Admittance Policy Deep Draught Vessels and Safety

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Abstract

The design of the admittance policy of the Euro-Maas channel to Rotterdam and the Western Scheldt is based on a probabilistic method. With this method, instead if the previously implemented deterministic method, the accessibility of the harbours and safety during the channel transit have been increased without additional dredging costs.

Keywords

Harbour, Probabilistic Admittance Policy, Waves, Vessel Movements, Safety

1 Introduction

The last few years, the nautical accessibility of the West-European harbours is again in the spotlights During the sixties and seventies a clear separation developed between harbours who could and harbours who could not adapt to the progressive scale enlarging of the bulk carriers For example, till the late fifties the maximum draught in Rotterdam, Antwerp as well as Hamburg was all the same around 40 feet

During the next decades the maximum draught with which the port of Rotterdam could be accessed, kept pace with the huge scaling up of the crude oil-tankers and bulk-carriers. At the moment, each year 350 channel-bound vessels (draught more than 17 40m) arrive at Rotterdam, with a maximum draught up to 22 55m (74 feet) Vessels heading for the Western Scheldt are limited to a draught of 15 00m Each year more than 400 vessels with a draught more than 11.00m bound for Flushing, Gent & Terneuzen or Antwerp

The design of the admittance policy of the Euro-Maas channel at Rotterdam and the Western Scheldt is based on a probabilistic method With this probabilistic method, a substantial improvement of the accessibility and safety of both channels has been achieved with only a minor change of infrastructure A further scaling up of the bulk carriers and crude oil tankers is not expected. Nevertheless, from the market an urge exists for minimizing the accessibility restrictions

The probabilistic admittance policy of Euro-Maas channel has proofed to enlarge the accessibility of the port of Rotterdam for already 10 years. For the Western Scheldt this method is recently introduced It is also intended to recalculate the IJ-channel at Amsterdam in the near future using this method.

Contents

This paper gives an explanation of the implemented techniques, with which the accessibility and safety of the port of Rotterdam and the Western Scheldt has been improved In the first section a brief introduction is given explaining some terms and expressions After a short view on the previously used deterministic method, the design process using the probabilistic calculation method is explained in section 3 The base of the probabilistic design is the safety of the channel transit Section 4 treats this subject. The schematization of all the information necessary for these calculations is treated in the next section (5) After a short explanation about some future developments in section 6 the paper is ended with a conclusion

For a more thorough explanation of the probabilistic calculation method, or just out of interest or curiosity, the appended bibliography gives a list of papers and books which can be consulted

2 Used expressions and terms

2.1 Tidal-Windows

Vessels with a draught of more than 20 00m with destination Rotterdam and vessels with a draught of more than 11.00m sailing at the Western Scheldt are *tidal-bound* and are provided with a *tidal-window* advice For these vessels, the available water level is not sufficient Only using the high tide they can reach the harbour

A tidal-window consists of two times, an opening time and a closing time (figure 2) Between those two times a vessel is allowed to enter the channel During the channel transit tidal-windows indicate the different opening and closing times at different locations. These set of tidal-windows shows during which time period at which location the tidal-bound vessels can safely sail the channel The tidal-window depends on vessel type, dead-weight, draught, astronomical water level, meteorological water effects and wave conditions Also the vessel speed and current are taken into account The more unfavorable the situation gets (e.g more wind or waves) the narrower the tidal window becomes In the most extreme situation no tidal window is available In this case the vessel has to wait for the next tide and better circumstances

2.2 Downtime and Inaccessibility-Percentage

The accessibility of a harbour can be determined using the *downtime* and the *inaccessibility-percentage* The downtime equals the percentage of the *time* during which a vessel can not access the

