the gate has to turn in closed position, the push-off device is switched off and the gate moves sideways through the water pressure and leans against the supports. In the past, instead of a push-off device, a spring construction would also have been used (fig. 7.98). The disadvantage of this is that the gate keeps leaking even in a closed position and with little lift.

In addition to the overweight of the gate, the tensile force of the cable winch gear determines the maximum vertical load of the rolling gate on the roller carriages. The load on the back roller carriage increases during opening and during closing, the load increases on the front roller carriage due to the elevated connection point of the tensile force (fig. 7.34). The largest bearing pressure occurs during movement at minimum lock level.

7.4.4.3.2 Sliding lower guides

As the horizontal load on the gate is small during movement, the horizontal wheels of the lower roller carriages are omitted. The vertical wheels of the lower roller carriages are equipped with flanges. Fig. 7.97 is an example of this. The lateral guide at the bottom of the gate initially comes from the sliding guides that are positioned on all four corners of the gate, at the bottom against the cladding (fig. 7.104). The sliding guides then glide along two tracks in the cunet at the bottom. These tracks also serve as gate sealing in a turning situation.

The choice in material of the sliding guides and tracks depends on the friction coefficient, the surface pressure during movement, the permitted wear in the standing time, the deformation, the temperature increase due to friction and the exchangeability. Usually, the sliding guides are made of stainless steel and the tracks are made of a synthetic material. In the end, this will result in a 10 to 15 times higher resistant force than the use of horizontal guide wheels. But, if the horizontal load is small, this is less problematic. Between the sliding guides, a slack bottom support is usually applied in longitudinal direction of the gate but this part will transfer little force during movement.

7.4.4.3.3 Gliding lower guides



Photo 7.28 Fixed load bearing shoe and hydrostatic bearing of sliding gate of Nieuwe Oranjesluis in Amsterdam

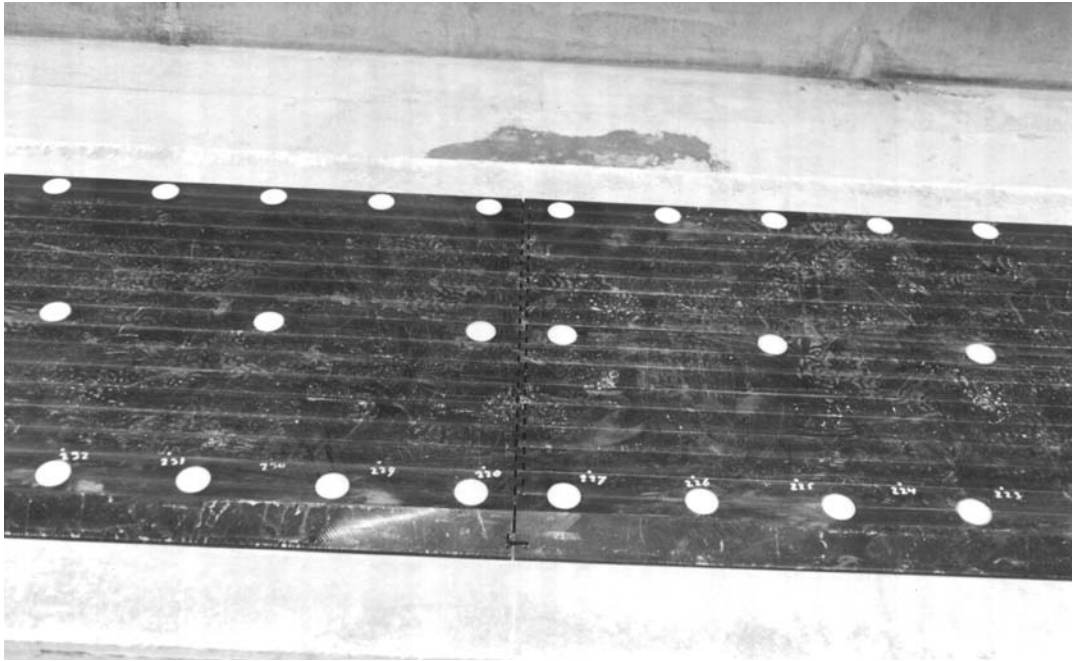


Photo 7.29 Synthetic slide of sliding gate of Nieuwe Oranjesluis in Amsterdam

For the rolling gates at Nieuwe Oranjesluis, the lower roller carriages were replaced by two hydrostatic bearings that carry the overweight of the gate. Hydro bearings are flat, round openings that are pushed slightly by means of water pressure. Water avoids the contours (photos 7.28 and 7.29).

Fig. 7.39 provides a schematic drawing of the bearing. The bearing is made of steel, is round and is equipped with four water chambers. These can each be pressurised independently of each other. The pressure is supplied by pumps that are housed in watertight areas in the gates (see fig. 7.38). The sideways resistance depends on the accuracy of the track on which the bearings slide. The bearing has flexible support so that it can adjust to small inclines. The bearing touches the track, sometimes over small areas of the profile. This results in lack of water film, which leads to resistance.

The gate is furthermore equipped with fixed bearings to ensure that the gate can (slowly) be moved to the end position, if the system malfunctions. The hydro bearings can be removed without lying open the gate. In the turning position, the gate rests directly on the hydro bearings. The pumping installation is inoperative at that time.

Indirectly, a sliding guide guides the gate along the track. The combination of guides and track results in a low frictional coefficient. The clearance between the guide and the track is as small as is practically feasible, which prevents the gate from making large to and fro motions under variable load.

7.4.4.3.4 Rolling upper guide

In order to guide the rolling gate at the top during movement, horizontal guide wheels are positioned on both upper sides of the entrance to the gate chamber (photo 7.30) and rails are positioned on both claddings of the gate. The guide wheels have to be mounted in front of the vertical supports of the gate, as the rails will transect the supports. If leakage is permitted at the top of the vertical supports, then the wheels can be positioned further back in the chamber. These guide wheels are also pushed out by means of a push-off device with little clearance between the wheels and the rails in order to centre the gate and keep it free of its bearings. If required, horizontal guide wheels can also be used in the same manner at the top of the entrance to the gate recess (see fig. 7.95 and 7.107).



Photo 7.30 Horizontal guide wheel of the sliding gate at Nieuwe Oranjesluis in Amsterdam

If the top roller guide has to consist of several guide wheels due to the dimensions of the horizontal load, a different construction is used whereby the guide wheels run on the gate and on the rails along the gate recess.

An upper roller carriage is fixed on the catch at the back of the gate that runs sidelong to the rails in the chute of the gate recess. (This chute also houses the tension cables of the operating mechanism.) The upper roller carriage has horizontal guide wheels on both sides that are pushed outward during movement by a push-off device in order to centre the gate and keep it free of the bearings. The forces of both load directions on the gate are absorbed on one side of the gate (fig. 7.106). A variation on this is a top roller guide with top roller carriages on both sides of the gate (fig. 7.102).

The top roller guide can also be a sliding guide. The space between the gate and the guides has to be sufficiently large that, during levelling, the water level in the gate chamber and gate recess is able to follow the water level in the lock chamber or outside the gate. This could result in the gate moving to and fro and it would be better to install a push-off device for the sliding guides. This makes it easier to use the runners.

7.4.5 Operating mechanisms and guides for lift gates

7.4.5.1 General

At present, lift gates are only used in large locks with a width of passage of 16 - 24 m. Due to the large movement that the gates have to make these gates are always moved by means of winch gear that is positioned in the towers on both sides of the lock chamber. Lift gates are balanced by means of two balance weights in order to limit the size of the winch gear. The towers serve as housing for the winch gear and guides.

The winch gear is fixed to both sides of the lift gate. The lift gate is attached to the balance weights by means of counterweight cables (or lifting cables), whereby the cables are diverted by means of a main pulley in the top of the tower. The gate or the counterweights are pulled with lift cables or pulling cables by means of the winch gear that is positioned either at the top or at the bottom of the tower. The winch gear consists of a cable drum, gear wheel, pinion, gear case, propulsion motor and one or several block or shoe brakes.

In the case of a rolling guide, guide wheels or rollers that slide along the rails are positioned on both sides of the gate at the top as well as the bottom. A push-off device keeps the gate free of its supports during movement and positions the guides on the rails. Often, sidelong guide wheels are used as well. For light load gates a sliding guide is used that consists of slides on the gate and synthetic slide strips.

7.4.5.2 Operating mechanisms

7.4.5.2.1 Counterweights and winch gear

In general, lift gates are balanced with a counterweight (divided over two balance weights) that limits the load on the winch gear. The following should be taken into consideration in determining the size of the counterweight. The gate cannot be completely balanced out as the weight of the gate has to exceed the counterweight. If the gate is closed, it requires a certain overweight (weight of the gate minus counterweight and upward force) to prevent leakage at the bottom edge. In order to lower the gate, the lift gate requires sufficient overweight to surmount the resistance of the gate guides due to gate load resulting from wind, wind wave or translatory wave load, the upward force of the gate under water and the resistance against the bending of the cables around the drums and pulleys. Furthermore, sufficient overweight is required to overcome the resistance if the gate has to close under the same conditions that it is required to open under.

The operating mechanisms of the lift gate have to cope with a heavy load in comparison to rolling gates. The most significant loads on the winch gear occur during lifting and lowering the gate due to the overweight of the gate and the additional weight caused by waste and ice on the gate. During lifting, the winch gear also has to overcome the resistance of the gate guides due to the load on the gate caused by waste, wind waves or translatory waves and the bending strength of the cables around the drums and pulleys.

The winch gear that pulls on the gate or on the counterweights is fitted with different cables to limit the dimensions of the drums and therefore the winch gear. A small machine room is important, particularly in the top of the towers. The reason for several cables is because one cable per drum results in such a thick cable that the drum diameter becomes extremely large. By applying two or four cables, the required machine room becomes much smaller. This is of particular importance if the winches are positioned on top of the towers.

Pulling the lift gate (or counterweights) with different cables requires extra provisions to distribute the load as evenly as possible. If the cables are just fixed to the points of suspension, this could lead to large differences in tractive effort per cable because of dissimilar cable elasticity or due to differences in the diameter of the grooves on the cable drums or cable pulleys. This problem can be solved in three different ways.

- *Spring construction*
Between every cable and suspension point, a spring construction is used whereby the springs compensate for part of the difference in elasticity of the cables. In fig. 7.110, four cables pull the gate up via spring constructions and twinbuckles. The twinbuckles are used to even out the spring tension in every cable during the mounting of the cables.
- *Spreader construction*
In using a spreader or force equalizing construction, the difference in cable forces is largely cancelled out. The solution using spreaders requires a heavily loaded structure that only functions well if all pivoting points are equipped with roller bearings. This solution requires more height and is comparable in cost to a spring construction.
- *Many cables*
If many thin and long cables are installed, the difference in cable force is small. However, this does require a long cable drum and (generally too) much space to attach it to the gate.

7.4.5.2.2 Placing

There are different ways to place winch gear and counterweights. Four methods are outlined in fig. 7.108.

- *Method A*
Both counterweights that hang on the gates by means of balance cables are as large as possible. Winch gear and pulleys are positioned in the top of the tower, in two rooms or combined in one as shown in fig. 7.109 and photo 7.31. The cable winch force is substantial.
- *Method B*
The gate is 90% balanced by four counterweights in total. The winch gear is always positively loaded by the weight of the gate. The small weights on the winch gear are just as large as the required overweight of the gate on the sill. The winch gear lifts the small weights at the end of closing. The required tractive effort on the winches is therefore considerably less than those in method A. The counterweight cables have a smaller load; the drum is heavier but the operating mechanism lighter.
- *Method C*
The small ballast weight is replaced by a spring on the counterweights. The winch pulls on the counterweight via the spring. At the end of the movement, the large weight is lifted slightly by the spring. The disadvantage of the space for the second weight is cancelled out. Just like in method B, the counterweight cables have a smaller load and the winch forces are less.
- *Method D*
Method D matches the description of method A, except that the winch gear is positioned below.



Photo 7.31 Operating mechanism of the lift gate of the new lock in Wijk bij Duurstede

The tensile force in the winches is lower when using method B and C but the cables carry a heavier load. Method C is preferable to method B as it does not require space for a second ballast weight. Both methods have the disadvantage that, given disconnection of the winches during inspection, the pressure on the sill is insufficient and it results in leakage under the gate. At large gates the solutions B and C supply insufficient advantages, at smaller coupled towers sometimes they do result in advantages.

In raised position the gate should not bang between the guides when there is wind load. For this purpose, the gate is suspended out of the centre of gravity.

Aesthetic requirements of the towers for the lift gates often radically influence the set-up. Two examples are explained.

The winch gear with 4 (pulling) cables in fig. 7.110 and photo 7.32 (method D) is positioned under the tower in order to design very slim towers in the complex. Advantages of this solution are that the machine room is very accessible for inspection and maintenance and that little inspection is required in the top of the tower (only cable pulleys and cables) which eliminates the need for a lift. Besides this, the slimness provides better access for road traffic over the gate. Disadvantages are that all the cables and the winch gear carry a heavy load and that the foundation of the cable winch carries a tensile load. Winch gear in the top of the towers enlarges the heads of the towers and generally also increases the dimensions of the towers because a lift shaft is required for inspections. However, the height of the tower can be limited. In fig. 7.109 (method B) the cable pulleys and the cable drum rotate on the same axle. Because the drum has a large diameter at its disposal, fewer and thicker lifting cables can be used. Disadvantages of this solution are related to investment and maintenance. For the replacement of one of the functional parts, all related components such as the gate, the ballast weights and the cable winch have to be blocked or disassembled.

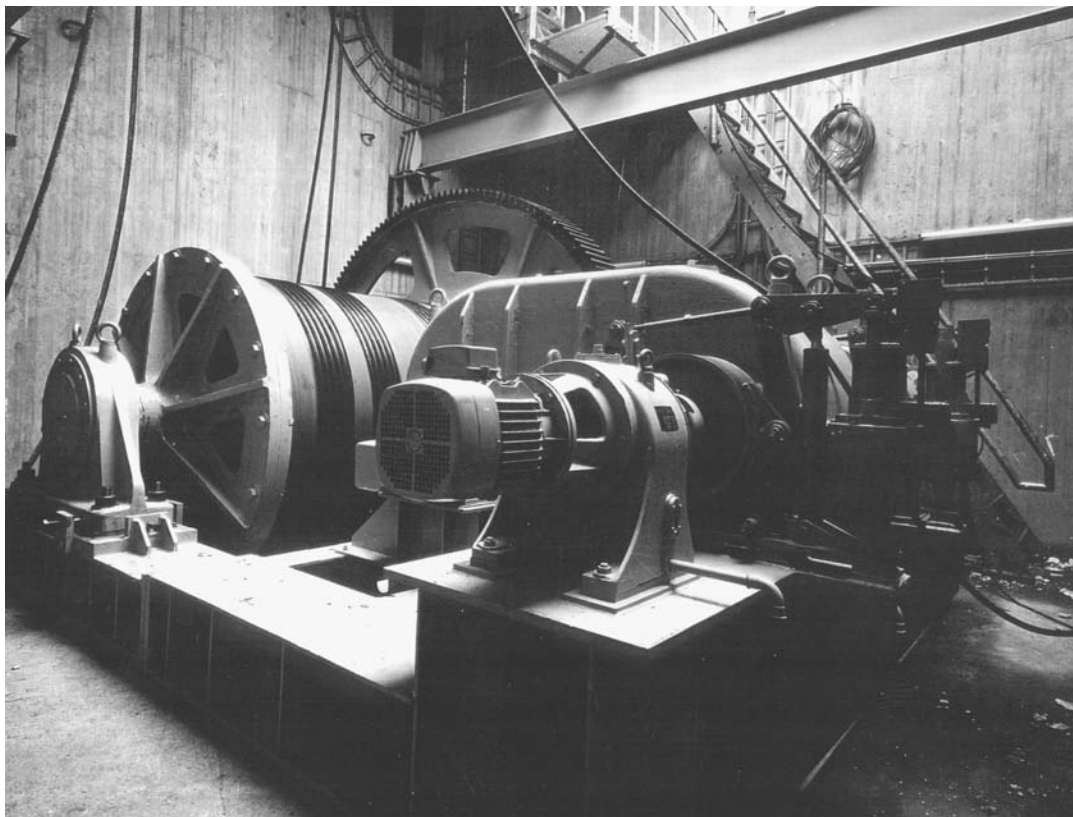


Photo 7.32 Operating mechanism of the lift gate at Kreekrak locks

7.4.5.3 Gate guides

7.4.5.3.1 Rolling guides

Lift gates that go through considerable horizontal load of wind, wind waves, translatory waves or vertical suction force because of flowing water under the gate during opening and closing, are guided by roller guides. Roller guides require very little additional tensile force from the winches because of their very low friction.

The rollers are guided over the rails in the recesses on both sides of the lock head and along the towers. Two or four rollers are mounted per side of the gate, depending on whether it is a one or two-sided retaining structure. The lower roller is mounted as low as possible; the upper roller is positioned as such that both rollers experience equal force of the maximum load during lifting. The use of roller guides is less problematic for lift gates than for rolling gates. If the lift gate is suspended above the water, the rollers can be inspected and maintenance can take place without having to exchange the gates.

Furthermore, side guides are used and rollers are used for the guidance of the balance weights.

Rollers roll along the rails. In general, standardized rail sections are used for this. For extremely loaded rails, very high quality pieces of flat bar steel are used. The part of the rails above the recess that has to be partly or completely removable in order to change the gate, is situated in front of the front wall of the tower.

The rails or the flat bar steel are mounted on steel foundation girders in the recesses that disperse the roller load lengthwise and widthwise. There are two possibilities for positioning the foundation girders: at the same time with the construction of the concrete work or to fix them to with anchors in the concrete in the recess. In the first option, an adjustment construction is used (see fig. 7.112). The advantage is that the foundations can be so accurate vertically and in equidistance, that adjustment of the rails is not necessary, which results in considerable time gain in construction. In the second option, the foundation beams are fixed to the concrete by means of anchors and are subsequently grouted in (fig. 7.113). The transfer of the roller guide to load the concrete is not as good as it is in the first option however, this option is cheaper than the first option. In fig. 7.114 the guide is mounted through the wall, together with the guide of the ballast weight. This is an example of how the mounting should be used in order to use sliding formwork to pour the tower.

7.4.5.3.2 Push-off device

In closed position, the gate rests against the vertical supports. To change from a resting position to a rolling position and the other way around, requires a push-off device.

The lever system is shown in fig. 7.116 whereby the rollers are in pushed on position. Because of the construction with four rollers per gate side, the system is suitable for two-sided retaining. When the long lever is lifted by means of a tie rod, the rollers move sideways. This pushes the gate into the middle position and it comes loose from the supports while the rollers lie against the rails. The gate can be lifted if the support is away from the tie rod. If the gate rests against the left support, the left rollers push the gate to the middle position. The same applies to the right support and the right rollers. If the gate is under low load, a separate operating mechanism is not required and the tie rod is attached to the winch gear. A disadvantage of this is that the cables are not taut when the gate is closed and they can bang in windy conditions.

Usually gates under heavy load, thus with large rollers, are equipped with a system with its own operating mechanism. A lever construction requires substantial space and it is very heavy. The separate operating system can be electro-mechanical or electro-hydraulic. Because the push off does not need to be large, roller axels are used whereby the rollers rotate around an eccentric locking section. By turning the axels, the rollers mainly move sideways. Fig. 7.118 shows such a mechanical operating system with two rollers for a one-sided retaining structure. The disadvantage of this solution is that the operating

mechanism has to be housed in a watertight section of the gate, which makes inspection and maintenance more difficult. Fig. 7.115, likewise with two rollers and one-sided turning, shows an alternative option. The axels that the rollers rotate around are turned by moving the lever up. Fig. 7.117 provides a schematic overview of the push-on/ push-off device of the lift gates of the Kreekrak locks. Fig. 7.113 shows a solution of an operating system with four rollers and two-sided retention with a hydro-motor that can work under water. The hydro-motor is powered by electrically driven pumps in the top of the gate.

Selecting the type of operating mechanism is often difficult because every option has advantages and disadvantages. For constructions under light load with small rollers the use of winch gear is a good and simple solution. Rollers under heavier load can have an operating mechanism under water such as a hydro-motor or hydraulic cylinder, whereby the operating source is positioned in a space in the gate (watertight if necessary).

7.4.5.3.3 Sliding guide

The simplest form of gate guidance is a sliding guide. A considerable advantage of the lack of rails is a much shallower recess. A synthetic guide is mounted on the concrete work and the gates are equipped with stainless steel sliders. The steel sliders on a synthetic track result in relatively low frictional resistance. The required surface of synthetic tracks depends on the surface pressure, the permitted wear and tear and the temperature increase due to friction. Compared to rolling gates, the cooling of synthetics in air at lift gates is less favourable. The vertical synthetic guide is adjusted by means of bolts in a recess in the concrete work of the gate recesses (fig. 7.120). This is subsequently filled with mortar.

7.4.5.3.4 Rolling or sliding

A roller guide requires extra investment in the shape of rollers and an operating mechanism. The gates are heavier because of the rollers and therefore the balance weights are also heavier. The winches are under smaller load. All this in comparison to a sliding guide of which the seal of the gate is slightly less effective, the recesses less deep, the winches slightly heavier and the balance weights smaller.

For gates that are under less load when lifted, that is to say hardly experience any influence of waves, a sliding guide is sufficient. Gates under heavier load usually have a rolling guide.

7.5 Sliding mechanisms and lock paddle operating mechanisms

7.5.1 Sluice gates and operating mechanisms at gate openings

7.5.1.1 General

Sluices for openings in gates are used for levelling and sometimes they are also used for flushing. Levelling is started by lifting the sliding mechanism whereby discharge increases with the increase of the flow through opening. The chamber fills (or empties) while the lift over the gates decreases. At a certain moment the lift has decreased by so much that the discharge also decreases even though, as a general rule, the openings have not completely opened yet. A little while later, the openings are completely open (sluice gates are lifted completely) and some time later the lift over the gate is just 0.10 m for example. The gates are then opened and the lock is either filled or emptied. During the opening of the gates, the gate sluices remain open and are only closed once the gates are completely opened. During the closing of the gates, the sluices gates remain closed. The gates should leave the gate chambers slowly to avoid large suction force.

The levelling openings are positioned as low as possible in the gate and spread over the complete width of the gate. As mentioned previously, standard measurements are used for the width of these levelling openings (1.40, 2.15 and 2.60 m). The total width of the opening amounts to 60% of the width of passage of the lock. The height of the openings depends on the length and lift of the lock but is usually between 0.75 and 1.75 m. In general, there are at least four openings per head so that, should one of the sluice gates malfunction, an acceptable flow pattern is maintained in the lock. The shape of the openings and the slide speed result from hydraulic research.

Two kinds of operating mechanisms are used for moving the lock paddles: a hydraulic cylinder or a spindle. In the past, rack drives were also used but this operating mechanism does not have any advantage over the two other operating mechanisms. It is hardly possible to give preference to one of the first two types, except under particular circumstances. The operating mechanism must be able to deliver the maximum required tensile force in order to open the lock paddle under maximum lift. The lifting speed of the lock paddles is usually low and amounts to 2 - 10 mm/sec. From a hydraulic perspective, it could be necessary for this speed to be varied during lifting (slow start) and/or for the speed to be fixed dependent on the initial lift over the gate.

Sometimes, lock paddles are also made suitable to discharge water from a higher reach. During discharge, the navigation lock is out of operation. The construction of the lock paddles does not change for discharge purposes. Usually, due to the required discharge capacity, only the lift height is increased and the shape is adjusted. Only part of the lock paddle height is used when levelling. An example can be seen in fig. 7.121. For levelling, the lower part with 6 openings is used. Thus, a limited width of the openings is used, which means that the lifting speed of the lock paddle does not need to be very small. During discharge the full width behind the lock paddle is utilized: the lifting speed is not of importance here and could be the same as for levelling. A disadvantage of such a solution is the large lifting force during levelling as the lift load acts across the complete surface. However, splitting it up into several units is complicated and less economical.

7.5.1.2 Lock paddle

At a one-sided turning lock paddle, the lock paddles are situated on the high water side (fig. 7.122 and photos 6.8, 6.10 and 6.12). The lock paddle is constructed from a stiffening plate or a solid, thick plate. The stiffening plate is found on the low water side and is provided with synthetic strips along its profile. Along the profile of the opening, steel strips have been mounted so that when the lock paddle is in a closed position, the water pressure presses the synthetic strips against the steel strips. There are U-shaped vertical lock paddle guides on the gate, equipped with steel strips between which the gate slides during the movement. For this, the lock paddle on the uncladded side has slides on the corner points and also on the sides. The top and bottom rim of the slide have to be so stiff that the guide does not get damaged due to deflection under load and that it does not get stuck behind the support during descending.

If the gate is bilaterally retaining and some leakage is permitted, the construction in fig. 7.122 is adhered to with the exception that synthetic strips are fitted to both sides of the lock paddle profile with minimal clearance to the guides.

Lock paddles that have to retain bilaterally and have to seal well to prevent loss of water are provided with a rubber fender profile on the one side that functions as a support for the negative retention (fig. 7.123). The rubber profile pre-stresses the lock paddle in the guide. The rubber is positioned on the side where the load is greatest (cladding side). The least pre-stressing is required to also seal negatively. Because of the pre-stress, the tensile force of the operating mechanism has to be increased slightly. Two-sided sealing lock paddles are applied in all two-sided turning gates, thus also for bilaterally retaining single pivot gates.

7.5.1.3 Operating mechanisms

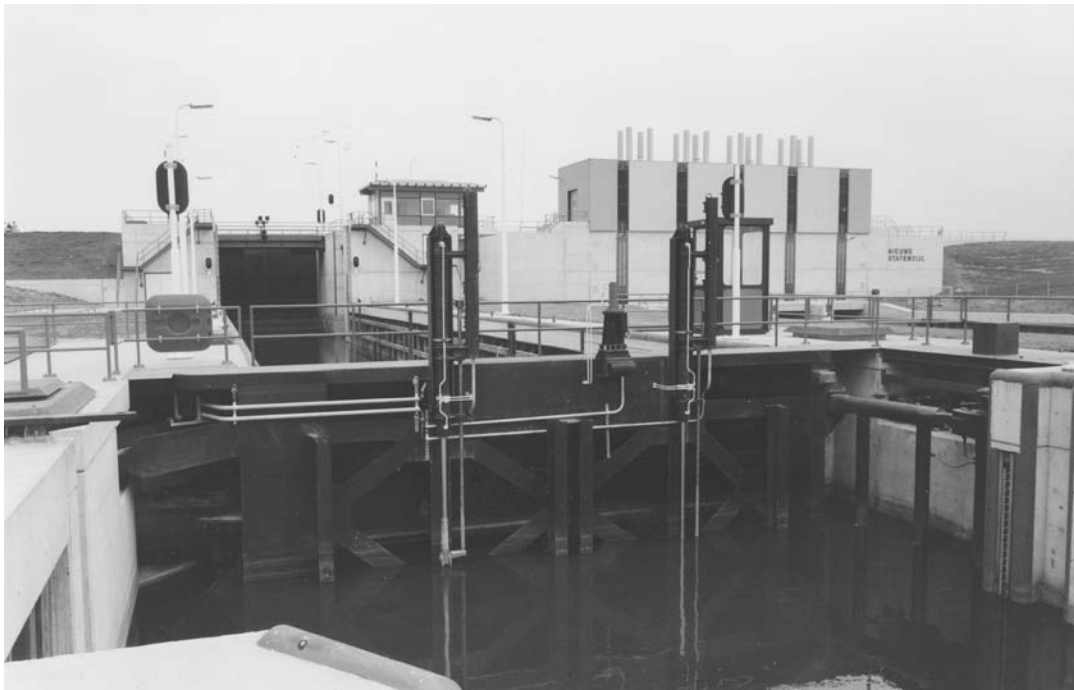


Photo 7.33 Hydraulic cylinder lock paddle operating mechanism of a single pivot gate of the lock at Nieuwe Statenzijl

In the past, many straight rack drives were designed as operating mechanisms for lock paddles (photos 7.14 and 7.19). At present, operating mechanisms are either hydraulic or with spindle.

Hydraulic operating mechanism

A hydraulic operating mechanism for a lock paddle consists of a cylinder with a suction rod and a piston rod and the operating source required for oil pressure consists of a tank with accessories. The cylinder is mounted or hinged to the gate, depending on the position of the paddle with regard to the bottom of the cylinder. Preferably the cylinder is positioned high enough on the gate that the seal around the suction rod remains above the canal level or average high water level. This enables maintenance in case of oil leakage without removal of the gate (fig. 7.125).

From a constructional point of view, it generally turns out that the cylinder with suction rod is mounted downward on the gate. This is less logical, given the lifting and lowering power; the available surface of the piston and rod side is inversely proportional to the required forces. Positioning the piston the other way around requires an extra set of rods and a less favourable position on the gate.

The required tensile force during lifting depends on the maximum lift over the gate and therefore on the friction of the slides and tracks. It also depends on the own weight of the lock paddle and possible cross forces. In case of a calamity, it could be necessary to stop the levelling immediately. The lock paddles should therefore be able to close under lift. The necessary force to be able to close is less than the force required to open due to the weight of the lock paddle.

The operating unit consisting of oil pump, electro-motor, accessories, oil tank etc. can be positioned in a water free space in the gate. The advantage of this is that gate exchange requires little time as the electrical connections just have to be disconnected and reconnected. Disadvantages are that the available space on mitre and pivot gates is limited which makes inspection and maintenance more difficult and that the spare gate with operating mechanism cannot be stored horizontally.

The operating mechanism can also be positioned in a water free area in the lock head or in a room above. This certainly is the case if locking levels are high in respect of the top of the lock gate. The large advantage of this is that the water free room can be made easily accessible. Through the application of rapid action coupling, hydraulic pipes can be reconnected quickly after gate exchange though testing the system could require some time (this is to say, a longer reconstruction time).

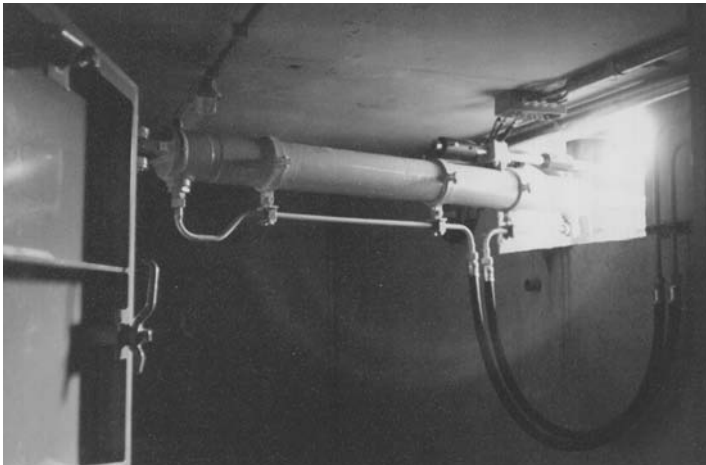


Photo 7.34 Hydraulic cylinder gate operating mechanism of wooden, single pivot gate of the lower head of the lock in Almere

Spindle operating mechanism

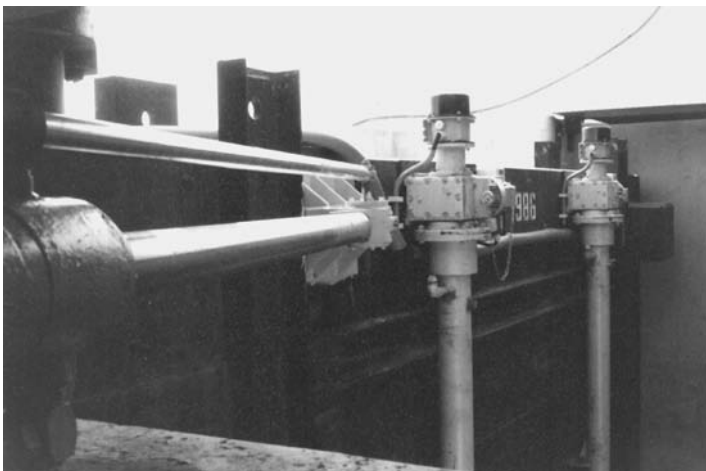


Photo 7.35 Hydraulic cylinder gate operating mechanism and spindle operating mechanism of lock paddles of wooden, single pivot gate of the lock in Almere

A spindle operating mechanism (fig. 7.126 and 7.35) is a mechanical operating mechanism of which the rotating motion of the motor is transferred via geared transmission to the linear motion of a nut. By preventing the movement of the nut, the nut moves with the tie rod attached in the shape of a pipe in vertical sense. The construction is watertight, just like the piston rod of the hydraulic operating mechanism. The movement can also take place under water.

The operating mechanism is not susceptible to floating waste and if equipped with an ice scraper, it is not sensitive to ice formation. Mechanical damage due to floating ice or due to collision is prevented by a (hinged) protective hood around the tie rod.

The spindle operating mechanism is constructed into a unit that is simple to mount to a console of the gate (fig. 7.126). The unit is slightly longer than the cylinder for the same stroke of the lock paddle. This is because the operating mechanism is mounted at the top. For gates in a high water level, this part sticks out above the gate. This could possibly be a reason to choose for a cylinder operating mechanism. Just like the cylinder operating mechanism, the spindle can be used for large tensile forces.

7.5.1.4 Connecting lock paddles to operating mechanism

Connecting a lock paddle to the operating mechanism can be realised in a number of ways, depending on the height/width ratio of the lock paddle, the mounting of the operating mechanism to the gate and the way in which the paddle is guided.

A rectangular lock paddle with a small height/width ratio needs extra provision in the sense of four side guides on the corners. In vertical sense the side guides are too close together which means that the paddle can get stuck if there is a difference in friction between the left and the right sliding guide. This can be strengthened by the difference in friction between the left and right side guides. In arrangement A of fig. 7.128 the lock paddle in the drawing can turn due to the influence of the connection formed by the friction differences of both slide guides until the side supports B and O and O1 are up against the guides. The mounting at points 1 and 3 are ball-and-socket joints to prevent the operating mechanism from experiencing forces if the sliding guides undergo possible deformation due to inaccuracies in adjustment or manufacture. Point 2 is connected with transverse strength. If calculations show that the guide will tighten itself (fig. 7.129), another arrangement will have to be chosen. The permitted height/width ratio cannot be standardized as this is dependent on the sliding materials that are used.

To prevent tightening, arrangement B (fig. 7.128) has an extended frame so that the side guides are further apart. Likewise, in arrangement C the sliding guide and the operating mechanism in the section of the guide are linked closely together, which results in the guide only needing two side guides. The latter arrangement is slightly preferential because the dimensions of the sliding guide are not important.

7.5.2 Sliding mechanisms and operating mechanisms in lock culverts

7.5.2.1 General

Generally, lock culverts with accompanying culvert valves are mainly found in inland navigation locks with large lift (5 to 7 m for the upper head) to very large lift, in very large locks for marine navigation (width of passage of in excess of 24 m) or in locks with a salt/fresh separation system.

In inland navigation locks for large to very large lift, the water is dispersed evenly over the wet cross section of the chamber as a result of the use of lock culverts that discharge into an energy dissipating chamber in the upper head. During the filling process, the vessels have an undisturbed situation (fig. 7.130). In such cases it is also sensible to use lock culverts for both lock chamber walls in the lower head in order to dissipate the energy of the jets from the lock culverts in the lower reach by making the two jets collide with each other. In very large marine locks, an undisturbed position of vessels can be achieved through good use of the lock culverts, for instance through a levelling system in the bottom via the lock culverts (fig. 7.131) or through lock culverts that are directed at the gate. In locks with a salt/fresh water separation system according to the Kreekrak system (also called the Duinkerken system) an extensive culvert system with sluice gates is used for the intake and discharge of salt water to the various basins.

In contrast to lock paddles, lock culverts are expensive in construction and maintenance. This is because of the culverts and the sluice gate housing (civil part) and the sliding guides with operating mechanisms and lay open facilities (steel and mechanical part). The culvert valve is positioned in the deepest part of the lock culvert to prevent air suction behind the valve. Cavitation must be prevented. The valve is positioned in a valve shaft and upstream and downstream of this, shafts for stop logs are positioned for maintenance to the culvert valve. During maintenance to the culvert valve, half the system comes to a stop which leads to a doubling of the levelling time. Sometimes is possible to circumvent a valve housing by placing a valve in a deep, separate shaft in front of the actual culvert mouth (fig.7.132, recreational lock Almere).

7.5.2.2 Sluice gates

Two kinds of sluice gates are used: sliding gates or roller gates. Just the same as at other operating mechanisms, the choice between rolling and sliding is an assessment based on cost in conjunction with the sliding guide operating mechanism.

Most culvert valves for one-sided turning are currently executed as sliding gates. This is because the synthetic sliding materials have improved as such that they are extremely wear resistant and have a low level of friction. The extra tensile force for the operating mechanism with regard to the use of rollers is not as large while the possibilities and knowledge with regard to hydraulic operating mechanisms have improved vastly. The combination of a sliding gate with a hydraulic cylinder qualify much sooner. The large advantage of sliding gates is the simple construction and the absence of rotating parts under water. Gate guides are constructed according to the same principle as that of lifting gates: see the paragraph concerned.

The sliding gate in the lock culvert of the navigation lock in Almere is a vertical sliding gate that does not differ much from the usual sliding gate. Fig. 7.135 provides an overview of the gate. The lift here is 5 to 6 m and therefore comparable to a sliding gate. Fig. 7.134 shows a drawing of the vertical sliding gate for the lock culvert in the upper head of lock Panheel.

Sometimes, rolling gates are used at very high lift. The lock culverts for one-sided turning in the locks at Maasbracht (fig. 7.133) are equipped with rolling gates. At 12 m the lift is quite large for Dutch concepts. In retaining position, the gate rests on the rollers. It seals by means of a rubber profile at the top and sides of the gate and a wooden bottom edge. The water pressure pushes the lip of the profile. Because of the large load around the profile, the profile is supported by a steel profile.

Furthermore, rolling gates can be used when little or no leakage is permitted and a push-on/push-off device is applied. Such a push-on/push-off device is easier to combine with roller axels than with other constructions.

Figure 7.136 gives an example of a two-sided turning gate (marine lock Terneuzen). It concerns a rolling gate that seals well against leakage without requiring a push-off device. For this purpose, the gate has a tapered shape with two claddings. The seal is flexible and is positioned on both sides of the gate, against the tapered end logs. If the gate, not under horizontal load, drops down to the sill, all seals (also in front of and behind the gate) are slightly pushed in. On both sides, the rollers are then free of the rails by about 5 mm. If the pressure on the gate subsequently increases, the gate seals well from the beginning. The seal cannot be pressed in any further than the clearance available to the rollers from the middle position between the rails. The rollers subsequently take over the load of the water pressure. They also have to do this during lifting.

The sluice gate is perforated between the claddings in order to let water into the lower edge via the shaft so that it can disperse from there. This is meant to ensure that the flow under the sluice gate on the upstream side of the bottom edge gives way to prevent possible vibrations of the gate.

7.5.2.3 Operating mechanisms

Kinds of operating mechanisms

In essence, operating mechanisms for lock culverts are the same as those in front of the lock gates: a hydraulic or a spindle operating mechanism. There is no difference between the operating mechanisms

for sluice gates for one or two-sided turning. A hydraulic operating mechanism is more suitable for high sluice gates with a long stroke; the spindle operating mechanism is more suitable for low sluice gates with a short stroke. The lift height corresponds with the height of the lock culvert and lies somewhere between 2.5 and 4 m. This is much less for a recreational lock.

Forces on operating mechanisms

The tensile force on the sluice gate for lifting, next to its own weight and the friction(s), also depends on the magnitude of the suction force of the water flowing through under the gate. This in turn, depends on the shape of the bottom of the sluice gate, the speed of the water and the lift height of the sluice gate. The magnitude of the suction force can only be influenced by optimal shaping of the bottom edge. This is a sharp bottom edge with the smallest possible bearing surface on the sill and a construction that tapers upward at an angle of 60° (fig. 7.142).

Operating mechanisms for roller gates have to be able to lift the gates; the gates drop down due to own weight, also under maximum water pressure. The energy released during the lowering has to be absorbed by the operating mechanism. The operating mechanism has to be equipped as such that the gate can reach the sill. The last part of the movement is a (small) free fall, elastic deformation or, in the case of a double-acting cylinder, a pressure switch in combination with the measurement of the covered distance of the sluice gate. The latter is to prevent the lowering action from stopping too soon.

Operating mechanisms for sliding gates have to pull as well as push. The latter is only required when, during lowering, the weight of the sluice gate is insufficient to conquer the frictional forces.

Set-up under capstone level

The requirements for the set-up of operating mechanisms are often contradictory. On the one hand, the operating mechanisms have to be positioned as high as possible above canal level or maximum locking level because inspection and maintenance has to take place without having to lay open the culvert. On the other hand, it is often important to have an unobstructed view of the lock terrain and the lock approaches. Local elevations are not highly desirable. The operating mechanisms then have to be set-up below lock terrain level.

At navigation locks on a canal there is little height available because the difference in retaining height of the lock and the canal level is usually quite small. At locks in tidal areas, more space is available height wise because the maximum locking level is usually lower than the retaining height. Different parts are, albeit incidental, temporarily under water.

Hydraulic operating mechanisms can be placed under capstone level in two ways. This is done by positioning the cylinder horizontally or vertically:

- *Horizontal cylinder*
An example of a horizontally positioned cylinder can be seen in fig. 7.136 (details in fig. 7.137) whereby the cylinder is connected to the tie rod of the culvert valve via a lever. The horizontally placed cylinder has the advantage that the basement space is small, the hydraulic system uncomplicated and the cylinder has a small stroke and is always accessible. The disadvantages are that the coupling between the culvert valve and the cylinder is a heavy construction with many rotating points and that a constant lifting speed requires a continual speed regulation from the operating mechanism.
- *Vertical cylinder*
An example of a vertically positioned cylinder can be seen in fig. 7.138. This cylinder is a simple and inexpensive solution that requires little space. However, the disadvantages are that the cylinder can only be inspected in hoisted position at locks with little difference in retaining height and canal level and that the cylinder is difficult to access at high water levels (tidal areas) while the complete operating mechanism has to be removed for exchanging the valve.

The preference clearly depends on the requirements to be set. The vertical cylinder is an inexpensive solution of which the advantages and disadvantages are accepted. The horizontal placement offers better maintenance possibilities.

Set-up above capstone level

Sometimes it is acceptable for the operating mechanism to protrude above the capstone level. This is the case when the hoisting height of the sluice valve is very large and/or the lock culvert is not situated very deep. The vertical cylinder can be mounted in different ways, either to the roof of a building if present or to a frame suspension (fig. 7.140 and 7.141).

Fig. 7.141 also shows that it is possible to exchange the lock valve without removing the operating mechanism. For this purpose the shaft has been widened above the lifted position. The valve is hoisted to the required height by the cylinder. The valve is then transferred to a mobile lifting device and removed through a hatch in the roof.