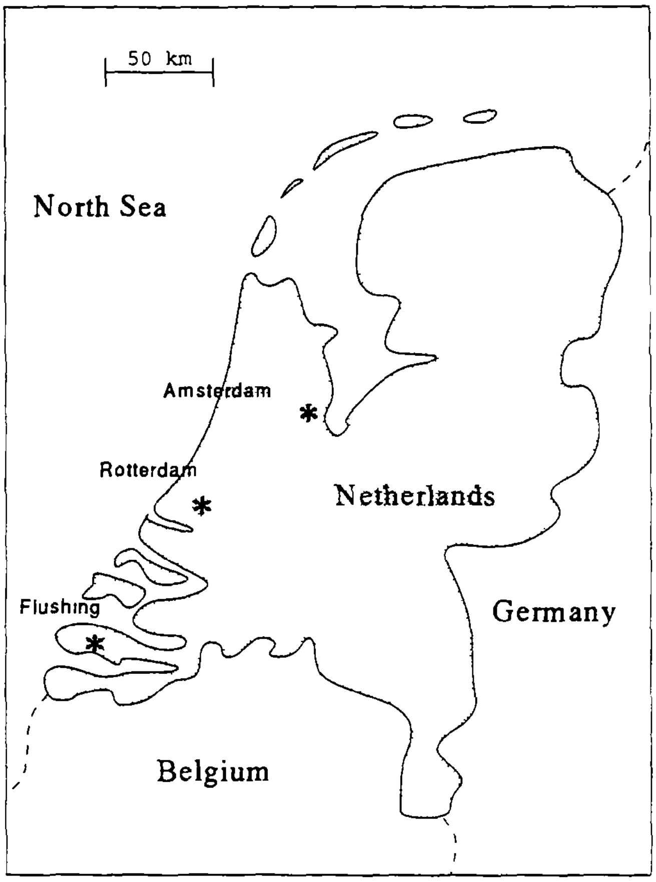

Figure 1 Major harbours in The Netherlands

harbour because there is no tidal-window available. The inaccessibility percentage equals the percentage of the *tides* during which no tidal-window can be provided, due to unfavorable water level or extreme waves.

These two values are quite different For a vessel it is most important that there is an opportunity each tidal cycle during which it can reach the harbour It is less important how long this opportunity exist during the tidal cycle For example, if during four tidal cycles a tidal window exist which is a continuous period of 1 hour each tide, the downtime equals 84%, but the inaccessibility percentage equals 0%!

3 Design of Tidal-Windows

3.1 Deterministic Method

Till 1985 a deterministic admittance policy has been used for the Euro-Maas channel. The Western Scheldt used this method till November 1995 The admittance of vessels was based on a fixed keel clearance percentage. The relation between the minimal keel clearance and the maximum draught was calculated by adding up the squat[1] vertical movements, sounding inaccuracies and sanding to the draught of the vessel, as explained in figure 3.

These additions are equal to the maximum anticipated effects due to the factors mentioned before The sum of all these additions determine the minimal gross keel clearance The ratio between the gross keel clearance and the draught is called the keel clearance percentage At table 1 the percentages of the major Dutch harbours are mentioned.

Using these keel clearance percentages the accessibility of the channel can be determined At the Western Scheldt, the maximum draught was determined for the predicted water level at the most critical location along the channel At the Euro-Maas channel and the IJ-channel tidal-windows were calculated at different locations along the channel, taking account of the changing water level during the channel transit

3.2 Probabilistic Method

At this moment, the Euro-Maas channel [13] and the Western Scheldt have a probabilistic designed admittance policy, instead of a deterministic policy as described in section 3 1 All possible wave and water level conditions as well as ship characteristics are considered and used for determining an optimal accessibility. But instead of using discrete additions, each factor is translated into a probability distribution with a mean value and a variance All the probabilistic distributions are combined and determine together the probability of touching the channel bottom.