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Figures and tables

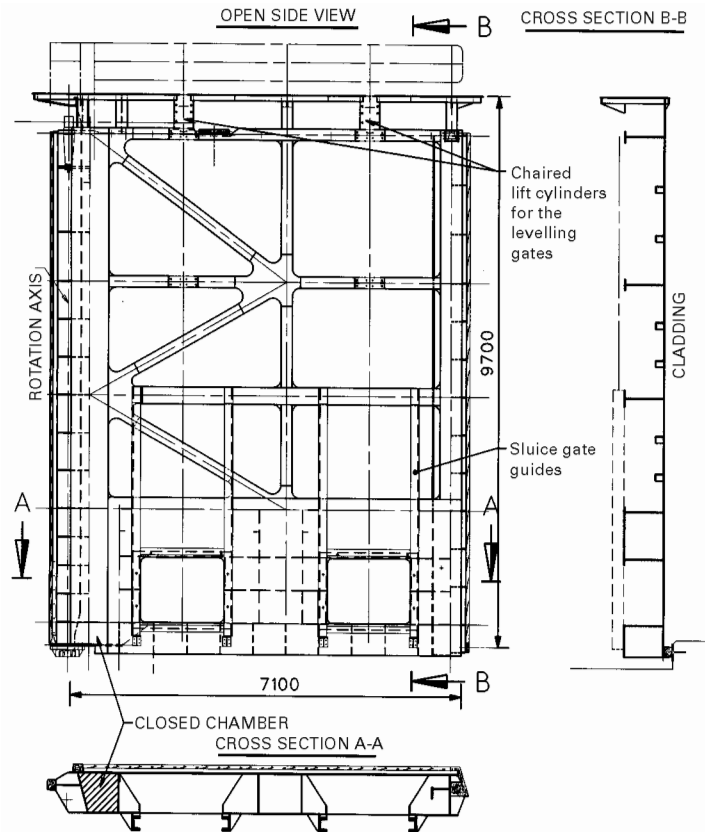


Figure 7.1 Overview iron mitre gates with closed chamber and diagonal connectors

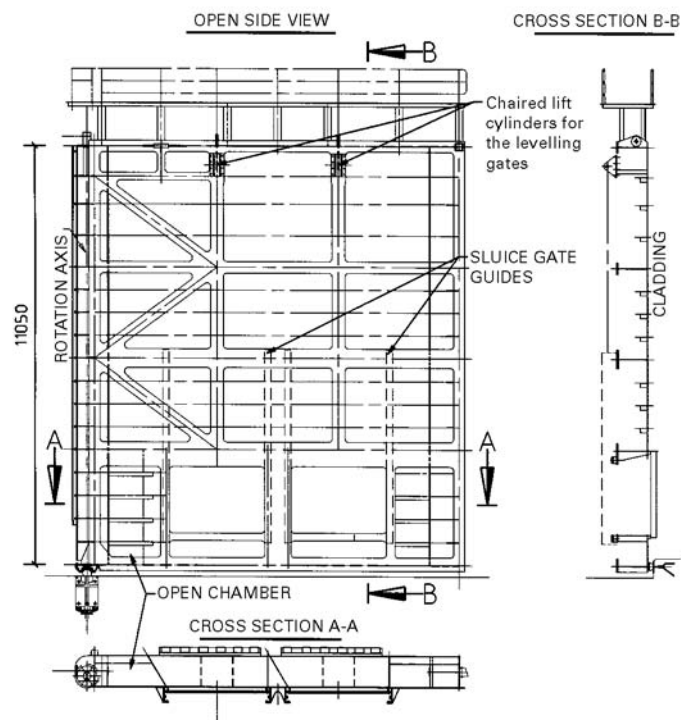


Figure 7.2 Overview iron mitre gates with open chamber and diagonal connectors

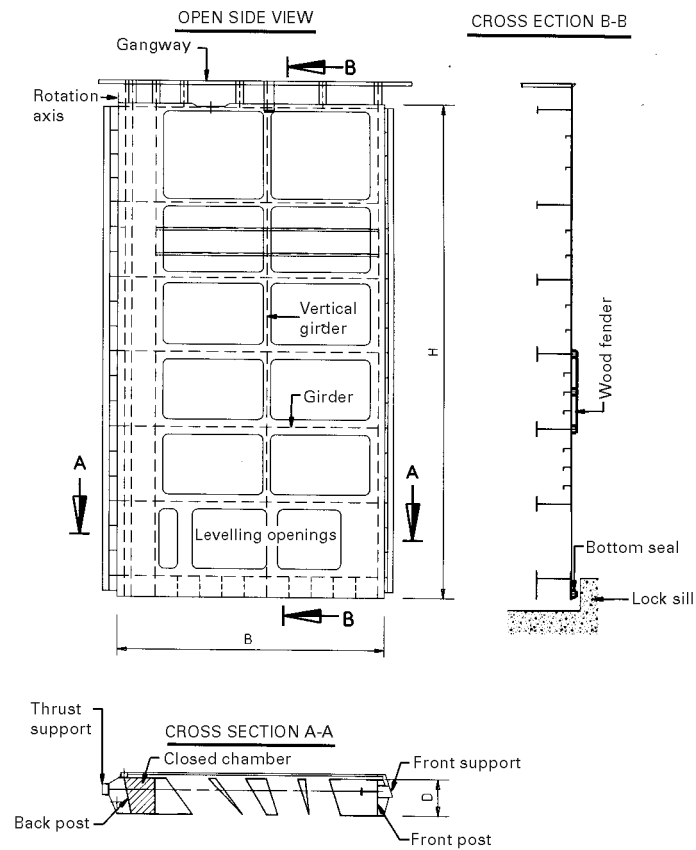


Figure 7.3 Overview steel mitre gates

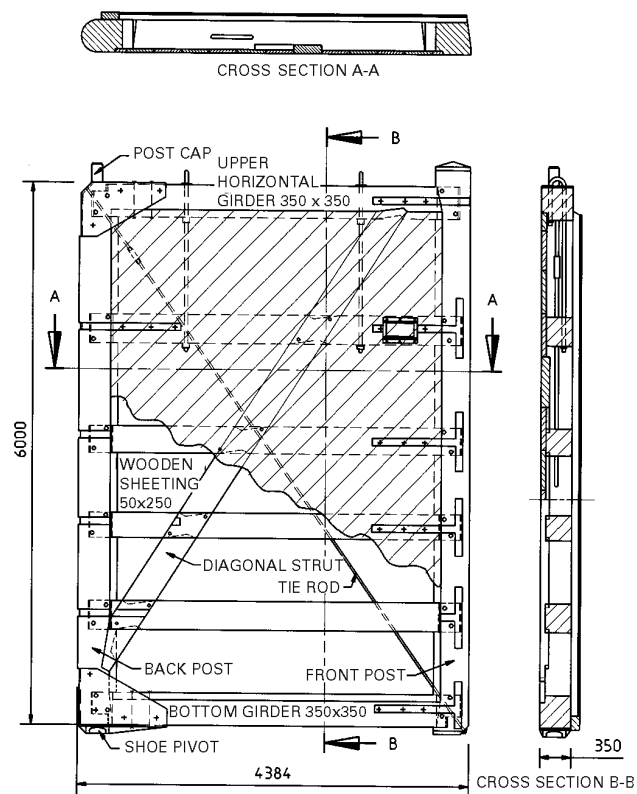


Figure 7.4 Overview wooden mitre gates

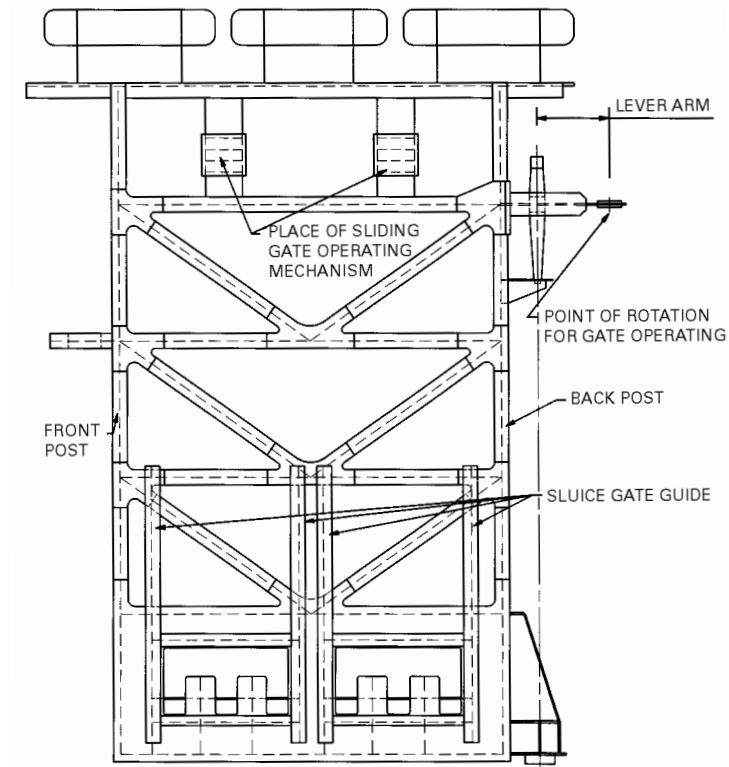


Figure 7.5 Overview single leaf pivot gate (Head gate of Fig 7.57)

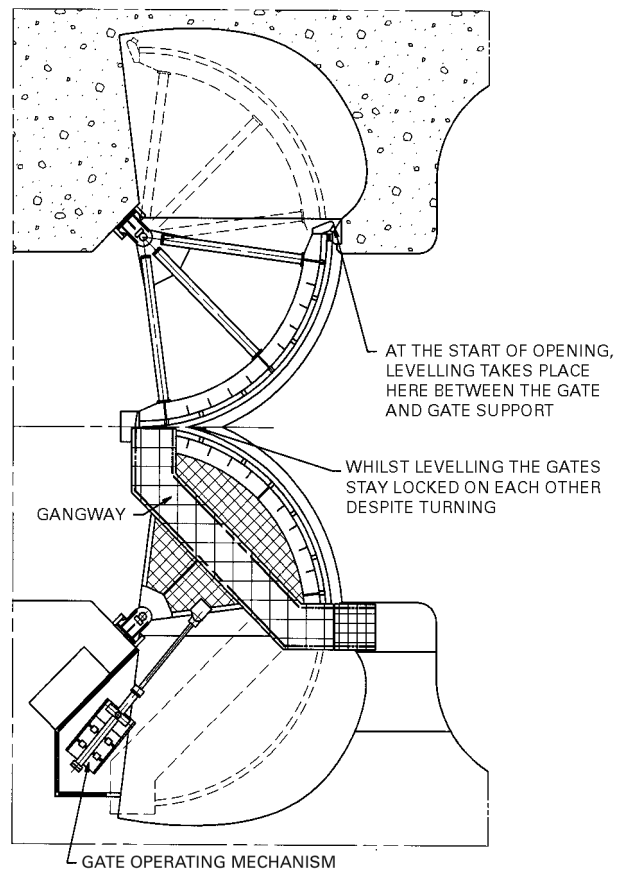


Figure 7.6 Overview tainter gate with vertical axis

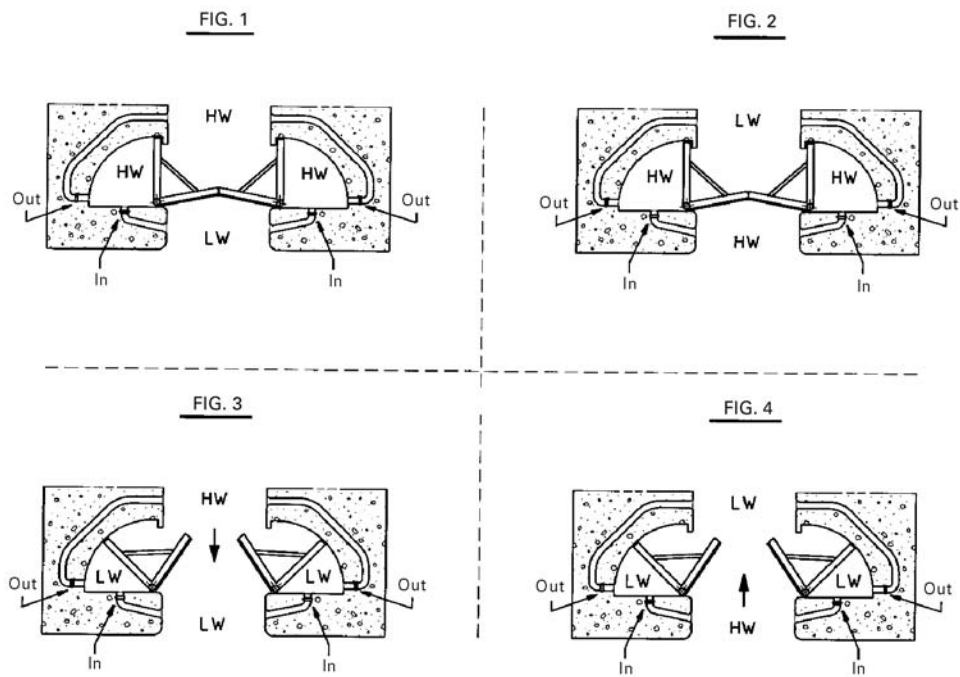


Figure 7.7 Working principle wing gates

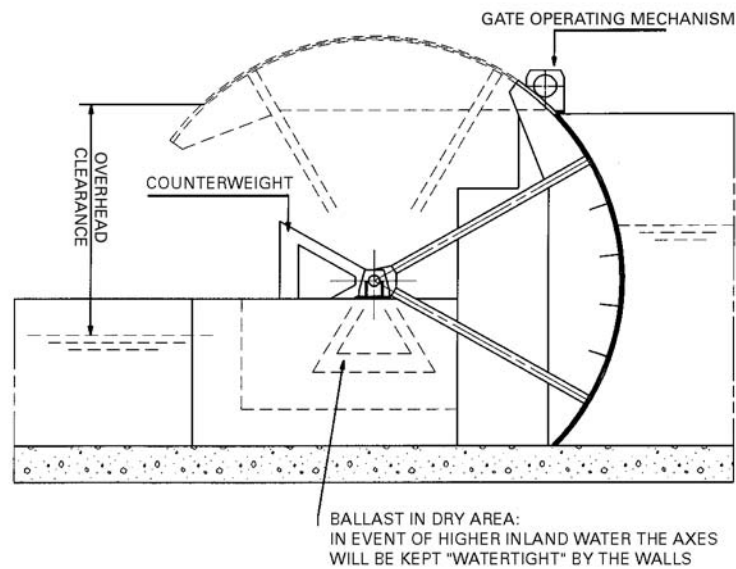


Figure 7.8 Overview of tainter gate with horizontal axis

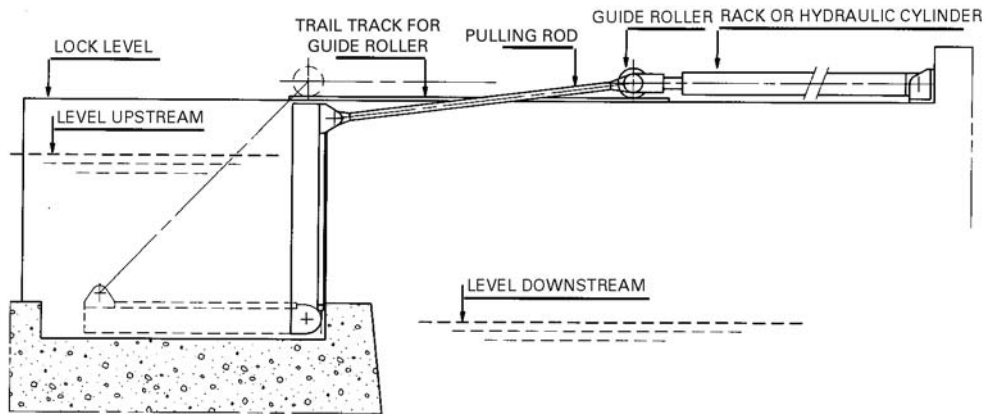


Figure 7.9 Overview tumble gate with rotation axis under water

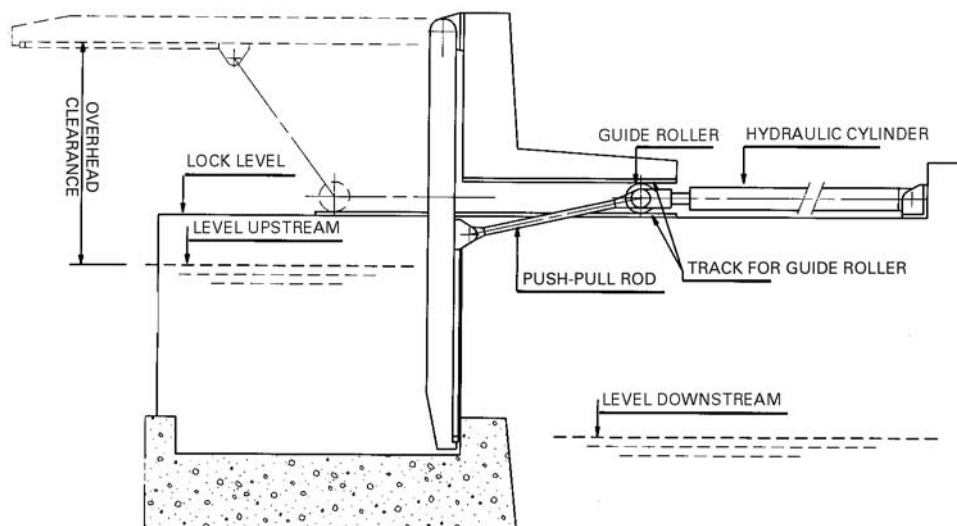


Figure 7.10 Overview tumble gate with rotation axis above water

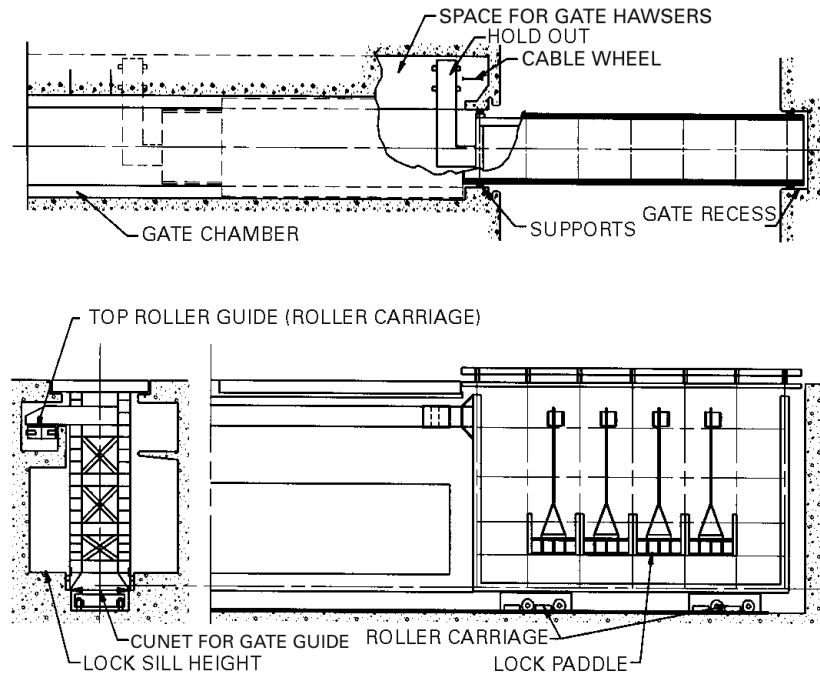


Figure 7.11 Overview horizontal rolling gate with levelling openings

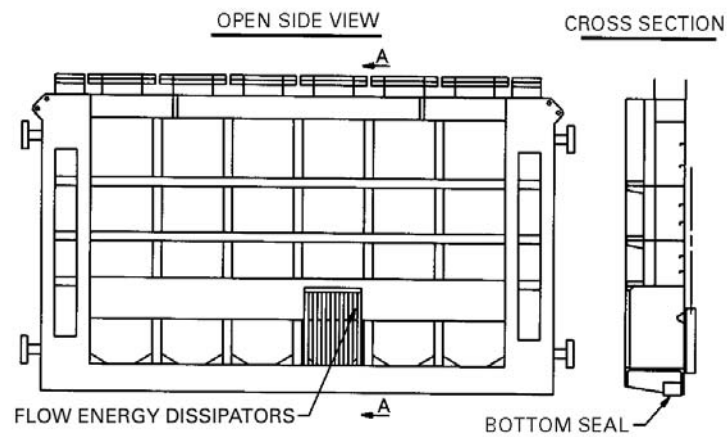


Figure 7.12 Overview lift gate with levelling openings

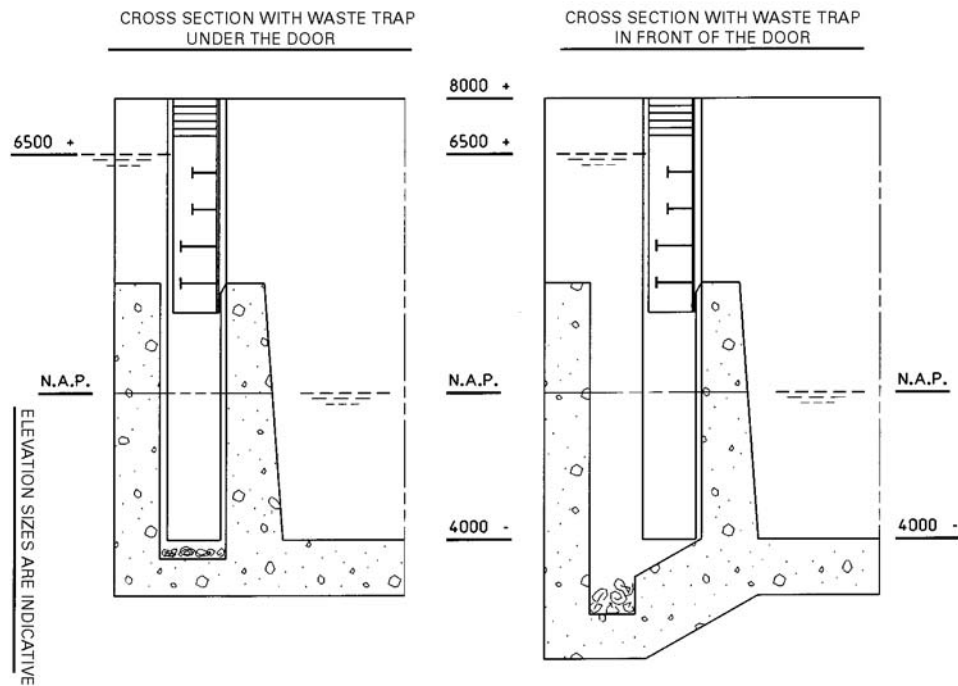


Figure 7.13 Overview drop gates in an upper head

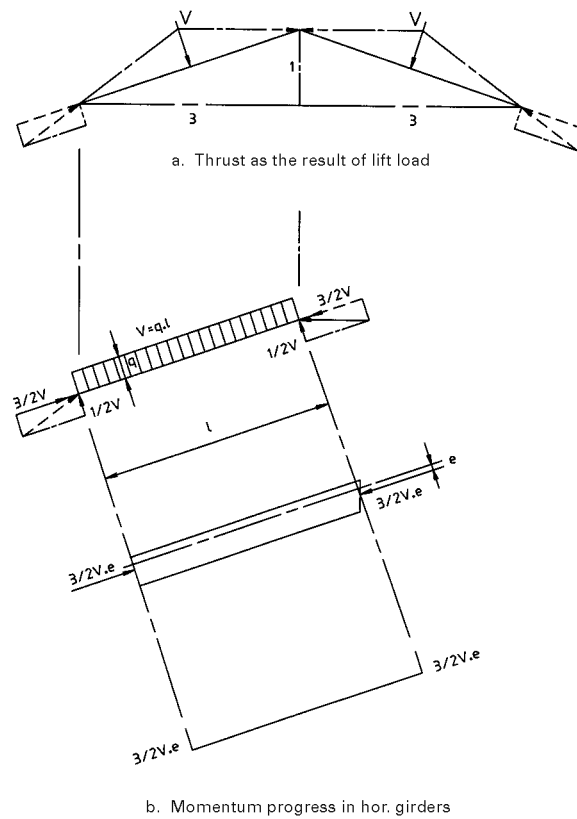


Figure 7.14 Force on mitre gates

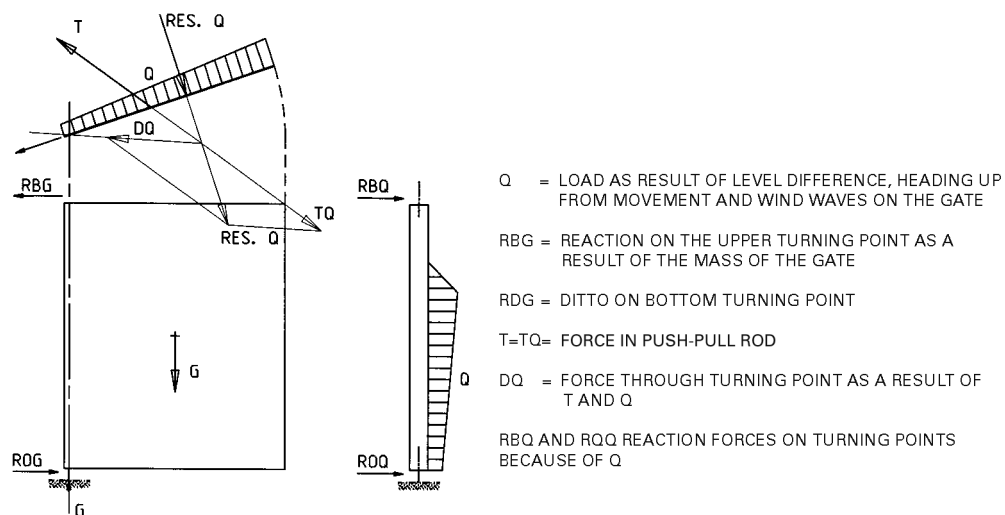


Figure 7.15 Force on moving mitre gate

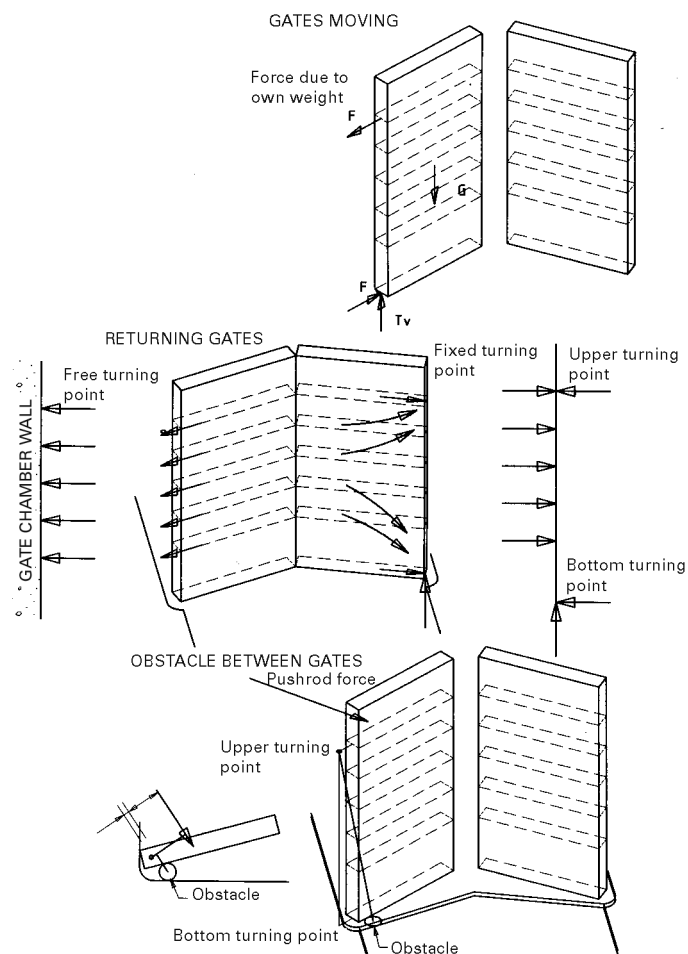


Figure 7.16 Load acting on mitre gates

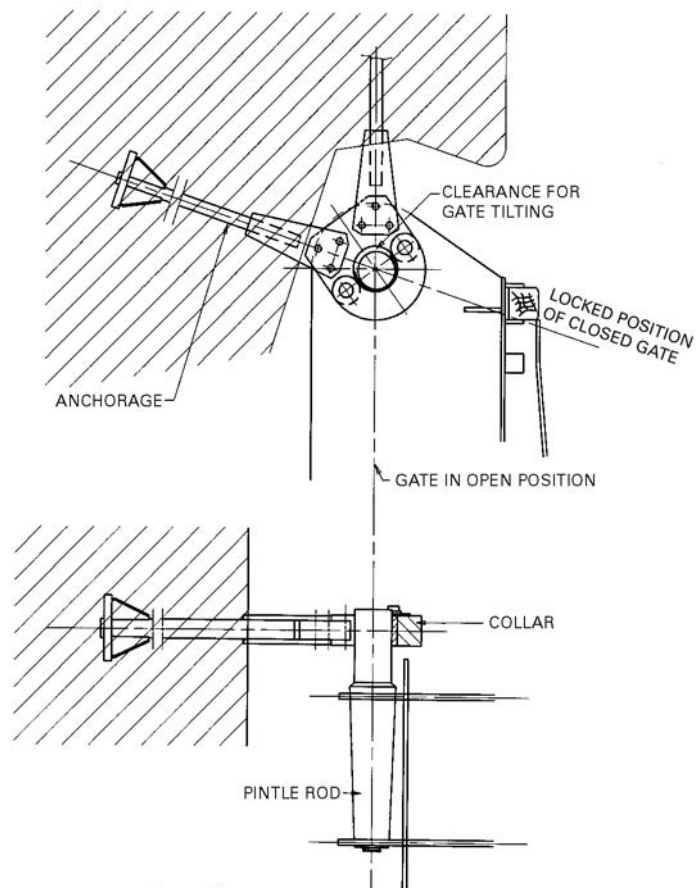


Figure 7.17 Pintle rod and collar of a mitre gate

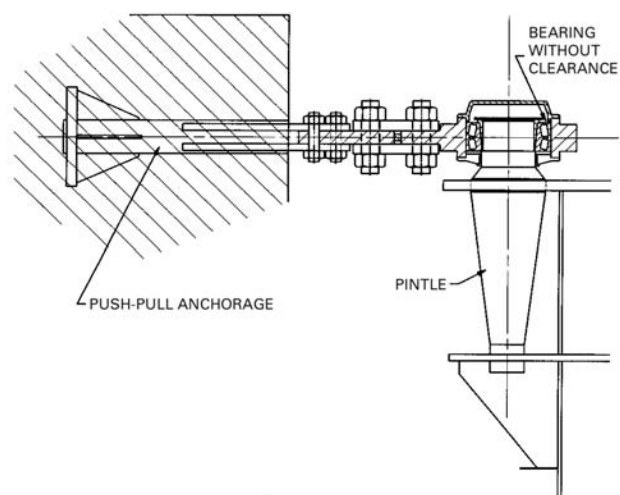


Figure 7.18 Clearance free upper bearing of a mitre gate

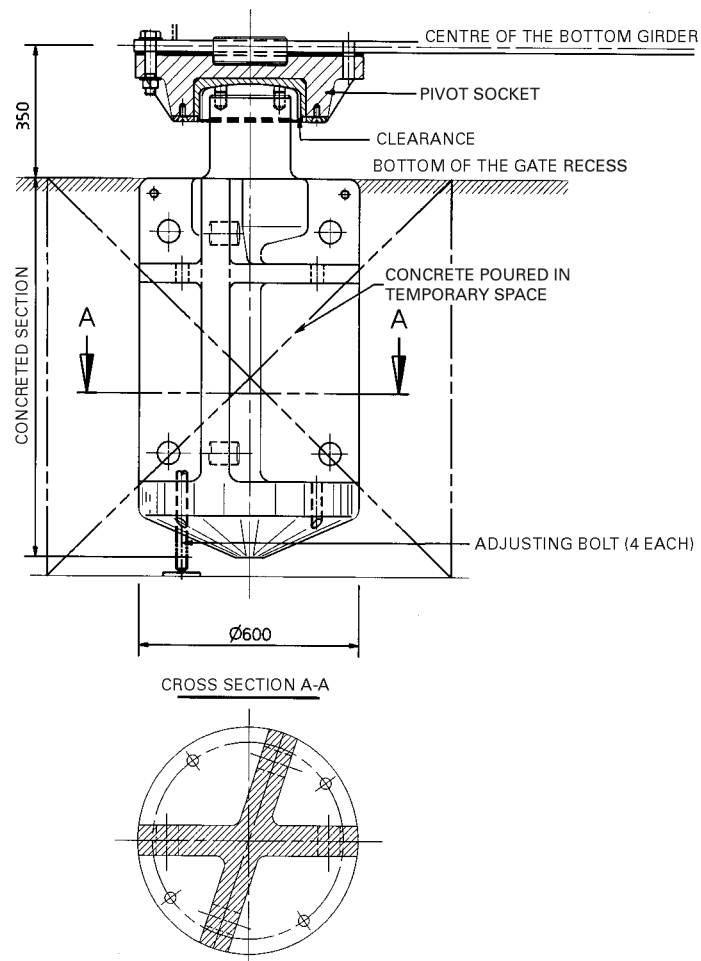


Figure 7.19 Pivot with pivot socket of a mitre gate

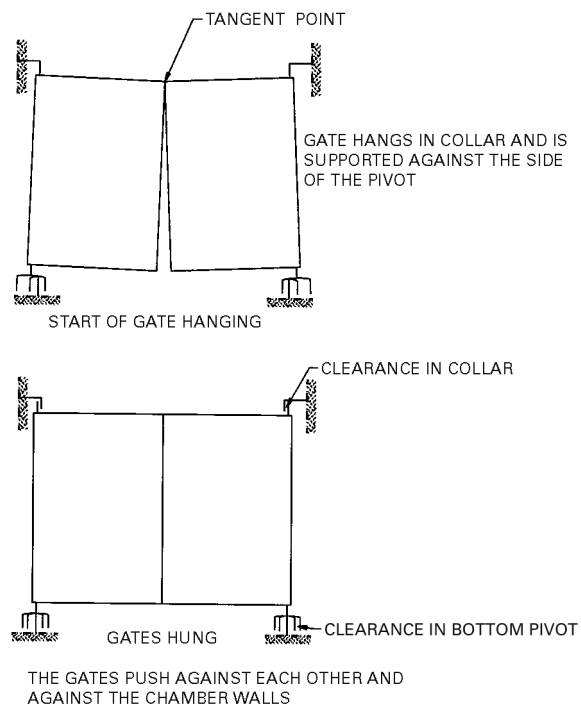


Figure 7.20 Tilting of mitre gates

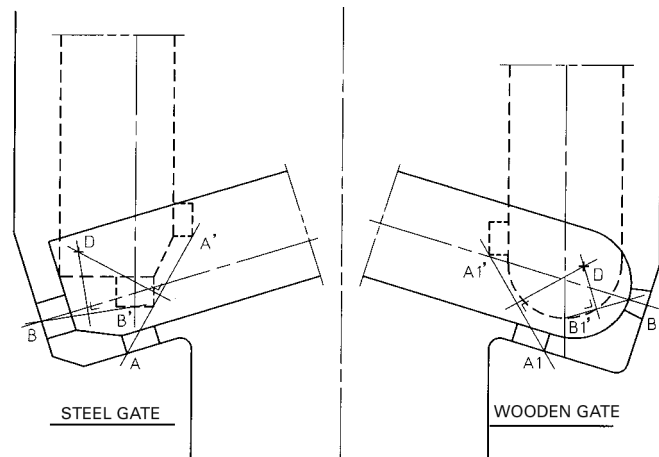


Figure 7.21 Design of the free turning point in mitre gates

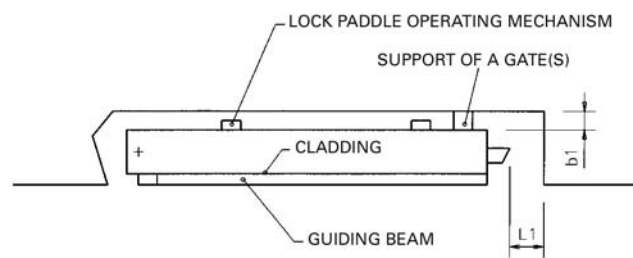


Figure 7.22 Position of mitre gates in gate chamber

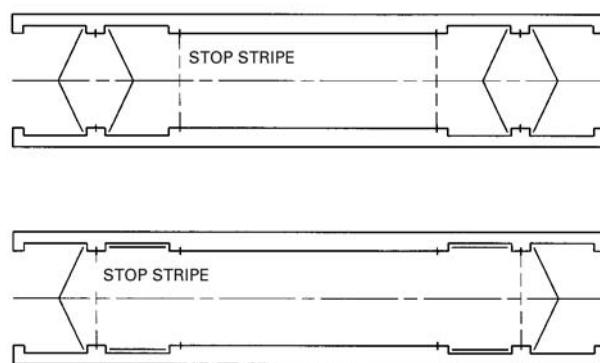


Figure 7.23 Effective chamber length between stop stripes in double mitre gate set.

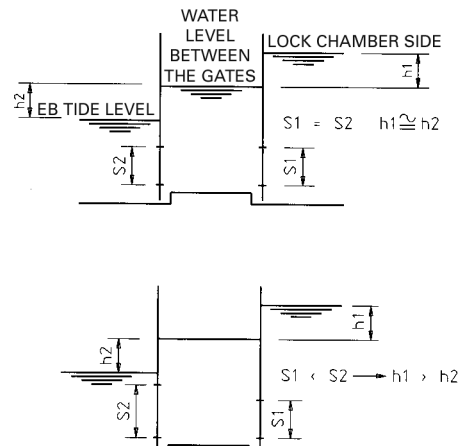


Figure 7.24 Water levels between ebb and flood gates at double mitre gate set

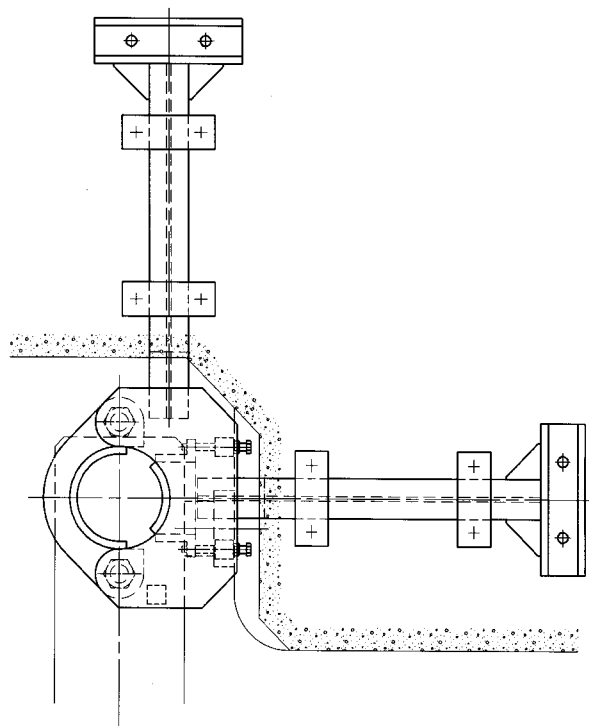


Figure 7.25 Collar of a single leaf pivot gate

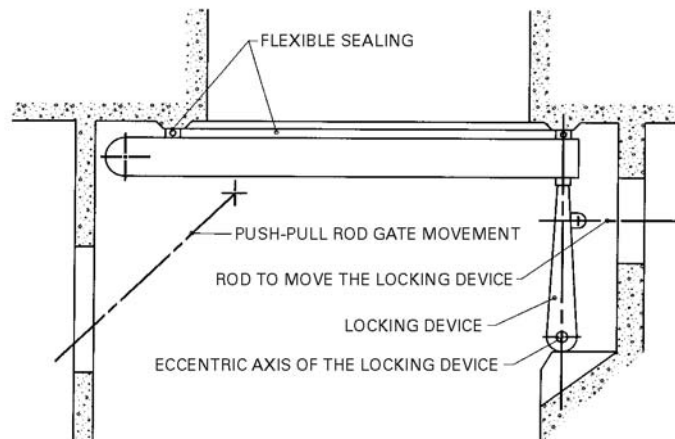


Figure 7.26 Diagram of a single leaf pivot gate with movement mechanism and framebolt shaped locking device

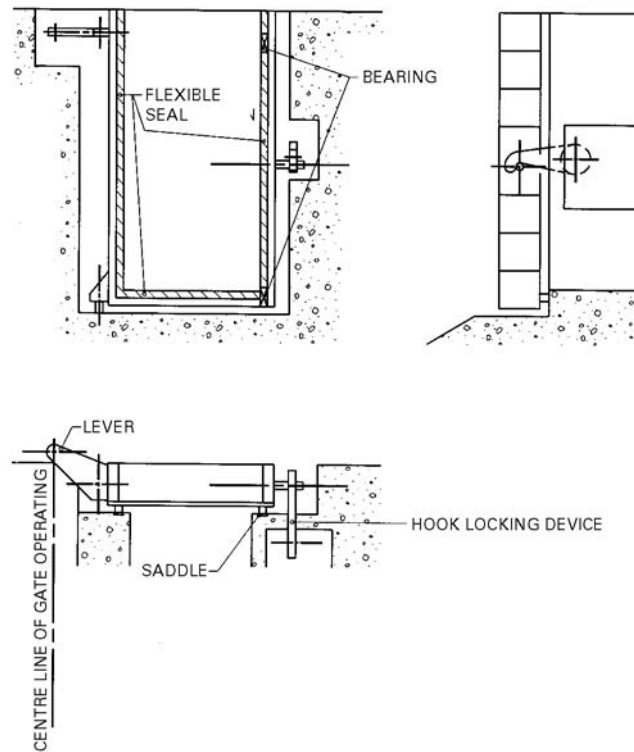


Figure 7.27 Pivot gate diagram with operating mechanism and hook locking device

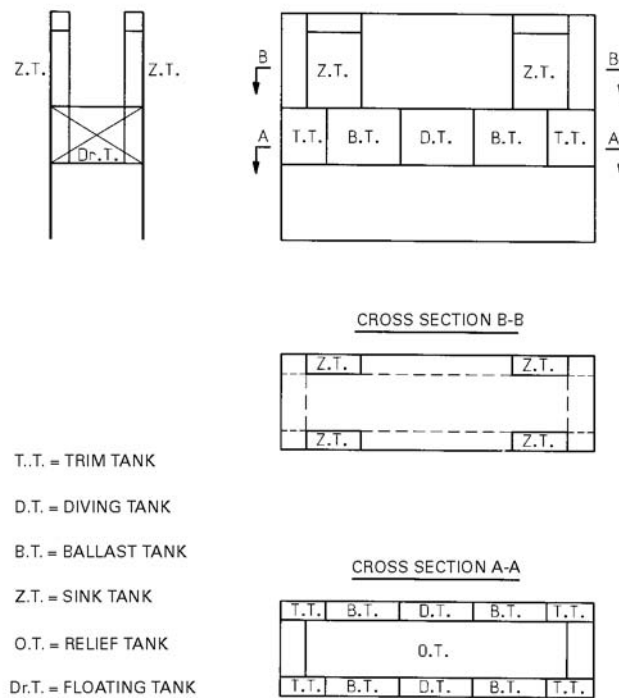


Figure 7.28 Rolling gate with tanks for floating transport

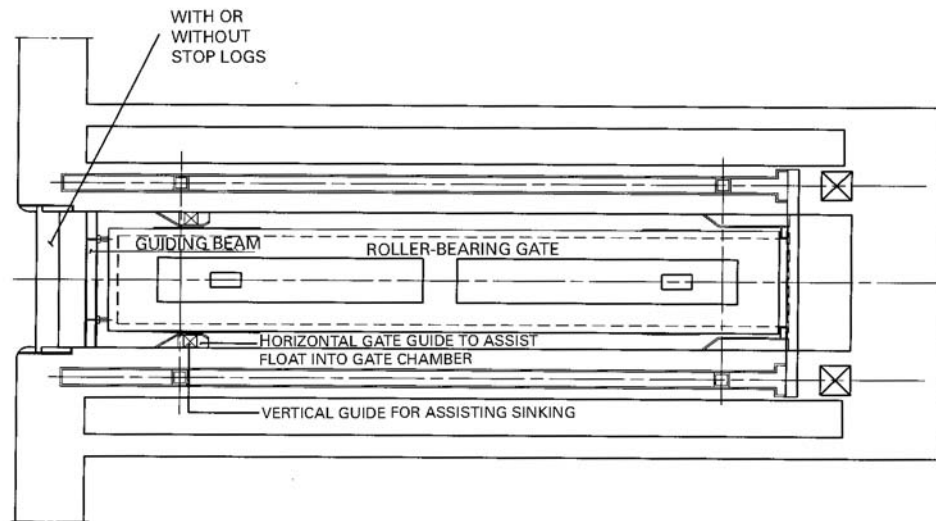


Figure 7.29 Rolling gate floating in closed gate dock

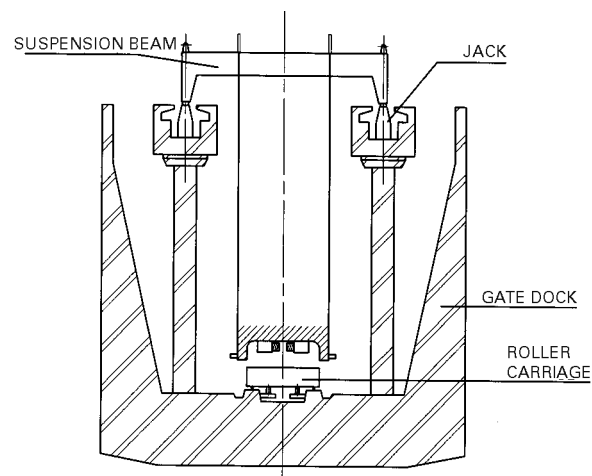


Figure 7.30 Rolling gate suspended between two beams in the gate dock

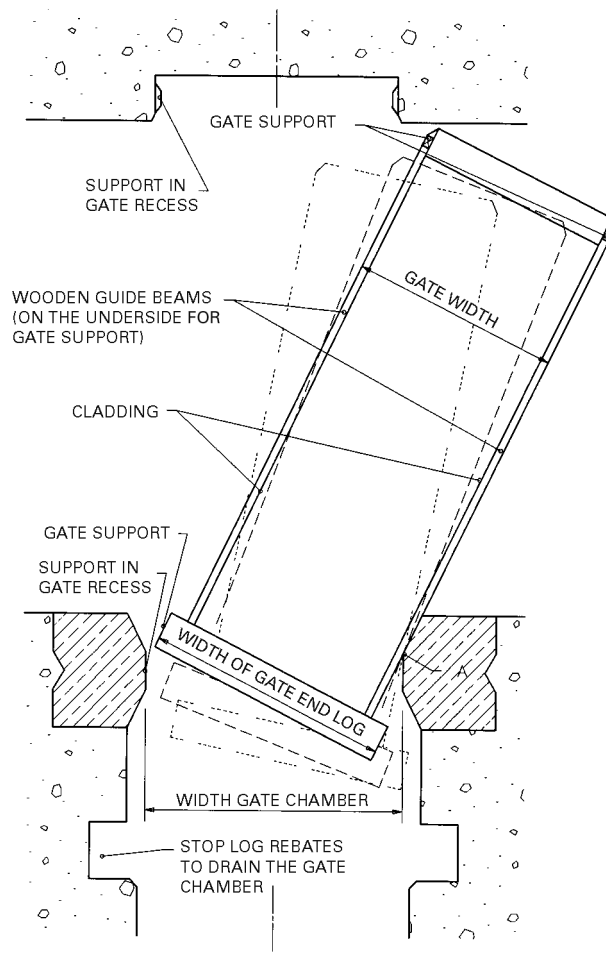


Figure 7.31 Entering the floating gate into gate recess

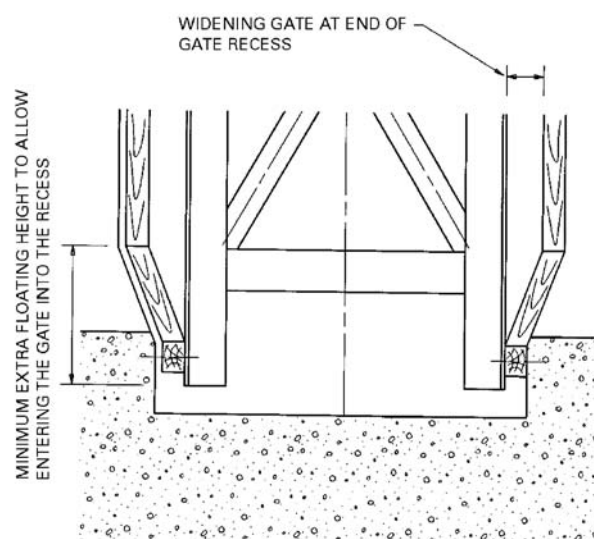


Figure 7.32 Tapering of end log with lower support of rolling gate

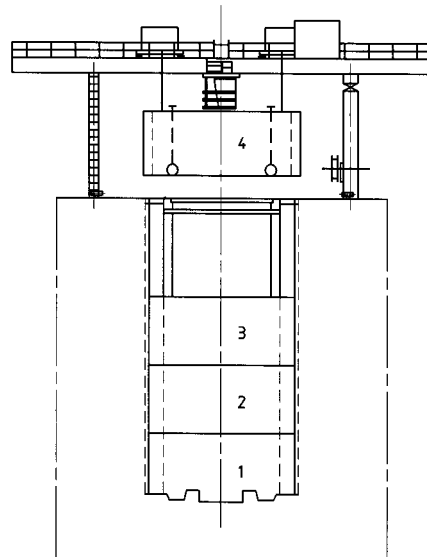


Figure 7.33 Placing stop logs with a mobile lifting device in roller-bearing gate chamber