The result of the probabilistic calculation are tidal-windows, inaccessibility percentages and downtimes These tidal-windows and the according probability of touching the channel bottom conform to predefined safety criteria as described at section 3 5 Now it is

[1] draught increase caused by the speed of the vessel (section 5 6.2)

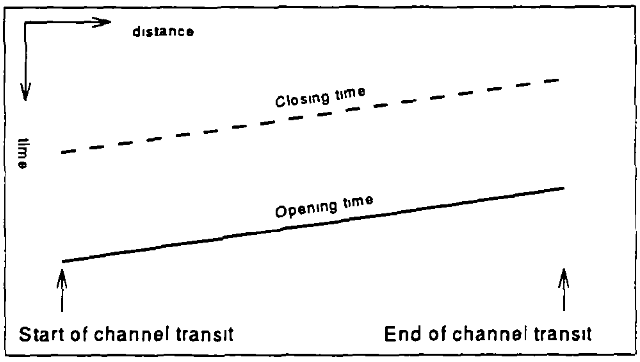

Figure 2. Tidal-Window

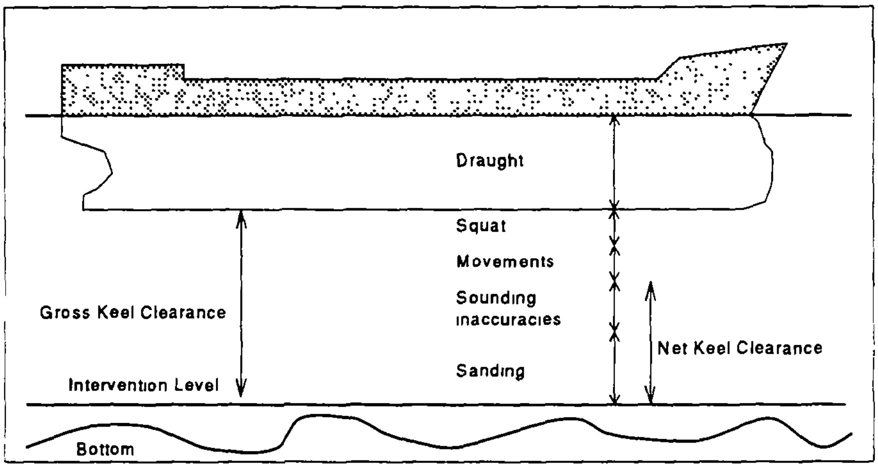

Figure 3. Keel-clearance and additions

possible. using these safety criteria, to weigh the dredging costs against accessibility of the port

The reliability of the tidal windows depends on the input data The predictions and measurements of the water and wave conditions which occur in the channel have a certain inaccuracy The probabilistic design method takes full account of prediction reliability as well as spreading of measurements The exact design process is described in section 3 3

3.3 Probabilistic Design Process

The theory of the probabilistic design is explained in [12]. This theory has been used to develop a program called HARAP (HARbour APproach) HARAP calculates the probability of touching the channel bottom during a channel transit It simulates a transit of a vessel. The process of determining the tidal-windows is explained in figure 4

During such a transit first the water level is determined. Information about astronomical and meteorological water levels, current, vessel speed and wave climate is used This results in the calculation of the keel clearance across the channel Next the vertical movements of the different types of vessels are added which depend on the wave climate The final result at this stage is one optimal tidal-gate

This optimal tidal-gate consists out of one time the optimal time to start the channel transit with minimal probability to touch the bottom of the channel given all the circumstances at that moment

This process is repeated for all the different combinations of circumstances As explained in [12], it is possible to divide all the circumstantial parameters into regimes or classes Instead of calculating with all the different values only the mean or representative value of a regime is used. Regimes are used to characterize the different water level effects, vessel types and wave climates. The number of required calculations is significantly reduced by using this technique

For each combination of regimes a tidal-window is calculated All the probabilities for touching the bottom of the channel of all the transits are added up This sum is compared to a safety criterion (section 3 5) Finally the different tidal-windows are enlarged, reduced or removed, changing the total probability of touching the bottom of the channel, till the required criterion has been reached.