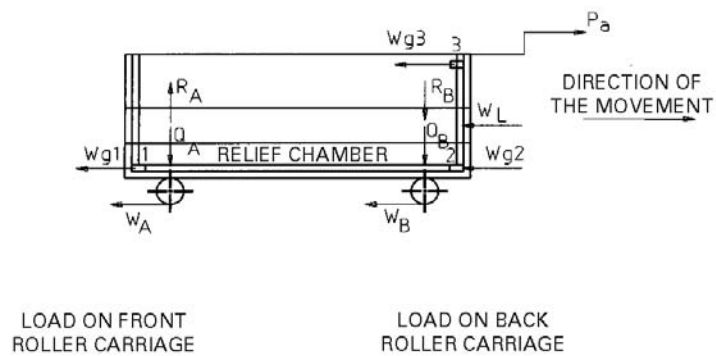


Figure 7.34 Vertical load on roller carriages during gate movement as a result of the tractive effort of operating mechanism

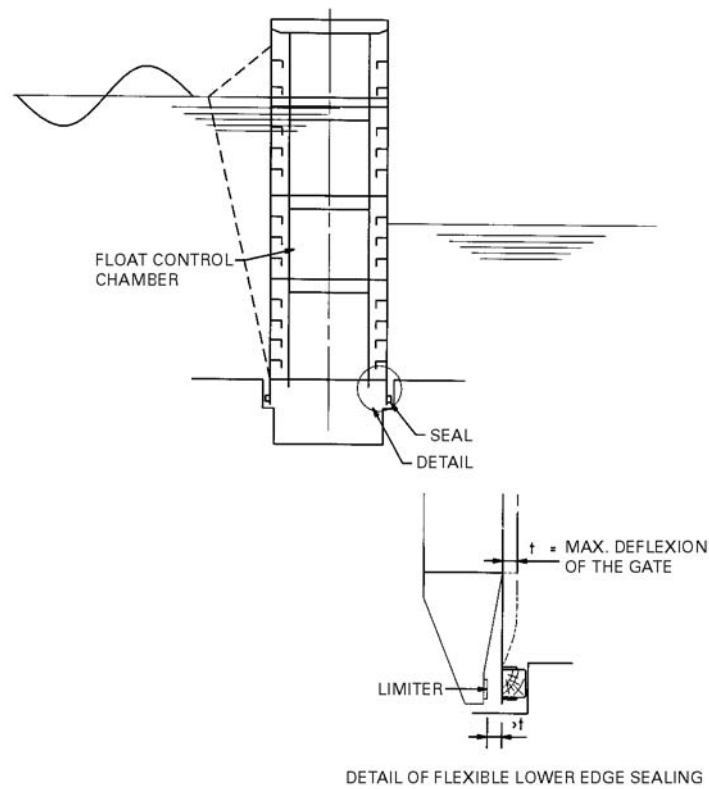


Figure 7.35 Cross section of roller-bearing gate with lower edge spring sealing

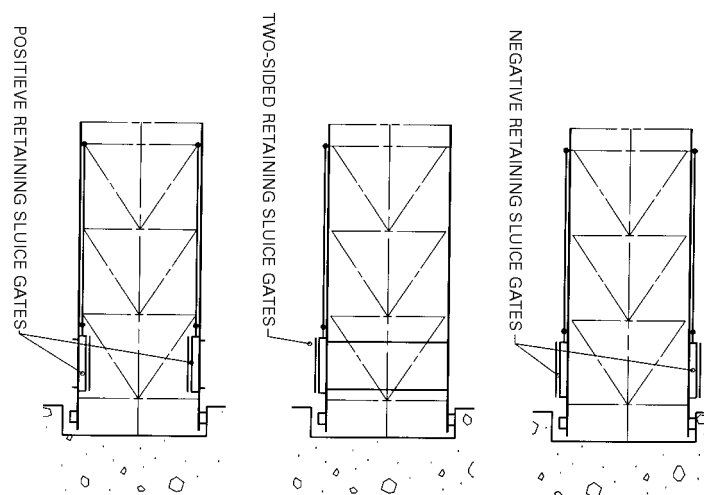


Figure 7.36 Levelling sluice gates in a roller-bearing gate

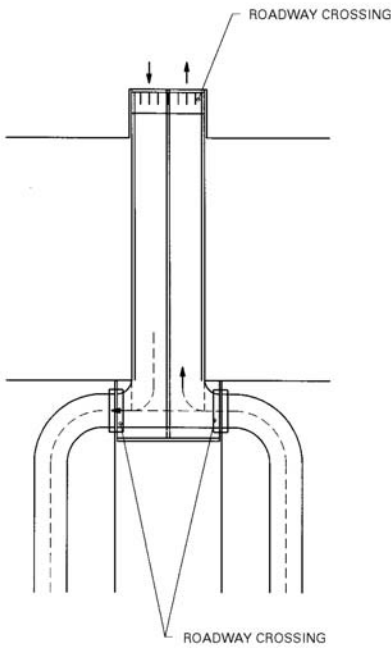


Figure 7.37 Road traffic over a roller-bearing gate

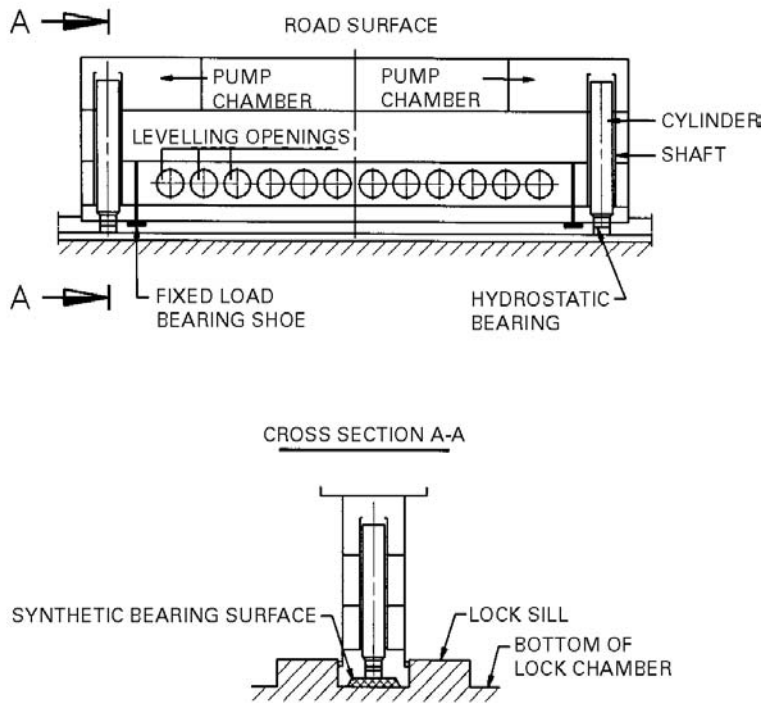


Figure 7.38 Diagram of hydro-installation in a sliding gate

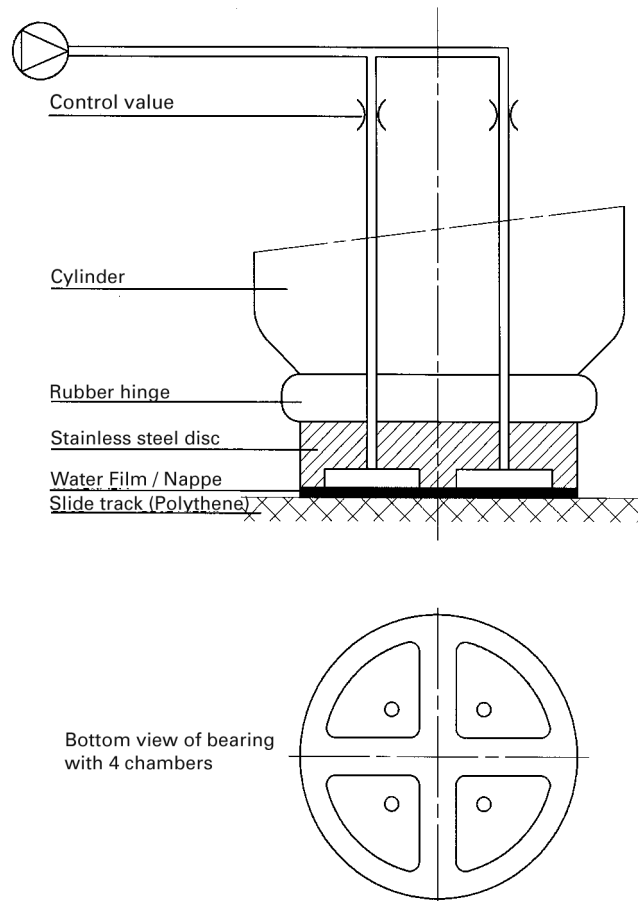


Figure 7.39 Hydrostatic bearing of a sliding gate

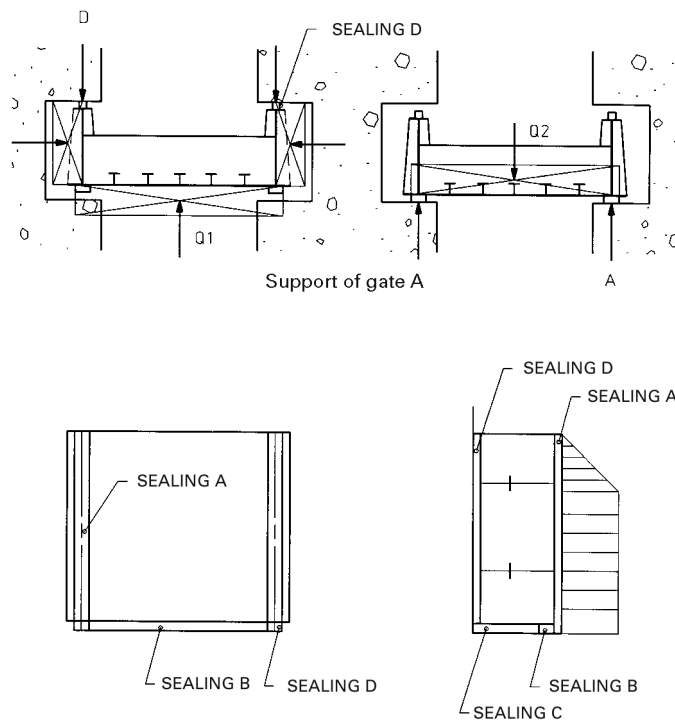


Figure 7.40 Gate support and sealing of a two-sided retaining lift gate

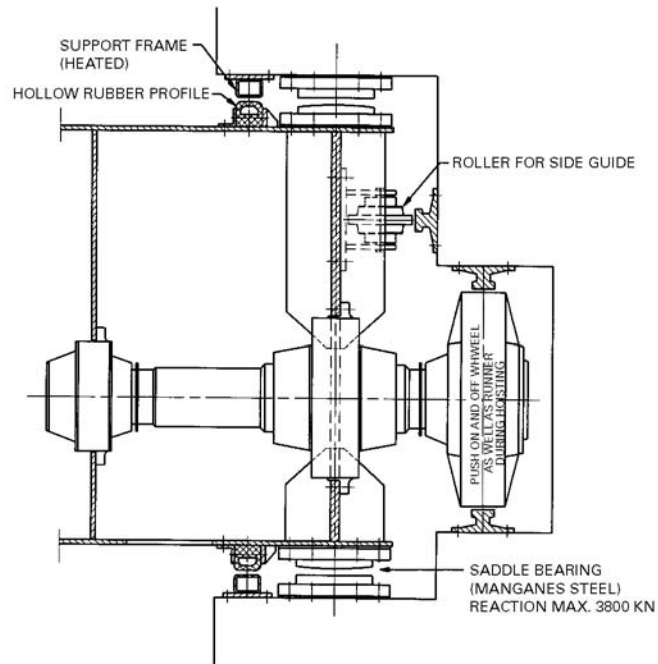


Figure 7.41 Support by means of saddles and two-sided working push-off device for a lift gate

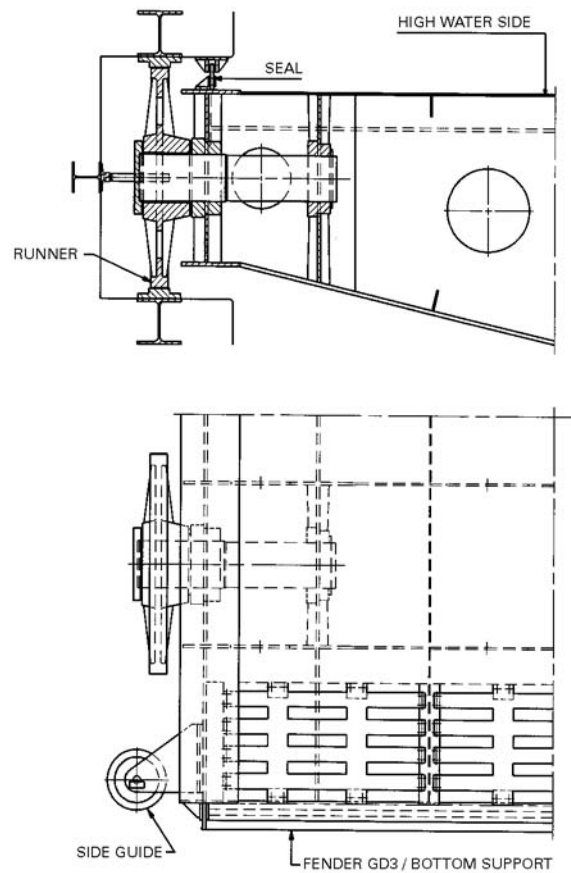


Figure 7.42 Support of the rolling guide of a lift gate

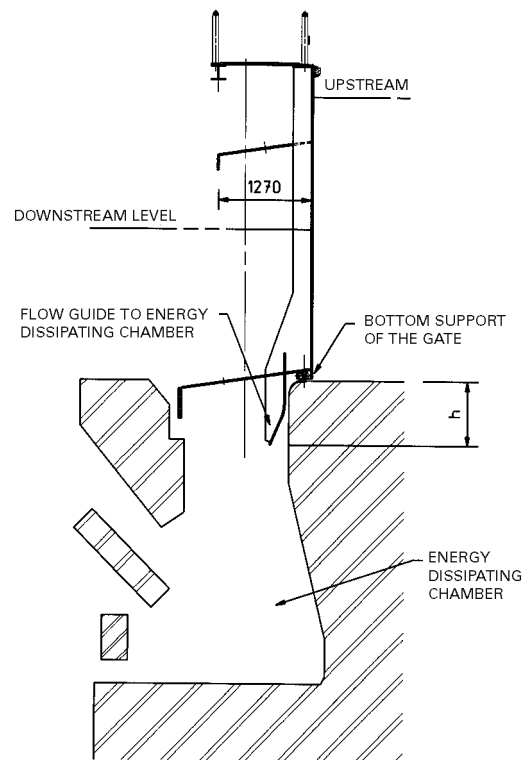


Figure 7.43 Energy dissipating chamber for a lift gate

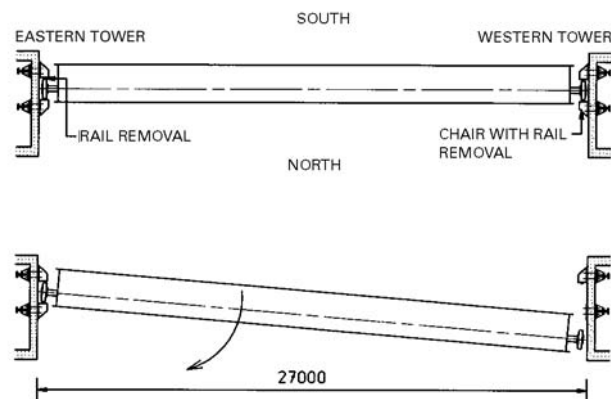


Figure 7.44 Removal of runner guides from a lift gate

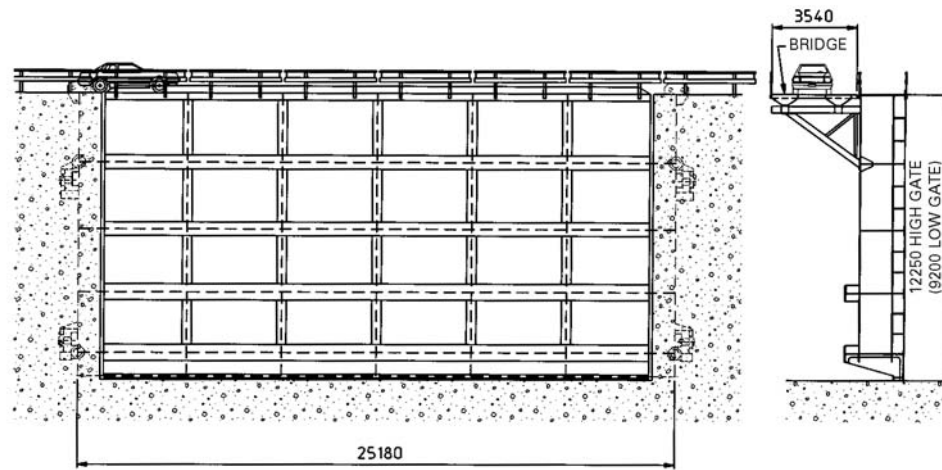


Figure 7.45 Roadway over a lift gate

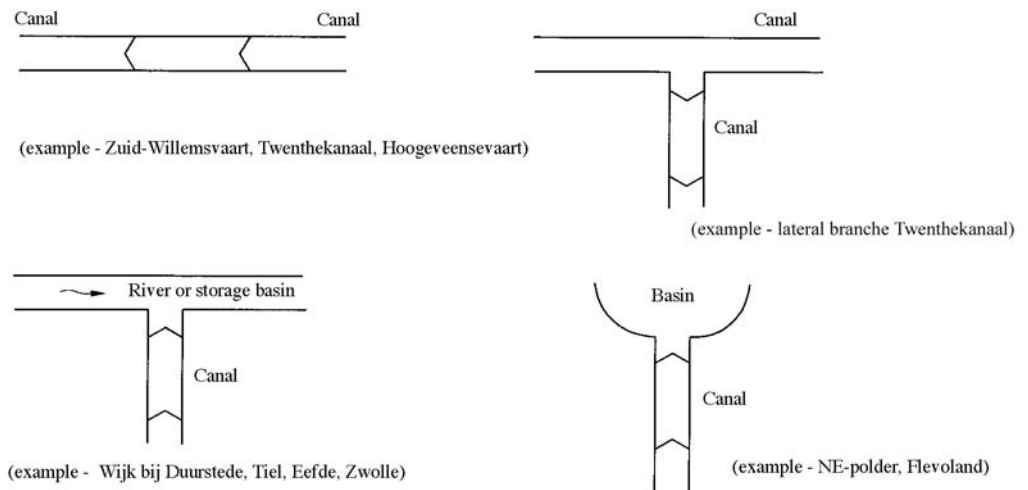


Figure 7.46 Examples of one-sided retaining locks

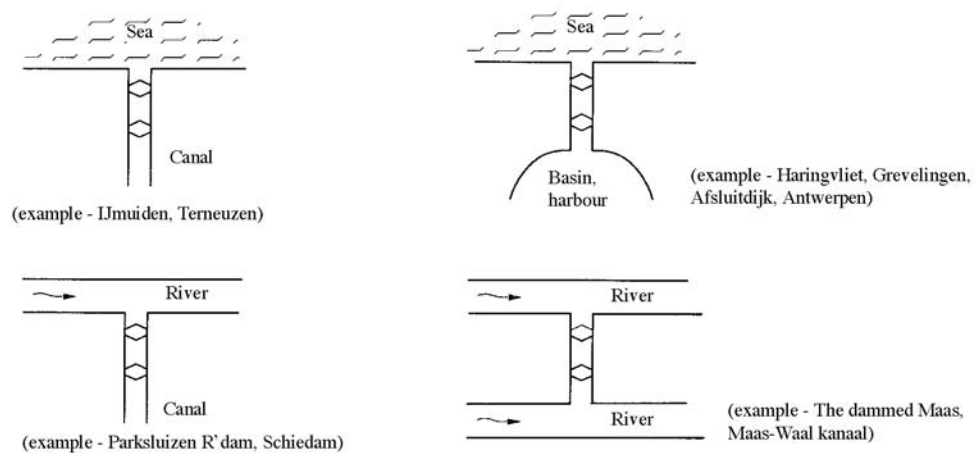


Figure 7.47 Examples of two-sided retaining locks

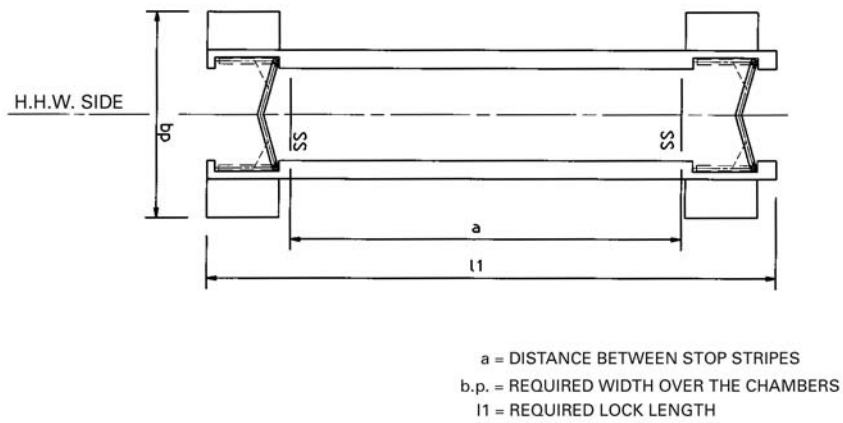


Figure 7.48 One-sided retaining structure of a lock with mitre gates

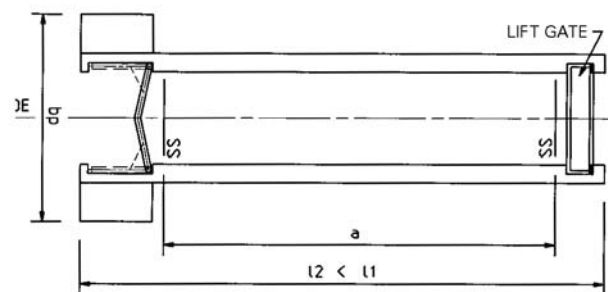


Figure 7.49 One-sided retaining structure with mitre and lift gates

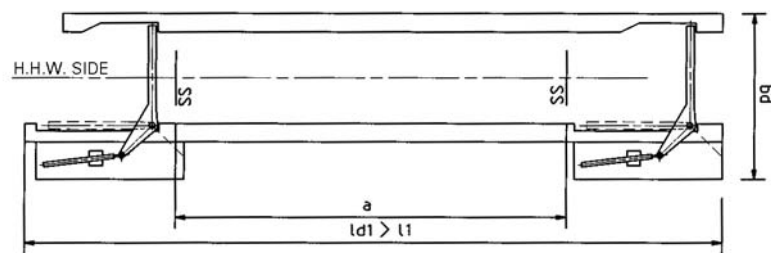


Figure 7.50 One-sided retaining structure with pivot gates, solution 1

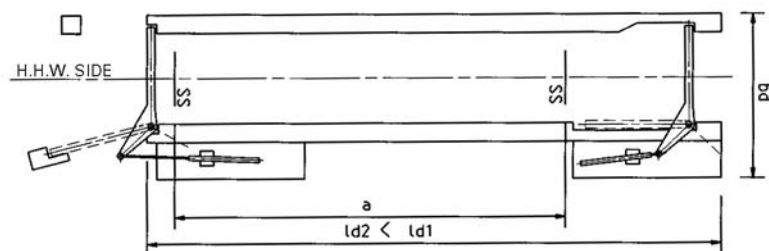


Figure 7.51 One-sided retaining structure with pivot gates, solution II

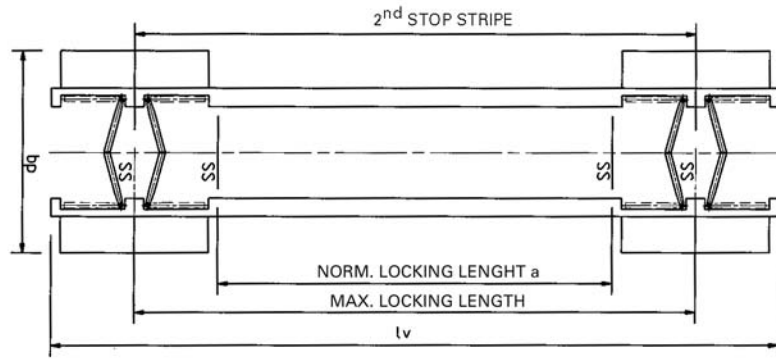


Figure 7.52 Two-sided retaining structure with double mitre gate sets

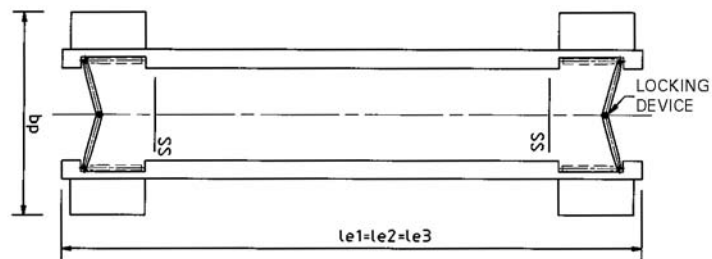


Figure 7.53 Two-sided retaining structure with mitre gates and locking device, solution 1

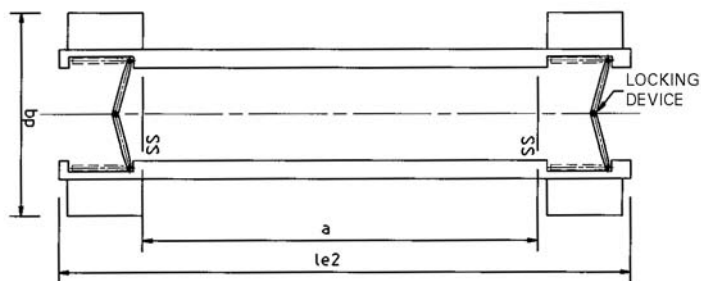


Figure 7.54 Two-sided retaining structure with mitre gates and locking device, solution 2

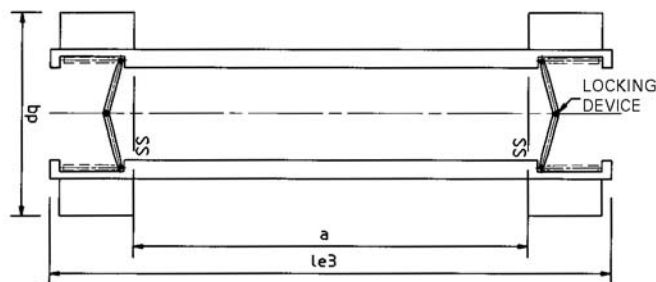


Figure 7.55 Two-sided retaining structure with mitre gates and locking device, solution 3

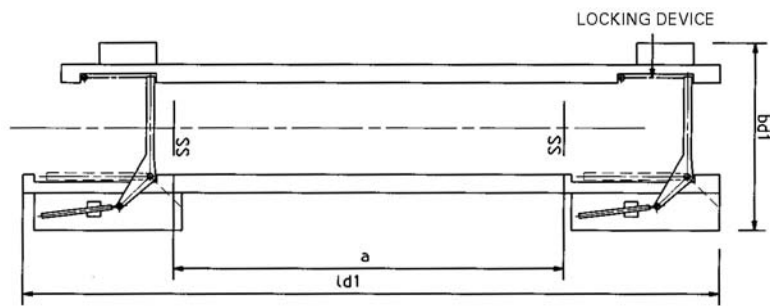


Figure 7.56 Two-sided retaining structure with pivot gates, solution 1

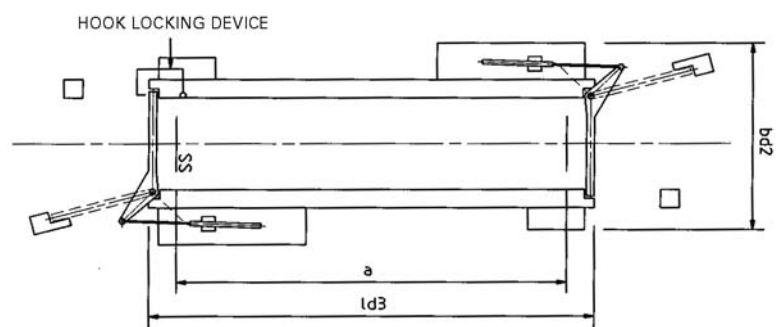


Figure 7.57 Two-sided retaining structure with pivot gates, solution 2

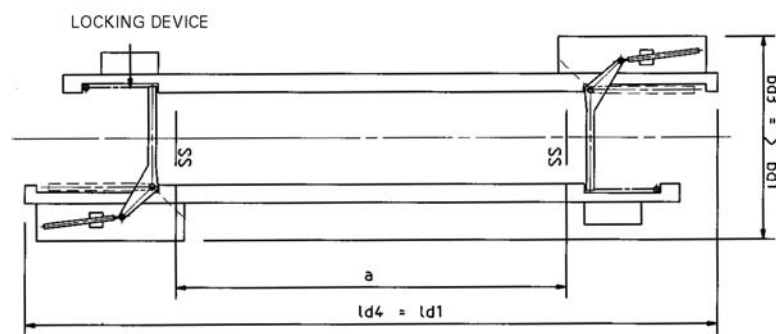


Figure 7.58 Two-sided retaining structure with pivot gates, solution 3

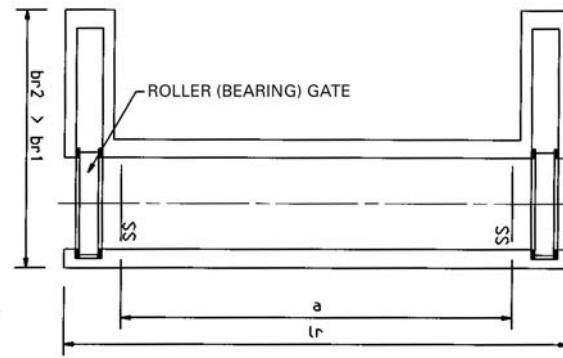


Figure 7.59 Two-sided retaining structure with roller (bearing) gates

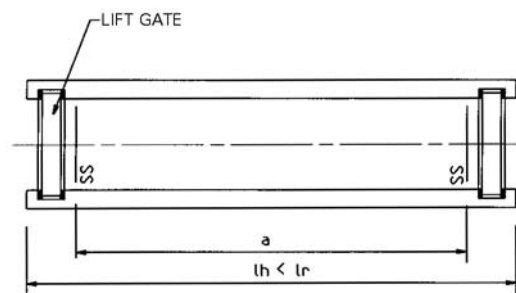


Figure 7.60 Two sided retaining structure with lift gates

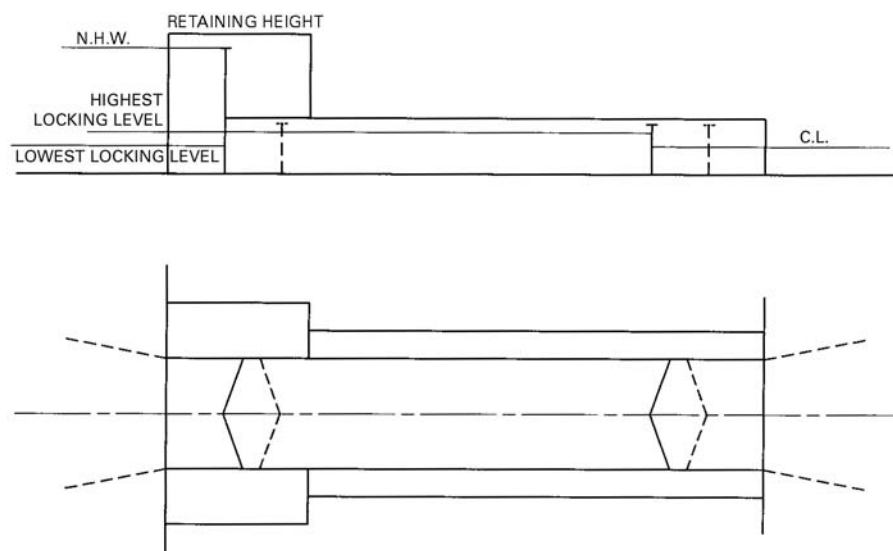


Figure 7.61 Diagram of a two-sided retaining structure with double mitre gates and low reserve barrier

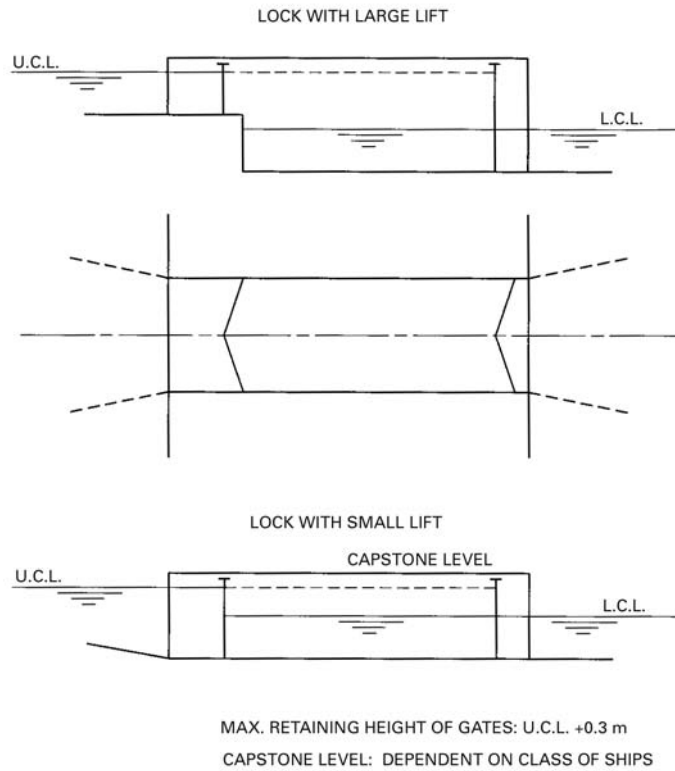


Figure 7.62 Diagram of a one-sided retaining structure with cladding level on head and tailgate

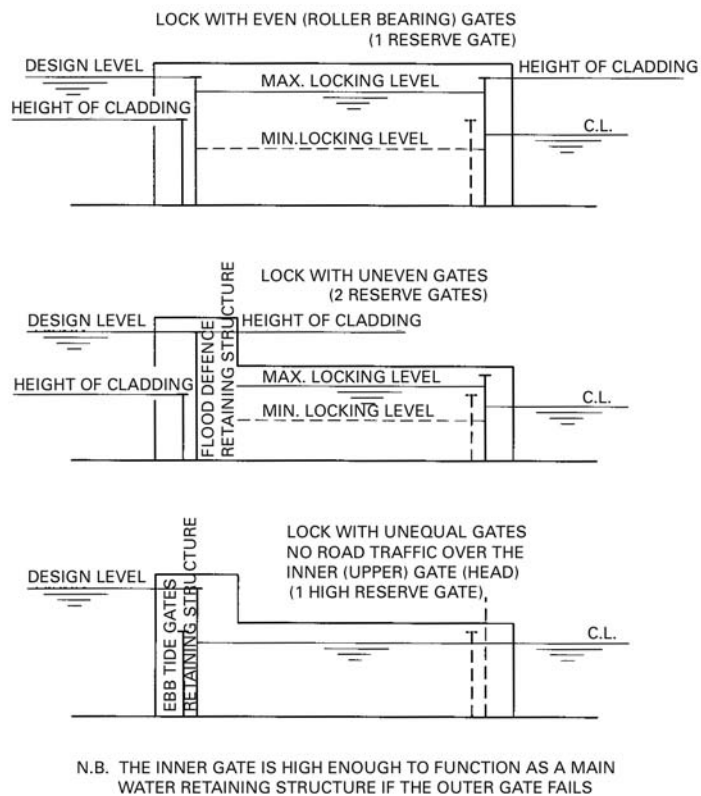


Figure 7.63 Two-sided retaining structure with roller (bearing gates) in a tidal situation

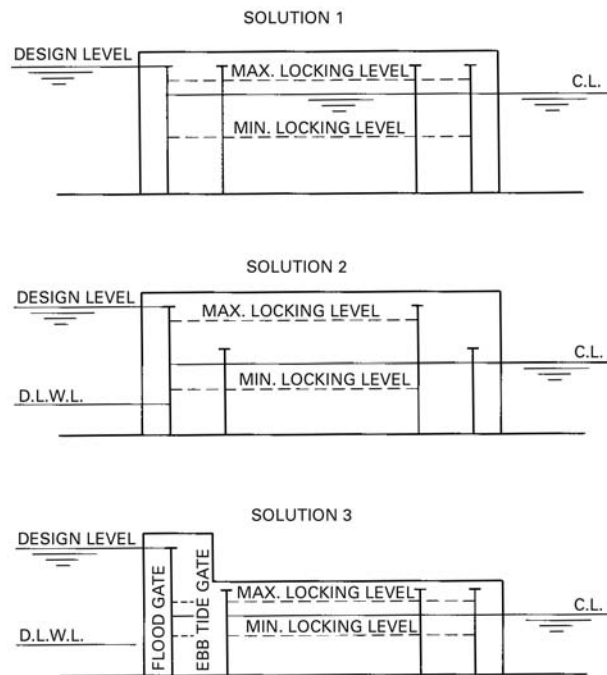


Figure 7.64 Two-sided retaining structure in a tidal situation with a double mitre gate set

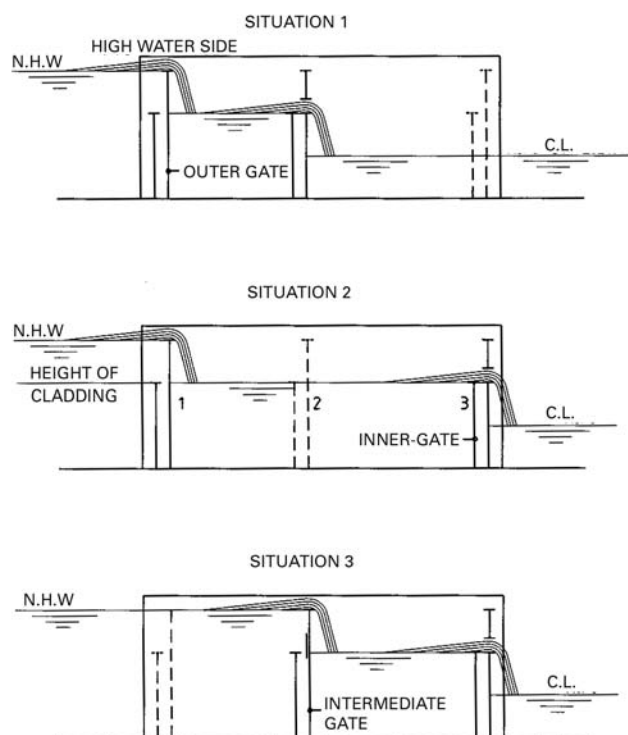


Figure 7.65 Cascading retention in lock with roller (bearing) gates and intermediate gates

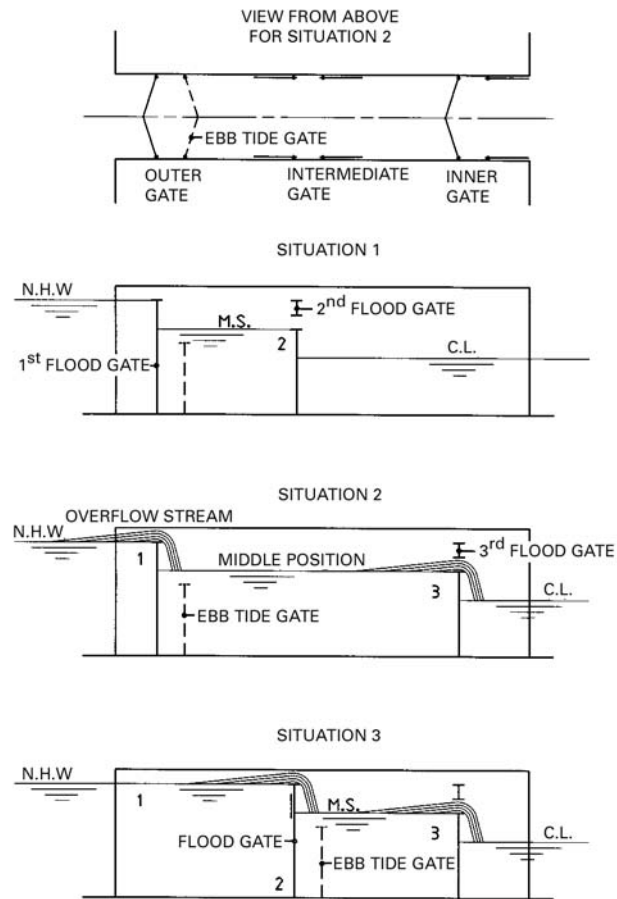


Figure 7.66 Cascading retention in lock with mitre gates and intermediate gates

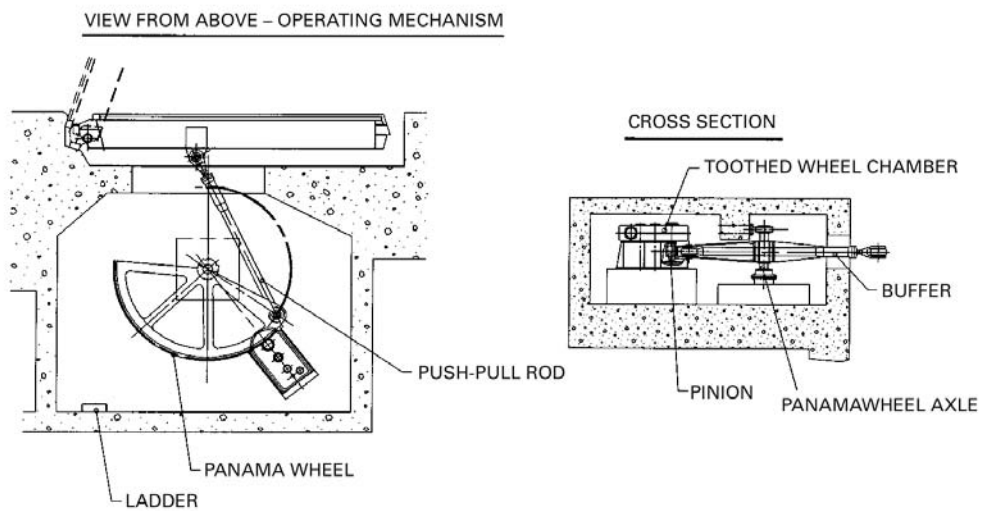


Figure 7.67 Position of propulsion with Panama wheel for a mitre gate

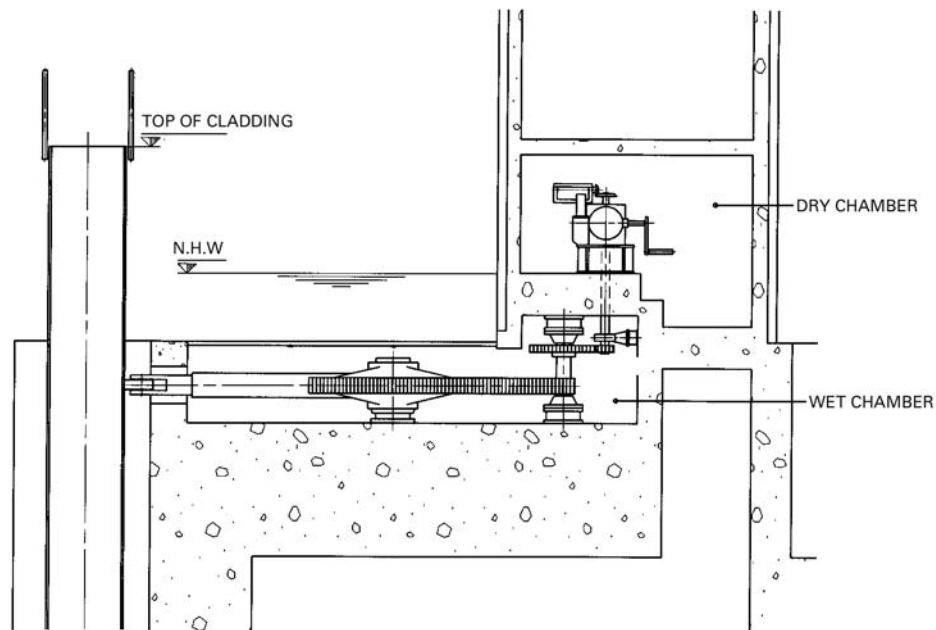


Figure 7.68 Position of operating mechanism of a Panama wheel for a lock in a river

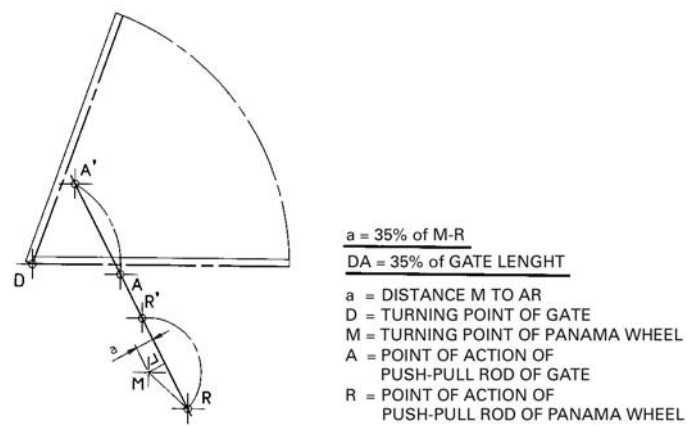


Figure 7.69 Diagram of Panama wheel for mitre gate (standard solution)

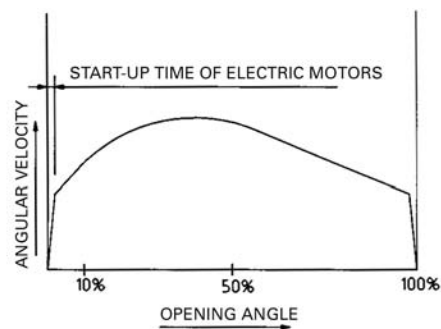


Figure 7.70 Progress of angular velocity of a mitre gate with use of a Panama wheel (solution figure 7.69)

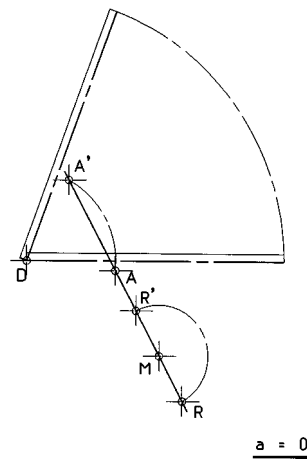


Figure 7.71 Diagram of a Panama wheel for a mitre gate (complete Panama operation)

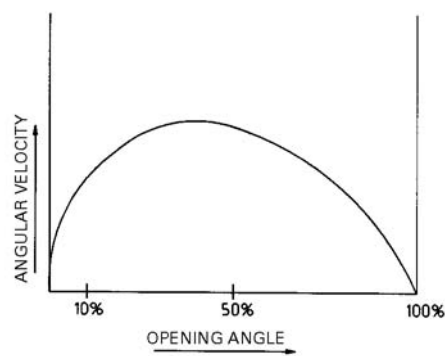


Figure 7.72 Progress of angular velocity of mitre gate in the use of Panama wheel (position figure 7.71)

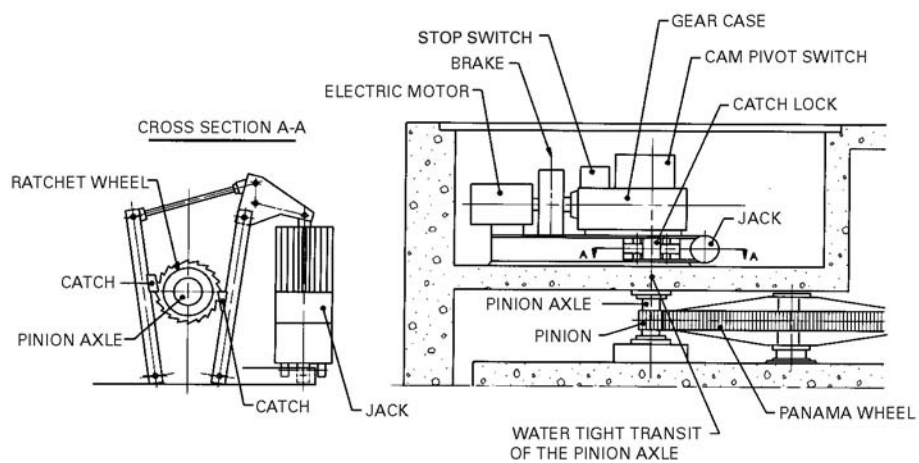


Figure 7.73 Lock of operating mechanism of Panama wheel on pinion axle

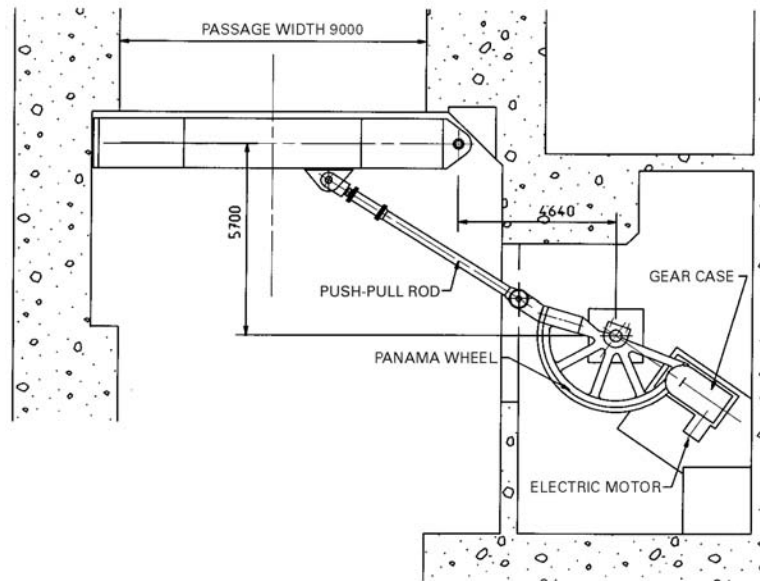


Figure 7.74 Pivot gate operating mechanism for Panama wheel (yacht lock Krammer)

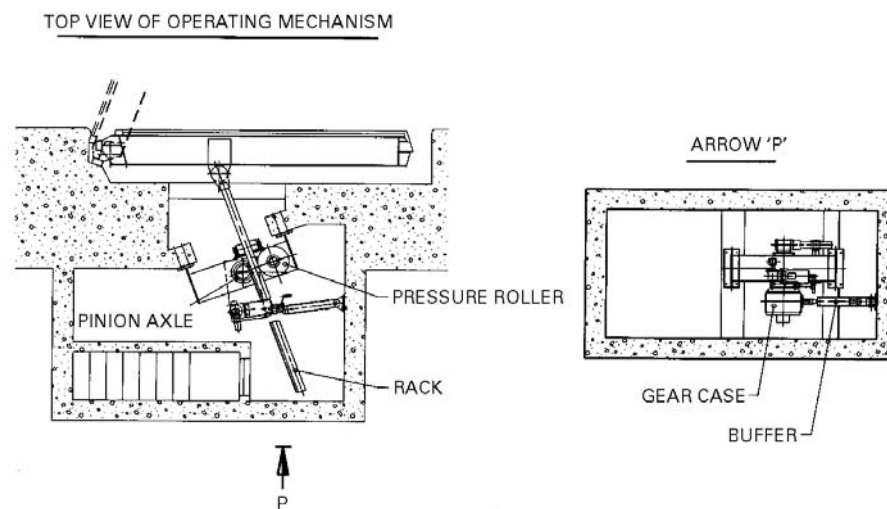


Figure 7.75 Operating mechanism for a mitre gate straight rack (one-sided retaining lock)

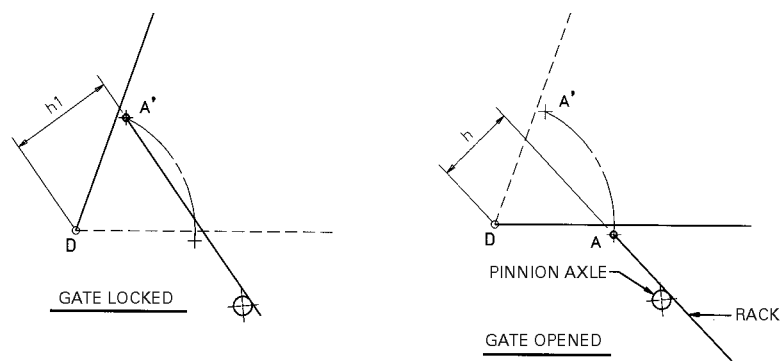


Figure 7.76 Diagram for a straight rack for a mitre gate

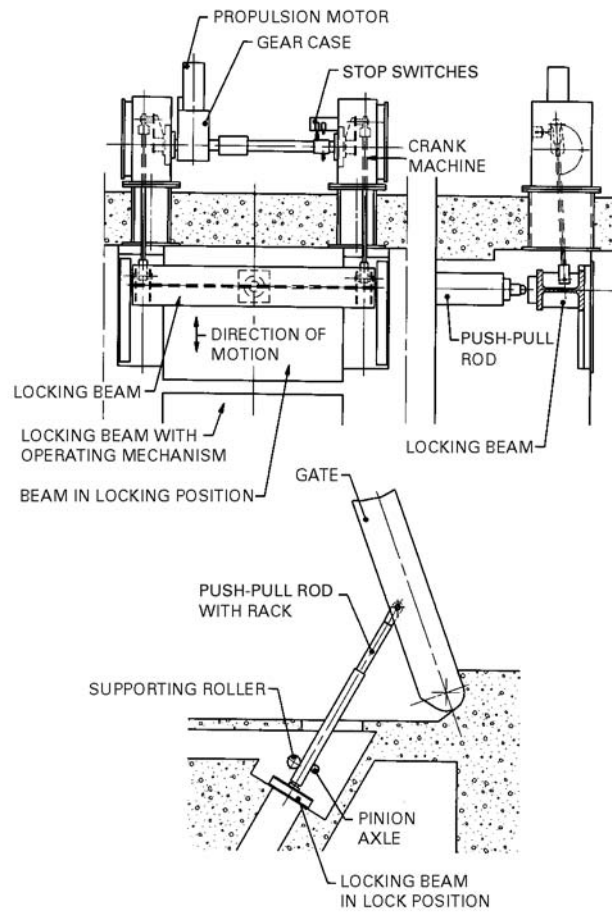


Figure 7.77 Locking of straight rack behind push-pull rod for mitre gate

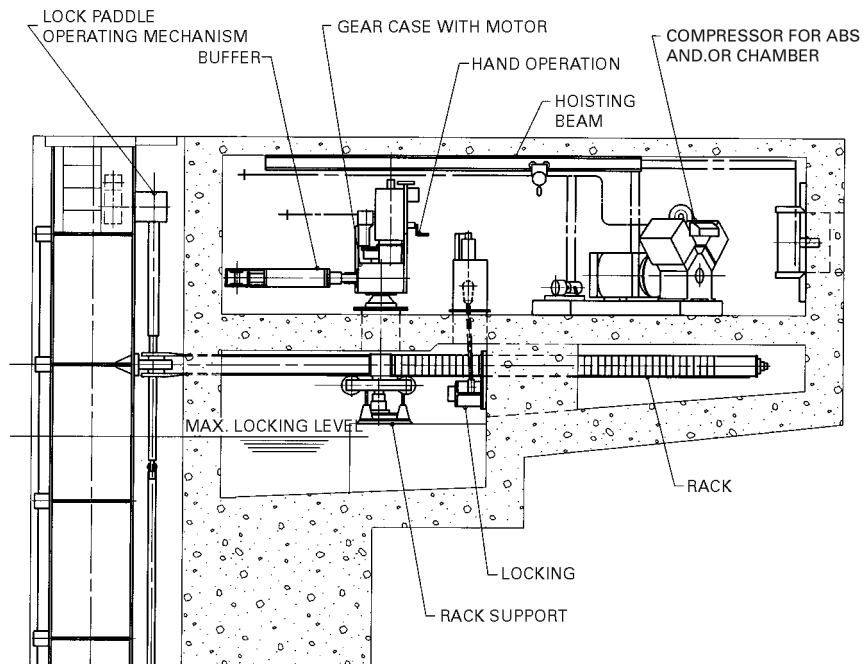


Figure 7.78 Propulsion for mitre gate for straight rack (Koopvaardersschutsluis, sea side)

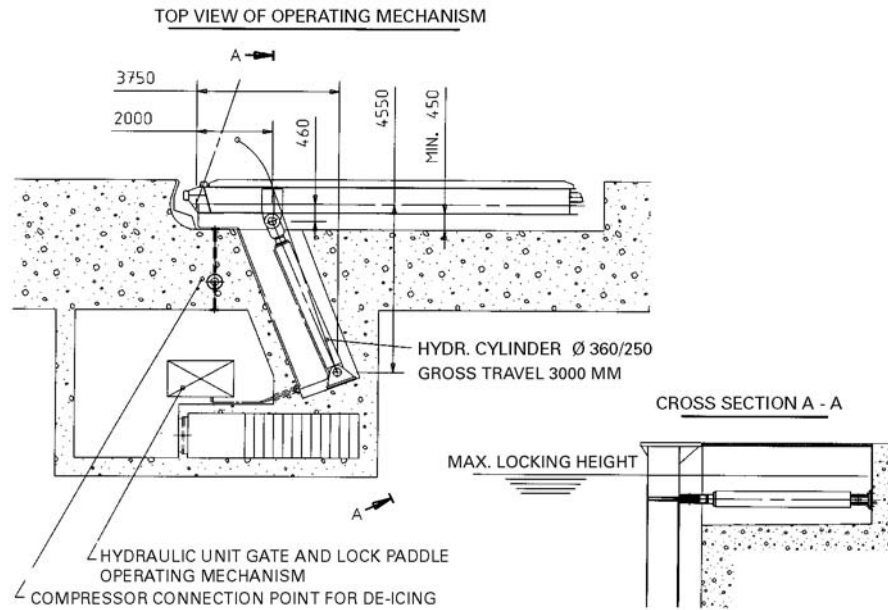


Figure 7.79 Propulsion for mitre gate through hydraulic cylinder

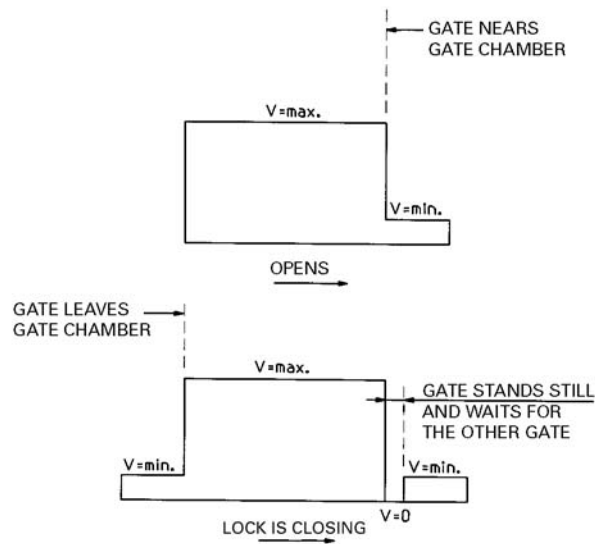


Figure 7.80 Diagram of cylinder-speed by propulsion of mitre gate with a hydraulic cylinder

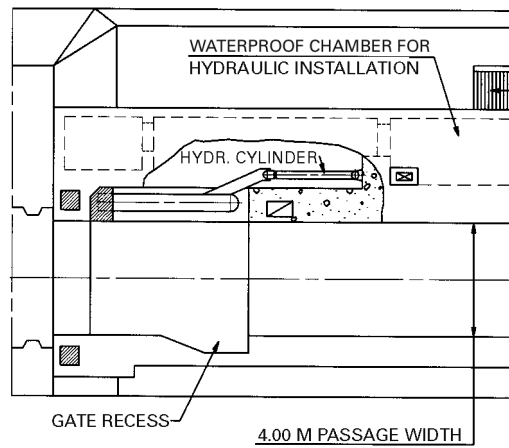


Figure 7.81 Propulsion of a pivot gate with hydraulic cylinder (Almere-harbour Lock, upper head)

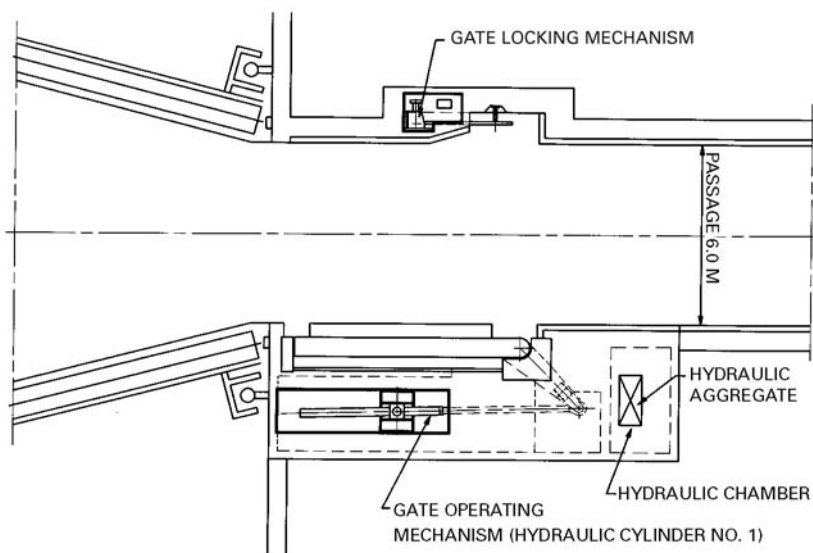


Figure 7.82 Pivot gate propulsion by hydraulic cylinder (Bergsediep Lock)

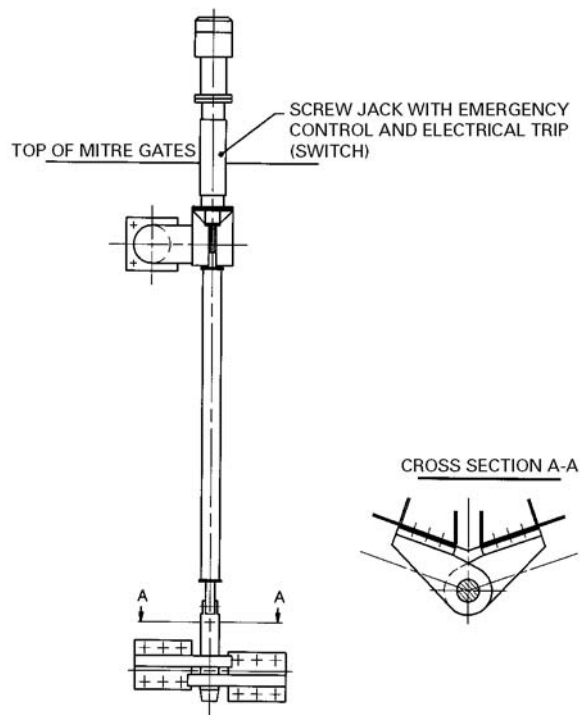


Figure 7.83 Locking pin on mitre gates

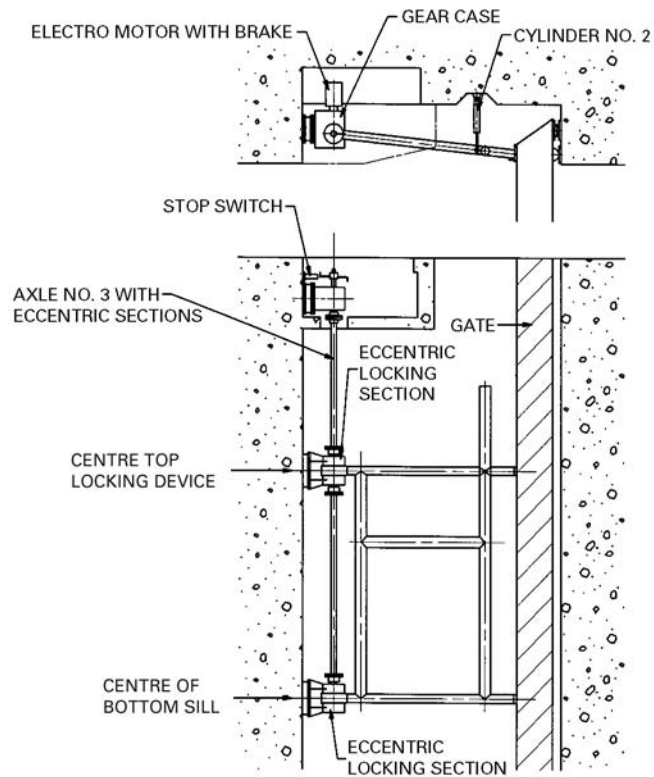


Figure 7.84 Locking of pivot gate with frame locking device (Lock Bergsediep)

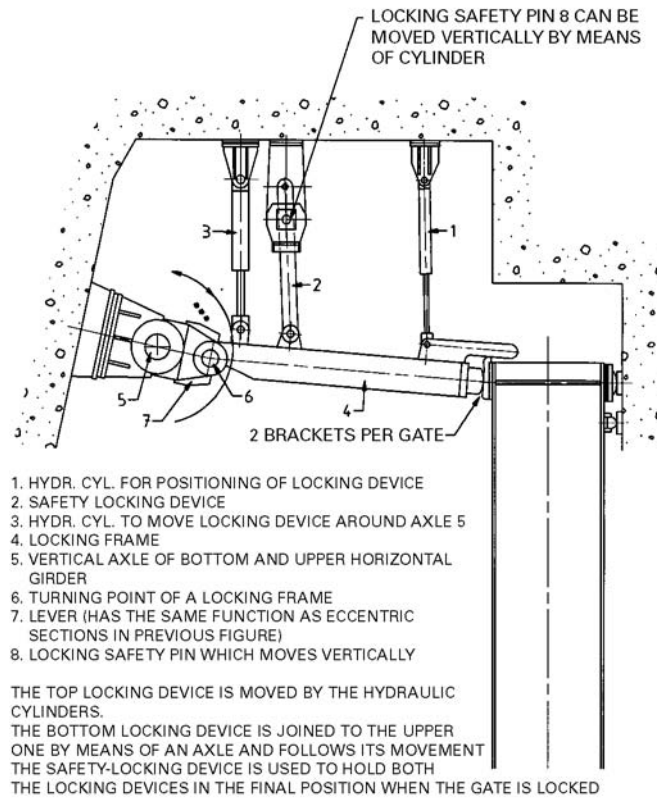


Figure 7.85 Top view of locking of pivot gate with a frame lock (Lock Nieuwe Statenzijl)

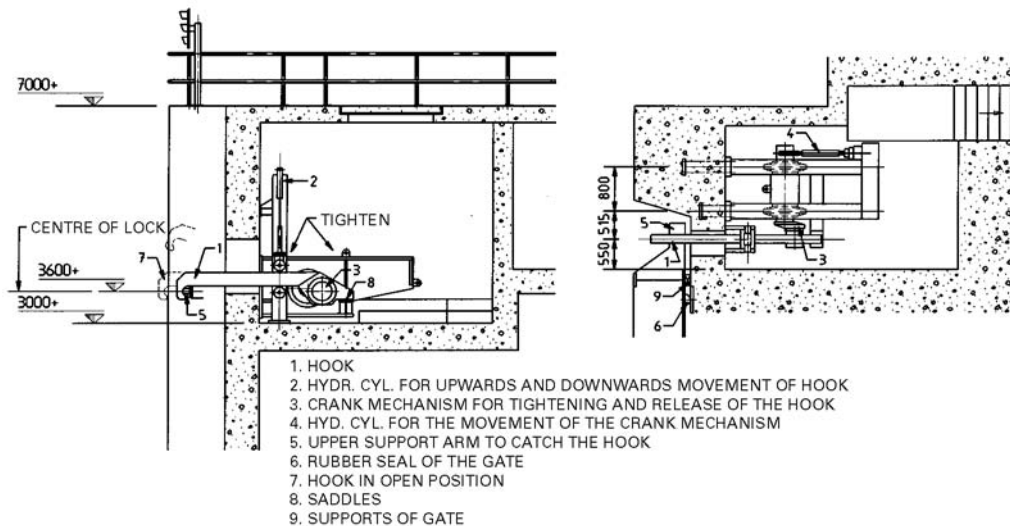


Figure 7.86 Locking of a pivot gate with hooked locking device (Lock Gorinchem)

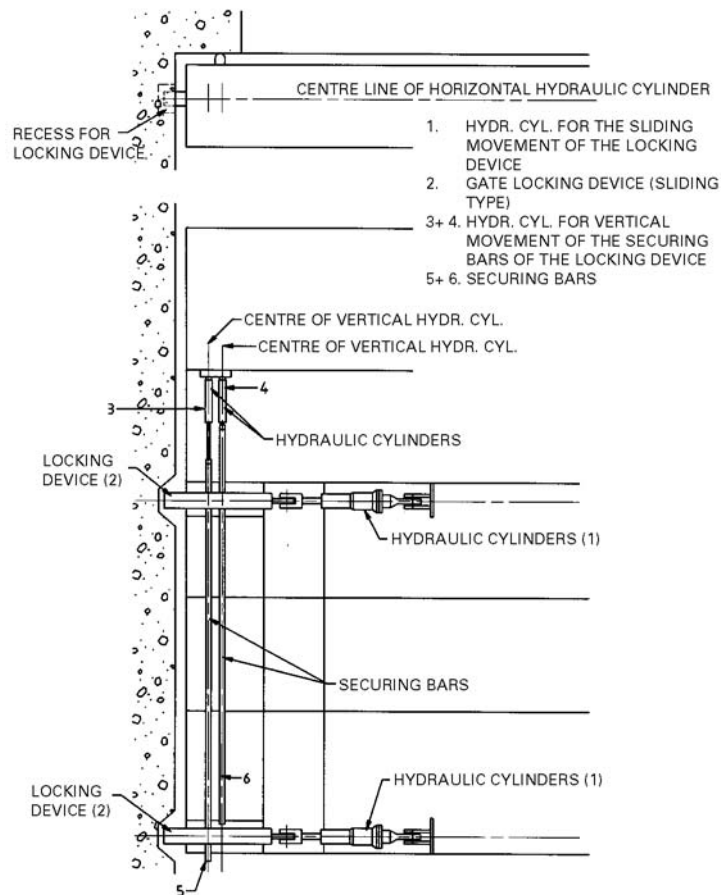


Figure 7.87 Pivot gate locking device with sliding lock (Jachtensluis Krammer)

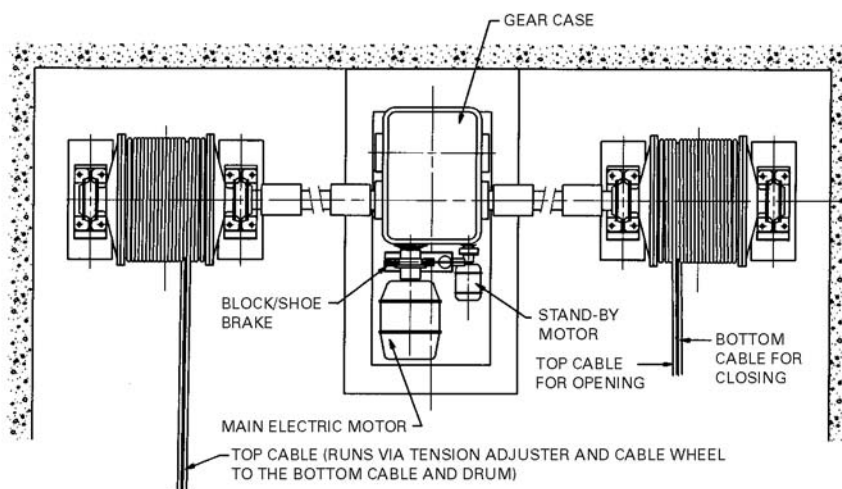


Figure 7.88 Operating mechanism for a rolling gate with two-sided operating mechanism with two cable drums (Marine lock Terneuzen)

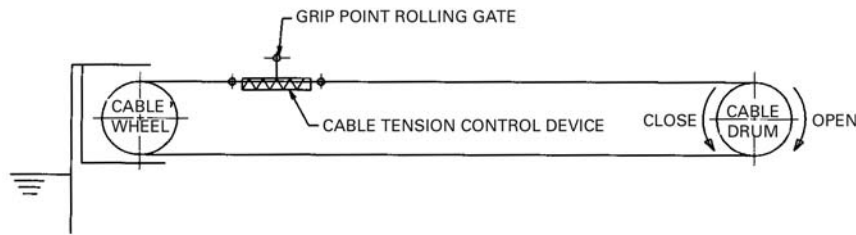


Figure 7.89 Cable operating mechanism

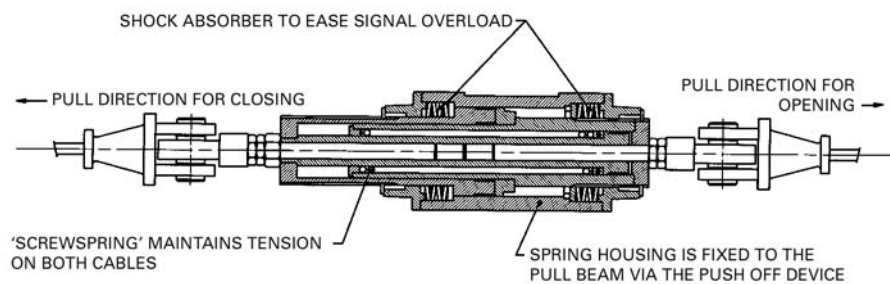


Figure 7.90 Cable tension control device (double acting)

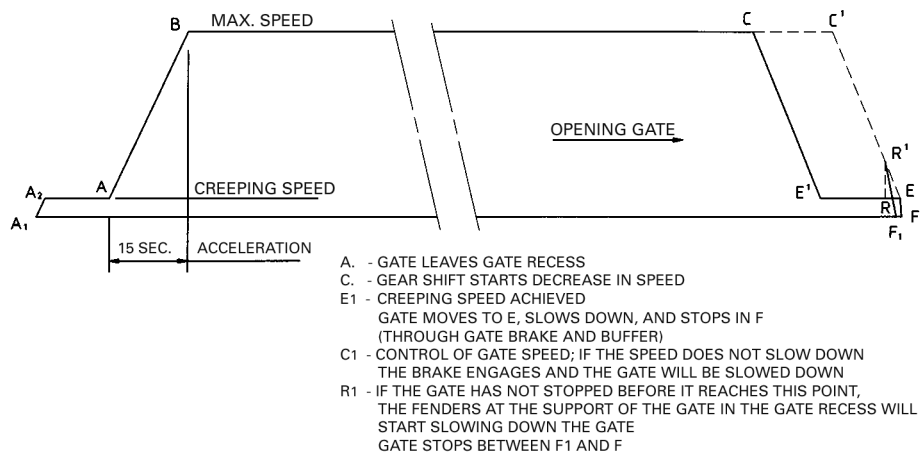
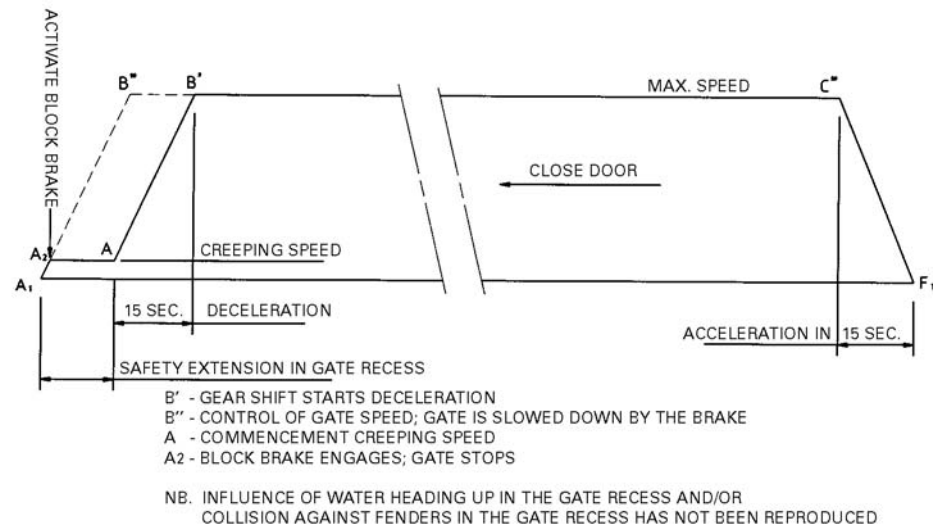
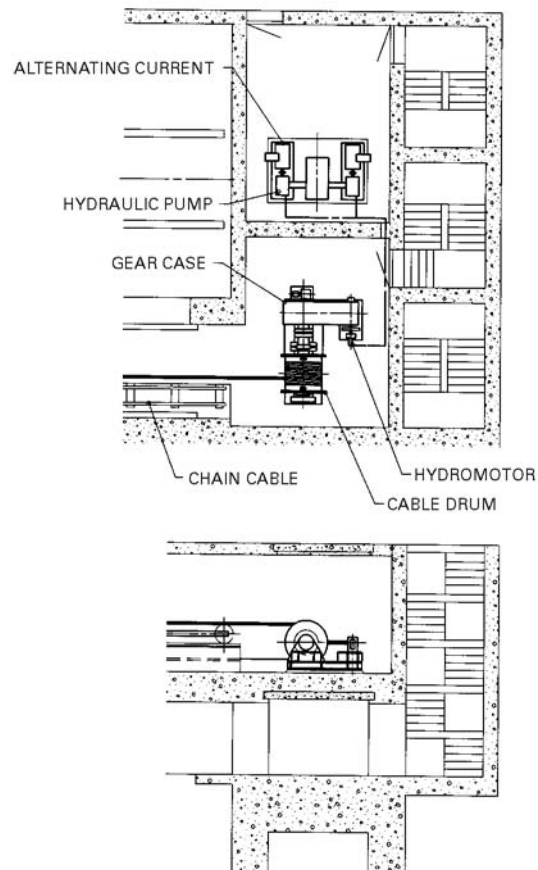


Figure 7.91 Speed course of rolling gate on opening



Figuur 7.92 Course of speed of rolling gate on closing



FOR DIAGRAM OF CABLE COURSE SEE FIG. 7.89

Figure 7.93 Operating mechanism of rolling gate with a one-sided operating mechanism and cable drum (Middensluis Terneuzen)

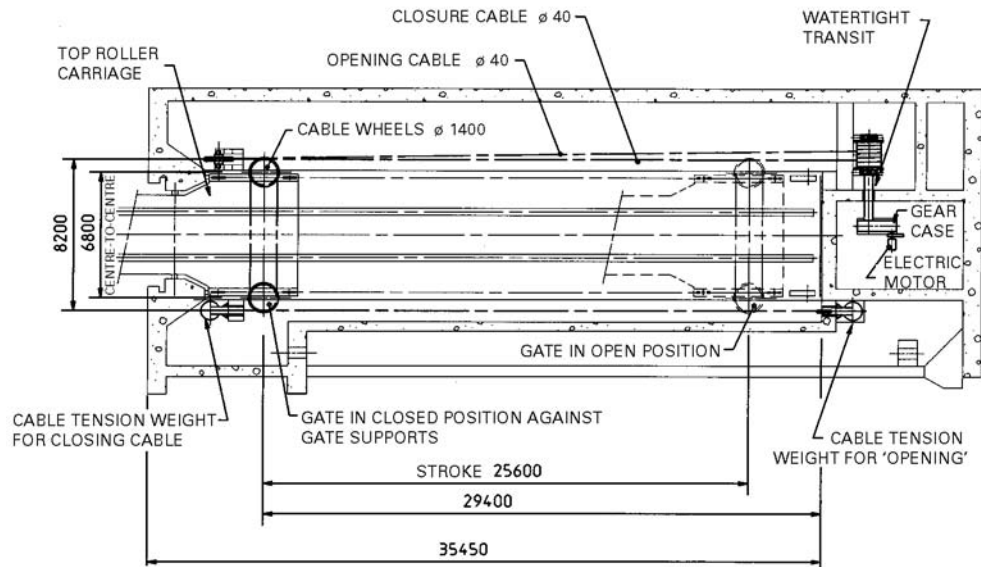


Figure 7.94 Operating mechanism of a rolling gate with a two-sided operating mechanism and single cable drum (Navigation lock Hansweert)

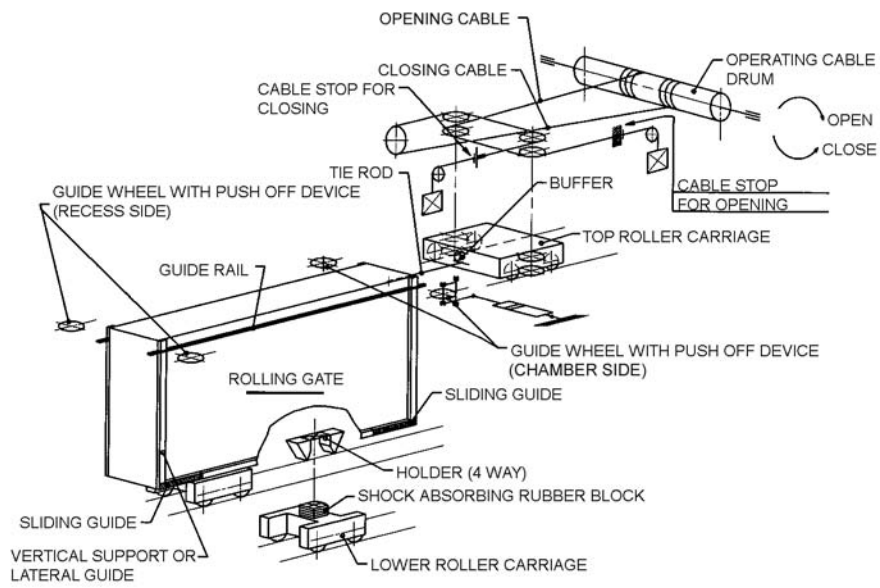


Figure 7.95 Principle working of operating mechanism of a rolling gate (Navigation lock Hansweert)

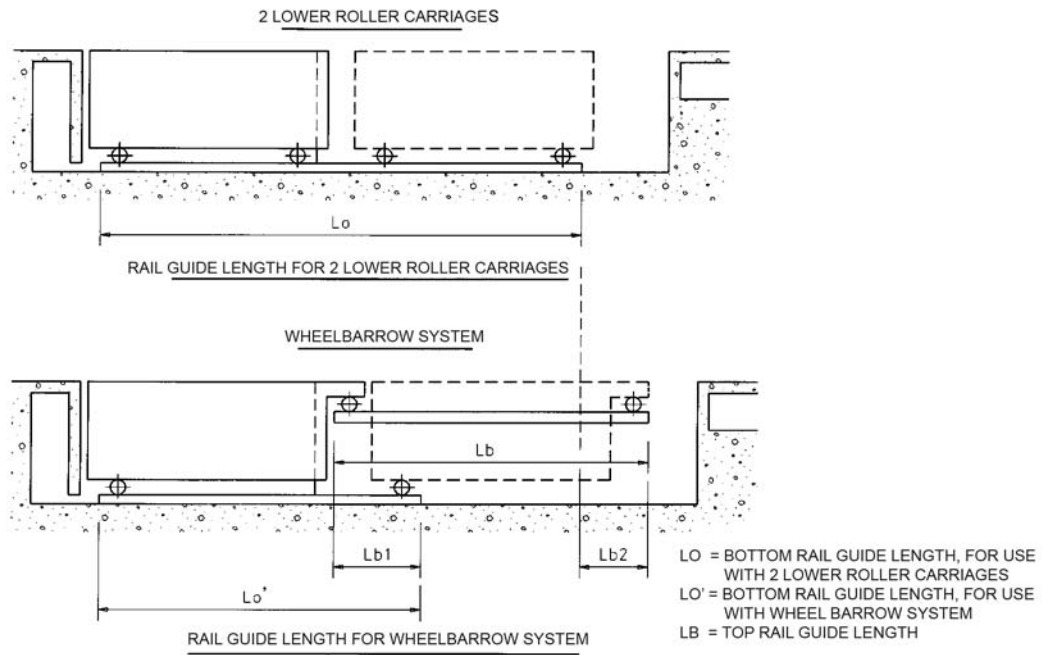


Figure 7.96 Required rail length for a rolling gate

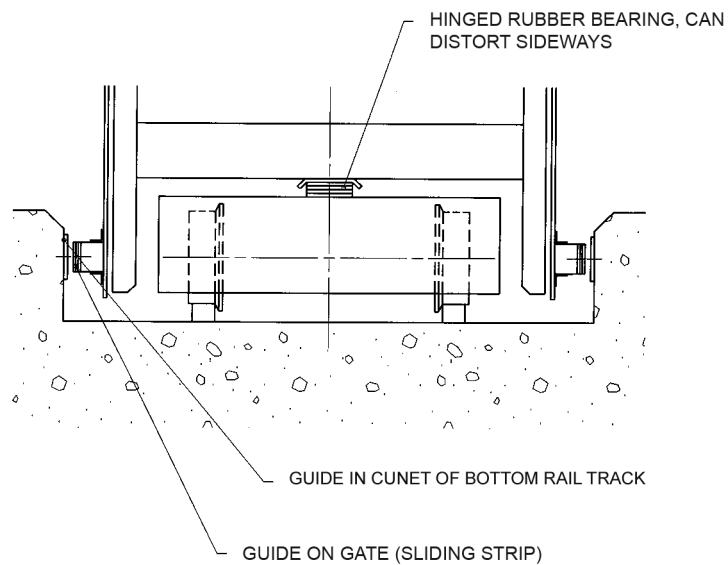


Figure 7.97 Horizontal guide for rolling gate along the support of the gate

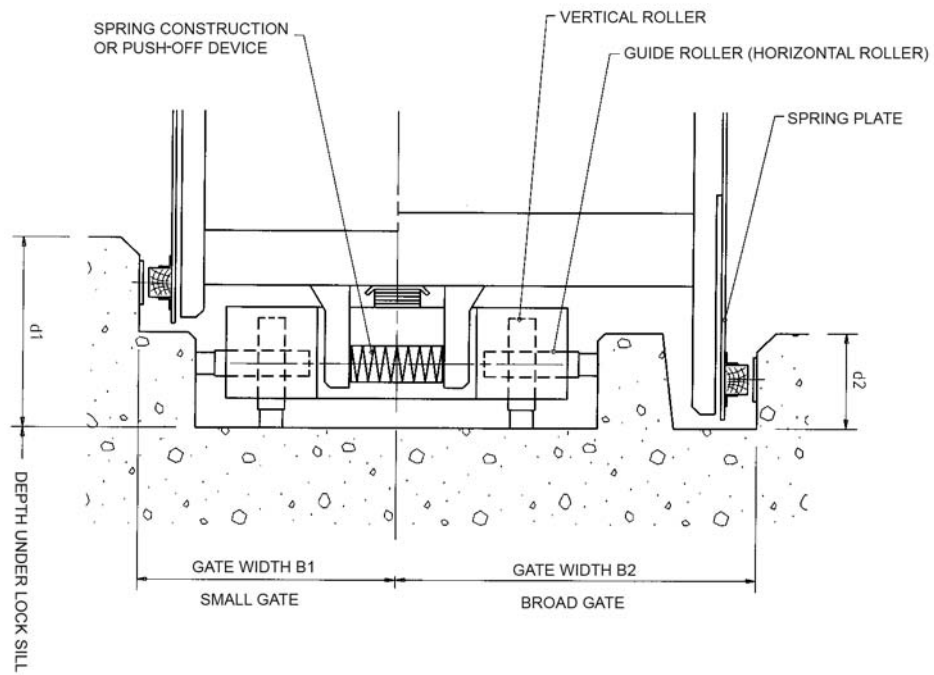


Figure 7.98 Horizontal rolling gate guide with double rollers on the lower roller carriage

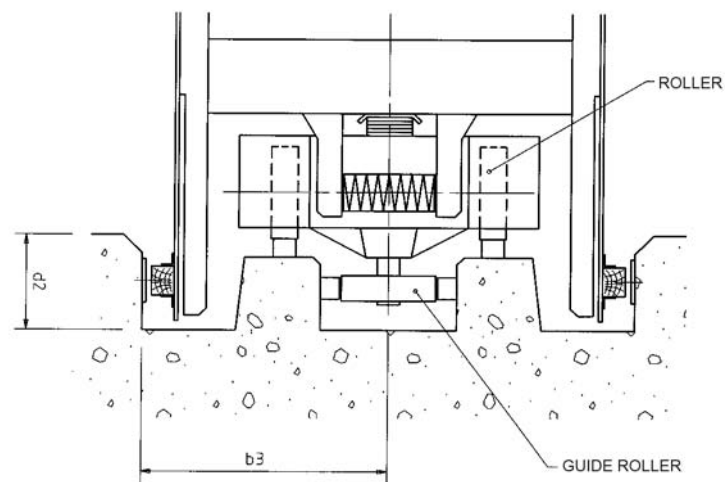


Figure 7.99 Horizontal rolling gate guide with single rollers on the roller carriage

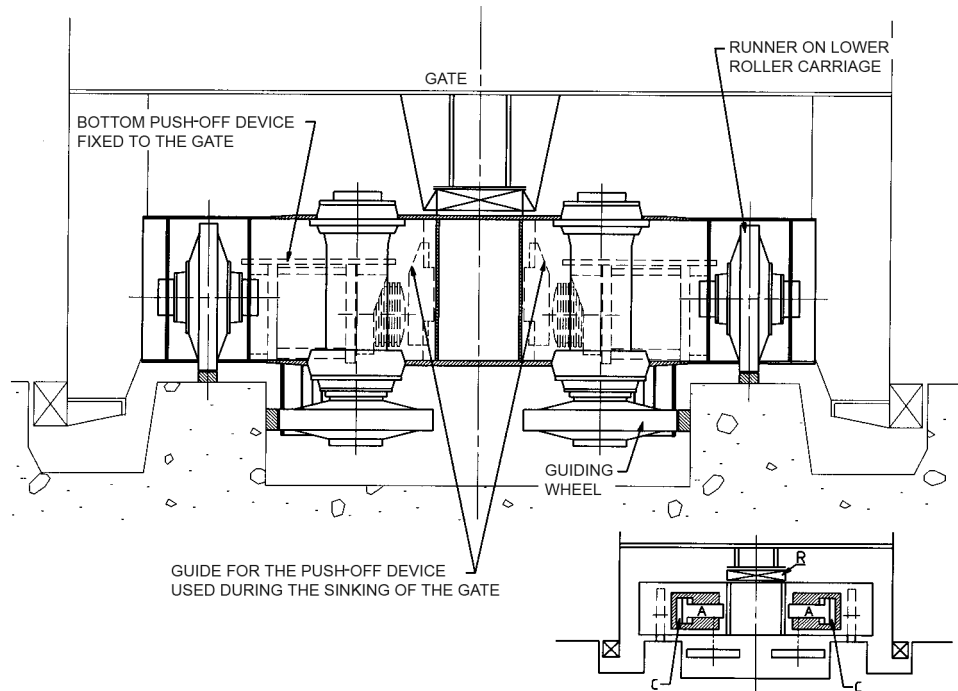


Figure 7.100 Horizontal rolling gate guide with push-off device (under, Marine lock Terneuzen)