Finally, a sensitivity analysis can be done to optimize the chosen regimes, as showed by the dashed arrow in figure 4. The result is a optimized set of tidal-windows for all the different combinations of regimes. For each vessel type a inaccessibility percentage and downtime is calculated to determine the resulting accessibility of the channel and port

Channel	Keel-Clearance	
	Outer area	Inner area
Euro-Maas channel	20%	10%
Western Scheldt	15%	15%
IJ channel	17 5%	15%

Table 1 Minimal gross keel-clearance

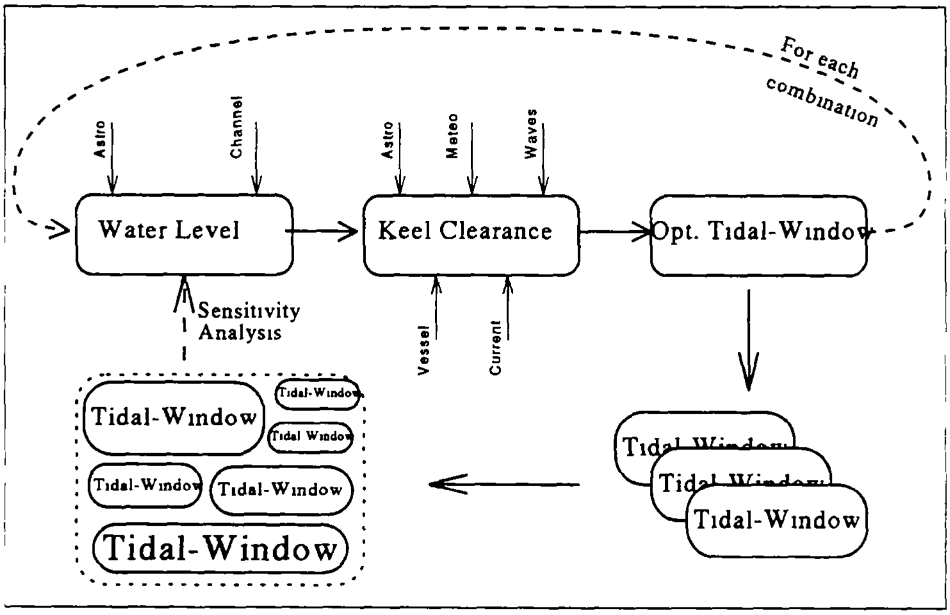

Figure 4. Process of calculating tidal-windows

3.4 Advantages and Disadvantages Probabilistic Method

The deterministic method is based on additions which determine the keel clearance. Mostly these additions are at the outside calculation, making sure that the safety is guaranteed. This results in a keel clearance which is at most times much to large An advantage is the simplicity of this calculation method It is possible to calculate the keel clearance by hand.

The probabilistic method, however, can not be calculated by hand But the determined keel clearance is much more precise With the same channel depth a much better accessibility can be achieved. Another advantage is the predetermined safety level Now it is possible to weigh the accessibility, the required channel depth and the desired safety level

The probabilistic calculations are based on the chance of touching the bottom of the channel. The result of the calculation is a predefined risk of the vessel entering the channel, and not a minimal keel clearance This is sometimes quite difficult to accept and makes it impossible to compare the keel clearance of both calculation methods However the accessibility percentages can be compared

3.5 Safety Criteria

As explained in section 3.3, the calculation and optimization of tidal windows is done by determining the total probability of touching the channel bottom This probability must be less or equal to a predetermined safety criterion For the Dutch channels this safety-criterion is determined as

- **During 25 years the chance of touching the channel bottom which maximum minor damage must not be more than 10%.**

Using a Poisson distribution, a chance of 10% equals a probability of 0.105 touches each 25 years [4] This chance is equal to one touch of the bottom of the channel each 237 years (25/0 105 = 237) Taking into account the number of tidal bound vessels in the channel during 25 years, and the fact that only one out of ten occurrences results in more than minor damage, results in the criterion used by HARAP[2]

Besides the above mentioned safety criterion, two other criteria exist The first criterion, the *manœuvering* criterion makes sure that

- **The keel clearance never is less than 1 *m*.**

Finally the *single transit* criterion defines that

- **The chance that a vessel during its transit touches the channel bottom must always be less than 1% at all (weather) conditions.**

Despite the fact that the last two criteria almost never limit the size of the tidal window, these criteria are necessary to guarantee a safe transit under all conditions, because the general criterion only limits the total probability of touching the bottom of the channel of all vessels together.

[2] For the Euro-Maas channel 6250 vessels use the channel and are tidal bound each year This results in 0 105 × 10/6250 = 1 68 × 10^{-4} as the safety criterion used by HARAP

4 Safety

To ensure maximum and safe cargo deliverability in a given port, a proper balance must exist between excessive and insufficient required underkeel clearance. Historical data and new calculation methods have been used to determine the minimal underkeel clearance and the safety criteria used for the probabilistic calculation [10] Also a study of the human factor has been done

Not only the vertical movements of a vessel determine the safety of entering a channel Also the horizontal movements are important Cross current is a major problem for many harbours For example, the tidal windows of Flushing, Rotterdam and IJmuiden are restricted for some type of vessels due to cross current

For the Euro-Maas channel a full risk-analysis has been done for the entrance channel General accepted safety criteria have been used for the first calculations Taken into account was the fact that the chance of touching the channel bottom should be less than the chance of collision and running aground Therefore the determination of the safety criterion can be split up in two parts

- chance of collision,
- chance of running aground

4.1 Collision

To determine the chance of collision the complete traffic information of one year is taken into account All these vessels have a known origin and destination With this information the chance of one vessel encountering an other vessel can be determined Three different types of encounters are taken into account

Head-on encounter A head-on encounter occurs when two vessels sail in opposite direction, while the course of both vessels have an angle between 150° and 180°

Crossing encounter A crossing encounter occurs when the course of the two vessels have an angle between 60° and 150°

Overtaking encounter When the angle between the course of the two vessels is between 0° and 60° an overtaking encounter takes place

An encounter does not directly result in to an accident. The next step is to relate the database of real accidents with the information of encounters This makes it possible to calculate how many encounters result into an accident or collision An example of the calculations for the entry channel to Amsterdam, the IJmond-channel, is the following table (2). The risks for collision has been determined for different routes and has been split up to the different kinds of encountering The figures are based on *Mean Collision Rates* which are calculated as explained before More information about this subject can be read in [9].

4.2 Running Aground

Touching the bottom of the channel or running aground at the coast mostly does not result in any damage for the environment [15]. The Dutch coast is sandy and not very steep In case a vessel runs aground it is not expected that any oil will leak out of the tanker. For this reason the risk of running aground is less important than the risk of collision

The risk of running aground are expressed in *Area Stranding Opportunities, ASO* [9], which are calculated using the stranding opportunity of a single vessel and the stranding opportunity at a specific location. Table 3 gives an example of some values for the ASO at the IJmond-channel Again these figures have been calculated for different routes The fact that running aground occurs due to restrictions of the maximal draught is taken into account

4.3 Cross Current

As mentioned in section 4, vessels with draughts of over 21 95m do have a cross-channel current restriction near the harbour entrance This restriction has been implemented in the probabilistic admittance policy as a period during which no vessels with draughts of over 21.95m are allowed to enter the harbour However, the risk which is being taken at the moment of entering the harbour is not taken into account Instead of a probabilistic calculation a deterministic restriction is used. At the moment an investigation has been started to examine the relation of tide, wind and current to predict the cross-channel current Also the risks are taken into account, which can be implemented for example as the other safety criteria (section 3.5)

4.4 Human Factor

Last but not least is the human factor A lot of simulations have been done[11] Also analysis have been done about the behavior of pilots on deep draught vessels Finally, continuously a logbook is being kept up to date containing information about the piloting of the vessels to the Rotterdam harbour This logbook can be used to examine specific situations during the navigation of the vessels