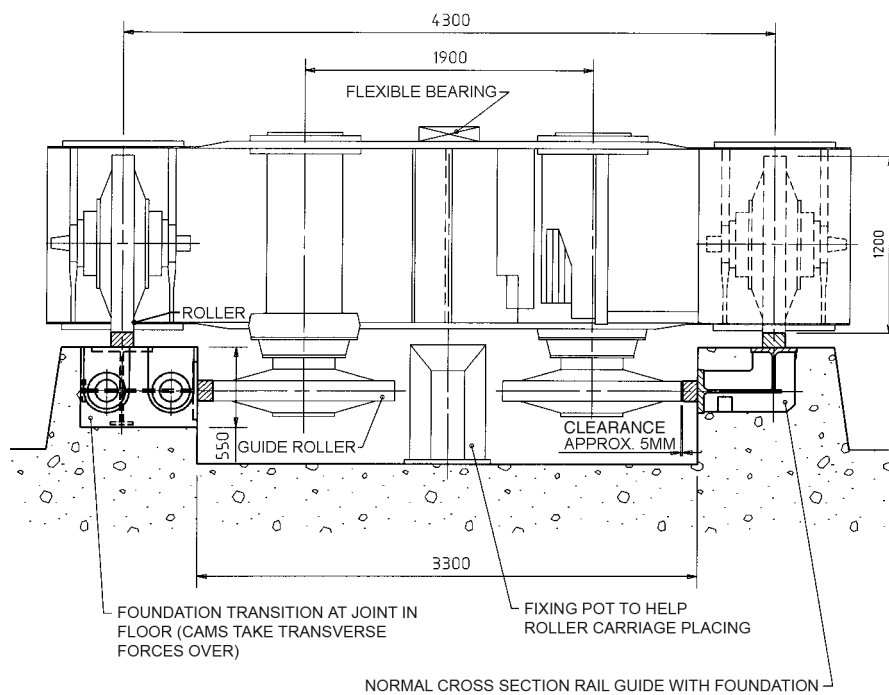


Figure 7.101 Rail track with foundations for lower roller carriage (Marine lock Terneuzen)

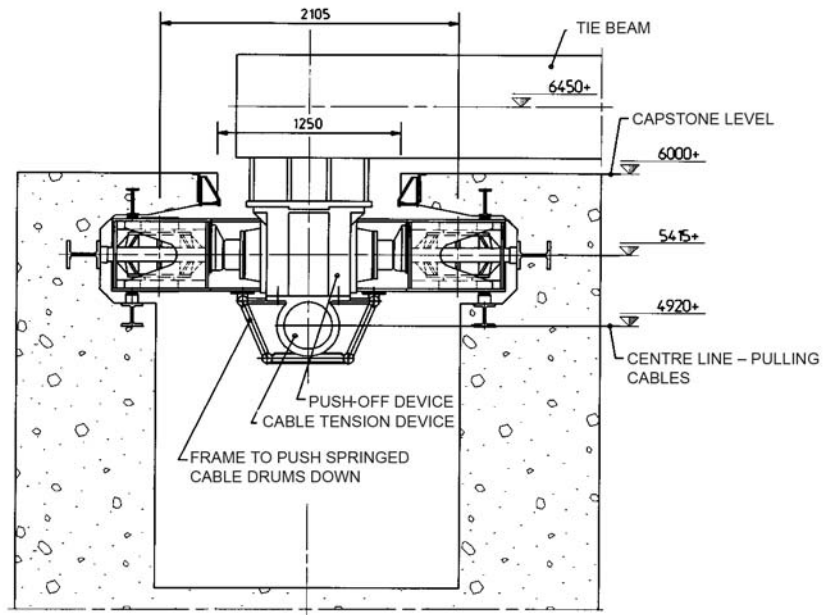
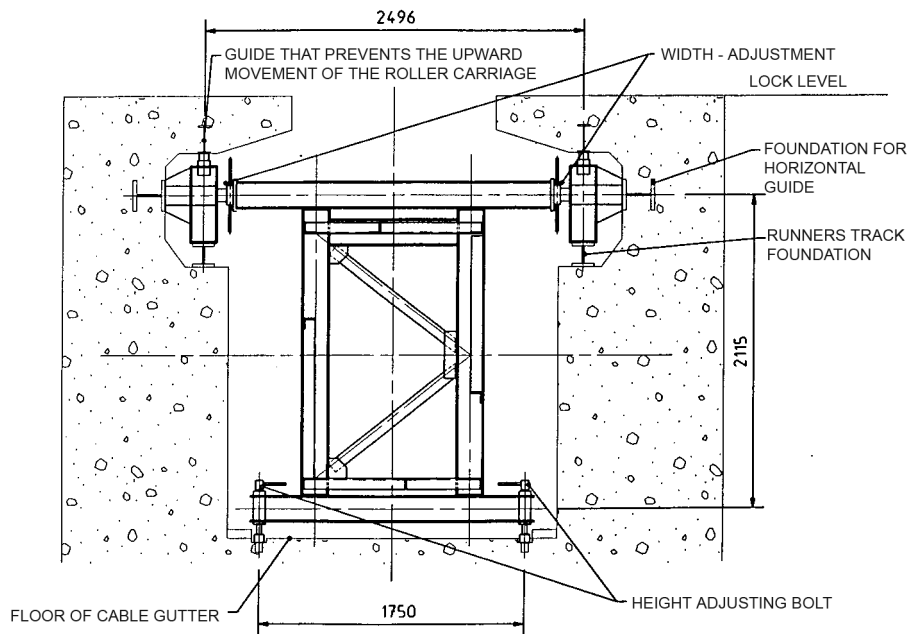


Figure 7.102 Horizontal rolling gate guide with push-off device (Marine lock Terneuzen, top)



FOR TOP ROLLER CARRIAGE SEE FIGURE 7.102

Figure 7.103 Adjustment construction for the top guides (for the top roller carriage of figure 7.102)

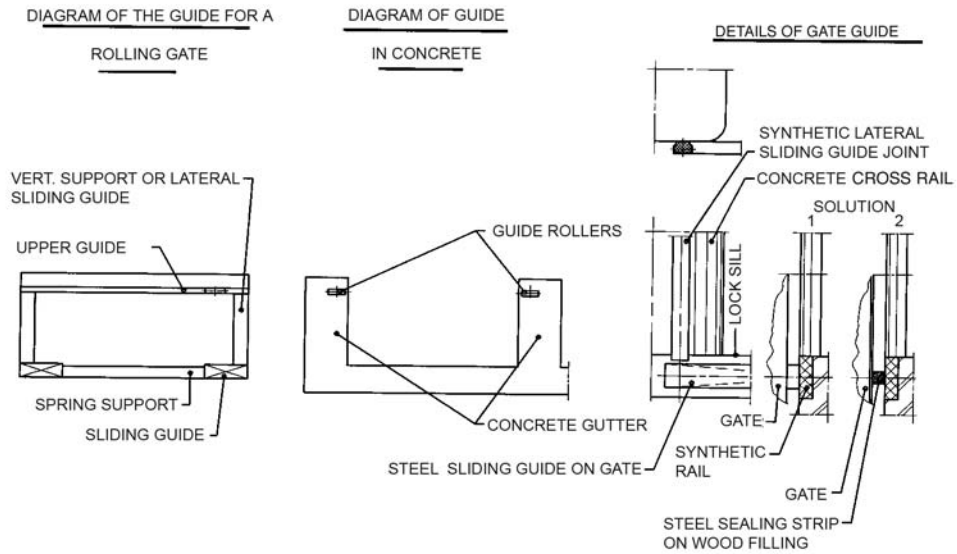


Figure 7.104 Diagram of rolling gate guide (Lock Hansweert)

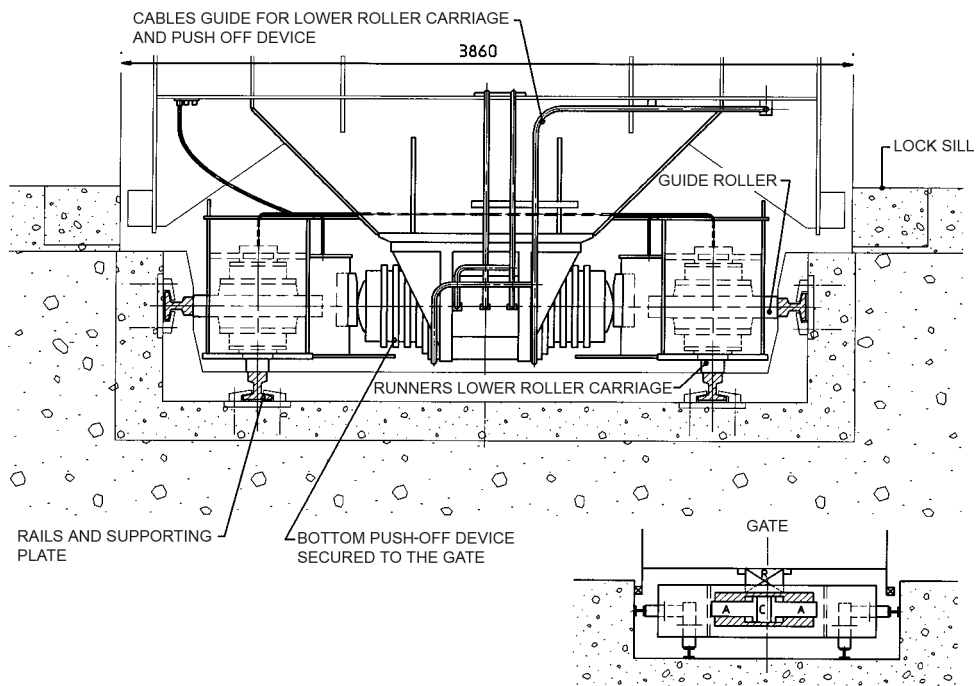


Figure 7.105 Horizontal rolling gate with push-off device (Middensluis Terneuzen, lower gate)

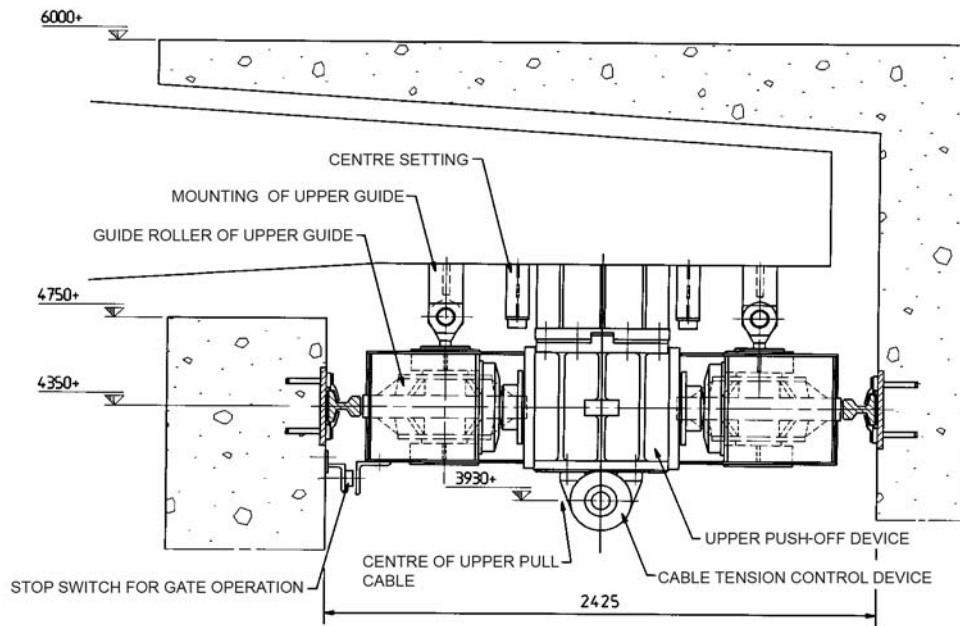


Figure 7.106 Horizontal rolling gate guide with push-off device (Middensluis Terneuzen, upper gate)

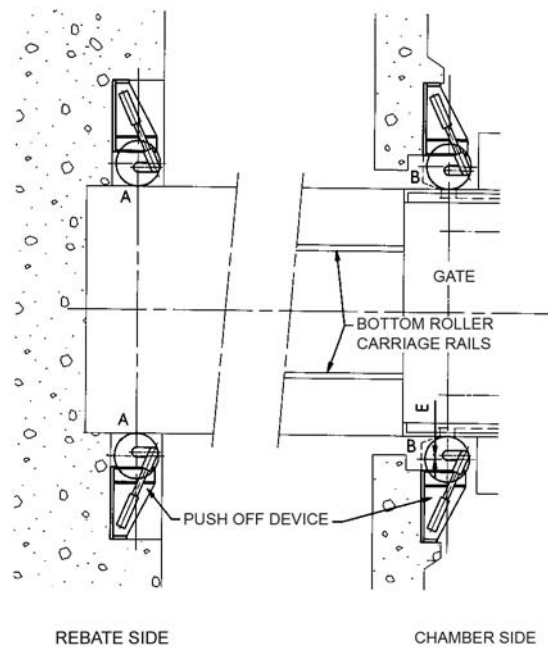


Figure 7.107 Horizontal rolling gate with push-off device (Lock Hansweert, upper gate)

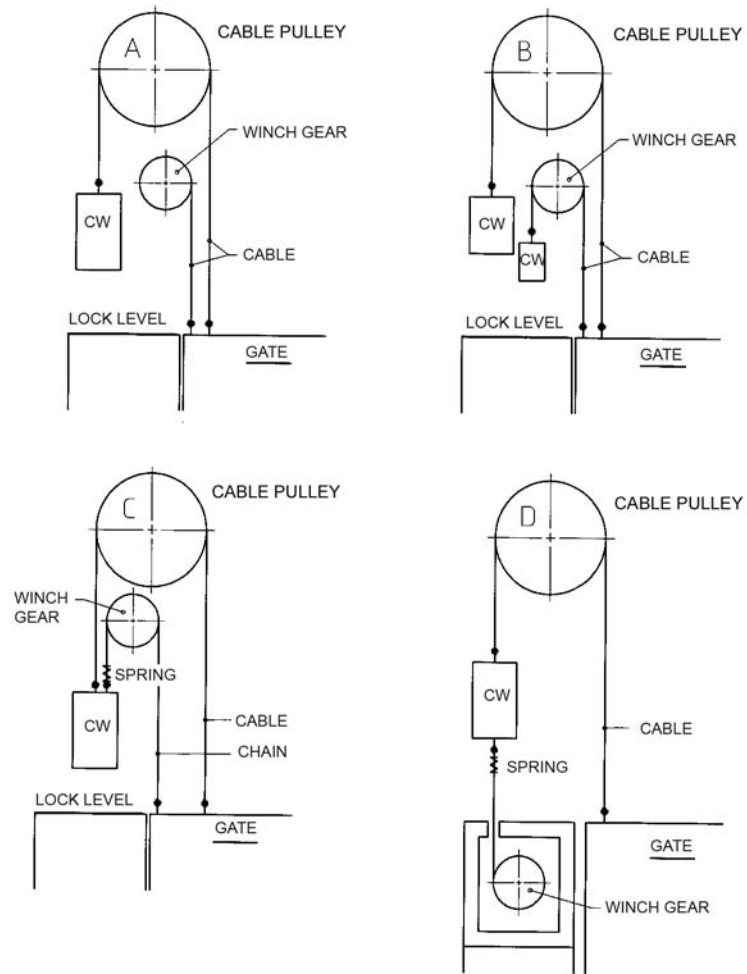


Figure 7.108 Position of winch gear and counterweights for operating mechanism of a lift gate

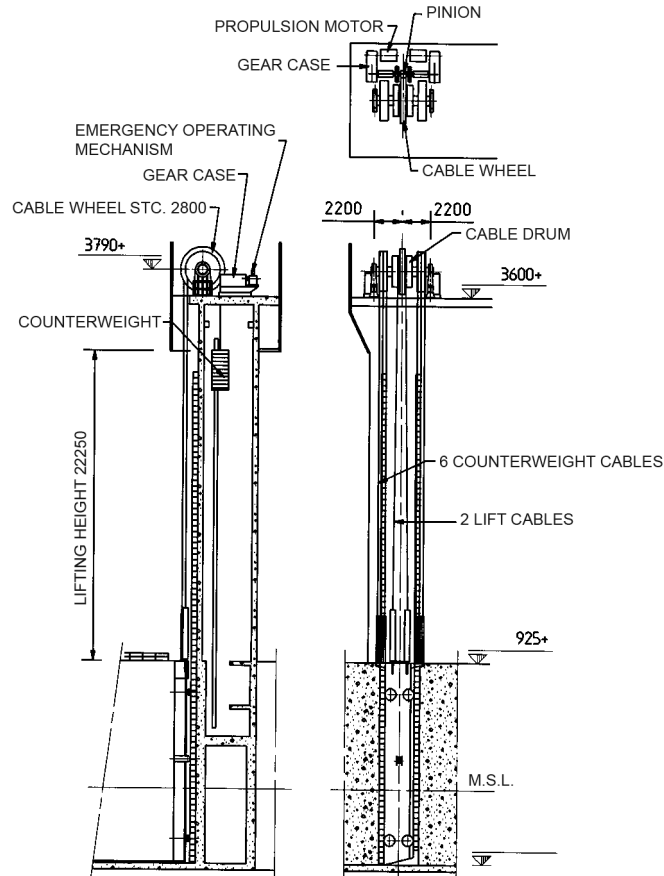


Figure 7.109 Operating mechanism for lift gate (Lock at Wijk Duurstede)

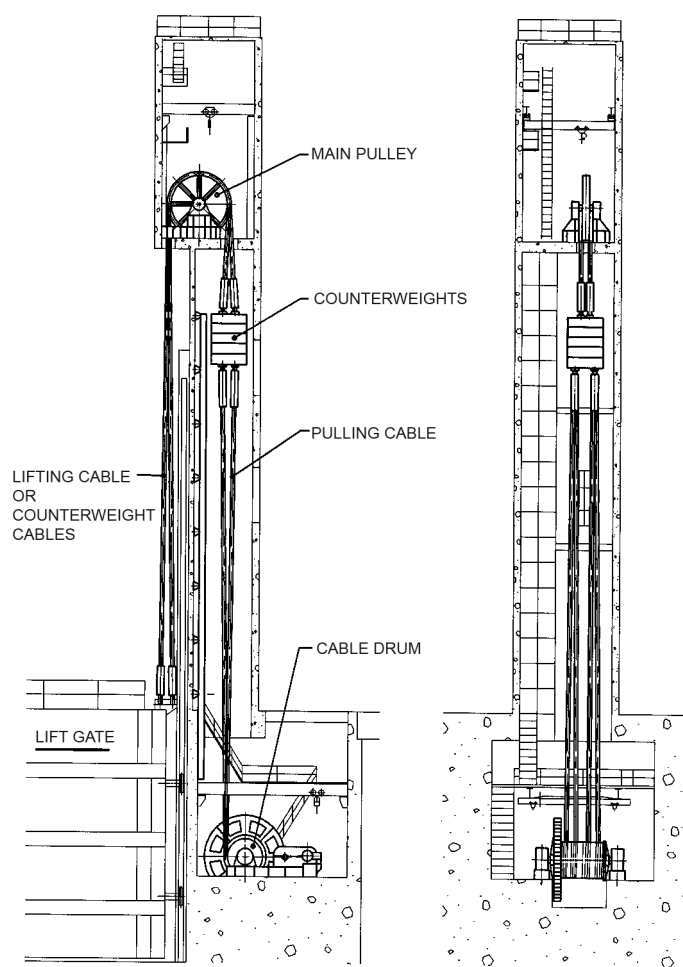


Figure 7.110 Operating mechanism for lift gate (Kreekrak locks)

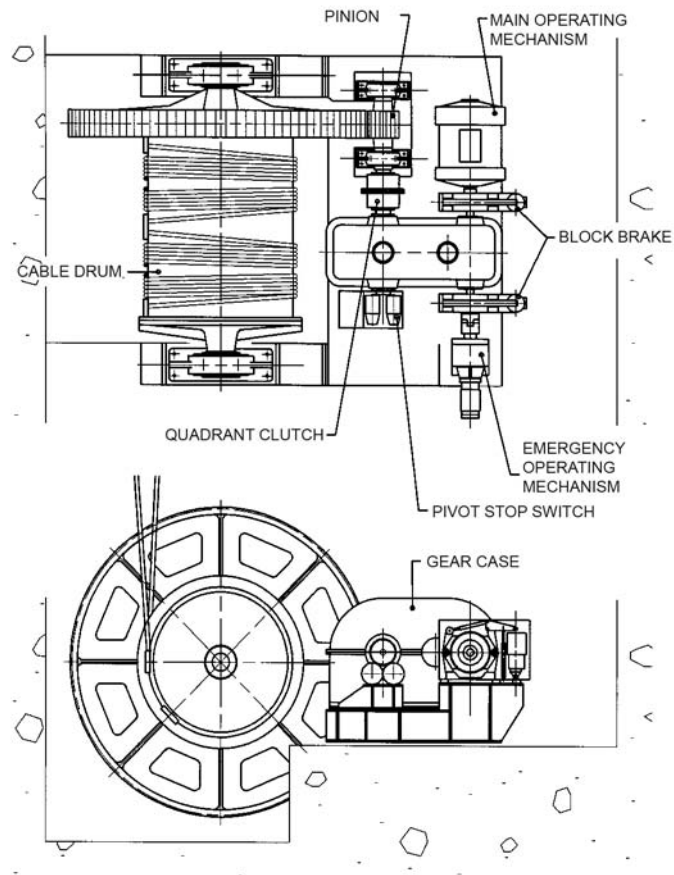


Figure 7.111 Composition of winch gear lift gate (Kreekrak locks)

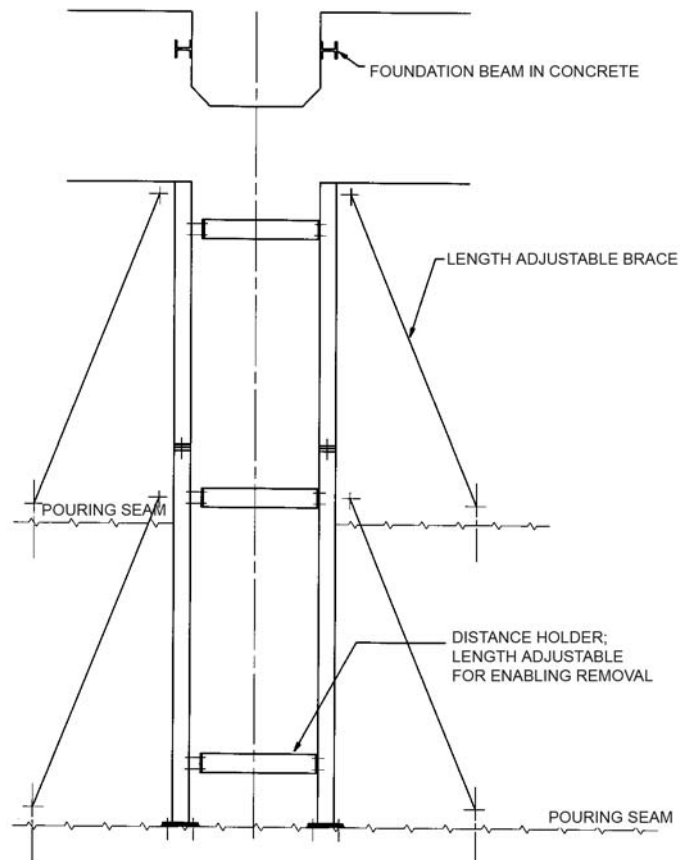


Figure 7.112 Adjusting and concreting of foundation beam

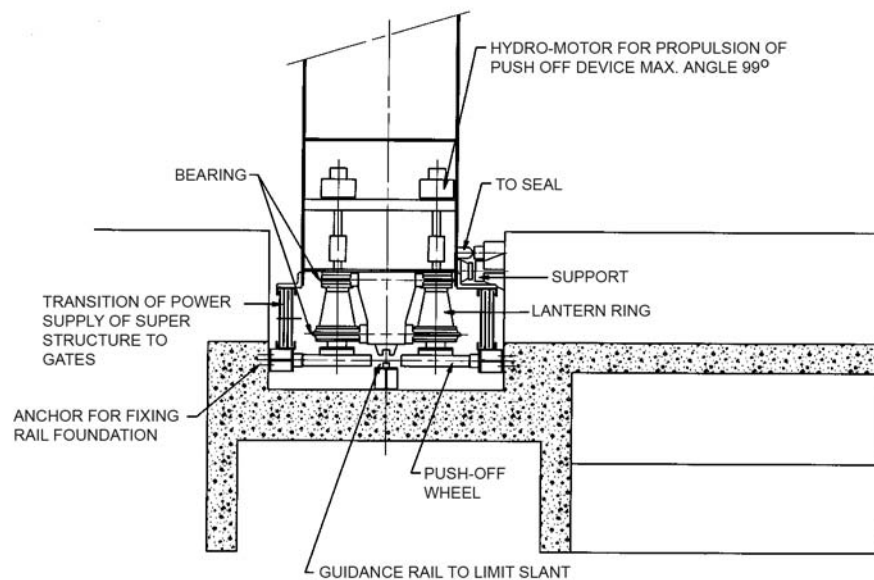


Figure 7.113 Lift gate guide and seal including anchoring (Lock Wijk bij Duurstede)

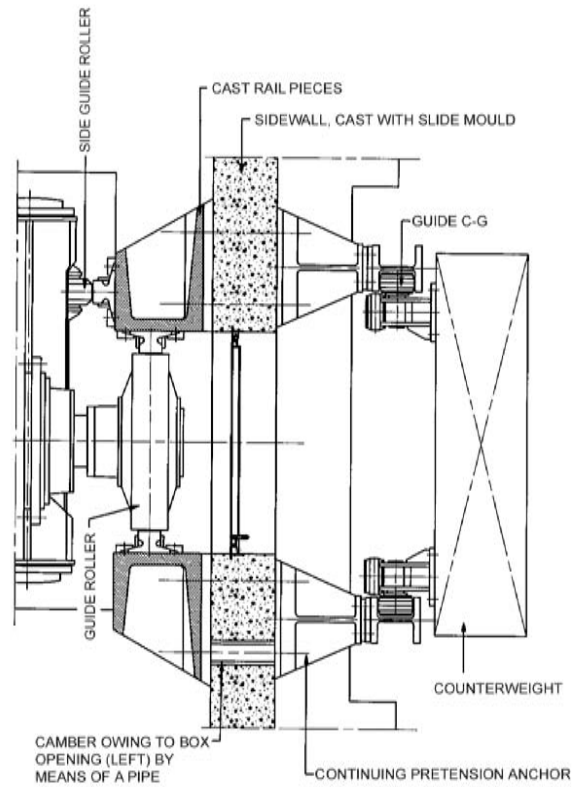


Figure 7.114 Rail construction with connection through continuous anchors

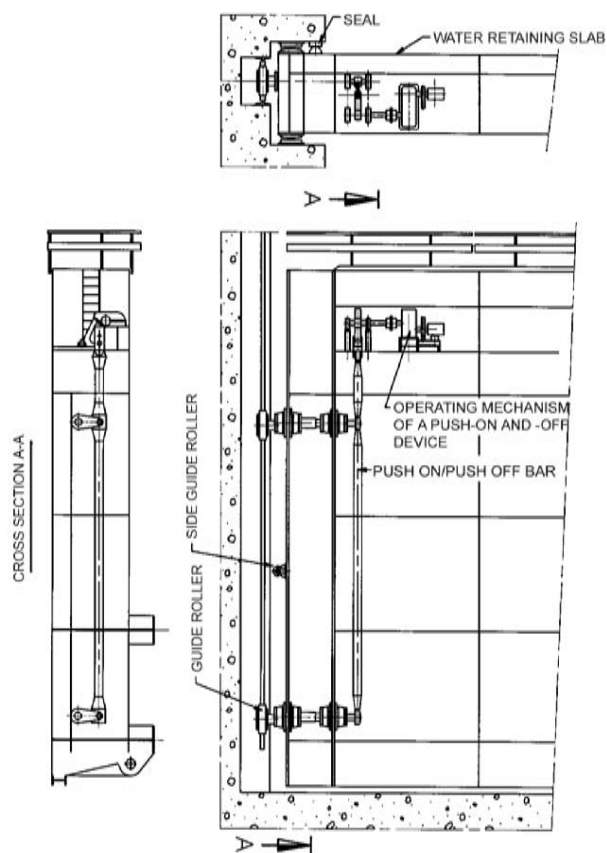


Figure 7.115 Place of guide roller and side rollers at lift gate

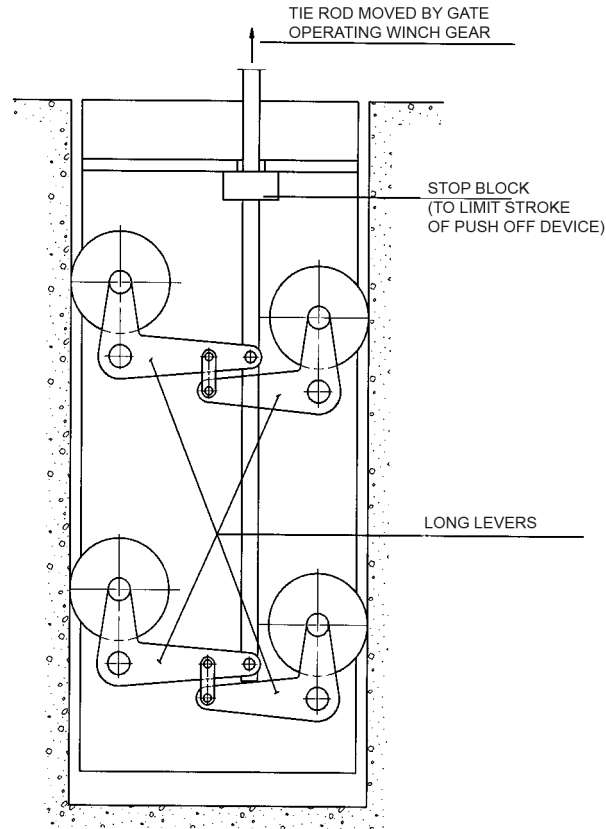


Figure 7.116 Principle working of a push-off device for a two-sided retaining lift gate

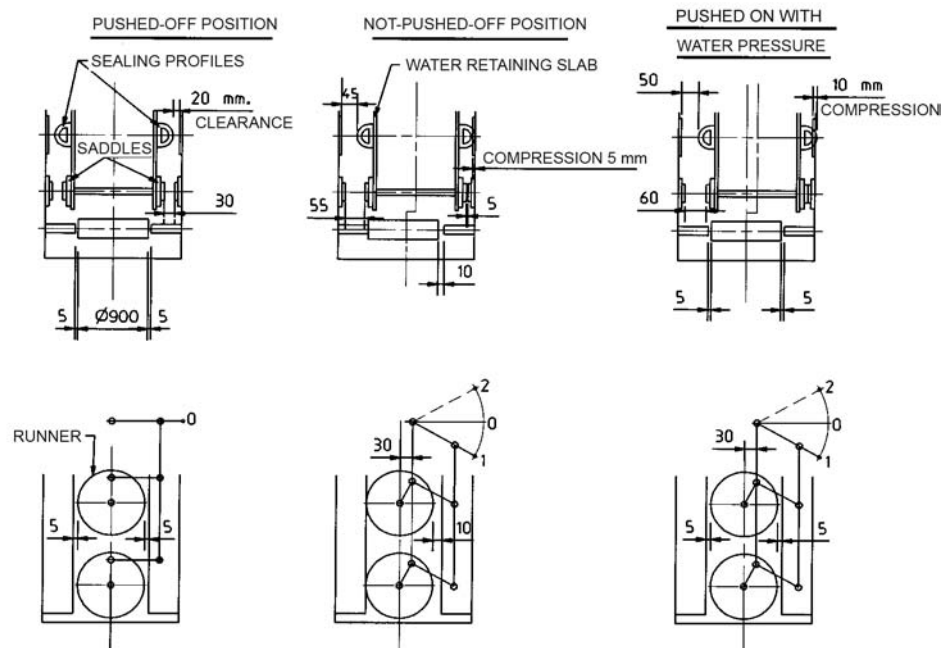


Figure 7.117 Diagram of pushing on and off of a lift gate (Kreekraaksluizen)

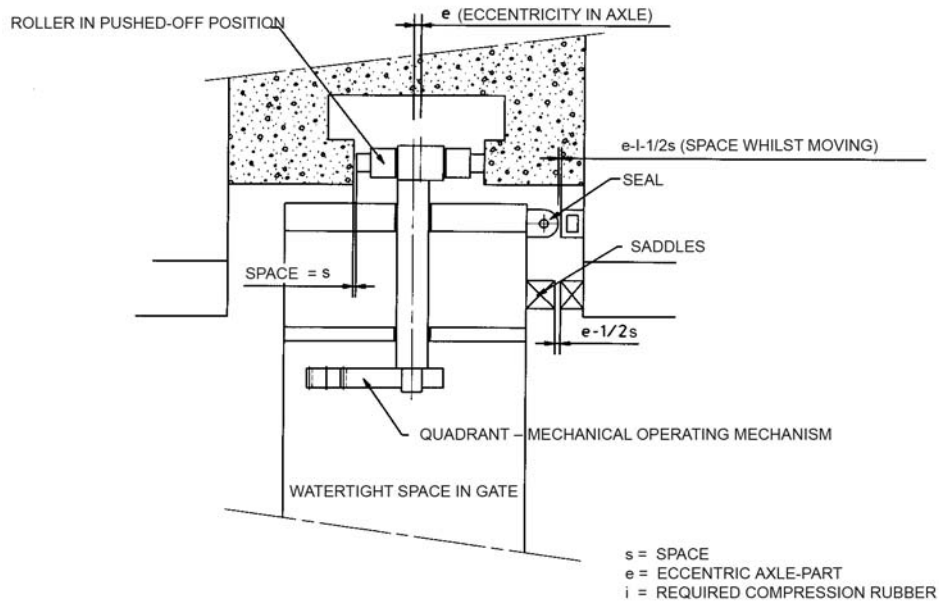


Figure 7.118 Diagram of push-off device for a one-sided retaining lift gate

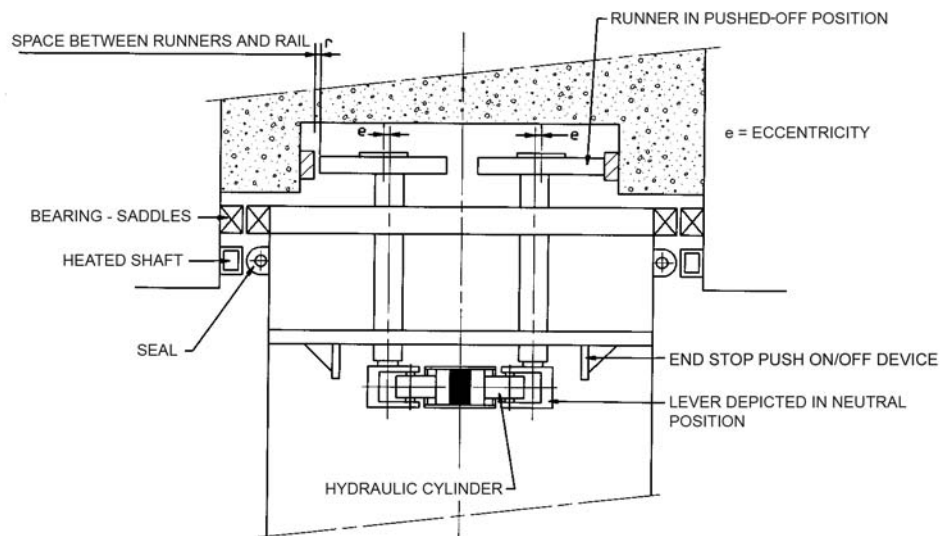


Figure 7.119 Diagram of a push-off device of two-sided retaining lift gate

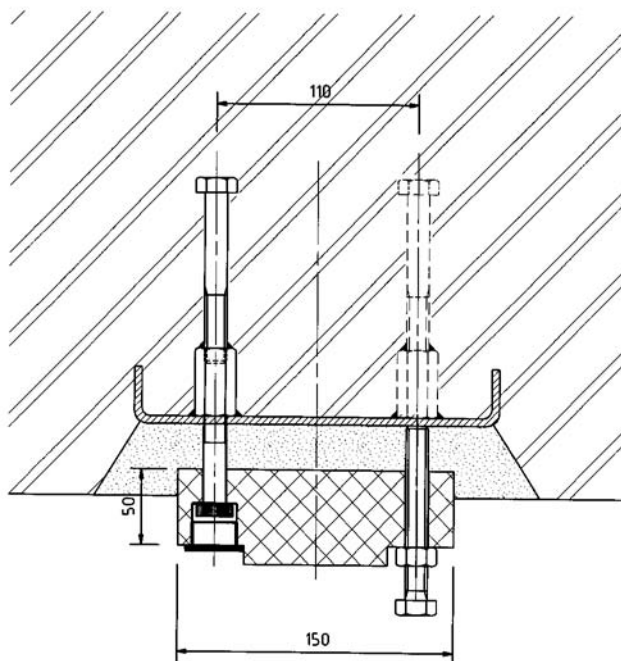


Figure 7.120 Setting of a guide in a recess

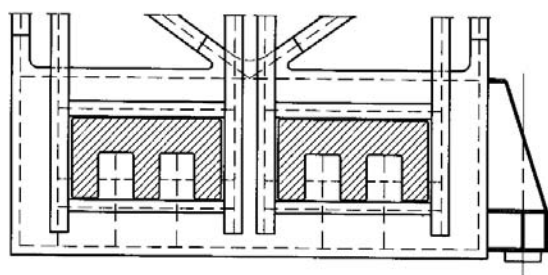


Figure 7.121 Adapted levelling openings (Lock Nieuwe Statenzijl)

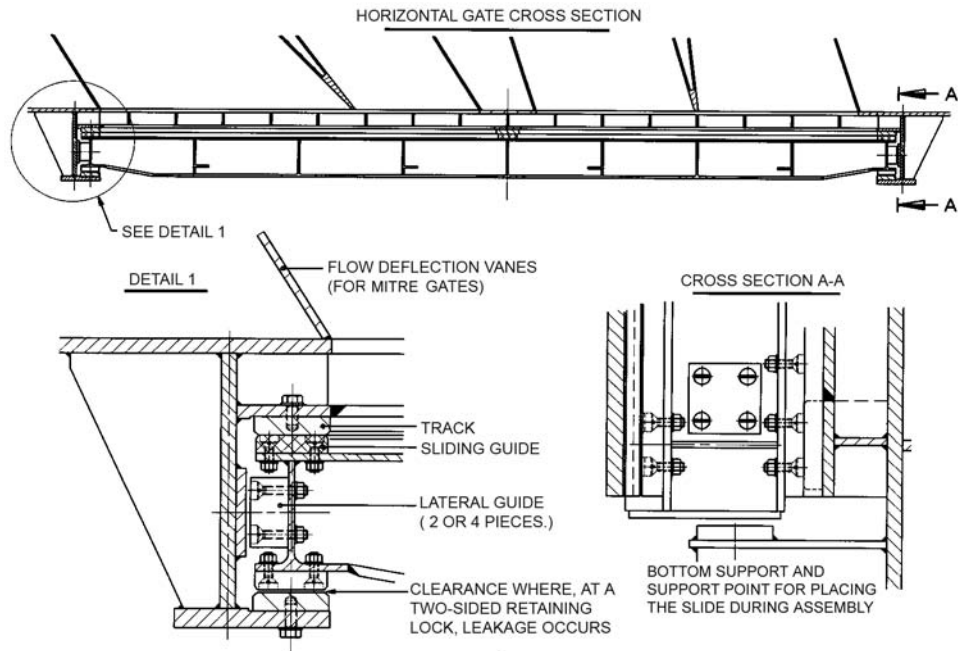


Figure 7.122 Lock paddles for one-sided and two-sided retaining lock with leakage tolerance

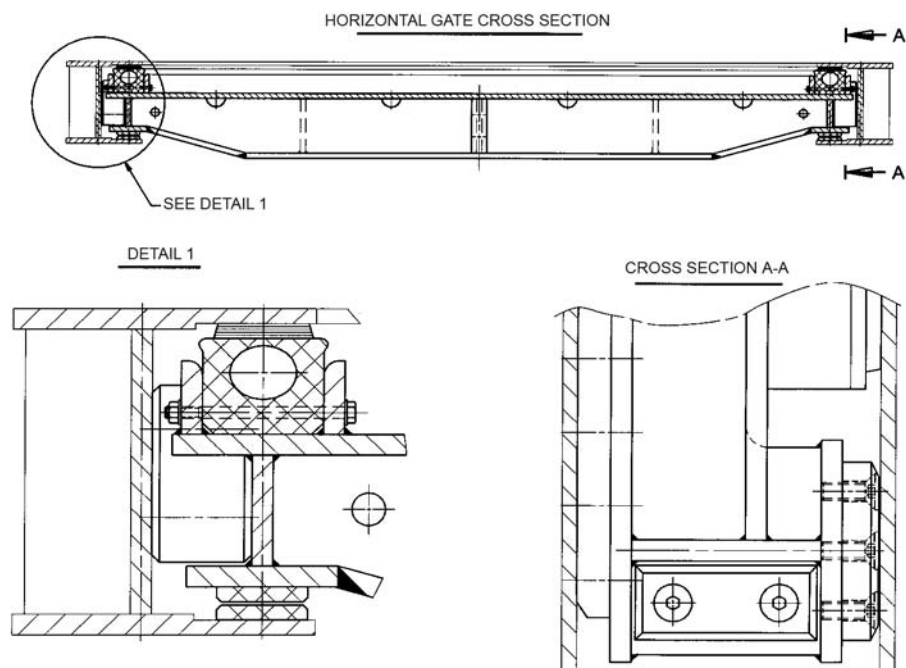


Figure 7.123 Lock paddle for two-sided retaining lock

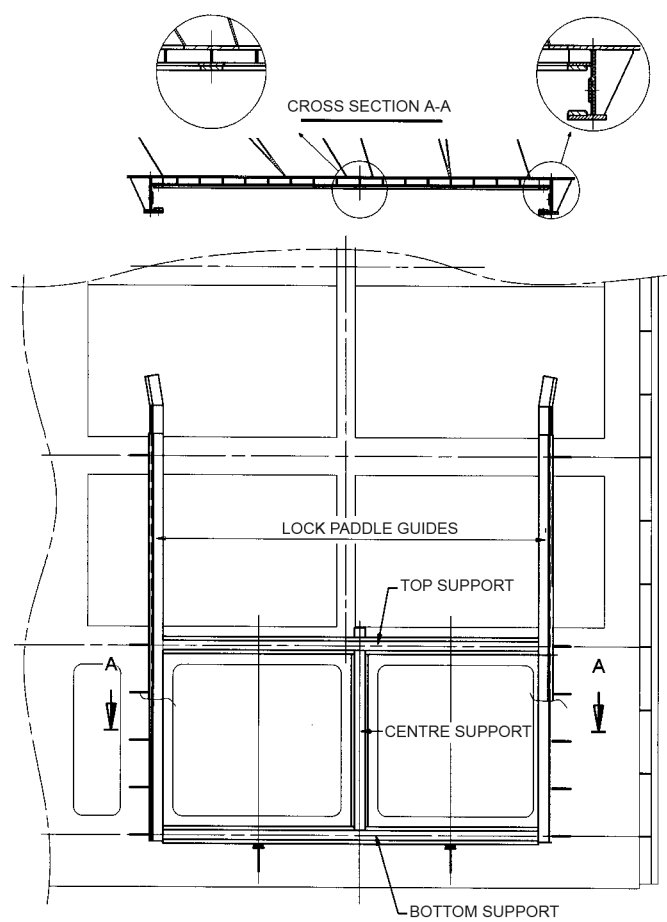


Figure 7.124 Lock paddle guides (for lock paddles of figure 7.122)