5 Schematization

Using some kind of schematization the amount of data can be reduced, making it possible to calculate the keel clearance and the tidal-windows with a computer program

As described in section 3 3 and [12] the meteorological and astronomical water levels can be divided in different regimes Also the low frequency distribution of the wave energy is schematized into one or two values and divided into regimes The different types of vessels can be characterized by a few parameters, and finally the channel has been divided into separate parts to simplify the input data

The Transport Research Center, the North Sea Directorate and the Directorate General of Shipping and Maritime affairs of the Ministry of Transport, Public Works and Water Management have developed the computer program HARAP This program uses the probabilistic theory and processes all the data The following sections explain all the information necessary to calculate the tidal-windows. More detailed information can be read in [12]

5.1 The Channel

Because within the channel there are a lot of significant variance of the water level and channel depth, the channel has to be divided into smaller segments The length of each segment must be chosen in such a way that the channel depth does not vary to much and that the water level variances during a segment transit are not more than the inaccuracy of other influences like depth inaccuracy

Route	Meeting	Overtaking	Crossing	Total
1	1.55×10^{-6}	1.68×10^{-6}	$22 93 \times 10^{-6}$	26.15×10^{-6}
2	4.14×10^{-6}	2.29×10^{-6}	29.71×10^{-6}	36.14×10^{-6}
3	$4 63 \times 10^{-6}$	3.81×10^{-6}	55.25×10^{-6}	63.69×10^{-6}

Table 2 Risks of collision

Route	ASO
1	18.1
2	27.0
3	32 6

Table 3· Values of the Area Stranding Opportunities (ASO)

5.2 Astronomical Water Level

The astronomical water level is represented as astronomical curves, with each a determined frequency of occurrence These astronomical curves are divided into regimes based on *tide-difference* The tide-difference is the difference between the high water level and the previous low water level. The water levels are specified relative to the *stroke-middle* The stroke-middle is the difference low water level and high water level (figure 5) The stroke middle is fixed with respect to a predetermined reference level. The advantage of this method is the significant smaller spreading within each regime, compared to the normally used method where the water level is determined directly relative to a predefined reference level

The regimes of the astronomical water level are based on the frequency distribution of the tide-difference. The limits of each regime are chosen in such a way that the spreading is minimal within this regime. The values which the HARAP program use, are the mean values of the different regimes

5.3 Meteorological Water Level

The meteorological water level is defined as the difference between the astronomical water level and the real water level measured during low and high water These meteo effects are deviations of the astronomical water level as caused by wind and air pressure effects Also the meteo effect is divided into regimes, based on the frequency of occurrence. Again the spreading is kept as low as possible by choosing the most optimal limits of the regimes

Because the stroke-middle as described in section 5.2 is by definition constant during one tidal cycle, it is also incorporated in the meteorological regimes

5.4 Current

For the HARAP calculations, the current can be defined using current speed and current direction. The current is important for determining a safe transit through the channel because·

- The cross-channel current limits the manoevrability near the harbour entrance, and
- The current is used for determining the squat of a vessel

The cross-channel current must be determined with measurements and calculation models. The current in the channel mostly is extracted from tidal stream atlasses cause almost no current measurement time series are available With this information the sailing speed of the vessel can be determined and the squat can be calculated

5.5 Wave Climate

The wave climate is important for determining the vertical movements of the vessels, and therefore should be studied carefully The wave climate can be divided into different wave directions and frequencies. For the Euro-Maas channel and the Western Scheldt the wave frequencies are projected to one wave direction which is the most critical one. The frequencies can be displayed using a wave energy density spectrum. For the Euro-Maas channel the wave frequency density spectrum has been schematized using the *lfe* parameter (figure 6)

The *lfe* parameter gives the amount of low frequency energy in the range between 0.03 and 0.1 This parameter is translated to a significant low frequency wave height, the He_{10}

$$He_{10} = 4\sqrt{m_0}, \quad m_0 = \sum_a^b (S(f)\Delta f) \tag{1}$$

In this equation $a = 0\ 03$ and $b = 0.10$ The frequency is f and the spectral density equals $S(f)$