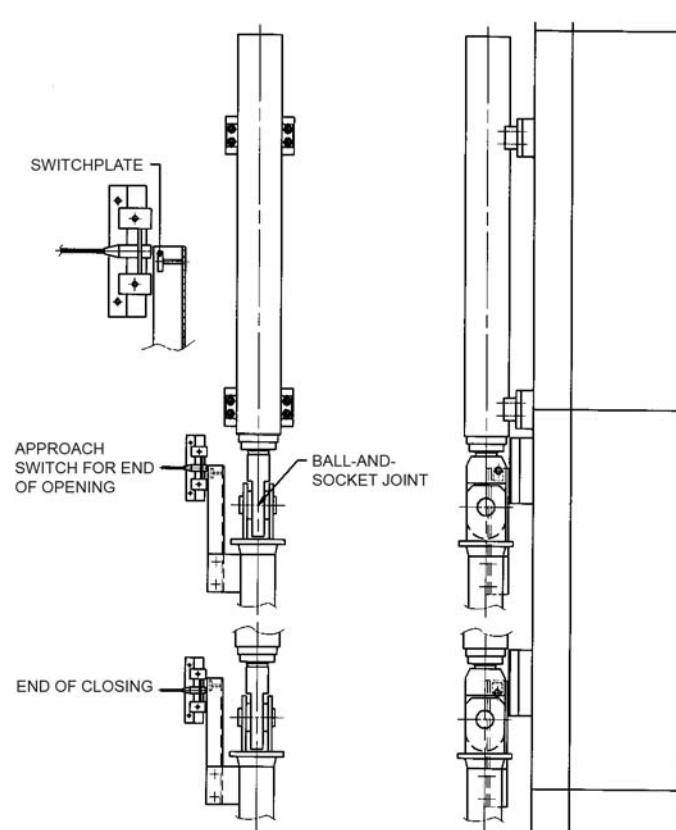


Figure 7.125 Lock paddle operating mechanism with hydraulic operating device

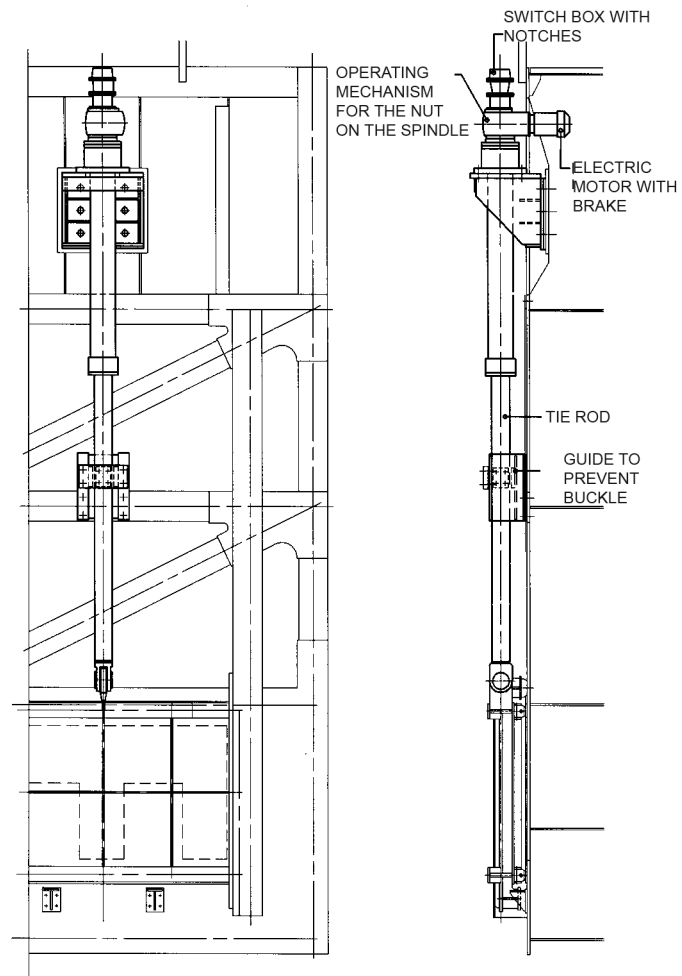


Figure 7.126 Lock paddle operating mechanism with spindle

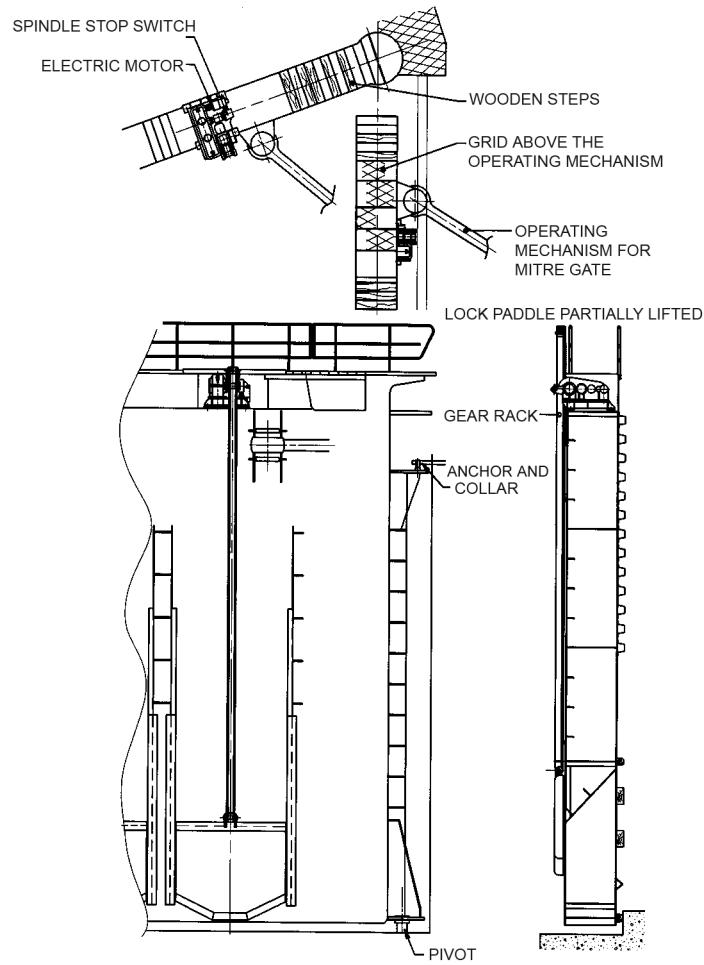


Figure 7.127 Lock paddle operating mechanism with rack drive

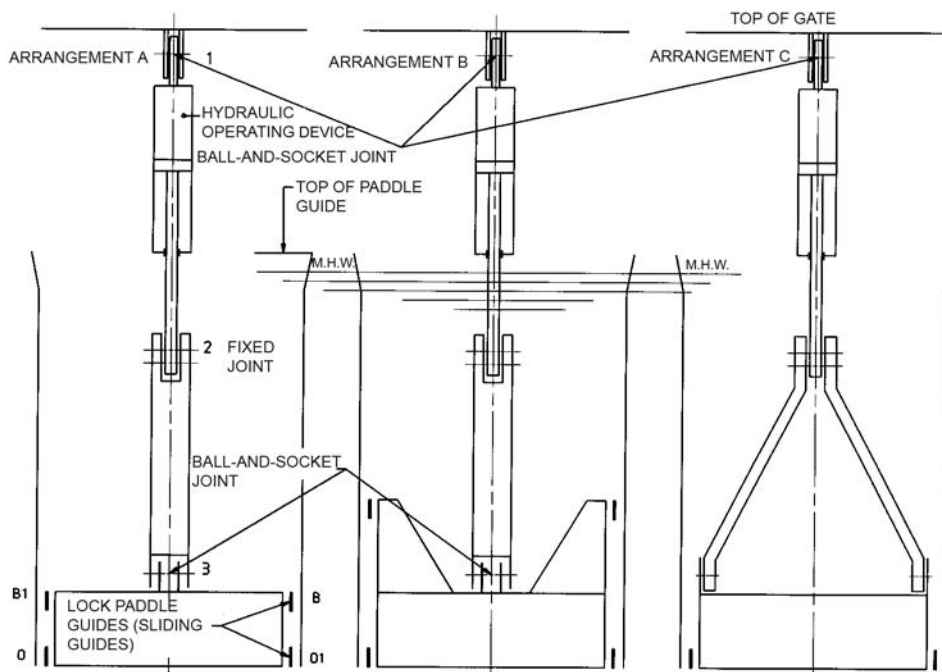
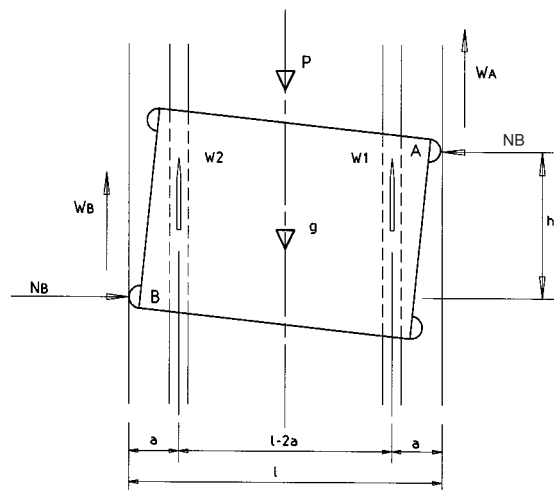


Figure 7.128 Connection of operating mechanism to lock paddles



NB = FORCE AS A RESULT OF THE DIFFERENCES OF FRICTION
ON THE RAILS DURING MOVEMENT
P = OPERATING FORCE ON GATE WHILST LOWERING

Note: IF h/l IS TOO SMALL THE GATE WILL JAM

Figure 7.129 Force due to the tilt of the gate in the guide

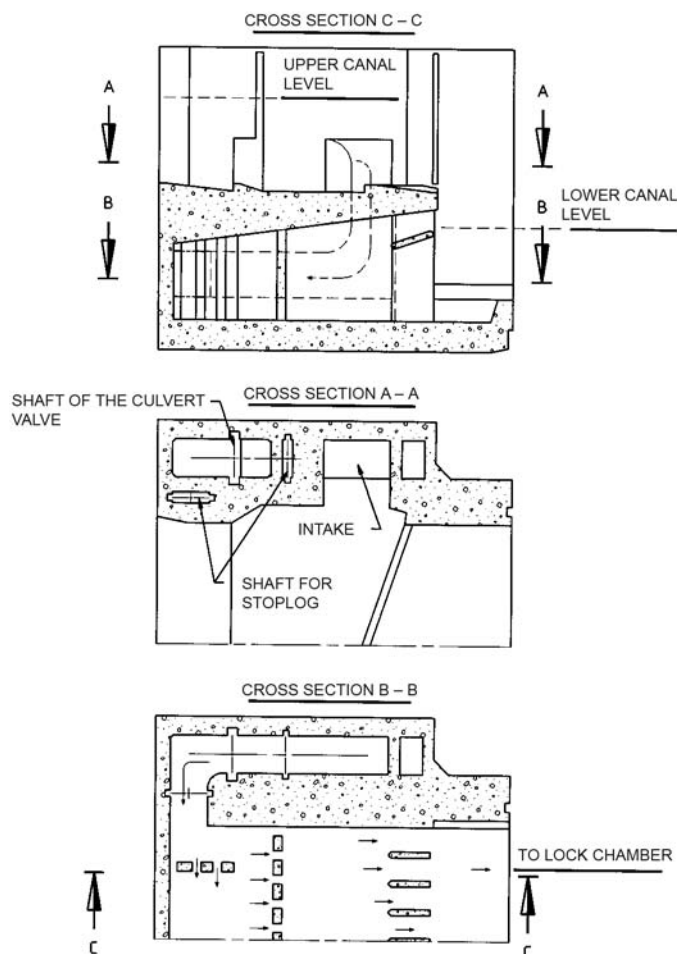


Figure 7.130 Culverts in upper lock head (Lock Maasbracht)

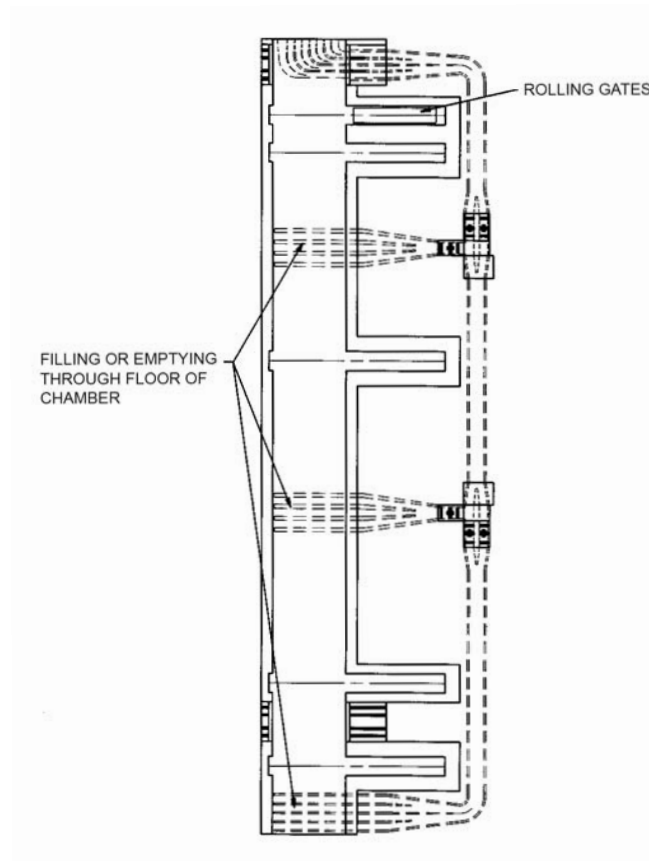


Figure 7.131 One-sided longitudinal culverts with floor grids (Marine lock Terneuzen)

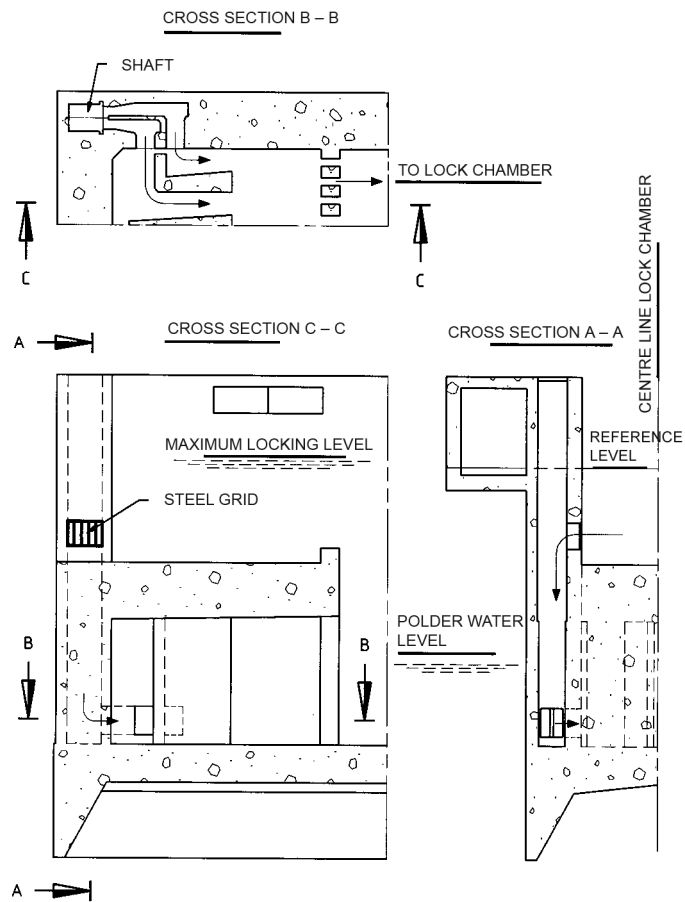


Figure 7.132 Culvert in upper lock head (Lock Almere- Haven)

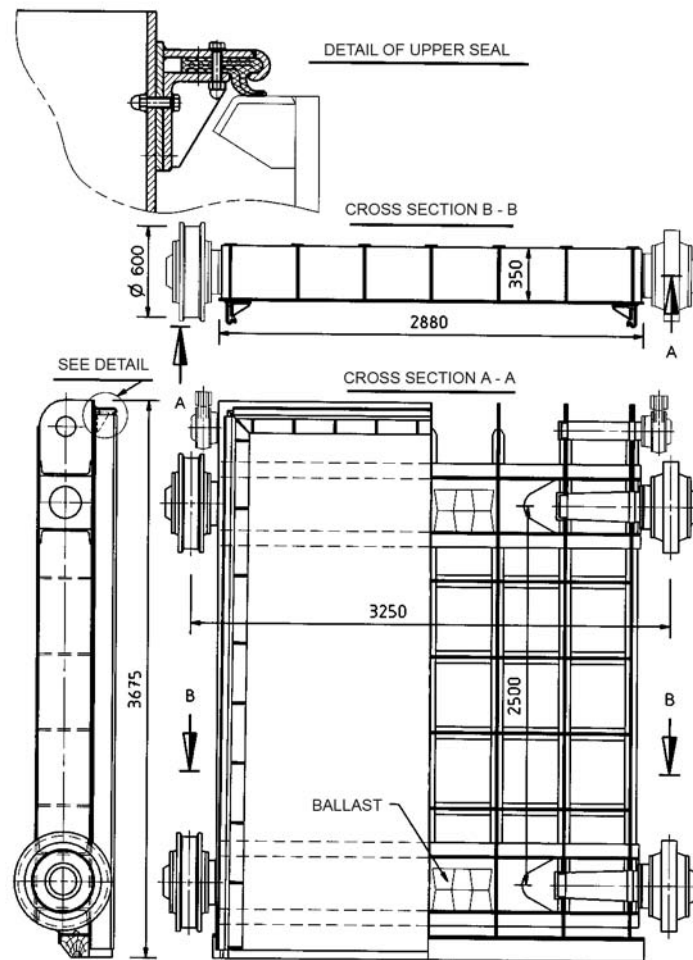


Figure 7.133 Vertical rolling gate (Lock Maasbracht)

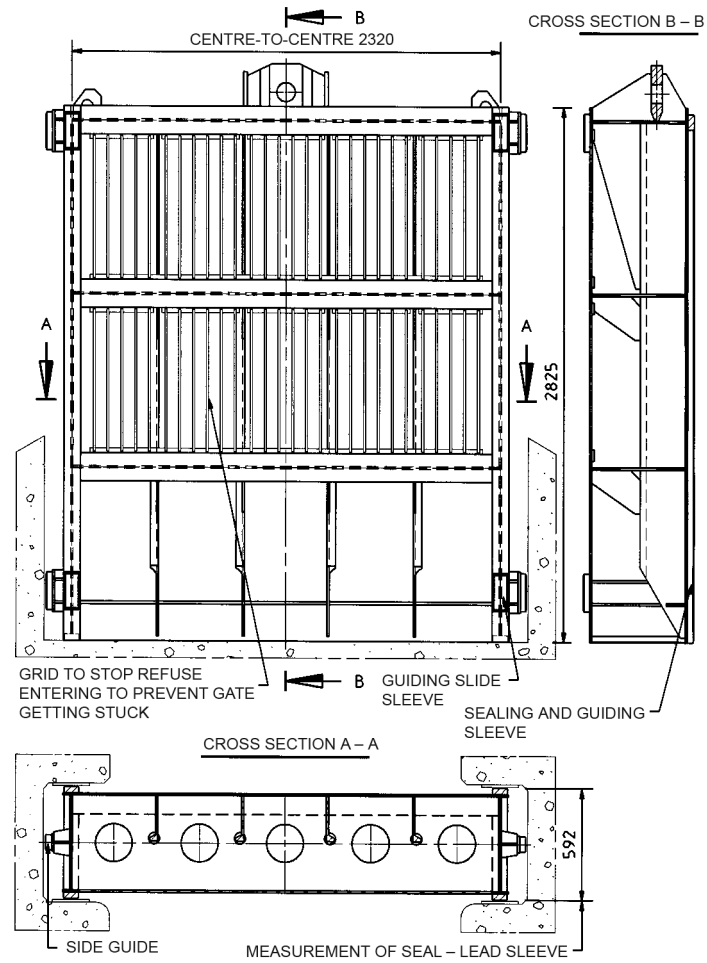


Figure 7.134 Vertical sliding gate (Lock Panheel)

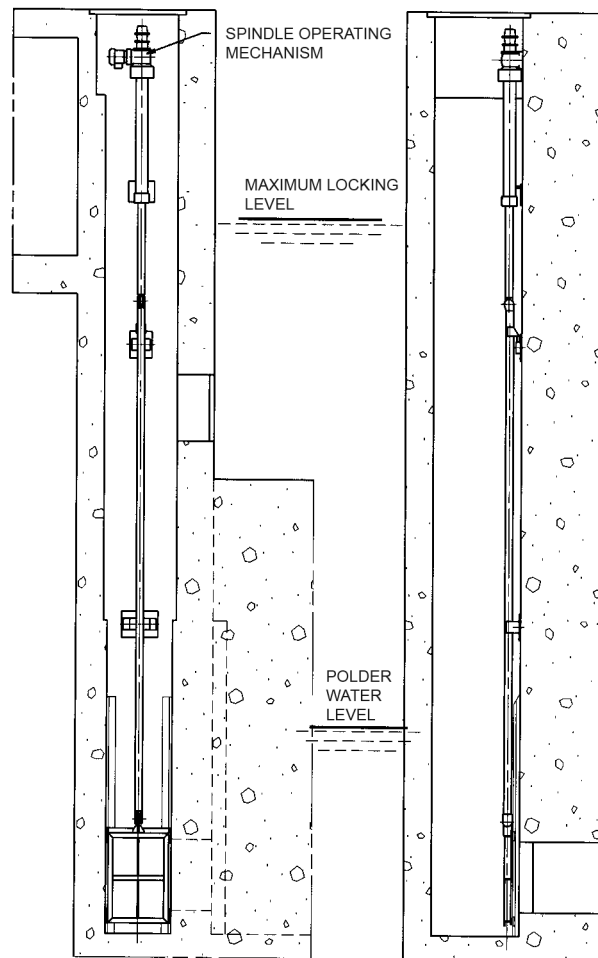


Figure 7.135 Culvert valve for one-sided retaining structure (Lock Almere-Haven)

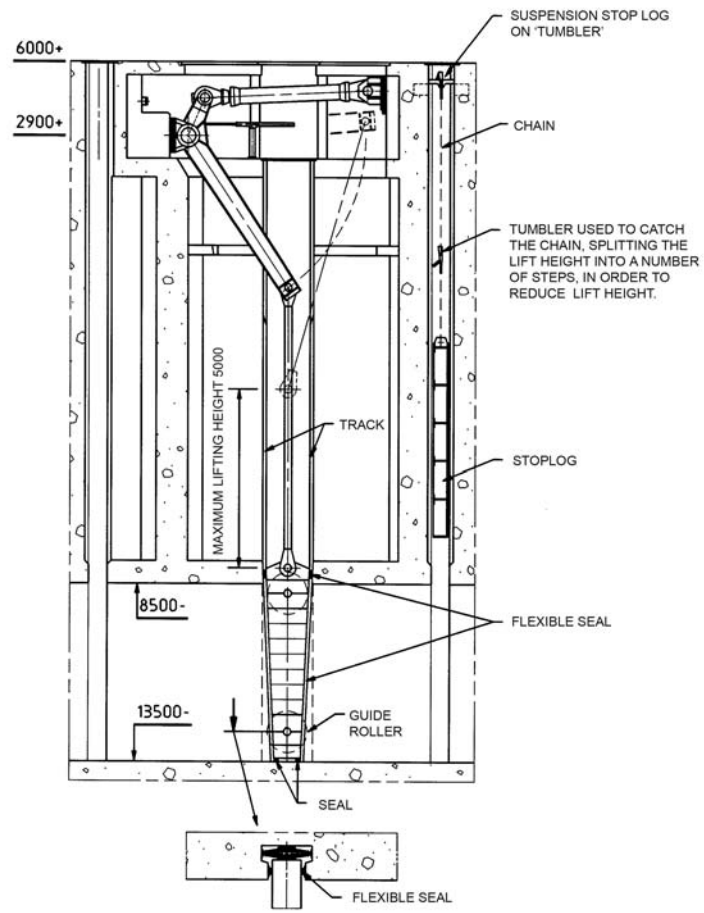


Figure 7.136 Culvert valve for a two-sided retaining lock

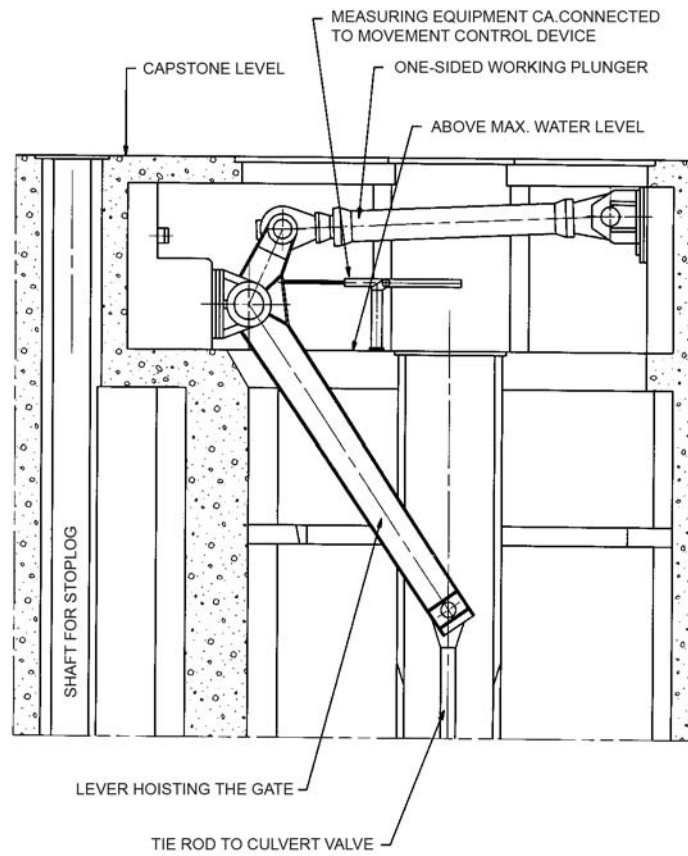


Figure 7.137 Culvert valve operating mechanism with horizontally positioned cylinder

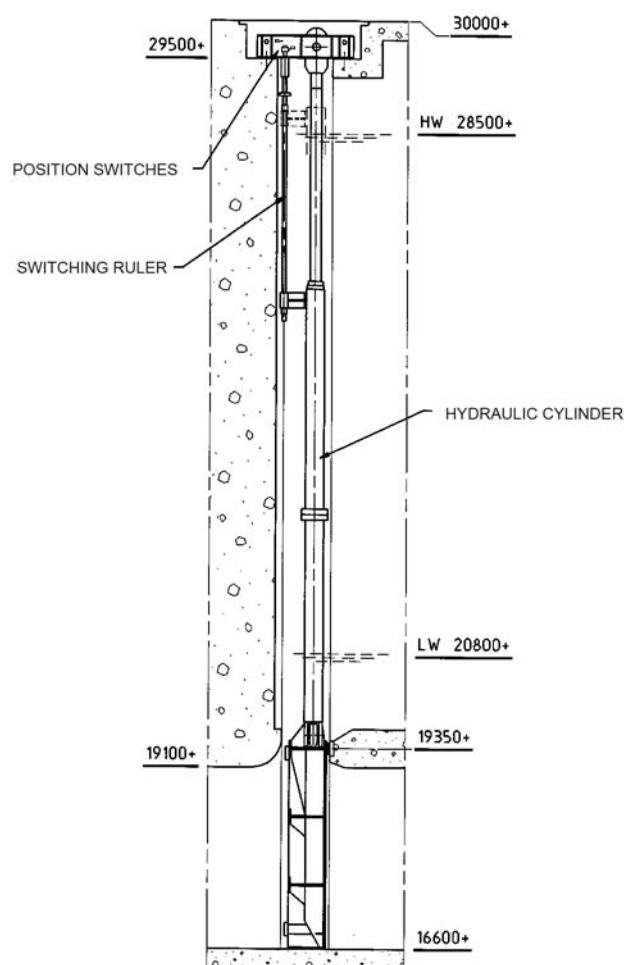


Figure 7.138 Culvert valve operating mechanism with a cylinder under the capstone level (Lock Panheel)

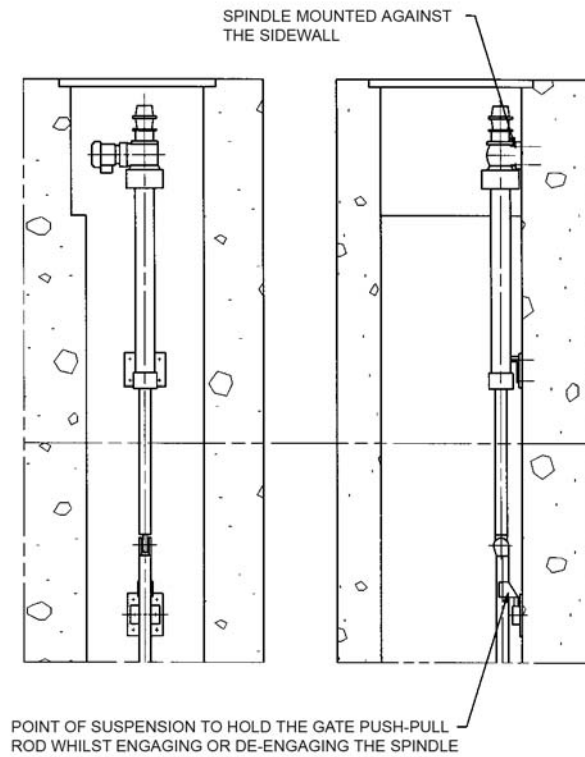
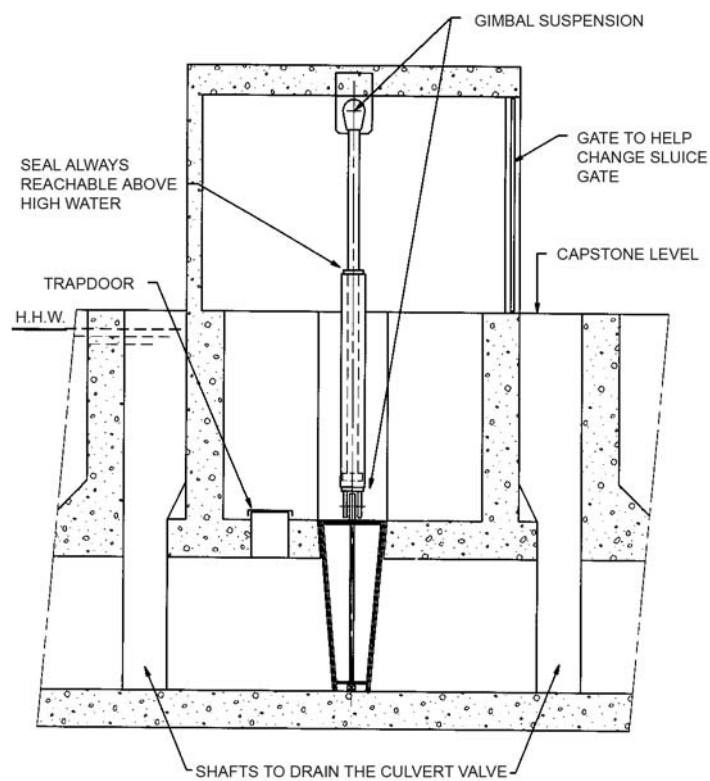


Figure 7.139 Culvert valve operating mechanism with spindle under capstone level (Lock Almere-Haven)



N.B. WHEN CHANGING THE ROLLING GATE THE OPERATING MECHANISM MUST BE REMOVED

Figure 7.140 Culvert valve operating mechanism with cylinder above capstone level

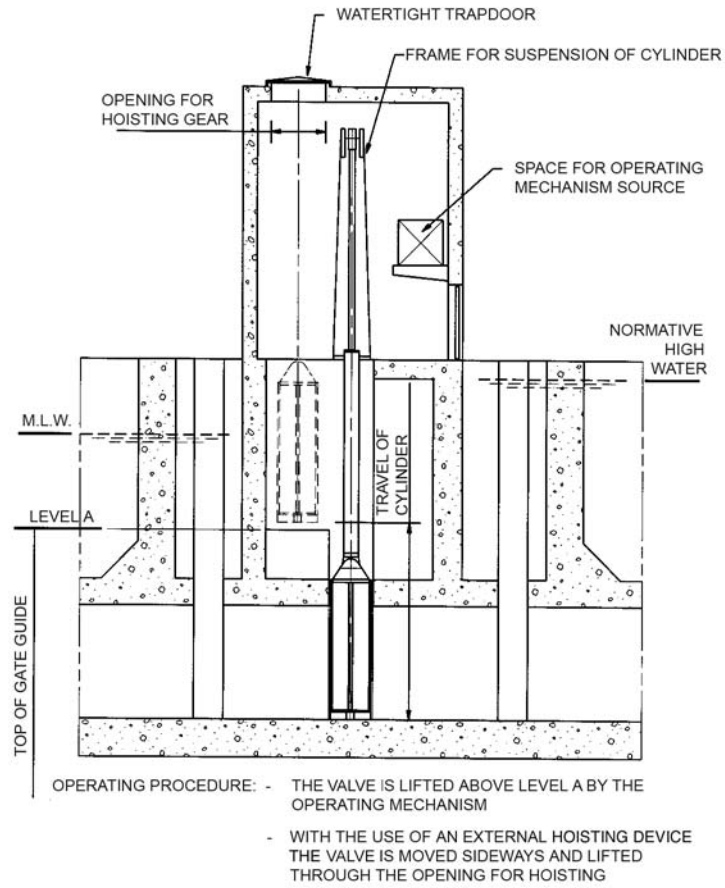


Figure 7.141 Changing of culvert valve without removal of operating mechanism

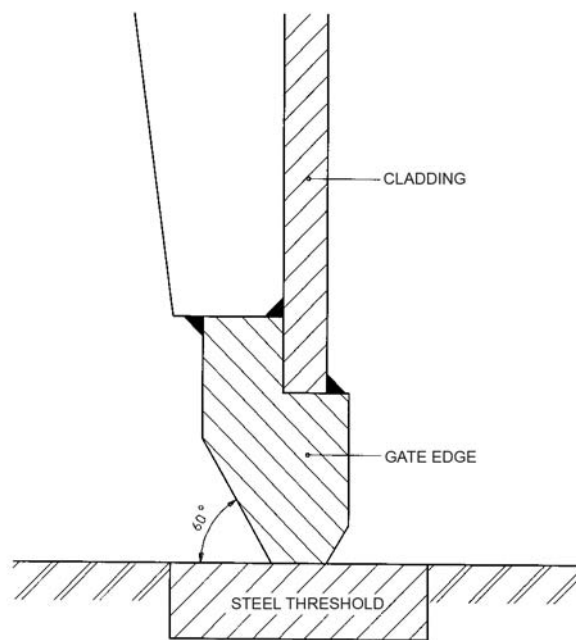


Figure 7.142 Shaping of bottom support of a culvert valve

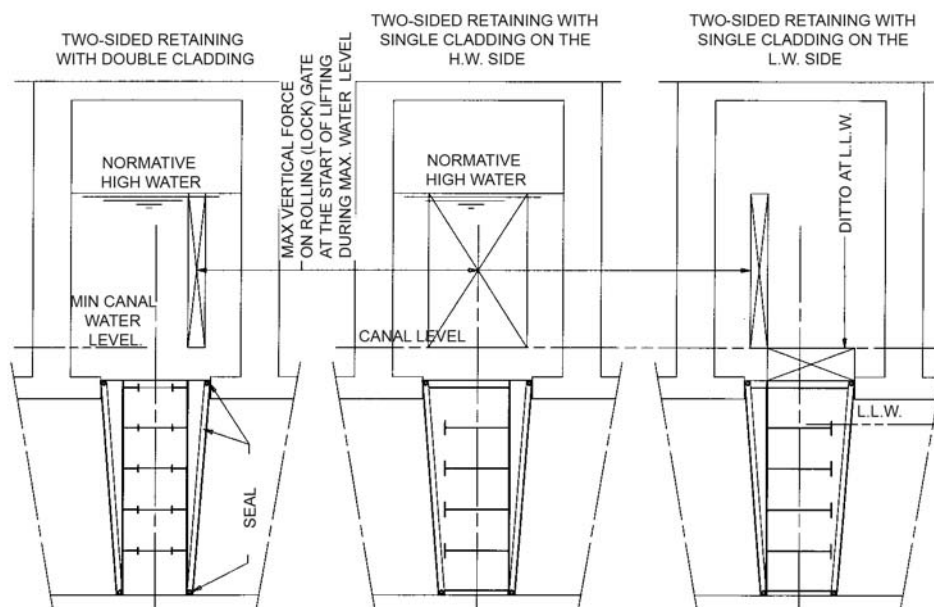


Figure 7.143 Vertical force on rolling (lock) gate at the start of lifting

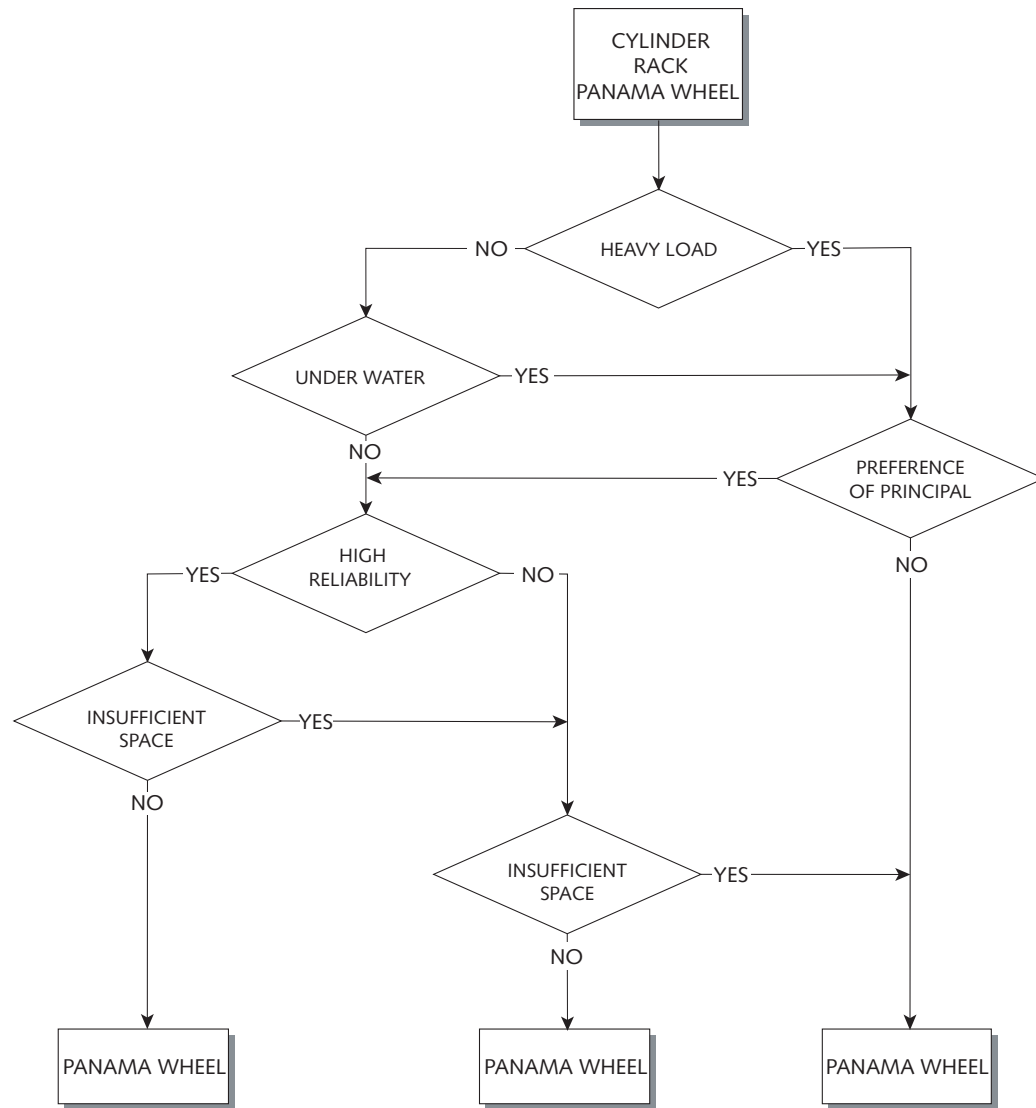


Figure 7.144 Decision outline: selection of type of operating mechanism for the benefit of mitre gates, pivot gates and gate lock securing devices

Type lock	Lock width	One-sided turning mitre gates	Double set mitre gates	Two-sided turning mitre gates	One-sided turning pivot gate	Two-sided turning pivot gate	Two-sided turning rolling gate	One-sided turning lift gate	Two-sided turning lift gate
Two-sided turning marine lock	Small 6-10 m Medium sized 10-16 m Large 16-24 m Very large > 24 m		X X X	X X X		X X	X X		
Two-sided turning inland navigation lock	Very small 4-6 m Small 6-10 m Medium sized 10-16 m Large 16-24 m		X X X	X X X		X X X	X		X
One-sided turning inland navigation lock	Very small 4-6 m Small 6-10 m Medium sized 10-16 m Large 16-24 m	X X X			X X			X X	

Table 7.1 Gate type as function of type of lock and passage width

Aspect	Weighing factor	One-sided turning mitre gates	One-sided turning pivot gates	One-sided turning lift gates
				
Construction cost	0.15	9	7	5
Maintenance	0.20	7	8	5
Reliability	0.25	7	8	9
Durability	0.05	9	8	7
Locking capacity	0.10	7	5	9
Environment	0.05	7	8	5
User-friendliness	0.15	9	7	8
Impermeability	0.05	5	9	9
Total score		7.6	7.45	7.15

Table 7.2 Choice matrix for one-sided turning, medium sized inland navigation lock, lock width 10-16 m with report marks

Aspect	Weighing factor	One-sided turning mitre gates	One-sided turning pivot gates	One-sided turning lift gates
				
Construction cost	0.15	3	2	1
Maintenance	0.20	2	3	1
Reliability	0.25	1	2	3
Durability	0.05	3	2	1
Locking capacity	0.10	2	1	3
Environment	0.05	2	3	1
User-friendliness	0.15	3	1	2
Impermeability	0.05	1	3	2
Total score		2.05	2.05	1.9

Table 7.3 Choice matrix for one-sided turning, medium sized inland navigation lock, lock width 10-16 m with scoring

Aspect	Weighing factor	Two-sided turning mitre gates	Two-sided turning pivot gates	Two-sided turning rolling gates
				
Construction cost	0.15	9	7	4
Maintenance	0.20	8	9	6
Reliability	0.25	7	8	9
Durability	0.05	9	8	7
Locking capacity	0.10	7	5	8
Environment	0.05	9	7	5
User-friendliness	0.15	7	8	8
Impermeability	0.05	5	9	9
Total score		7.6	7.55	7.1

Table 7.4 Choice matrix for two-sided turning, medium sized inland navigation locks, lock width 10-16 m with report marks

Aspect	Weighing factor	Two-sided turning mitre gates	Two-sided turning pivot gates	Two-sided turning rolling gates
				
Construction cost	0.15	3	2	1
Maintenance	0.20	2	3	1
Reliability	0.25	1	2	3
Durability	0.05	3	2	1
Locking capacity	0.10	2	1	3
Environment	0.05	3	2	1
User-friendliness	0.15	1	3	2
Impermeability	0.05	1	2	3
Total score		1.8	2.25	1.95

Table 7.5 Choice matrix for two-sided turning, medium sized inland navigation lock, lock width 10-16 m with scoring

Aspect	Factor	Electro-mechanical operating mechanism	Electro-hydraulic operating mechanism
Operating mechanism under water	0.05	3	7
Required forces	0.15	4	6
Required space	0.15	4	6
Problems during frost	0.05	4	6
Durability	0.15	5	3
Set-up on capstone level	n.a.	-	-
Collision risks	n.a.	-	-
Operating time of lock	0.05	5	5
Reliability	0.15	6	4
Maintainability	0.15	4	5
Cost aspect	0.1	4	6
Total score		4.5	5.0

Table 7.6 Choice matrix for gate operating mechanism of Krabbersgatsluizen (inland navigation/recreation lock), lock width 12.5 m, two-sided turning, max. pos. lift 3.20 m and max. neg. lift 1, with report marks



Photo 8.1 Outer head (foreground) and inner head (background) of the navigation lock in Nieuwe Statenzijl

Chapter 8 Lock heads

8.1 Introduction

The design, shaping and lay out of a lock head completely depends on the type of gate and corresponding operating mechanism to be used. For this reason, after addressing the functional requirements of the lock head in par. 8.2, the shaping is addressed in par. 8.3. A subdivision is made in respectively heads with mitre gates, pivot gates, rolling/sliding gates and lift gates.

For all these gates, facilities have to be poured into the concrete construction to provide for supports, turning points and guides. In order for the gates to function well, these facilities have to be provided with greater accuracy than normally expected in concrete constructions. For this reason, par. 8.4 is dedicated to the measures that need to be taken, such as the execution of recesses and the placement of adjustment constructions.

Par. 8.5 deals with the possible structures and construction methods for lock heads. In cross section, the construction consists of a reinforced concrete basin that is built without hinges in view of retaining its shape. Occasionally hinges are used in the bottom slab but only when it concerns wide and deep marine locks equipped with rolling gates (Terneuzen). Special facilities are then required for the steel foundations and the installation of the rail guides. The construction methods that qualify are: the execution by means of dewatering the excavation (provided that pumping is permitted), a steel sheet pile screen with bed/bottom sealing or a pneumatic caisson.

Par. 8.6 provides indications on the variants that are possible in different situations. Certain variants are particularly suited to lock heads with large dimensions (wide and deep) and others are used when pumping is not permitted.

Figures and tables are found at the end of this chapter and are followed by an appendix.

8.2 Functional requirements

Design, shaping and construction of the heads have to meet the following requirements.

1. The heads have to enclose the space through which the vessels should be able to safely and rapidly sail into and out of the chamber. The required width, depth and height levels can be derived from par. 4.2 and par. 4.4. The sections of the heads that adjoin the chamber are used, inside the stop stripes, for mooring the vessels and keeping them moored during the raising and lowering through the lock (levelling).
2. The heads must provide room for the gates and their operating mechanisms in such a manner that the gates remain outside the free profile for navigation in opened condition and are as invulnerable as possible to collision. In retaining position the gates must be able to transfer their load to the heads, whereby poured supports ensure proper water sealing between the turning points and the heads. For opening and closing the gates, apart from the operating mechanisms, turning points (for mitre and pivot gates) and guide facilities (for rolling, sliding and lift gates) are installed. Gate lock securing devices and recesses in the head are an absolute necessity for pivot gates that have to retain bilaterally. Besides the basement chambers for the operating mechanisms, the heads usually contain enclosed spaces for the electrical installation. For a more detailed description of the gate chambers, recesses, rabbets, super structures (lifting towers) and the like, we refer you to chapter 8.3.
3. Generally the gates are equipped with facilities that enable dry maintenance of turning points, bearing saddles, supports, guide rails and other constructions for gates that are mounted in and on the concrete. The lock can be laid open with the aid of stop logs or with local facilities such as pivot-inspection chambers. The concrete construction is always provided with rabbets for stop logs. This is often done for pivot-inspection chambers as well. If - in the case of stop logs - the complete head is laid open, rising has to be prevented by the weight of the head, tension piling and if necessary, with the weight of the ground next to the head by continuing the floor outside the walls.
4. At a lift of more than 6 m, filling and emptying of the chamber often takes place by means of lock culverts. Besides the lock culverts, space will have to be reserved in the lock heads for sluice shafts and for the operating mechanisms with facilities that make it possible to place, remove and execute maintenance to the sliding gates. In certain cases (among others at the lock complex in Born and Maasbracht) stilling chambers and bars were built under the floor of the entrance in the upper head to dissipate the energy of incoming water.
5. Where there are problems related to salt and fresh water separation, simple facilities such as rabbets for pneumatic barriers or more fundamental adaptations in the usual shaping and design of the heads and the chamber could be necessary (see chapter 21).
6. It is not unusual to plan moveable bridges at the heads. With respect to the larger headroom, the lower head is preferable for this. For locks in a tidal area this is not always the best solution while the lay out of the infrastructure could also require a junction at the upper head. Depending on the kind of bridge, room will have to be reserved for operating mechanisms and the like. Possibly for a bascule bridge while facilities are being put in place for the bridge bearing or support, balance posts (for a lift bridge) and the like.
7. The construction of the lock has to be able to absorb the load that results from ground and water pressure, operating mechanisms, navigation and land traffic. The navigation load includes vessel impact and hawser forces. Water pressures include the pressures exerted on the gates and possibly on the stop logs.

The construction has to be checked in both directions on strength, stability and stiffness: in cross direction perpendicular to the lock axis and in longitudinal direction parallel to the axis. In longitudinal direction it mainly concerns the stability and this is addressed in more detail in par. 13.6.2.2 and 13.6.2.4. Depending on the quality of the foundation and the costs, the foundation will either be executed as a foundation on steel, on ground consolidation or on piling. In some cases the pit in the sheet pile wall, which is used to build the head, later functions as the permanent foundation. The lock heads have to retain their shape sufficiently thus be executed with rigidity, for proper functioning of the gates and the operating mechanisms (movement, transfer of forces and water seal). See par. 8.4 for more extensive information.

8. The construction of the head has to be executed on compact ground and be watertight. The watertight requirement does not apply to basement chambers where operating mechanisms are set-up than can temporarily be under water without problems arising. The hydraulic propulsion of mitre and pivot gates is a good example of this. Other operating mechanisms such as cables for rolling gates, which are sensitive to salt water, are positioned in dry basement chambers where possible. For chamber floors, variants with a rubble layer are possible. Floors of heads are always executed with a closed, concrete slab. Waterproofing is not foremost here but the formulated requirements in point 7 with regard to the limited deformation of the head, thus the dimensional tolerance of supports and the like are foremost. Sealing does play a part in being able to lay open the lock for maintenance (see point 3 for this).
9. Surfaces that could be affected by passing vessels and surfaces along which the vessels could possibly moor should be executed as smooth as possible in order to provide a minimum number of points of action that could result in damage to the construction and/or the vessels. Protruding angles on the outside of the gate chambers and recesses are rounded off as much as possible and provided with steel corner protection profiles or other provisions. At expansion joints (transition between head and chamber) sizable bevelled edges will suffice. The connection between the wall of the head and the wall of the chamber should be executed as such that uneven deformation of these walls with differing levels of stiffness (and thus protruding angels susceptible to collision) do not yield a risk. If, for instance, the chamber is also executed as a reinforced concrete vessel this can be realized by creating a 'cog construction' at the expansion joint of the wall of the chamber behind a recess in the head side of the wall of the head. The more flexible chamber wall is then held by the stiffer wall of the head. At the change over to the leading jetty, protruding edges are out of place. For protection against hawsers and the like, steel capstone profiles are applied at the top of the walls.
The reinforcement of the upper sections of the heads is given a larger concrete cover than required by the vbc. This extra covering ensures that after possible damage caused by vessels (grooves, dents) sufficient covering remains to protect against corrosion of the reinforcement. The covering of the exterior walls amounts to 60 mm and 50 mm at the ground side.
10. Par. 2.4.3.1 provides a description of how the mooring facilities (mooring rings and bollards) for navigation must be situated on the chamber side of the head. On the side of the lock approach, the heads next to the gate chambers and recesses should also be equipped with mooring facilities required by working vessels during the assembly, disassembly and maintenance of the gates. If there are several gates in one head, mooring rings and bollards should also be positioned on the pier between the gate chambers and recesses.
11. With regard to the taking of measures to limit groundwater flow and the corresponding piping, there are no specific requirements for the lock heads but the measures apply to the lock body in its entirety. It does become a specific requirement if the chamber bottom is permeable (rubble layer on a filter). In both cases, piping and outflanking screens are installed at the heads. In the case of an intermediate head, this is only sensible if the chamber bottom is permeable or if in the case of a pile foundation, the formation of continuous cracks under the floor has to be prevented. Positioning the screens at the lock approach side of the heads is advisable because this limits the upward groundwater pressure underneath the upper head (favourable for longitudinal stability, also see par. 13.6.2.4).

Furthermore, possible erosion or other damage to the bottom of the lock approach will not directly lead to scouring beneath the heads and therefore to loss of stability. Positioning the screens on the lock approach side also offers the possibility of combining the screens with the abutment walls.

12. At both ends of the lock body, transitions have to be made between the box shaped lead-through of the fairway through the lock to the standard practice straight sided flanked cross sections of the lock approaches. This can be done as follows:
 1. earth-retaining abutment walls that are at a right angle to the lock axis are positioned on the lock approach side of the heads. If that is the case, the leading jetties are confined by guide structures;
 2. leading jetties and possible adjoining mooring areas etc. are confined by earth-retaining walls. At the place where these walls end on the canal side, abutment walls will have to be built at right angles to the canal axis to retain the difference in height between the terrain on both sides of the leading jetty and the canal slope.

The chosen solution depends on the situation and the costs. Seen from a navigation guidance and forces on the moving gates point of view, solution 1 is preferable.

Sheet piling leading jetties (solution 2) are currently only used for small locks.

13. Increasingly, the requirement is made that the groundwater level cannot be lowered during construction or that it can only be lowered to a limited degree. The consequences of this construction requirement are addressed in more detail in par. 8.5 and 8.6.
14. The situation and the available space could result in limitations with regard to gate selection (monopolization of space by the gate chambers of the rolling gates) as well as construction methods for the heads and the chamber. For that reason, it could be necessary to dismiss a construction pit with slopes but choose a circular cofferdam restricted by sheet piling. A circular cofferdam could also be a fitting solution for construction in open water (Nieuwe Oranjesluis). If construction is taking place next to an existing navigation lock, this existing lock is a precondition that cannot be tampered with. It is feasible however that, where it concerns neighbouring buildings or agricultural use of land, the possible additional costs of a narrow circular cofferdam weigh up against the costs of expropriation unless the latter is not a realistic option due to planning reasons. In situating a new lock next to an existing lock, it is conceivable that an economic optimum is found between a definite desirable position with both locks closely together and a solution whereby the second lock has more favourable construction conditions but has a larger intermediate distance. Apart from that, the stability of the existing lock is normative for the minimum distance between the two engineering structures.

8.3 Design and shaping of heads

8.3.1 Head with mitre gates



Photo 8.2 Lower head with mitre gates of Tweede Sluis in Lith

Fig. 8.1 gives the general shaping of the lock head and the spaces and facilities included for mitre gates and operating mechanisms. As stated in par. 7.4.2, various types of operating mechanisms could be used. In fig. 8.1, the areas are drawn for a hydraulic cylinder.

The gate chambers are in the walls. The gates have a thickness of $1/16$ to $1/20$ of the width of passage of the lock. If the gate is open, the front of the wood fender on the gates squares with that of the chamber wall and therefore with the piers of the head. In this position, the space between the gate and the gate chamber is equal to $0.4 \times$ the gate thickness; the space between the gate tip and the gate chamber in longitudinal direction of the lock is about 0.8 times the gate thickness.

At the chamber, the collar, or the fixed turning point, the pivot and the supports are mounted on the concrete construction. The pivot is fixed in the floor of the chamber by means of poured concrete. For the collar (top turning point with clearance) two vertical supports are used: one almost in line with the gate axis for force transfer and one at a right angle for force transfer and water sealing. Where it concerns large steel gates, sometimes two bearing chairs are used instead of a through support. Par. 7.2.2.4 and the corresponding fig. 7.21 indicate how the position of the unrestricted turning point for an upper turning point with clearance is determined and through this, the rotation axis of the gate, the pivot and the anchor and collar.

In the case of a fixed upper turning point, one support is sufficient and this solely takes care of the water sealing. The position of the turning point depends on the degree of compression of the sealing. The position of this turning point is therefore determined on constructive grounds.

Wooden supports are fixed to the gate chamber walls and in open position, the gates are pre-tensioned against this to prevent gate banging due to wind and vessel waves. The supports are also intended for absorbing possible vessel impact.

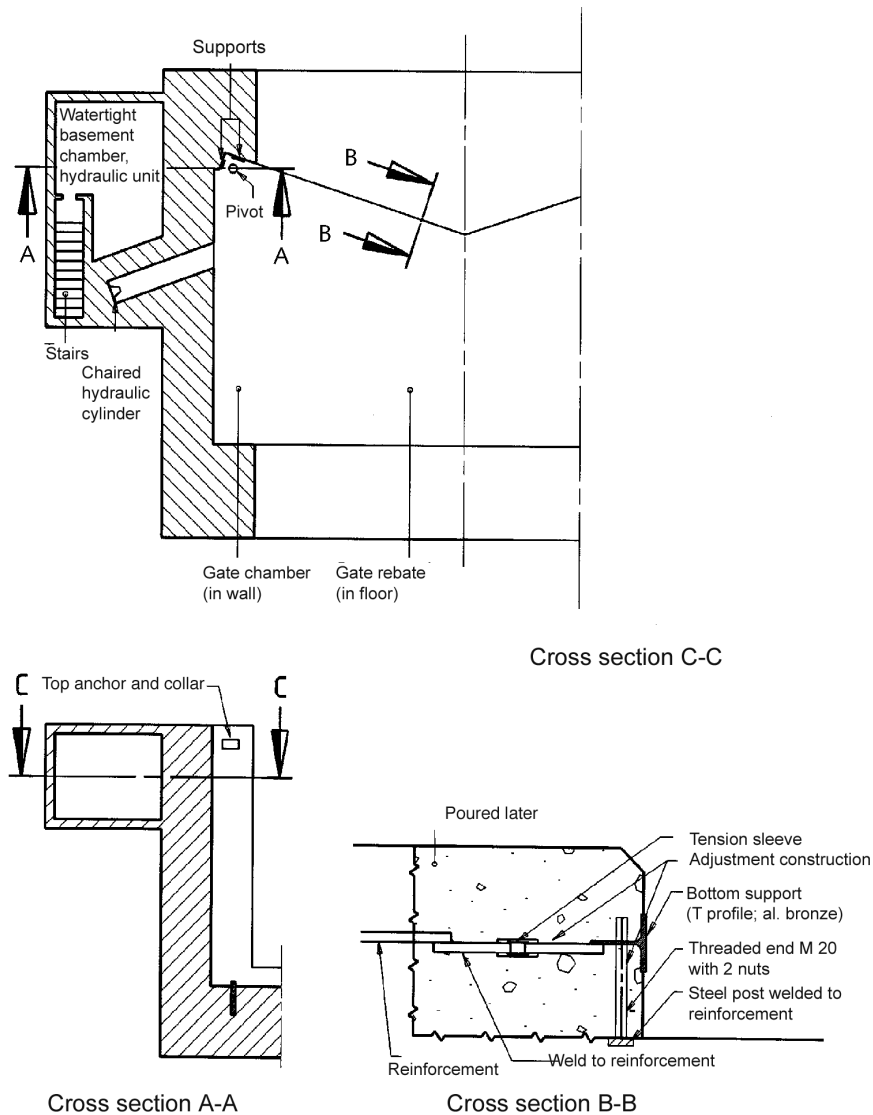


Figure 8.1 Example of shaping a head with mitre gates

The length of the pier next to the gate chamber (measured in the direction of the lock axis) has to be such that sufficient cooperating surface results for absorbing force from the gate in combination with the force caused by ground and water pressures on the wall. The defining cross section lies just above the floor where the moments (bending and torsion) and the transverse forces are the largest. Naturally, not only the length but also the thickness of the pier (perpendicular to the lock axis) plays a part in this. Sometimes the length of the pier is determined by the length that is required for the tensile anchor to be poured for the benefit of the top collar. At lock heads that can be laid open, the length of the piers have to be sufficient for installing stop log rebates and for the absorption of forces from the stop logs due to water pressure.

For making the bottom support of the gates, which is related to the water sealing and for the free movement required, a deepened camber is created in the floor of the head. The shape of this gate rabbet (name according to Jitta) is shown in cross section C-C of fig. 8.1. The bottom support of the gate is concreted into the vertical section that restricts the rabbet on the low tide side (cross section B-B, fig. 8.1). This bottom support only takes care of sealing the gate and does not transfer forces.

The depth of the rebate is the sum of the distance from the top of the floor to the centre of the support (a), the distance from the centre of the supporting frame on the gate to the bottom of the gate (b) and the clearance under the gate (c). This clearance is necessary to reduce the possibility of running aground against possible obstacles on the floor of the rebate (such as gravel) and potential sagging of the gate.

Measurement a is determined by means of the required width of the support (a T section of aluminium bronze, unless it concerns an unrestricted turning point) and the force transfer from the section to the concrete construction (even though the main function of the support is water sealing, forces will also lead in from here). At many of the existing locks the total rebate depth is 0.70 m with respectively 0.20 m for (a) and 0.20 to 0.25 m for (c). At present, the rebate depth usually is 0.50 m with 0.20 m for (a) and 0.15 m for (c).

Fig. 8.1 shows basement chambers for the hydraulic operating mechanism: one for the hydraulic cylinder and one for the tank, pumps and other hydraulic accessories. The first mentioned basement chamber can be flooded during high water levels, the second is watertight.

With a mechanical operating mechanism, the shaping of the basement chambers depends on the expected highest water level. If the water level, such as for locks in canals, is the same as the water level whereby the gates still have to be able to move, the complete operating mechanism is placed in one basement chamber above water level. All "sensitive" parts then remain dry. Examples of such basement chambers are given in fig. 7.67 and 7.75 of par. 7.4.2.

At locks with a high water level that is higher than the maximum locking level, the operating mechanism and the electrical equipment is positioned in a watertight space (see example in fig. 7.78 of par. 7.42). The rack drive or the Panama wheel is submerged during high water but it does not have to move at that time. If it does have to move, a hydraulic operating mechanism is mostly used.

In situations in which pumping is not permitted, it could be attractive to position the bottom of the basement chamber floors above groundwater level provided that the capstone level and the required vertical chamber dimensions allow for this. The section of the head that is below the basement chamber floor is executed in a steel sheet piling pit with bottom sealing, for instance a sub-aqueous concrete floor anchored to tension piling.

The aforementioned creates the impression that the complete operating mechanism should always be positioned in basement chambers under capstone level. However, if no requirements are set for an unobstructed view above and the unhindered passableness of the capstone level, it is possible for (part of) the operating mechanism to be positioned above that level. This solution is not used very often and is certainly not used if the retaining level is much higher than the maximum locking level.

8.3.2 Head with a single pivot (leaf) gate



Photo 8.3 Outer head with single pivot gates of the navigation lock at Nieuwe Statenzijl

Fig. 8.2 provides the general shaping of the head. In opened position, the single leaf pivot gate is positioned in the gate chamber. In closed position, the gate is at an angle of 90° to the lock axis whereby the tip of the gate is in the gate recess. If the single pivot gate turns outside the chamber, it is possible to leave out part of the gate chamber while the gate recess is left in tact for positioning a gate locking device for negative retention. It is even possible to leave out the complete gate chamber and gate recess if the gate turns outward and execute the lock as a hooked locking device (par. 7.4.3.2).

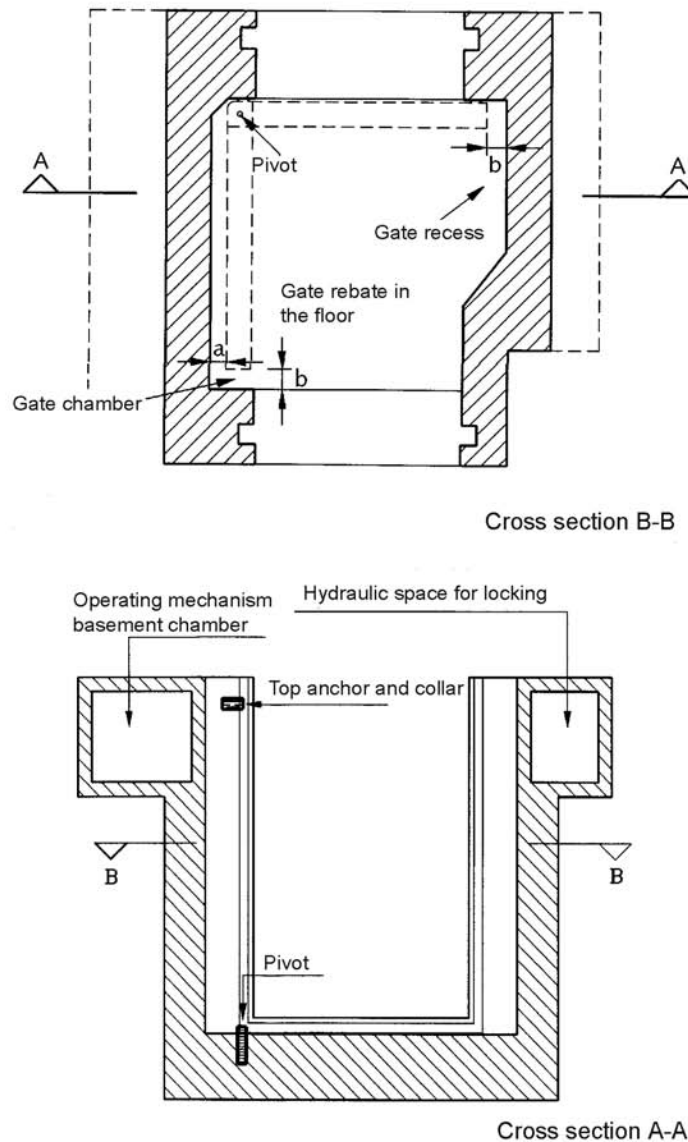


Figure 8.2 Example of shaping a head with a single pivot gate

For one-sided turning locks, a single pivot gate is used for width of passage up to 6 m. Usually, this gate is made of wood. For two-sided turning, a single pivot gate is used for width of passage up to 10 m and this gate is generally made of steel. The gate has a thickness of $1/6$ to $1/8$ of the width of passage of the lock. This is $2 \times$ the thickness of mitre gates at corresponding width. In opened position, the wood fenders on the fronts of the gates correspond with those on the chamber wall. The space between the gate and the gate recess wall in opened position (a) is about 0.4 times the gate thickness.

Due to the gate thickness, this measurement is considerable and is intended to prevent too large water pressure differences on the gate during movement in and out of the gate chamber.

The space between the tip of the gate and the wall (b) is about 0.8 times the gate thickness. This applies to both the closed position (at the gate recess) and the opened position (at the gate chamber).

The length of the gate recess is about half of that of the gate chamber.

Underneath the gate, in the floor of the head, there is a gate rebate with a depth of 0.45 to 0.60 m where the gate closes off against the sill in closed position and it also partly leans on this due to the large deformation of the gate.

The length of the pier next to the gate chamber (measured in the direction of the lock axis) has to be such that sufficient cooperating surface is created for absorbing the force from the gate.

In the gate chamber, mounted to the concrete construction, a bottom turning point – the pivot – and an upper turning point (fixed turning point with some clearance in the bush) are installed. The lift load is transferred to the gate chamber via the upper and bottom turning point.

The gate seals against the vertical supports in the gate chamber and the gate recess and against the sill in the floor of the head. At large load, the reactive force of the gate tip is transferred to the concrete of the gate recess by two saddles.

The same applies to a single pivot gate. Wooden supports are attached to the gate chamber wall against which the gate is pre-tensioned in opened position to prevent the gate from banging due to wind waves and navigation waves. The supports also serve to absorb possible vessel impact.

The operating mechanism of a pivot gate is usually a hydraulic cylinder that is set-up outside the passage profile. The gate has then been provided with a catch at the top of the gate (par 7.4.3.1). An operating mechanism basement chamber is positioned just below the capstone level for this operating mechanism.

If there is separate locking (a frame shaped locking device, a hook locking device, sliding locking device, see par. 7.4.3.2) in the case of a two-sided turning pivot gate, provisions are made for this in the gate recess. A hydraulic chamber is then situated against the gate recess, just under capstone level.

8.3.3 Head with a rolling or sliding gate



Photo 8.4 Gate chamber of rolling gate of the marine lock in Terneuzen



Photo 8.5 Gate chamber of the rolling gate of the push-tow lock in Hansweert



Photo 8.6 Gate chamber of the sliding gate of Nieuwe Oranjesluis in Amsterdam

At a head with a rolling or sliding gate, a gate chamber is created in which the gate is situated in open position. In the lock wall against the gate chamber, there is a gate recess. In closed position, the gate transfers its lift load to the walls. The sealing by the gate takes place against the lock walls at the gate recess and at the gate chamber. The gate furthermore seals against the cunet in the bottom of the lock head in which the gate moves.

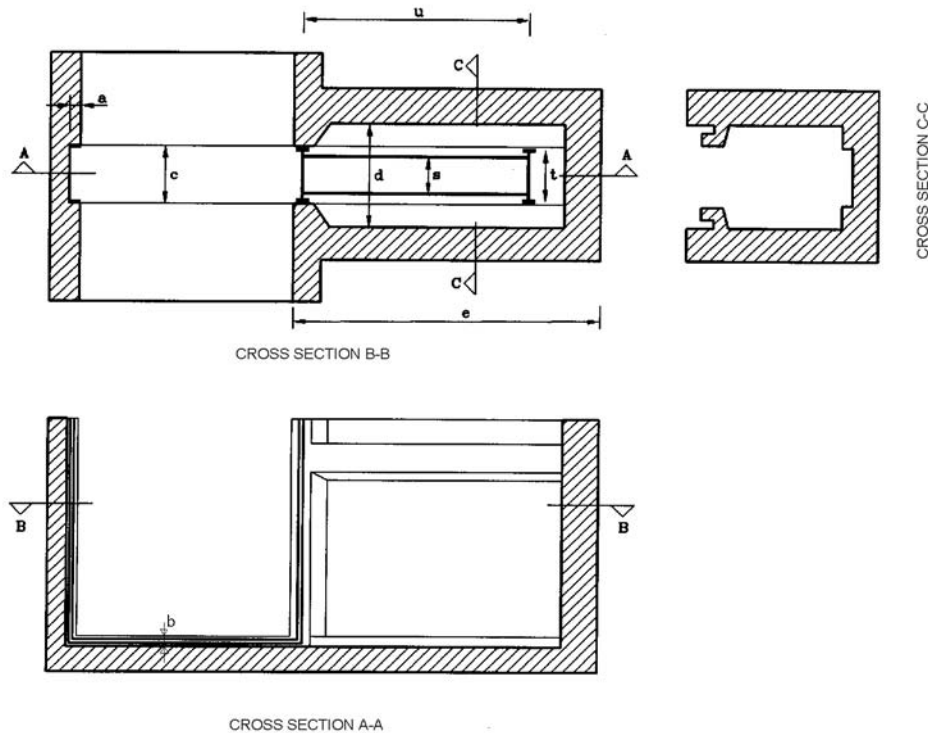


Figure 8.3 Example of shaping a head with a rolling gate

Rolling gates are used in locks with a width of passage from 16 m. The length of the head, that is to say in the direction of the lock axis, has to be such that the stability of the head is guaranteed at the largest lock lift over the gate; possible support by the lock walls is not taken into account here. The length of the lock head is rather short in comparison to mitre and rolling gates.

The lock head should hardly show and settlement differences with the gate chamber as the rail track for guide rollers runs from the lock head into the gate chamber. This sets high requirements to the foundation of the lock head and the gate chamber as well as the foundation of the rails. The lock head and the gate chamber integrate into one whole without the use of a joint. If the width of passage is larger than 24 m, a joint has to be used to absorb the transverse force as is the case with a cog construction.

It is necessary that the gate chamber can be laid open separately if the gate in the chamber requires maintenance; the maintenance of the chamber and gate guides can then take place under dry conditions. For this purpose, stop log rebates or something of the kind are positioned in the gate chamber opening.

If the lock head or the lock itself requires possible lying open, the stop log rebates should be positioned in the head, which is common up to 24 m. In larger locks, the lock head is not laid open but separate steel pits are used for maintenance of the trail track.

If the rolling gates are executed as double gates (outer head of Noordersluis in IJmuiden and outer and inner head of Westsluis in Terneuzen), then both gate chambers are combined with the lock head to create one whole. In the case of two locks with rolling gates situated closely together, the heads and gate chambers concerned could also be combined to form one whole (connected gate chambers at locks in Hansweert). For a very large marine lock such as the Noordersluis in IJmuiden, lock culverts with inlet and outlet openings were created in the lock walls around the gate recess and in the gate chamber walls. At the marine lock in Terneuzen, special culvert mouths were created in the bottom of the heads.

In fig. 8.3, the general shape of the head of a rolling gate is shown, including the gate chamber and gate recess. The water movement around the moving gate and the gate dimensions determine the shape of the gate chamber and the gate recess. Furthermore, sufficient space has to be available in the chamber for floating in a rolling gate and manoeuvring it into the gate chamber from the lock approach or the chamber (fig. 7.31 of par. 7.2.4.3).

Because of the gate movement, three measures are taken in order to limit the flow of water around the gate as much as possible. Firstly, the gate is kept as open as possible in longitudinal direction to enable the water to flow as unimpeded as possible through the gate while it is moving. Secondly, the sealing supports on the gate are not positioned against the cladding but are kept at a considerable distance from the cladding; this is done so that even at a small movement of the gate a large gap is created between the gate and the sealing so that the water can flow through freely. Thirdly, the gate has extra space around it in the gate chamber to limit wave height in the gate chamber during the gate movement. The extra space is also intended to make gate maintenance easier.

The thickness of the gate depends on the dimensions of the lower roller carriage as well as the required strength and stiffness of the gate (see par. 7.2.5 and fig. 8.3). The gate consists of two vertically connected cladding fields with sealing along the bottom and side edges on the bottom girder and the end posts. The distance between the cladding(s) mostly amount to 1/6 to 1/7 of the width of passage of the lock. The distance between the outside of the sealing (t) is at least 1 m larger than the distance between the claddings of the gate. The gate length (u), measured perpendicular to the lock axis, is about 1.1 x the width of passage. The gate is as open as possible in longitudinal direction whereby the blocking of the cross section of the gate is due to cross dimensions of the trusses, the water chamber and the vertical cylinders in the gate.

In the dimensions of the gate chamber and gate recess, the boundary between the concrete and the water is taken into consideration (see fig. 8.3). The considerations are addressed in par. 7.2.4.7.

The depth of the gate recess (a, thus perpendicular to the lock axis) is about 1 m (at a 24 m lock) to 2 m (at a large marine lock) and is determined by the size of the lift force that the gate transfers to the lock wall. Apart from that, the depth of the gate recess is determined by the necessity to guide the gate into or out of the recess during opening and closing, as well as the required flexible supports to slow down the gate in longitudinal direction.

The depth of the cunet in the bottom of the head and the gate chamber (b) depends on the type of bottom roller carriage, but usually amounts to 1 to 1.5 m (depth with regard to the top of the sill).

When viewed in the direction of the lock axis, the dimensions of the gate recess, bottom cunet and the gate chamber at the lock (c) are slightly larger than the distance between the gate sealing.

The distance between the gate chamber walls (d, in the direction of the lock axis) is about 1.3 to 2 times the distance between the sealing and partly depends on the chosen length of the gate chamber.

The length of the gate chamber (e), perpendicular to the lock axis, amounts to about 1.2 to 3 times the width of passage. For roller gates that are floated in (thus not hoisted from the water), the length of the gate is determined by the gate and the lower roller carriages; during maintenance of the roller gate in the gate chamber, it must be possible to hoist the roller carriages up behind the gate that has been laid open.

Rail tracks for the roller carriages are positioned in the bottom cunet. For sliding gates, an even concrete strip is made which is covered by a very smooth synthetic layer. The accuracy of the surface has to meet very high standards to prevent the water jet, on which the gate rests, from being inefficiently compressed away by the gate as this has an adverse effect on the yield of the pumping installation.

Vertical support strips for force transference and sealing are positioned next to the gate recess and the gate chamber near the lock walls. Supports for sealing are positioned in the cunet in the bottom of the lock head.

The operating mechanism pulls on the gate to open and close it. The tractive points are positioned above the highest locking level whenever possible, which prevents rust formation on the steel cables. The operating mechanism consists of a cable winch gear and usually a top roller carriage that is connected to the gate. For this top roller carriage, rail tracks are put in place through consoles of one or both gate chamber walls. The operating mechanism is positioned in a separate, watertight chamber behind the gate chamber.

The gate chamber has to be provided with facilities for placing the rolling gate on rails. If the rolling gate is very large, additional facilities have to be provided for:

- floating in the gate;
- keeping it afloat behind the stop logs;
- sinking it down onto the roller carriages in the gate chamber;
- ditto in the passage;
- supporting the gate at the bottom;
- hanging the gate to the top;
- positioning the stop logs;
- placing and removing the roller carriages;
- executing maintenance and repairs;
- accessibility of the gate and the gate chamber;
- the position of the pumping installation for rapid emptying of the gate chamber;
- filling the gate chamber up again;
- the (flexible) supports of the gate in longitudinal direction;
- changing the steel cables.

8.3.4 Head with a lift gate



Photo 8.7 Lock head of a lift gate of the Prins Bernard lock in Tiel



Photo 8.8 Lock head of a lift gate of the new lock in Weurt

A head with a lift gate is a simple shape and consists of a U shaped basin with a superstructure - two lifting towers and a lift-gate portal (fig. 8.4). The head can be short; the length is determined by the required stability of the head during retaining with a closed gate or during heavy wind with a lifted gate.

Gate recesses have been made in the lock walls for guiding the lift gate, transferring the lift force over the gate to the head and for the sealing the gate. To achieve this, vertical supports are mounted on all three sides. Rails are also placed in the recesses if rollers instead of slides are used on the gate as a guide. The gate is provided with a rubber sealing strip at the bottom edge and in closed position, it rests on a support strip that is concreted into the floor; the lock floor remains even. Stop log rebates are made in the lock walls.

In the past, a number of one-sided turning locks with larger lift were equipped with lift gates and an energy dissipating chamber in the upper head; the lock is filled there by slowly lifting the lift gate (fig. 6.3). The lift gate then seals on the top of the energy dissipating chamber. In line with the recesses, the lift towers or the lift portal are provided with guides for the gate in the shape of vertical support surfaces (for slides) or rails (for rollers). The lift towers are often positioned at some distance from the clear of the lock wall so that a walkway between the lock edge and the towers is possible and to avoid collisions with incoming vessels that have a high structure and sail in skew; the guides in the towers are then kept at a distance by means of jibs on the towers.

The aesthetics of the towers require ample attention.

Either the lift towers or the lift portal houses the cable winch gear and the counterweights. The winches could be positioned in the top of the tower or just below capstone level in the basement chambers next to the lock wall. See paragraphs 7.4.5 and 12.3.6.

Given the possible different deformations of the U shaped basin profile of the lock head and a lift portal, this portal sometimes has a separate foundation from the U basin or the towers are flexible.

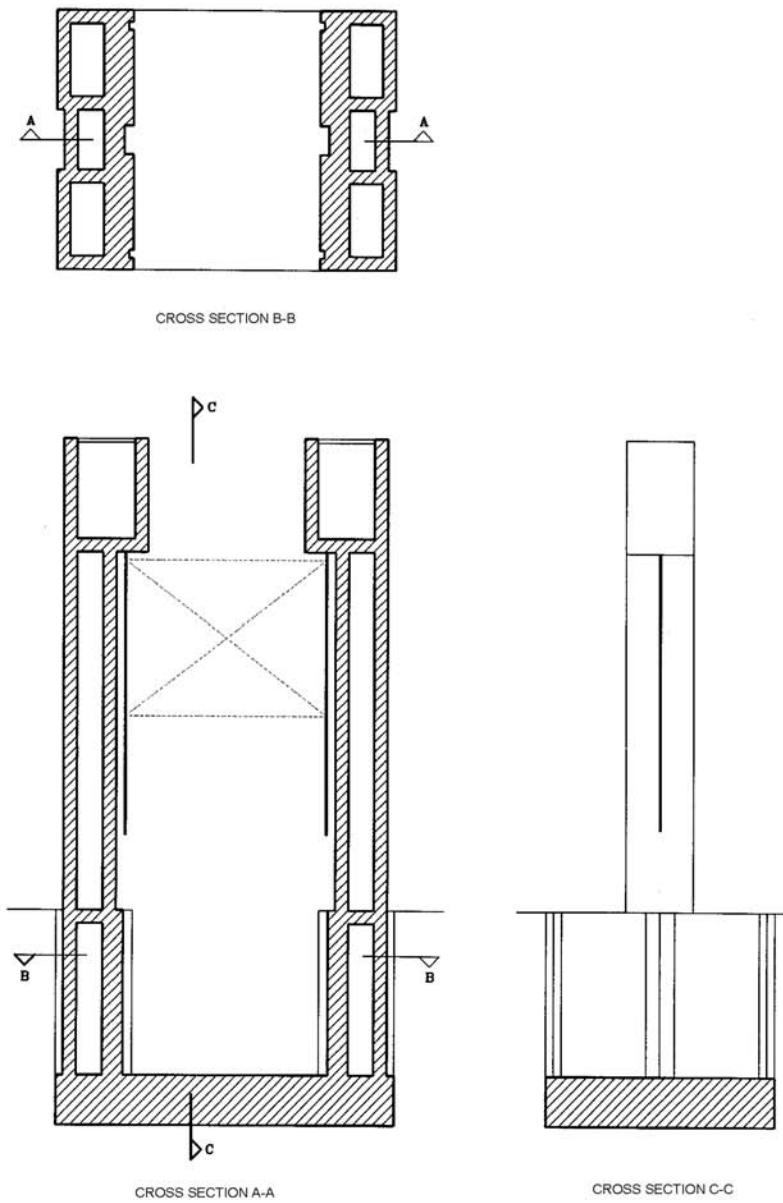


Figure 8.4 Example of shaping a head with a lift gate

8.4 Adjustment of poured concrete facilities

The previous paragraphs addressed the shaping of the heads for different kinds of gates. An important constructional aspect is that every kind of gate requires different kinds of poured concrete facilities.

Examples are: supports (force transfer and sealing), turning points (pivot and collar for mitre gates and pivot gates), guides (roller and lift gates), salt and fresh water slides etc. In addition, poured concrete facilities will be required for the operating mechanisms.

In order to guarantee proper functioning of the gates, the accuracy in measurements of these parts has to be slightly smaller (1/10 to 1/100) than those aimed for in relation to the concrete construction of the head. Think about mm rather than cm.

It does not only concern the accuracy obtained per poured part, it often concerns the position of the parts in relation to each other. The mutual position is not only dependent on positioning accuracy but also on the shape retaining of the head as stated in point 7 of par. 8.2 (the deformation under load must be minimal). The required positioning accuracy (and shape retaining) is a function of the type of gate, which is explained below.

- *Mitre gates*
Mitre gates are very sensitive to deviations. When given deviation, the gates cannot support each other well and therefore do not seal well. Where it concerns a top turning point with clearance, the thrust cannot be well spread over the gate chamber wall in vertical height.
- *Pivot gates*
Not sensitive to accuracy in vertical position of the gate chamber wall. It is sensitive to the position of the turning points with regard to each other and with regard to the vertical gate supports. The torsion stiffness of the gate necessitates that the two vertical supports tally with each other. In the case of two-sided turning gates the position of the support surfaces with regard to each other are important with a view to sealing during negative retaining. The more accurate the sealing is, the smaller the requirements are that need to be set for the locking device. This also applies to the local deviations from the vertical and horizontal area.
- *Rolling gates*
Rolling gates are sensitive to the position of the vertical supports with regard to each other. The gate must sometimes be able to absorb large torsion stress during opening and therefore it should be torsion stiff. If the vertical supports do not line up, the gate has to twist when in retaining position; the gate will also keep leaking when the water level rises until sufficient deformation is reached.

In order to achieve positioning accuracy, often temporary spaces are left open when pouring the shell of the structure. At a later stage, the parts are adjusted with the aid of an adjustment construction, for instance in the shell of poured concrete tendon grips, anchors or pre-tension rods. By accurate measurement and adjustment in regard to the shell of the structure, a much larger degree of accuracy is reached than if this is executed in relation to the formwork or reinforcement which is never static. The measuring usually takes place based on other parts that need to be poured in (for instance the collar in relation to the pivot). After the part that needs to be poured in is fixed in the correct position in the shell of the structure, for instance by means of bolts in a tendon grip or by welding to the starter bars, the remaining concrete is poured into the open space.

Examples of this working method can be seen in cross section B-B of fig. 8.1 in this chapter (bottom-support of mitre gates) and in chapter 7 in fig. 7.19 (pivot) and 7.120 (sliding guide of lift gate).

Quite often adjustment constructions are used, in the open space between the shell and the part to be poured in, certainly when there are set requirements for the smoothness of the side supports (leakage, force distribution) and to the exchangeability of the gates. Adjustment constructions are used just as often where it concerns prefabricated concrete supports.

In certain cases, preference is given to including the facilities directly in the shell construction rather than adjusting them later in open spaces reserved. If this is the case, heavy and stable adjustment constructions should be used in order to prevent the construction parts from moving because of the shaking caused by pouring the fresh concrete. An example of such an adjustment construction for pouring in lift gate guides, with braces and distance blocks, is given in fig. 7.112 of chapter 7.

The choice between creating open spaces and including it in the shell of the structure is determined by the costs and often this is left to the building contractor. Please note however that, as a rule, heavy adjustment constructions are expensive (depending on the required positioning accuracy) and that this makes the positioning of formwork more difficult. On the other hand, the advantage could be that the guides and such like are ready at the same time as the rising work, which results in time gain.

8.5 Alternatives for building and building methods

8.5.1 Introduction

Tables 8.5.1 to 8.5.4 provide alternatives for building and building methods for the chamber and the heads. A cross in the 4th column means that the alternative is suitable for a chamber and a cross in the 5th column means it is suitable for the head. Of the 19 alternatives, numbers 1 to 9 can be applied to both the chamber and the head. These are dealt with in par. 8.5.2. It concerns the principle of the cross section (walls and floor). Overhang or added on basement cellars, chambers, recesses, projections and the like form another chapter and the shaping of this was addressed in par. 8.3. Alternatives 10 to 19, only suitable for chambers, are addressed in par. 9.3. These alternatives do not meet the functional requirements for heads formulated in par. 8.2 point 2 and 7 (being able to house gates, operating mechanisms and the like and retaining the required shape).

Aside from this, please note that the *three columns on the right hand side of the tables* ("Suitable for lock size") *will be explained in par. 8.6, Pre-selection of the alternatives.*

8.5.2 Alternatives 1 to 9

Alternatives 1 to 9 are first described in broad outlines, divided into two groups. This is followed by an explanation of some of the alternatives. First, there are two general remarks.

A number of the alternatives could be used in combination with return pumping. This is not mentioned in the features of the methods in table 8.5 but is addressed in par. 8.6 and the corresponding tables 8.6.1 to 3.

Most of the alternatives have been used, either at locks or at tunnel slip roads. The same cannot be said for solutions 6 and 7. The necessary prefabrication, floating transport and sinking down of the chamber piece and the head pieces were only researched within the framework of a thesis at the Faculty of Civil Engineering at the Technical University of Delft by A.F. Pruyzers, "Verlenging sluis te Maasbracht" (1982). The objective of the study was to decrease the time required for activity due to extending the existing lock as much as possible.

In broad strokes, the variants can be subdivided into group A and B:

A numbers 1 to 7

The complete basin shaped cross profile is executed as a reinforced concrete monolith, at least in the completed phase. The floor has a constant thickness (up to now). The walls – at least those of the chamber – are slightly adjusted to the moment and transverse force progression. Exactly above the floor they have a thickness that is sufficient for absorbing the transverse force (up to now, generally without transverse force reinforcement). At the top, the thickness (order of 0.6 to 1.0 m) is determined by being able to pour concrete and positioning the mooring rings, bollards and ladder recesses. With a view to accommodating the facilities for gates and operating mechanisms and the required strength/stiffness, this narrowing of the wall is generally not used upward to the heads.

The choice between the different variants is determined by local possibilities and conditions as well as costs. Variant 1 offers the cheapest solution provided that space and groundwater (lowering) do not pose limitations.

B numbers 8 and 9

One or two concrete hinges are fitted to the floor of the reinforced concrete structure. With a view to shape retention of the heads, even though the monolith basin profile as described in A is preferential, these alternatives are suitable for wide and deep locks. At the 40 m wide marine lock in Terneuzen one hinge was used; two hinges were anticipated in one of the variants for the design of the not executed Baalhoeksluis (round about 1968), in which a width of 64 m was foreseen. The considerations for two hinges are: limiting the size of the pouring and averting the imposed tensions at unequal settings (as the sluice becomes wider the chance that the subsoil is of equal

quality over the complete width becomes smaller). Besides this, the negative effects of hydration warmth and shrinkage are limited somewhat.

Floor extension at the ground side of the wall is used to achieve a better spread of the own weight of the wall, particularly in the building stage. This limits the bending moments in the floor. In comparison to the constructions in group A, a larger adaptation of the wall and floor thicknesses to the moment and transverse force progress is striven for. For very large marine locks this is quite obvious, even though a floor of constant thickness without hinges was used for a similar lock in France.

After this explanation of groups, there are a few notes in relation to the individual alternatives.

Alternative 2:

In table 8.5 it is stated that the vertical groundwater partition of the construction pit is formed by a bentonite concrete screen. There are other possibilities: rented sheet piling sections, vertically positioned synthetic films and bentonite screens. The choice is determined by the cost and by whether the screen can remain in the ground (troublesome for future building activities, a permanent barrier for groundwater flow). The screens are continued into the impermeable layer. This can be a natural or artificially created (injection) layer. This layer has to be sufficiently deep under the bottom of the construction pit so that cracking is prevented during or after excavation of the pit (usually, a "safety margin" of 1.1 is required). Furthermore, such permeability (kD) has to be present that the groundwater withdrawal for the surrounding area remains below the acceptable levels. In the forecast calculations concerned, the discharge through the vertical screens also has to be taken into account. An injected layer is theoretically possible but will probably be too expensive compared to the other alternatives (costs of €182 to € 318 / m² ground between the screens). In addition to this, there is the fact that not all kinds of ground can be injected properly and that there are certain risks involved with regard to the intended watertightness. These risks have decreased as a result of improved injection techniques.

Alternatives 3 and 4:

Table 8.5 does not show that the sheet piling of a construction pit with a certain depth requires strutting and anchoring. Despite the fact that the struts are a hindrance to activities in the pit (for cranes) this sheet piling support is generally chosen instead of anchoring (in view of the costs). In deep pits, various rows of struts can be placed underneath each other. Sometimes the water in the pit is brought up to above groundwater level and this level is maintained until the underwater concrete floor has hardened (moment reduction).

In the table, construction pits 3 and 4 are drawn with over measure with regard to the width of the concrete structure for formwork and working space (as a rule an over measure of 1.5 m per side is adhered to). A variation on this is that the sheet piling is used as outside formwork for the permanent concrete structure. In this case, the construction pit is about 3 m smaller (less underwater concrete, less piling) but the sheet piling cannot be tensioned as is the case in the drawn solution (at least at tunnel slip roads). In addition, the locks of the sheet piling then have to be sealed very well otherwise seepage will transport up through the concrete particles that have not hardened yet. Furthermore, the wall reinforcement becomes more complicated. There problems can be partly overcome by strengthening the recessing by means of a coffer dam.

The underwater concrete floor is not even, either at the top or at the bottom. In order to be able to properly set the reinforcement of the floor and to guarantee coverage, a levelling layer is added to the underwater concrete floor. (The levelling layer is not drawn in table 8.5).

Depending on the finish of the underwater concrete, a levelling layer (usually concrete) is applied with a theoretical thickness of around 0.15 m. Theoretical, because the thickness as function of the finishing accuracy of the underwater concrete can vary from 0 to more than 0.15 m. Incidental peaks in the underwater concrete are removed.

In alternative 3, the thickness of the underwater concrete floor is determined from the vertical balance (not rising after dewatering). In alternative 4 the floor thickness is determined by execution technical considerations and sometimes by the shear stress between the pile shaft and the

underwater concrete and the bending tensile stresses in the underwater concrete floor. The latter is only the case at very high upward water pressure or applicable to piles that are able to absorb very high tensile forces. For reasons related to the execution, depending on the method of application, a thickness of 1.20 to 1.50 is used. At a thickness of 1.20 m a good pouring method is required, such as with a 'Hop-dobber'.

In appendix 8, comparative calculations were made for alternatives 3 and 4, respectively with and without tension piling. The rough calculations were made for a push-tow navigation lock and an inland navigation lock of CEMT class I. This shows that a solution with tension piling is considerably cheaper than one without. Solution 3 is only suitable at small upward water pressure, for instance at a very shallow lock, a naturally low water level or a combination of a cofferdam with very limited pumping.

Alternative 5:

Lit. [8.1] describes the sinking of pneumatic caissons for heads of the 12.6 m wide navigation locks at Helmond and Schijndel in the Zuid-Willemsvaart. The article also poses that at increased depth of the foundation level under ground level, the caisson method can become attractive in relation to alternative 3 and 4, which also do not require pumping. The reason that is given is that the required auxiliary construction and facilities such as air locks and compressors are hardly influenced by increased depth while for both cofferdam methods, all auxiliary constructions (sheet pile, tension pile and the like) need to be more robust. At the Zuid-Willemsvaart, the heads are sunk over approximately 9.5 m. General rules on when the caisson method could become competitive cannot be given as this depends too much on the local situation and the lock dimensions concerned. Consider a depth larger than approximately 8 m. The width of the lock plays a large role in this. A basin profile is twist flexible, which could result in large tensions occurring during sinking due to uneven bearing and setting.

Alternative 7:

The anchors shown in the figure of table 8.5 can be executed either as anchor bars with anchor walls or as grouted (ground) anchors. Struts are not possible because the prefabricated elements will have a large freeboard during transport.

Alternatives 8 and 9:

Fitting the hinges in the floor has the drawback that angular deflection could occur on both sides of the head on the lock axis. This could be detrimental to the rail track of the lower roller carriages for instance (this concerns very large locks in which rolling gates are used). This problem is largely overcome by fitting the rail profiles after the concrete structure of the head has been completed and most of the filling up has been done (Lit. [8.2]). An important part of the settlement (and thus the angular deflection) will have occurred by then. The steel rail foundations, which are stiffer than the rail profile, are interrupted at the position of the hinge but the parts on both sides of the interruption support each other.

8.6 Pre-selection of the alternatives

8.6.1 Introduction

Tables 8.5.1 to 8.5.4 and 8.6.1 to 8.6.3 provide directions that could help in making a selection from the alternatives given for the chamber and heads. The following paragraph is limited to a pre-selection of the building methods that are suitable for heads (numbers 1 to 9).

In par. 9.4.2 the building methods for chambers are addressed. *This is were, under "Point 8 and 9" an explanation is given in relation to column K in the tables 8.6.1 to 8.6.3, which only relates to the choice between chamber alternatives.*

8.6.2 Pre-selection of alternatives 1 to 9

Not all 9 alternatives are suitable for every head. For this reason, a preliminary selection is made according to situations in which certain alternatives are suitable to a greater or lesser degree.

In succession, these are:

1. cross dimensions of the head;
2. pumping is not permitted, permitted or permitted to a limited degree;
3. limited width available for the execution;
4. soil condition;
5. rising level of groundwater.

Other considerations could also play a part in the selection:

6. experience with the alternatives;
7. adjustment to the building method of the chamber.

Points 1 to 7 are addressed in more detail. Before that, please note once again that in the design, the emphasis is on finding the solution(s) of which the sum of the investments costs and the constant value of maintenance and replacement during the life span and the cash value of demolition are minimal. This naturally applies to the totality of the lock complex as well as to the parts such as lock heads, which cannot be seen as separate from the gate type, the building method of the chamber and such like.

Point 1, cross dimensions:

The *three most right columns of table 8.5* indicate which alternatives are suitable for locks with respectively small, medium, large and very large dimensions, perpendicular to the lock axis. A solid cross means it is suitable just like that; a dashed cross means: possibly suitable for the lock concerned.