For the Western Scheldt however a second parameter is used, the H_{res} value The H_{res} parameter equals the amount of energy in the range between 0.1 and 0.5

5.6 Vessels

Besides information about the waves, water level and current, also the specifications of vessels have to be determined For the port of Rotterdam, two types of vessel are considered The bulk carrier and the crude oil tanker At the Western Scheldt container vessels and bulk carriers are considered. All the different types of vessels react differently on waves and swell Also the squat depends on the type of vessel

5.6.1 Vertical Movements

To determine the keel clearance of a vessel, one has to know the vertical movements of the vessels due to waves and swell. The relations which are necessary to know have been determined based on a lot of tests An example is the test of a 200.000 DWT tanker [17] Models have been made [16] of different types of vessel and put into a water basin, simulating all the different (wave) conditions according to reality.

The vertical movements of a ship as induced by the low frequency wave energy are a combination of heave, roll and pitch motions Besides the wave energy spectrum, the vertical movements depends on:

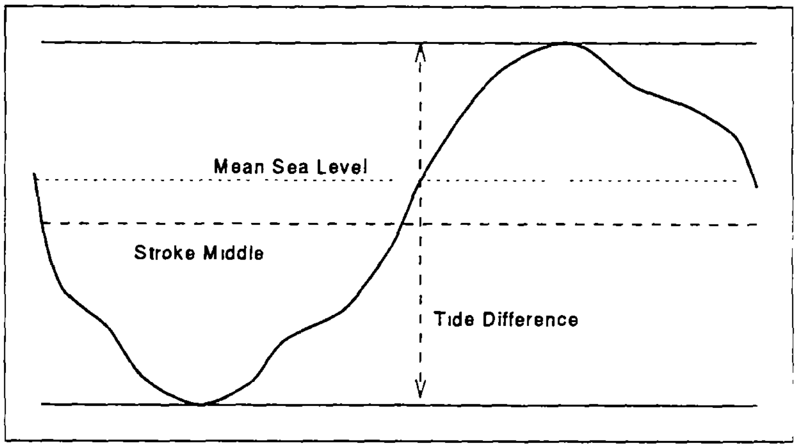

Figure 5 Astronomical water level

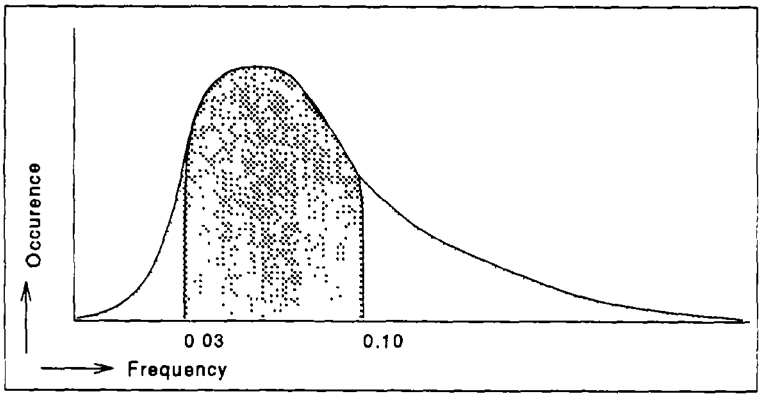

Figure 6 Wave frequency distribution,He_{10}

- type, size, deadweight, cargo, center of gravity, etc
- speed,
- wave angle.
- ratio between water depth and draught

Low frequency waves (swell) are the most important factor for the vertical movements For each wave spectrum a large data set of measured wave spectra is necessary For each type of vessel a ship movement spectrum is determined, using the response characteristic of that vessel This movement spectrum is then reduced to a single parameter, the H_mO_{sch} With linear regression methods this value can be related to a characteristic value of the low frequency wave energy He_{10}:

$$Z_s = a \times He_{10} + b \tag{2}$$

Z_s denotes the vessel movement and a and b are regression parameters The regression parameters depend on the speed, wave direction and the ratio of depth and draught

5.6.2 Squat

The squat is the draught increase of a vessel due to the sailing speed The squat depends on shape, water depth and speed. For the port of Rotterdam the simplified *Tuck-Taylor* [14] equation is used

$$Squat = C \times \frac{F_{nh}^2}{\sqrt{1 - F_{nh}^2}} \times \frac{\Delta}{L_{pp}^2} \tag{3}$$

C denotes the squat constant, Δ the water displacement and L_{pp} the length of the ship For the Euro-Maas channel a C value 1 75 has been used for the bulk carriers and 1.91 has been used for the oil tankers The Froude number F_{nh} equals:

$$F_{nh} = \frac{v}{\sqrt{gh}} \tag{4}$$

In which v denotes the speed, h the water depth and g gravity acceleration The speed is measured related to the ground, so current is taken into account

5.6.3 Speed and Vessel Regimes

At each segment of the channel a speed must be defined for each different type of vessel. All the information about the speed at the different segments together is called a speed regime. Totally three different speed regimes are defined for the Euro-Maas channel, a slow, medium and fast regime With the information about the different speeds the position of the ship can be defined. For the Western Scheldt no different speed regimes are used

6 Future Improvements

6.1 Neural Networks

In order to improve the rather coarse current restriction (5 4) in 1997 a permanent on-line current measurement location just next to the Maas channel will be installed In order to obtain current predictions experiments are being carried out using *neural networks*. In the IJ-channel a neural network proved to be very well able to predict the current [5] The Neural Networks are able to learn complex non-linear processes from examples Their principle is based on the working of the biological brain. Numerical models are not yet able to provide operational predictions because of the large spatial variation of the current The required fine grid models still ask too much computational time.

6.2 Individual Tidal Windows

At the moment, a tidal window is being calculated for a group of vessels, not for a individual vessel (section 5.6 3) Within this group, the most critical vessel is used for determining the vertical movements. In contradistinction to before, when only model tests were possible, now computer calculations can reliably determine the vertical movements

In august this year a project has started to measure the exact movements of large vessels, in order to validate the calculations Accelerations, speeds and displacements are measured, together with accurate information of the wave energy, in order to better tune the response functions to the individual vessel

Large vessels like the *Berge Stahl* with a draught of 74 feet are calculated with their actual size, instead of the sizes defined by the group it belongs to. This way much more accurate calculations are possible This means that the draught of the specific vessel must be given with great accuracy.

The goal is to determine an individual tidal window for every vessel. calculating the vertical ship movements of that vessel, given the predicted wave spectrum, besides using the predicted water level curve instead of the astronomical and meteorological water level regimes

It is to be expected that these investigations will significantly increase the accessibility of the port of Rotterdam.

6.3 Safety Horizontal Manœuvering

As explained in section 4.3 the cross-channel current does limit the accessibility of the Rotterdam harbour An investigation has been started to examine the risks related to the difficult manœuvres which have to be taken while entering the harbour. This includes a thorough study of the safety criteria used for the probabilistic calculation method

7 Conclusion

The probabilistic calculation method is a great improvement compared to the deterministic method. Although, the process of schematizing the necessary information and optimizing the computer calculations is quite complex and time consuming.

However the resulting tidal-windows are very accurate and considers all the different weather and wave conditions the vessel can meat during the channel transit. The new probabilistic admittance policy for the Euro-Maas channel resulted in a very high accessibility of the port of Rotterdam.

The admittance policy design of the channel can be optimized using a pre-defined safety criteria, ensuring a safe channel transit The vessels at the Western Scheldt profit by the use of the recently implemented probabilistic calculation method, the risks of touching the bottom of the channel have been minimized. With new improvements, being developed right now, even better results are expected for both channels

Without any additional costs for dredging the safety and accessibility of a harbour can be increased using the existing channel configuration

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