Because the dimensions in civil construction have a less distinct influence on the choice of the alternatives than does the choice of the gate, the five categories with dimensions from table 7.1 of par. 7.3.1 (choice lock gates) have been concentrated to three in table 8.5. For this, the following translation key was used:

From par. 7.3.1		Table 8.5	
Description	Lock width (m)	Description	Lock width (m)
Very small and small	4-6 resp. 6-10	Small	4-10
Medium-large and large	10-16 resp. 16-24	(Medium-) large	10-24
Very large	>24	Very large	>24

The classification in table 8.5 is not "fixed" as the choice for the structure and the building method is also dependent on the depth of the floor with regard to ground level (bending moments in the wall, upward pressure against the floor). This depth is in turn determined by the type of navigation vessel and by the lift over the lock. Because of this, a (medium-) large lock with a large lift could end up in the classification "very large". In sorting by dimensions - depending on the actual situation - certain caution is called for.

In placing the crosses in the dimension columns, the decision was mainly made from experience gained in previous structures. Not drawing from previous experience, in the sinking down method (6 and 7) an X was not placed at "Very large", as the freeboard during floating transport will probably be large at wide locks (and therefore also the ballast introduced later). This could also apply to sluices with a width of 24 m. For this reason, a dashed cross was placed at (medium-) large.

Point 2, possible limitations to pumping:

At present, lowering the groundwater level is often not permitted, sometimes not at all and sometimes only to a limited degree whereby the time unit per quantity of pumped water is bound to an upper limit. This could mean that some of the alternatives are not suitable in certain situations. Therefore, *column 2a of table 8.6* has crosses to indicate which alternatives require pumping and *column 2b* indicates in which limited pumping will suffice. Limited does not mean to say that the necessary discharge will remain below the previously mentioned upper limit. This will have to be checked in each case. *Column 2c* indicates for which of the alternatives return pumping could be considered. Where there is a cross in the column, such as for alternative 1 (reinforced concrete monolith, executed in a drained construction pit), pumping remains a requirement but whether this is complete or partial return pumping depends on the surroundings. (In the case of complete pumping, the total discharge is returned to the bottom). For a number of alternatives (among others 2, a monolith with screens into a non-permeable layer), pumping is usually not required but with limited pumping, use can be made of a non-permeable layer that is situated relatively high, which would burst open without pumping. In this case, it is also conceivable that return pumping is used, more so because the discharge returned is smaller than it is in alternative 1 where the groundwater level has to be decreased to below the construction pit floor. This is the reason why dashed crosses were put in columns 2b and 2c (possible limited pumping with or without return pumping) while under the heading "Comments" an explanation is given why the dashed crosses have been included. In alternative 2, it concerns making an alternative suitable despite an impermeable layer that is situated too high. Alternative 3 also has dashed crosses in the columns 2b and 2c to indicate that limited pumping, possibly in combination with return pumping, could provide a more economically sound solution than would be the case without pumping. This consideration is stated under the heading "Comments".

Point 3, limited width available for execution:

Column 3 of table 8.6 indicates with a cross which building methods require only a limited width for construction purposes. Limited in the sense that less width is required than is the case in a construction pit between slopes. For that matter, it only concerns the terrain width outside the final structure. Other choices, such as choosing roller gates, determine the width of the head.

Point 4, soil condition:

If the ground has insufficient bearing power, alternatives 1, 2, 8 and 9 could be executed with piles or ground improvement could be considered if the bearing layer is not too deep below the floor of the head. Variant 3 goes over into variant 4 if piles are used. In the case of a pneumatic caisson (alternative 5) pile foundation is possible even though this is usually not necessary for locks. There is experience with this type of execution in relation to bridge piers (van Brienenoord) and bascule basements. A pile foundation is possible for variants 6 and 7 (prefabricated elements manufactured elsewhere), albeit it that these piles easily absorb pressure but find it more difficult to absorb tension. However, in the normal execution of these kinds of variants upward forces should be compensated for by the own weight, possibly multiplied by ground weight if the floor is extended to outside the ground side of the walls (another possibility is securing the construction against the ground with grouting or ground anchors).

Looking at the whole, all variants can be executed irrespective of the soil condition. In essence, it is no problem to drop one or two variants due to bad soil conditions. This point is only addressed for the sake of completeness as this could play a role in the pre-selection of chamber variants (par. 9.4).

Point 5, rising level of groundwater:

The rising level is naturally contributory to the required discharge of the pumping and with that, the horizontal expansion of groundwater level lowering. If the extraction is too large, this could be a reason for selecting an execution method without pumping, with limited pumping or with return pumping (see 2 previously).

The distance between the phreatic plane and the bottom of the floor of the head is also a determining factor in the choice between alternatives 3 and 4, a thick underwater concrete floor or an underwater concrete floor anchored to tension piling.

As is shown in par. 8.5.2 under the heading "Alternatives 3 and 4" and the corresponding appendix 8.1, a thick underwater concrete floor is generally financially unattractive in comparison to an anchored floor. A thick floor is only appropriate at small upward water pressure, for instance at a very shallow lock, a naturally low water level or a combination of a construction pit with limited pumping.

Point 6, experience with the alternatives:

Extensive experience was gained during lock building the Netherlands with variants 1, 3 to 5 and 8. Variant 2 has not yet been used for locks but it has been used for tunnel slip roads and the like. There are no particular risks to this alternative, aside from those that could be associated with inadequate soil investigation. The depth, the thickness and the 'permeability' of the impermeable layer as well as the volume weights of this layer and the layer above have to be accurately assessed. To prevent unnecessary seepage, it is important that drilling and probing is executed outside the surrounding bentonite screen. If this provides insufficient insight into the soil conditions, the holes caused by probing in the impermeable layer inside the bentonite screen have to be securely sealed after the fact. In the past, we have had very bad experiences with boreholes that were not sealed well at tunnel slip roads (too much seepage which led to an undesirable decrease in groundwater level in the surrounding area).

Alternative 9, a floor with 2 hinges, has not been applied yet. However, we do not expect this variant to alternative 8 to lead to any special risks. Extra attention will have to be paid to checking the calculations on deformations which will have to remain inside the applicable values for gates and supports.

Actually only alternatives 6 and 7, both with prefabricated elements that are manufactured elsewhere and floated in, are totally new options for lock building. Wide experience with this method has been gained in tunnels, quay walls and the like. However, if these variants are used for the preliminary design of a lock, they will require more scrutiny than the other variants simply because new applications could lead to unexpected aspects.

Point 7, adjustment to the construction method of the chamber:

The execution of the heads cannot be seen as separate from the execution of the chamber, even though it is not necessary that the same construction method is applied. Different methods could be used for the heads of one lock. The building method(s) selected for the heads, in relation to the building method for the chamber, should result in the lowest total cost for the lock.

NUMBER OF ALTERNATIVE	CHARACTERISTICS		Suitable for		Suitable for lock size		
	Final construction	Building stage	Chamber	Head	Small	(Medium) large	Very large
1	Reinforced concrete monolith (possibly with pile foundation)	Construction pit, pumping	X	X	X	X	X
2	As 1	Construction pit, bentonite concrete screens into the impermeable layer	X	X	X	X	X
3	As 1 (no pile foundation)	Sheet pile pit, thick underwater concrete floor	X	X	X	X	X
4	As 1 (always pile foundation)	Sheet pile pit, thick underwater concrete floor, tension piling	X	X	X	X	X
5	As 1	Pneumatic caisson, built on ground level	X	X	X	X	

Table 8.5.1 Alternatives

NUMBER OF ALTERNATIVE	CHARACTERISTICS		Suitable for		Suitable for lock size		
	Final construction	Building stage	Chamber	Head	Small	(Medium) large	Very large
6	Final construction Reinforced concrete monolith (on steel foundation)	Prefabricated elsewhere, floating transport, sunk into cunet with slopes	X	X	X	X	
7	As 6	As 6 but the cunet is bordered by anchored sheet pile	X	X	X	X	
8	Reinforced concrete construction with one hinge	Construction pit, pumping	X	X			X
9	Reinforced concrete construction with two hinges	Construction pit, pumping	X	X			X
10	Reinforced concrete L walls with rubble layer on filter	Construction pit, pumping	X		X	X	X
11	Terre armee walls, rubble layer on filter	Construction pit, pumping	X		X	X	X

Table 8.5.2 Alternatives

NUMBER OF ALTERNATIVE	CHARACTERISTICS		Suitable for		Suitable for lock size		
	Final construction	Building stage	Chamber	Head	Small	(Medium) large	Very large
12	Anchored dam / deep walls provided with wood fender. Rubble layer on filter	Limited, dry excavation. Rest excavation and filter, rubble layer in the wet	X		X	X	X
13	Anchored dam / deep walls provided with wood fender. Thick underwater concrete floor	Limited, dry excavation. Rest excavation and underwater concrete floor in the wet	X		X	X	X
14	Anchored dam / deep walls provided with wood fender. Thin underwater concrete floor (possibly reinforced) anchored to tension piling	Limited, dry excavation. Rest excavation and pile driving and underwater concrete floor in the wet	X		X	X	X
15	Anchored dam / deep walls provided with wood fender. Constructive reinforced concrete floor	Limited, dry excavation. Rest excavation and pile and underwater concrete floor in the wet. Construction of floor in the dry	X		X	X	X
16	Reinforced concrete retaining wall (including relieving plate) on pile and deep wall. Rubble layer on filter	Limited dry excavation. Pile and sheet pile driving from bottom dry excavation. Rest excavation and filter /rubble layer in the wet	X			X	X

Table 8.5.3 Alternatives

NUMBER OF ALTERNATIVE	CHARACTERISTICS		Suitable for		Suitable for lock size		
	Final construction	Building stage	Chamber	Head	Small	(Medium) large	Very large
17	Reinforced concrete retaining wall (including relieving plate) on piles and deep wall. Thick underwater concrete floor	Limited dry excavation. Pile and sheet pile driving from bottom dry excavation. Rest excavation and floor in the wet	X			X	X
18	Reinforced concrete retaining wall (including relieving plate) on piles and deep wall. Thin underwater concrete floor (possibly reinforced) anchored to tension piling	Limited dry excavation. Pile and sheet pile driving under retaining wall from bottom dry excavation. Rest excavation, tension piling and floor in the wet	X			X	X
19	Green chamber between slopes, provided with bank and bottom lining and guide structures	Wet excavation (upper part possibly in the dry). Underwater lining placed in the wet, dry finishing upper parts of slopes. Piles can be driven while floating. Finishing of guide structure above water line	X		X	X	

Table 8.5.4 Alternatives

ALTERNATIVE		2a	2b	2c	3	K	Remarks
NR	Characteristics	Requires pumping	Limited pumping required	Combination pumping with return pumping conceivable	Limited execution width	Chamber can be laid open and floor is closed	
1	Monolith, pumped construction pit	X		X		X	
2	Monolith, screens into the impermeable layer		X	X		X	X (2b) could be sensible in order to make use of a layer that is too high. X (2c) is very conceivable in that case.
3	Monolith, sheet piling pit with unanchored underwater concrete floor		X	X	X	X	X (2b) could be sensible in order to make use of a layer that is too high. X (2c) is very conceivable in that case
4	Monolith, sheet piling pit with underwater concrete floor and tension piling				X	X	
5	Monolith, pneumatic caisson				X	X	
6	Monolith, prefabricated elements sunk in cunet	*				X	* = Probably no pumping, probable pumping at dock
7	Monolith, prefabricated elements sunk in cunet with sheet pile	*			X	X	* = Probably no pumping, probable pumping at dock
8	Construction with 1 concrete hinge, pumped construction pit	X		X		X	

Table 8.6.1 Pre-selection

ALTERNATIVE		2a	2b	2c	3	K	Remarks
NR	Characteristics	Requires pumping	Limited pumping required	Combination pumping with return pumping conceivable	Limited execution width	Chamber can be laid open and floor is closed	
9	Construction with 2 concrete hinges, pumped construction pit	X		X		X	
10	Reinforced concrete L walls, rubble layer, pumped construction pit	X		X			
11	Terre amee walls, rubble layer, pumped construction pit	X		X			
12	Anchored sheet piling, rubble layer		X	X	X*		X (2b) could be favourable for limitations in sheet piling moments. X (2c) is very conceivable in this case. * = required width depending on anchor walls or grout/ground anchors
13	Anchored sheet piling, thick underwater concrete floor		X	X	X*	X	As in 12
14	Anchored sheet piling, underwater concrete floor with tension piling		X	X	X*	X	As in 12
15	Anchored sheet piling, underwater concrete floor with tension piling, constructive floor		X	X	X*	X	As in 12
16	Reinforced concrete L wall on piling and sheet piling and rubble layer		X	X	X		X (2b) could be favourable to avoid wood fender, obtain shorter sheet piling and limit sheet piling corrosion. X (2c) is highly conceivable in this case.

Table 8.6.2 Pre-selection

ALTERNATIVE		2a	2b	2c	3	K	Remarks
NR	Characteristics	Requires pumping	Limited pumping required	Combination pumping with return pumping conceivable	Limited execution width	Chamber can be laid open and floor is closed	
17	Reinforced concrete L wall on piling and sheet piling and thick underwater concrete floor		X	X	X	X	As in 16
18	Reinforced concrete L wall on piling and sheet piling and thin underwater concrete floor with tension piling		X	X	X	X	As in 16
19	Green chamber between slopes, provided with bank and bottom lining and guide structures						

Table 8.6.3 Pre-selection

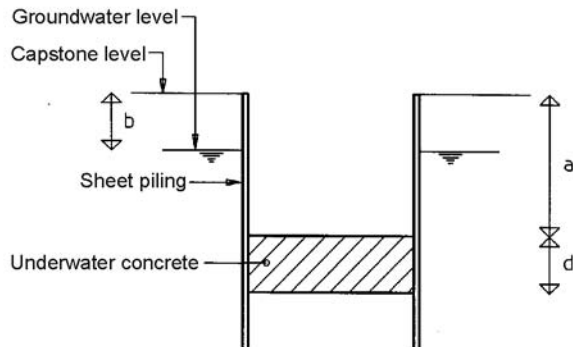
Literature:

- [8.1] Bongers, R.P. en van de Haterd, G.W.J., 'Pneumatisch afzinken van sluishoofden', Cement 1995, nr. 5, pag. 63-66.
- [8.2] Roelofs, D.J., 'De nieuwe sluizen te Terneuzen', OTAR 54 (1969) nr. 12.

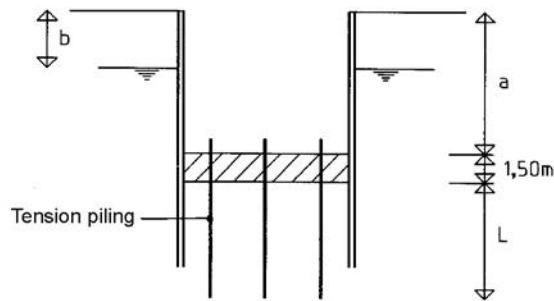
Appendix 8.1 Calculation examples for underwater concrete floor with and without tension piling

(Respectively alternatives 3 and 4, corresponding with par. 8.5.2)

For a rough comparison of both alternatives, a significantly simplified calculation is provided hereafter (see fig. 8.5).



Thick underwater concrete floor without tension piling



Thin underwater concrete floor with tension piling

Figure 8.5 Calculation examples for underwater concrete floor

General starting points:

- reference level is the capstone level of the navigation lock;
- the top of the underwater concrete floor is a m under the capstone level, the highest groundwater level during the execution is at b m under the capstone level;
- weight by volume of the underwater concrete amounts to 23 kN/m^3 , that of the ground under water to 10 kN/m^3 ;
- the safety against buoyancy must amount to 1.2. Roughly, this amounts to a γ of 0.9 for own weight and ground and to a γ of 1.1 for upward water pressure.
(Remark: For safety against bursting open during the temporary phase of the tunnel slip roads, a central safety coefficient of 1.1 is used instead of the 1.2 mentioned here).

Determining the thickness (d) of the underwater concrete floor without tension piling (alternative 3):

Balance calculation with regard to the top of the underwater concrete:

$$\begin{aligned} d \times (23 - 10) &= 1,2 \times (a - b) \times 10 \\ \text{of} \\ d &= 0,923 \times (a - b) \quad [\text{m}] \end{aligned} \quad (8.1)$$

Determining the piling length (L) at an underwater concrete floor with tension piling (alternative 4)

It is assumed that:

- for execution technical reasons, the underwater concrete floor has a thickness of 1.50 m;
- for determining the pile length, the binding soil criterion (the ground weight to be activated) is normative, not the friction along the pile shaft;
- L is the length across which the pile is situated in the ground. For the actual pile length, L has to be multiplied with the thickness of the underwater concrete floor (1.50 m), the thickness of the filling layer and the required welding length in the constructional reinforced floor.

The balance calculation (with regard to the top of the underwater concrete) is:

$$\begin{aligned} L \times 10 + 1,5 \times (23 - 10) &= 1,2 \times (a - b) \times 10 \\ \text{of} \\ L &= 1,2 \times (a - b) - 1,95 \quad [\text{m}] \end{aligned} \quad (8.2)$$

Comparison of underwater concrete floor without (alt. 3) and with (alt. 4) tension piling

Push-tow lock

It is assumed that the level difference at the top of the underwater concrete floor and the capstone is $a = 13$ m and a level difference of groundwater and capstone of $b = 4$ m. At $a = 13$ m one can think of a push-tow lock (2.5 m from capstone to HLL = highest locking level, 3.35 m lift, 5 m water depth at LLL = lowest locking level, 2 m constructive floor and 0.15 m filling layer), whereby the groundwater level is slightly above the mean between HLL and LLL.

Without tension piling, a required underwater concrete floor thickness of as much as 8.31 m results from formula (8.1).

At tension piling and a floor thickness of 1.5 formula (8.2) provides a pile length of 8.85 m. If we start from a permitted tensile force of 600 kN (smooth pile 0.4×0.4 m²) in the use phase (without taking the safety coefficient into account), then 1 pile has to be inserted per 8.5 m² ground surface of the construction pit. A calculation will have to show whether the adhesive stress between the piling and the underwater concrete and the bending tensile forces are acceptable, but also without extra checks this does not seem to be a problem.

In the comparison between alternatives 3 and 4, $8.31 - 1.5 = 6.8$ m³ underwater concrete stands against $1/8.5 = 0.118$ pile per m² of construction pit. The pile length has been calculated at 8.85 m. The actual length of the piling will be about 12 m as the piling has to be continued into the constructive floor. Per m² construction pit it is $12 \times 0.118 = 1.42$ m pile.

The cost prices are calculated at € 91.-/ m³ for underwater concrete and € 59.-/m for underwater driven pile. These prices are excluding general execution costs, profit, risk, A.K and VAT and based on a price level of 1995. This means that per m² of construction pit, 6.8 times € 91. - - $1.42 \times € 59 = € 534.27$ of additional costs for an unanchored floor. Per construction pit (estimated width for a push tow lock of 31 m) this adds up to about € 16,556.82. On top of this there are the costs for deeper excavation and for more expensive sheet pile (these must be longer and have a higher section factor).

Inland navigation lock class I

A similar calculation was made for an inland navigation lock of CEMT class I. Here, it is assumed that a is 9 m (1.5 m from capstone to HLL, 3.35 m lift, 3.0 m water depth at LLL, 1 m construction floor, 0.15 m

filling layer) and a b of 3.0 m (groundwater level just above the mean between HLL and LLL). The width of the construction pit is estimated to be 11 m.

The additional costs of the unanchored underwater concrete floor in relation to a floor that is anchored to tension piling amount to approximately € 336.- per m² ground surface of construction pit and about € 3,700.- per m of construction pit. The same applies here with regard to increasing the additional costs with the extra costs related to excavation and sheet piling (plus strutting or anchoring).



Photo 9.1 Lock chamber of the navigation locks at Maasbracht

Chapter 9 **Lock chamber**

9.1 Introduction

Par. 9.2 addresses the requirements that are set for the shaping, design and construction of a lock chamber. Distinction is made between the requirements that apply to all locks and the requirements that apply to a specific situation.

In light of Tables 8.5.1 to 4, par. 9.3 provides an overview of the nineteen alternatives for construction and building methods that meet the general functional requirements and possibly also meet some of the specific situations. Because nine of the solution principles for chambers are also suitable for the heads, these have already been addressed in par. 8.5. In par. 9.3, a reference suffices.

Par. 9.4 provides assistance for a pre-selection of the alternatives, presented in par 9.3, for the design of a certain situation. In other words: which alternatives are appropriate for a certain lock chamber? For the nine solution principles, suitable for both chambers and heads, the pre-selection refers to the previous chapter (par. 8.6). Examples of lock chambers of recently built navigation locks are provided in par. 13.8.

9.2 Functional requirements

The shaping, design and construction of the chamber has to meet the following six requirements:

1. The construction of the lock chamber has to, possibly in combination with the adjoining parts of the heads, enclose the space that the vessels have to sail into, moor and remain moored during levelling in a safe and efficient manner. After locking, the vessels have to be able to sail away and leave the navigation lock. The required length, width and height measurements necessary for this process are given in par. 4.4 and 4.6. This space, required by navigation, needs to be a fixed enclosure preferably as narrow as possible in order to limit the quantity of water necessary for filling and emptying as much as possible (short levelling times, limited lockage water loss and potential salt penetrations).
2. The construction has to be able to absorb the ground and water load (which also includes forces that are transferred from the heads in longitudinal direction) as well as the forces that are caused by navigation. The latter also include vessel impact, hawser forces, potential falling anchors and eroding loads caused by propeller jets and other water currents that are caused by vessels. In addition, the construction must be resistant to currents due to filling and emptying.
3. The construction has to be executed as such that the property of the material does not let soil pass through and is preferably watertight. The latter can be deviated from for constructions of the floor (if a rubble layer on a filter is applied).
4. The surfaces against which the vessels moor and that can be impacted by vessels sailing by have to be executed as smoothly and evenly as possible. The intention is that there are a minimum of contact points that could cause damage to the construction and/or to the vessels. If the desired level of smoothness is achieved by positioning facilities in front of the construction, such as a wood fender for sheet piling, these facilities have to be durable and impact resistant while replacement has to be uncomplicated. The same requirements apply to floating frames and fenders that are sometimes used in marine locks for absorbing the collision energy or for preventing the backing up of friction effects during the mooring and sailing out of vessels with large vertical surfaces. If no facilities are provided in concrete constructions, it is recommended that a larger cover on the reinforcement is used than stipulated in the VBC. This extra cover ensures that sufficient cover remains after possible vessel damage to the concrete surface (grooves, dents) so that the cover still protects the reinforcement from damage by corrosion. For this reason, the chamber walls on the chamber side have a cover of 60 mm and 50 mm on the ground side.
5. For the mooring and keeping the vessels moored, the upper sections on the top surfaces are equipped with mooring rings and bollards. In the case of marine locks, bollards are also positioned on lock coping level. The heights at which these facilities have to be provided, the in-between horizontal distances and the hawser forces exerted on these facilities are stated in par. 2.4.3.
6. For the accessibility of vessels and for the safety of people that fall in the water, ladders are positioned in sunken recesses in the upper sections of the chamber. The distances between the ladders are provided in par. 2.4.13.2.

In addition to the abovementioned requirements, the following additional requirements could be set for the construction and the building method of the lock.

7. If, for maintenance technical reasons, the lock should be completely or partly laid open (this requirement is hardly ever set at present), constructions with water pervious floors (rubble layering etc.) will not be possible. There are two exceptions, namely if it is permitted to lower the ground water level during maintenance periods and/or when the walls of the lock chamber (for instance sheet piling screens) are continued into a natural, impermeable bottom layer that provides sufficient security against bursting up. The lying open of the chamber requires relatively high

investment to prevent heaving (extra weight or tension pile). These investments have to be weighed up against the frequencies, the necessity and the ease of maintenance in dry conditions. Please note that the parts that actually require maintenance are positioned in the head and not in the lock chamber.

8. In special cases, it could be necessary to apply piping and/or an impermeable floor (therefore no rubble layer) in view of possible water losses. As a rule however, these are generally minor water losses. On the other hand, an impermeable floor of the chamber has the advantage that piping screens can be shorter than they would be in a chamber with a rubber layer on a filter construction.
9. Increasingly, there is a requirement that the groundwater level may not be lowered or only lowered to a limited degree, even in the construction phase. For locks where this requirement is set, many of the solutions in Table 8.5 cannot be used. Table 8.6 provides an overview of which variants involve groundwater lowering. Apart from a few exceptions (for instance those with steel sheet pile and a rubble layer as floor) constructions that are built without pumping lead to higher construction costs than constructions where pumping is permitted.
10. As a rule, the heads will be the determining factor for the width (perpendicular to the lock axis) of the space monopolization. Yet, the available space, for instance due to the presence of an existing lock, can be a precondition for the chamber. Not in relation to the final design and shaping but in relation to the building method to be used. Please note that an existing navigation lock is a precondition that cannot be tampered with. Where it concerns certain buildings nearby (houses etc.) or agricultural use it is conceivable that the additional costs related to a narrow construction pit are weighed up against the costs of expropriation, unless expropriation is not a realistic possibility due to planning authority reasons. In situating a new lock next to an existing lock it is possible to find an economic optimum. For the final situation, the desired position of both locks is close next to each other while for the construction of the second lock, a larger in-between distance could be more attractive. We stress however, that the heads are the determining factor as a rule, while the stability of the existing lock is normative for the minimal distance between both structures.

9.3 Alternatives in construction and building method

9.3.1 Introduction

In *Tables 8.5.1 to 4* of par. 8.5 of the previous chapter "Lock heads", 19 alternatives are provided for construction and building methods of chamber and heads. A cross in the *4th column* of the table means that the alternative is suitable for a chamber and a cross in the *5th column* means that it is suitable for a head. All of the 19 alternatives can be applied to chambers. Numbers 1 to 9 are suitable for both chambers and heads and have already been dealt with in par. 8.5. Numbers 10 to 19 are addressed in par. 9.3.2, while the *3 columns on the right hand side of the tables* (Suitable for lock size) will be explained in more detail in par. 9.4.2, pre-selection of the alternatives, under point 1.

9.3.2 Alternatives 10 to 19

First of all, alternatives 10 to 19 are described at a high level and divided into 4 groups, which is followed by a more detailed explanation per alternative. Before that however, there are two remarks of general nature that need to be made.

A number of the alternatives could possibly be combined with return pumping. This is not stated in the characteristics of the methods in Table 8.5 but this is addressed in par. 9.4.2 under point 2, where column 2c of Table 8.6 is explained.

Most of the alternatives and/or parts thereof have been applied in the Netherlands, either in locks or at tunnel slip roads, with the exception of the points stated below:

- chamber walls of terre armée, variant 11, have been studied but not yet applied; experience has been gained abroad with quay walls;
- reinforced underwater concrete floors, named as possible variant in solution principles 14 and 18 have been applied in tunnels in the Netherlands, but not yet under large lift pressures except for repairs during the construction of the Zeeburgertunnel.

The above mentioned certainly does not imply that these alternatives or parts thereof could not be used but that at least, more in-depth preparation or investigation is required than would be the case with the more used solution principles.

At a high level, the variants can be subdivided into four groups (the numbering starts with C because groups A and B, which are also suitable for lock chambers, have already been addressed in par. 8.5.2).

C numbers 10 and 11:

The walls are executed as gravity constructions, which are stable without strutting the floor. Type 10 has been applied, among others, at the 68 m wide entrance lock in Berendrecht (Antwerp) albeit that the top layer (deviating from what has been drawn in variant 10 in the table) largely consists of prefabricated profiled concrete slabs that are positioned on top of a filter, between the noses of the floors of the gravity walls. In Berendrecht, these profiled concrete slabs do not have a strutting function. An advantage of variants 8 and 9 as opposed to variant 10, is said to be that the construction pit can be smaller (less earth moving etc.) seeing as the walls require a shorter rail on the ground side: at 8 and 9 the walls and the rail on the ground do not need to be stable because the horizontal load is mostly transferred to the floor. Whether this is indeed an advantage can only be determined by means of a cost comparison in which the costs of all parts and activities have been analyzed.

D numbers 12 t/m 15:

The walls consist of sheet pile profile or deep walls. For sheet pile profiles, in view of mooring and grazing by vessels, these profiles are often provided with wood (or synthetic) rails and, if necessary, girders. In the case of deep wall, concrete aprons are used to below the lowest water level.

The anchoring of the walls has been drawn in the table as an anchor wall with anchor bars. Usually, ground anchors are used. The choice is made based on costs and the available space. Ground anchors, which are applied at a large angle to ground level, could even be positioned under

buildings though this is not always permissible or permitted. A large angle to ground level, sometimes also necessary to reach load bearing layers, has the disadvantage that the horizontal load on the wall is absorbed less effectively. Besides this, a large downward force is introduced to the wall.

The activities for these alternatives can be executed with limited pumping or no pumping at all. The anchor bars for the walls are laid out on the bottom of a shallow excavation while the piles for the walls are driven or made from this level. Often, this bottom is positioned just above groundwater level so that no pumping is required at all. However, this does not always mean that the least expensive solution is obtained. A height level determined by the groundwater level could be unfavourable to a combination with anchor forces and moments in the wall. Besides, in the case of ground anchors, it could be more attractive to install several rows of ground anchors on several layers. Further excavation as well as possibly driving the piles and the pouring of underwater concrete can take place completely without pumping. In alternative 12 it could be considered to pour the rubble layer in dry conditions. One of the advantages (no pumping) will be lost unless the groundwater level is naturally low or if some pumping has to take place for the heads anyway.

The choice between variants 14 and 15, on whether or not to put a concrete construction floor on top of the underwater concrete floor, is determined by the confidence that the designer has in the quality of the underwater concrete. Completely watertight underwater concrete floors have not been made very often. Leakages can occur along the piles and the sheet pile because of tears and imperfections. Crack formations can be limited in long chambers by using separating sheet piling (perpendicular to the longitudinal axis of the lock) which also has the advantage that they limit the size of the pouring. Reinforced underwater concrete would yield advantages with regard to limiting the width of cracking and result in a better load transfer (limiting the calculated cost of the floor and the piling). With regard to leakage, please note that the discharge is generally not large as it usually concerns small lift. Only in the case of the chamber being laid open for maintenance does the unfavourable situation arise. Wide cracks can lead to danger of erosion (the piling derives its bearing power from the enclosing ground).

E numbers 16 to 18:

The reinforced concrete retaining wall on piling and sheet piling is suitable for larger retaining heights, where regular anchor sheet piling would become too expensive. There are many examples of quay walls and a few examples of locks. This construction offers, among others, the following advantages:

- 1 the sheet metal relief of the horizontal concrete floor (whereby horizontal grain-to-grain stresses on the sheet piling decreases);
- 2 the short span of the sheet piling.

The following can be added to this:

- 3 the smooth mooring surface for vessels, whereby wood fender is not necessary like it is with sheet piling;
- 4 the limited corrosion of the sheet piling, which can now permanently remain under water;
- 5 the limited (or complete lack of) pumping as the piling and sheet piling is driven from a shallow excavation pit, in which the retaining wall is also built, while the remaining excavation and the placement of the filter and rubble layer or the underwater concrete and possible tension piling can take place in the wet.

Point 5 is in slight contradiction to points 3 and 4. If the choice is made for no pumping, generally the bottom of the retaining wall is positioned at a high level. This does lead to the possibility that vessels could get stuck under the protruding edge of the floor of the retaining wall at low water levels. In that case, wood fender is required, unless it concerns a lock for large marine vessels, where floating frames or fenders are already applied. Besides, the sheet piling will probably not be permanently under water and corrosion will take place.

F number 19:

This group only concerns one variant, the green chamber that derives its name from the upper sections of the slopes being covered with grass. This group has been added to make the choice

complete. This solution has not been applied for a long time, due to the unnecessarily large lock gate (the part above the slopes), which leads to long levelling times, extra water loss to the lower reach etc. This alternative will only be found in renovations but it is not unthinkable that this type will be considered in the future for small (recreational) locks based on the friendly character of the green chamber. However, the extra water loss will have to be acceptable.

After this explanation on groups, there are a few supplementary notes for a number of the specific alternatives.

Alternative 12 and 16:

The rubble layer on the filter forms an open floor. This can also be realized by placing vertical filter tubes in the underwater concrete floor that are filled with rubble or filter material as shown in fig. 9.1. The figure also shows that it would be sensible to position the filter tubes closer to each other nearer the head. After all, this is where the undisturbed rising of the groundwater level is the largest. This concentration of filter tubes also achieves that the lift over the underwater concrete floor, relevant to the vertical balance, remains below acceptable levels.

Different to a rubble layer, a bracing action can be attributed to the underwater concrete. This bracing is limited however and only concerns the increase of the load on the sheet piling after the construction stage; for instance the lift load over the walls at high groundwater and low chamber water levels.

Alternative 13 and 17:

The underwater concrete floor has to be very thick if it is a requirement that the chamber is laid open for maintenance, as stated before in par. 8.5.2 in the comparison between the alternatives 3 and 4. In the case of such a requirement preference will be given to alternatives 14, 15 and 18. In general, alternatives 13 and 17 will only be sensible options if a relatively small lift occurs over the underwater concrete floor.

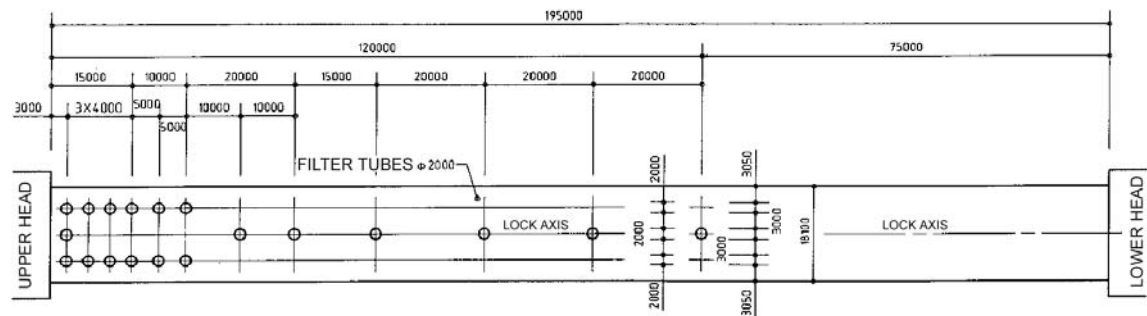
Alternative 14 and 15:

The costs of 14 will be substantially lower than the costs of 15. The reason for selecting 15 could be that the designer of the lock has too little confidence in the quality of an underwater concrete floor. It is conceivable that if reinforced underwater concrete is applied on a larger scale than usual, the designer could have more confidence.

Alternative 18:

It is theoretically conceivable after this alternative with underwater concrete (possibly reinforced) anchored to tension pile, to have this followed by an alternative with a constructional reinforced concrete floor on top of the underwater concrete floor just like this is done in 15, after 14.

That variant was left out of Table 8.5 because the L wall on piles and sheet piling (18) will as a general rule be applied for larger retaining heights than regular anchored sheet piling (14) thus for larger rising levels under the floor. It is not likely that the chamber will be laid open at those larger rising levels (such a design would be expensive). Therefore, the floor only needs to be designed on lift forces at a low chamber water level and a high groundwater level, which does not make an extra constructional floor very sensible. Naturally, the opposite load also has to be taken into account: a high chamber level and a low groundwater level. The pressure will then be on the piling.



Top view of underwater concrete floor with filter tubes

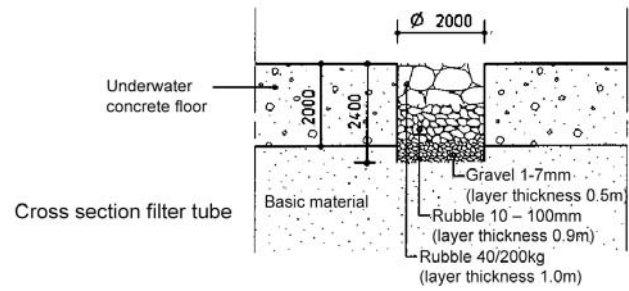


Figure 9.1 Underwater concrete floor with filter tubes

9.4 Pre-selection from the alternatives

9.4.1 Introduction

In Tables 8.5.1 to 4 and 8.6.1 to 3 of par. 8.5 and 8.6, directions are given that could help in making a selection from the various alternatives for chamber and heads. Par. 9.4.2 is limited to the pre-selection from the alternatives 10 to 19, which are only suitable for chambers. The pre-selection from numbers 1 to 9, suitable for both chambers and heads, have already been dealt with in Par. 8.6.2.

9.4.2 Pre-selection alternatives 10 to 19

Not all alternatives are suitable for every chamber. For this reason, selections are made according to situations in which alternatives are more or less suitable. These are, in succession:

1. diagonal dimensions of the chamber;
2. pumping, no pumping or limited pumping permitted;
3. limited width available for execution;
4. soil conditions;
5. rising levels of groundwater;
6. experience with the alternatives;
7. adaptation to building method(s) of the heads,
8. chamber can be laid open;
9. floor is watertight.

In the pre-selection of the alternatives for the heads in par. 8.6.2, points 1 to 7 have been addressed in the same succession as the chambers. For chambers, points 8 and 9 have been added above. Not because these possible requirements specifically apply to chambers but because all the alternatives that are suitable for heads (that would be alternatives 1 to 9, which are also suitable for chambers) have a closed floor and can therefore be laid open. What is more, it is often the case that lying open is a point of departure for a head but is hardly ever required for a chamber.

Points 1 to 9 are addressed below.

Point 1, diagonal dimensions:

In the three most right columns of Table 8.5 it indicates which alternatives are suitable for locks with respectively small, (medium) large and very large dimensions perpendicular to the lock axis. In par. 8.6.2, under point 1, an explanation is given on which measurements are considered to be in which category. A solid cross in the columns means that the alternative is suitable for the lock measurements indicated in the heading concerned. In placing the crosses, judgement was made mainly on experience gained in the Netherlands. As will be explained in the following, in some cases this was departed from.

The experience with alternative 10 is, to the best of our knowledge, limited to very large marine locks in Belgium. Therefore, a solid cross was placed in "very large". However, as this method could possibly be conceivable at small diagonal dimensions, a dashed cross was put under the heading "Small and "(Medium) Large". (NB. This is debatable).

Alternative 11 had similar treatment, but it should be noted that there has been no experience with chamber walls of terre armée (see point 6 below).

In alternatives 12 to 15, under the heading "Very large", dashed crosses have been placed because sheet piling at such depth could possibly be less suitable. (Combination walls and deep walls could be more suitable). Previously, it has been stated that the green chamber (alternative 19) may be used for recreational locks in the future. For that reason, a solid cross was put in the column "Small". Because this solution is theoretically possible at larger locks, a dashed cross was put under "(Medium) large" even though this could hardly be considered realistic.

Point 2, possible limitations to pumping:

At present, lowering of groundwater levels is often not permitted; sometimes not at all, sometimes only to a limited degree, whereby the amount of pumped water per time unit is restricted by an

upper boundary. This could mean that some alternatives are not eligible in certain situations. For this reason, in *column 2a of Table 8.6*, crosses indicate which alternatives require pumping and in *column 2b*, which can suffice with limited pumping. Limited does not mean to say that the required discharge will remain below the previously mentioned upper boundary. This will have to be checked in each case. *Column 2c* indicates in which of the alternatives return pumping could be considered. Where a cross is placed in the column, such as for alternative 10 (reinforced concrete L walls, executed in a construction pit with pumping), pumping remains necessary. Depending on the surroundings, complete or partial return pumping is added (in the case of complete pumping, the complete pumped discharge is returned to the ground).

In alternatives 12 to 18, dashed crosses are placed in columns 2b and 2c to indicate that limited pumping, possibly in combination with return pumping, could lead to a more economic solution than no pumping at all. This is further explained in the column "Remarks".

In alternatives 12 to 15, it is indicated that limited pumping could be favourable for the limitation of sheet piling moments. This means that with limited pumping, it is possible to position the anchoring of the sheet piling lower than would be the case without pumping, at least if report has it that there is a relatively high groundwater level. Lower anchoring reduces the required moment of resistance but increases the anchor force on the other hand. An optimum has to be sought, whereby the costs of the limited pumping and possibly that of return pumping should be taken into consideration. Such an investigation makes sense only if limited lowering of groundwater is permitted and – if this is not the case – when return pumping is acceptable in relation to the environment and the permit issuer. In alternatives 16 to 18, under the heading "Remarks" mention is made of why limited pumping and thus a lower building level of the reinforced concrete footing of the retaining wall could be favourable. A more extensive explanation is given in par. 9.3.2 under E, numbers 16 to 18.

Point 3, limited width available for execution:

In *column 3 of Table 8.6*, a solid cross is used to indicate which building methods require only limited width during the construction phase. Limited in the sense that less width is necessary than would be required for a construction pit between slopes. For that matter, it exclusively concerns terrain width outside the final structure while it can also be said that the heads monopolize more width than the chamber does.

For alternatives 12 to 15 (anchored sheet piling chambers), under the heading "Remarks", it states that the required width depends on the type of anchoring: anchor walls or ground anchors. For alternatives 16 to 18 (L walls in piles and sheet piling) a limited construction pit is required, to the underside of the L walls.

Point 4, soil conditions:

If the subsoil under the walls has insufficient load bearing capacity, alternatives 10 and 11 are not the most suitable solutions to apply. Both are gravity constructions that become so heavily dimensioned that they are stable as they are. The point of departure is however, that the subsoil contains sufficient bearing capacity. The application of piling in order to transfer the loads, including the own weight, to deeper levels does not fit in this concept.

If the substandard layers below the foundation level are not very thick, it could be worth considering whether the gravity constructions could be designed on soil improvement (replacing the flexible soil by compacted sand).

The other variants, numbers 12 to 19 can also be applied in case of unsuitable soil conditions due to the nature of the constructions. However, it could be a necessity to apply soil improvement under the rubble layer on the filters (numbers 12, 16 and 19) or the underwater concrete floor (numbers 13 to 15, 17 and 18), possibly covered by a filtering cloth. This will prevent the mixing of substandard layers with filter material or underwater concrete. Soil improvement will certainly be necessary if thick layers of underwater concrete (numbers 13 and 17) have to be put on very flexible ground. If soil improvement has to continue over too large a depth, alternatives 13 and 17 could become unattractive (longer and heavier sheet piling and more earth moving).

Point 5, rising levels of groundwater:

The rising level is indeed contributory to the required discharge of the pumping and thereby to the horizontal expansion of the groundwater decrease. If the drawoff is too large, this could be a reason to select a realization without or with limited pumping or with return pumping (see 2 above).

The distance between the water table level and the underside of the chamber floor also contributes to the choice between alternatives 13 and 14, respectively 17 and 18, a thick underwater concrete floor and a thin underwater concrete floor anchored to tension pile.

As is shown in par. 8.5.2 under "Alternatives 3 and 4" and the corresponding appendix 8.1, a thick underwater concrete floor is generally financially unattractive in comparison to an anchored floor. A thick floor only qualifies if the resulting upward water pressures over the floor are small, thus when the rising level of the groundwater is not much higher than the lowest water level in the chamber. A large lift can be considerably reduced by including vertical filter tubes in the floor (fig. 9.1 and par. 9.3.2 under "alternative 12 and 16").

Point 6, experience with the alternatives:

Early in par. 9.3.2 it was indicated which variants and/or parts thereof have not been previously applied in lock building in the Netherlands: chamber walls of terre armée (alt. 11) and reinforced underwater concrete (alt. 14 and 18). To this we add that alternative 10 has only been applied at very large marine locks in Belgium.

This is not to say that these alternatives or parts thereof cannot be used but means that at least more in-depth preparation or investigation is required than is the case with the more usual variants.

Point 7, adjustment to the building method(s) of the heads:

The realization of the chamber cannot be seen as separate from that of the heads, even though it is not necessary to use the same building method. One must choose a building method for the chamber which, in synergy with the method chosen for the heads, leads to the lowest costs for the complete lock. For that matter, both heads do not need to be built according to the same method.

Points 8 and 9, chamber can be laid open respectively floor is watertight:

Both points are combined here and in *column K in Table 8.6* because for both lying open the chamber (functional requirement from par. 9.2) as well as for possibly limiting or preventing water level losses and/or piping (functional requirement 8) a watertight floor is required. In further elaboration however, dimensional differences could appear: being able to lay open the chamber will after all lead to larger upward water loads. As stated in functional requirement 7, these days it would rarely be a requirement that the chamber has to be laid open for maintenance (this is different for heads). In a number of cases however, it could be desirable that the floor is watertight.

Column K was provided with a solid cross if the alternative concerned complies with points 8 and 9, whereby 8 will naturally need heavier dimensioning.

Crosses were placed at all variants with concrete or underwater concrete floors, both at numbers 1 to 9 which can be applied to chambers and heads, as well as at numbers 13, 14, 15, 17 and 18 that are only suitable for chambers. No crosses were added to the other variants in column K, which all have a rubble layer on filter and are only suitable for chambers.

For point 8 (can be laid open) this is not possible just like that but, if a watertight floor is required in view of water losses, it could be considered whether the rubble layer could be penetrated with a asphaltic bitumen. This is only economically viable if the resulting upward force for the load situation "Low chamber water level with high groundwater level" is small. It is even possible to execute the rubble layer and the penetration in dry conditions but this requires very heavy pumping and this leads to losing many of the advantages of the alternatives with rubble layer.

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Colofon

"Design of locks" consists of two parts, of which this book is the first part containing chapters 1 to 9. The Civil Engineering Division of the Directorate General of Public Works in Utrecht published both parts in Dutch in June 2000.

The Civil Engineering Division of the Directorate General of Public Works is responsible for the policy preparation and the execution of projects that concern the wet and dry infrastructure. The technical details in the field of navigation locks, scouring sluices, weirs, flood retaining structures and pumping stations fall under the responsibility of the Department Wet Infrastructure of the Civil Engineering Division.

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Final edit Dutch:	prof.ir. A. Glerum dr.ir. A. Vrijburcht
Figures:	Directorate General of Public Works Civil Engineering Division, Wet Infrastructure, Hydraulic Engineering
Photos:	Primarily Directorate General of Public Works Geometrical Division and Civil Engineering Division. For more detail, see photo credits part 1 and 2
Text correction:	P.L. Spits, Vught
English Translation:	Charlotte Friedman, Technical Translation & Training, Emmeloord
Graphic design:	Dratex, Lelystad
Print:	Feiko Stevens Printing, Emmeloord
Binding:	Bookbindery Abbringh, Groningen

ISBN 90-369-3305-6

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