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Dimensioning and Design of Boat Passages and Locks for Boats for Pleasure and Entertainment

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1. Description of the Problem with Designing Boat Passages

The boat passage is a construction for touring aquatic sports. By means of such constructions, drops can quickly be passed when going downstream, without using a lock.

Within the boat passage, the flow processes are regulated by changes in the cross-section and changes in the bed height via flow resistors within a relatively short flow section. A differentiation should be made between the following discharge processes:

1. Very irregular discharge at the upper and lower end of the boat passage, i.e. acceleration at the inlet and delay at the outlet.

2. Normal discharge in the boat passage channel, i.e. uniform discharge condition.

The physical processes are different, since the flow characteristics of an irregular discharge, such as depth, velocity and velocity distribution, change in the flow direction.

Velocity profiles develop in reaches with an irregular discharge and the water depths adapt to the normal depth Y_u of the regular discharge.

The uniform discharge conditions depend on the influence of the gravity effect. In practice, universal passages with a width of 2.3 m have proved themselves (ref. [1]). However, considerable shortcomings have been observed during operation at several boat passages which have already been built.

For this reason, questions regarding the existing relations between basic parameters of the flow and the design of the passage have been answered by means of a physical model, of a scale of 1 : 3. Investigations of a 2.3-m-wide universal passage concerned the following:

- the passage inlet,
- the passage channel,
- the passage outlet.

The following results were obtained.

2. Flow Dimensions

Usually the energy loss, which is distributed over a certain reach below the energy dissipator creating the loss, is taken into account within one cross section (ref. [2]).

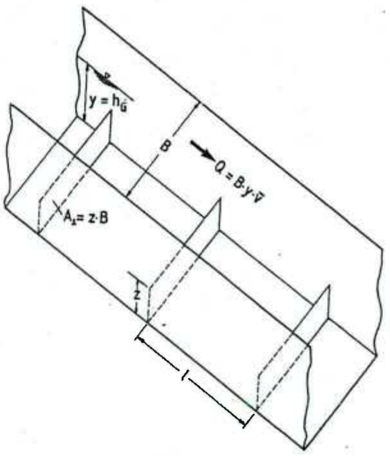

Figure 1
Schematic drawing of a boat passage with paddles

At the same time the local energy loss ΔH with the coefficient of hydraulic friction c_w can be shown in a direct relation as below (1)

$$\frac{\Delta H}{C_w} = \frac{A_\perp}{A_1}\cdot\frac{v^2}{2g} \qquad (1)$$

in which:

$A\perp$ is the projected area of the flow resistors perpendicular to the flow direction, and

A_1 is the $B \cdot y$ cross-section area being passed in the undisturbed section, where B is the width of the channel and y is the water depth.

The two magnitudes Δ and C_W are in a fixed ratio one to the other (equ. 1). However, this means that the coefficient $\Delta H/C_W$ can be used for the determination of the total hydraulic friction, i.e. of the surface friction and of the form friction of the boat passage channel.

Equation (1) can be used for the relation between the coefficient $C_W/\Delta H$ and the flow velocity

$$\bar{v} = (C_w/\Delta H)^{-0.5}\,[(2gBh_G)/A_\perp]^{0.5} \qquad (2)$$

and the water depth in the passage channel

$$h_G = [(C_w/\Delta H)(A_\perp \cdot Q^2)]^{1/3}/(2.7B) \qquad (3)$$

in order to obtain more information regarding the still incomplete knowledge of flow conditions.

2.1 DISCHARGE

Discharge Q is a function of the inlet water depth h_E. It can be influenced only very slightly by the constructional elements of the boat passage (Figure 1).

2.2 DEPTH OF WATER

Within the passage channel there is a constant water depth h_G beneath the acceleration reach (ref. equ. 3). For a constant inlet water depth h_E, depth h_G depends mainly on the form friction coefficient of the flow resistor rows C_W, as well as on the flow resistor area $A_\perp$ projected in the flow direction (see Figure 2).

I_s	ΔQ	h_E in m			
		0,60	0,90	1,20	1,50
1:20	m³/s	0,12	0,30	0,11	0,06
	%	8	10	2	1
1:25	m³/s	0,22	0,47	0,40	0,36
	%	15	15	8,6	5,6

Figure 2a

Flow quantity Q depending on the inlet water depth h_E (gradient of the passage channel 1:17)

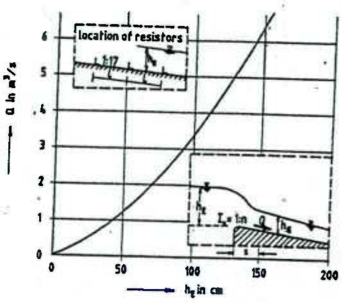

Figure 2b

Decrease ΔQ with a lower gradient (0.6 ≤ h_E ≤ 1.5 m)

2.3 LENGTH OF THE ACCELERATION REACH

The reach of the boat passage, beginning at the inlet with an inlet water depth h_E down to a point x in the channel, at which the water depth (h_G = const.) and the average flow velocity ($\bar{v}$ = const.) have reached the steady state, is defined as the acceleration reach and marked with the letter "s".

It depends mainly on the inlet water depth and is only slightly influenced by:

- the gradient of the passage channel, and
- the resistance of the row of flow resistors $C_W/\Delta H$.

For practical use the following dimensions can be assumed:

Table 1
Length of the acceleration reach s depending on the inlet water depth h_E.

h_E in m	0.60	0.90	1.20	1.50
s in m	5	8	15	25

J_s	arangement of resistors	inlet depth h_E			
		0,60m	0.90m	1,20m	1,50m
1:17	Normalstellung	17,20	16,70	11,90	9,60
	40°	23,80	21,40	14,60	12,80
	0.5 0.5	18,90	17,60	13,20	10,40
		18,30	18,20	14,30	13,90
1:20		18,50	16,70	14,00	13,20
1:25		20,60	20,90	17,40	16,10
1:25	arrow like 1:5 in plan	36,70	28,30	23,60	22,10

Figure 3

$C_W/\Delta H$ values (1/m) for differently arranged flow resistors and the bed slope in the boat passage channel I_s = 1:17 - 1:25 (distance between rows of flow resistors 0.50 m)

2.4 FLOW VELOCITY

The flow velocities or course also depend on the inlet water depth. On the level of the inlet at h_E = 0.6 m, velocities of 0.5 m/s, and at h_E = 1.5 m of 1.0 m/s may occur (Figure 4).

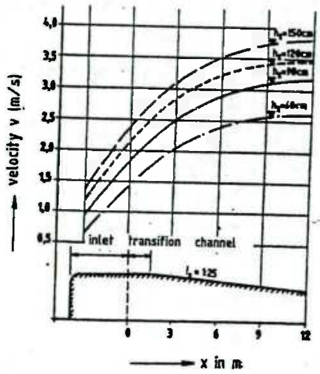

Figure 4

Flow velocity in the passage channel in relation to the distance from the passage inlet (inlet see Figure 5)

These initial velocities are then accelerated along a flow section of 6-12 m to constant final figures of about 2.5 m/s at h_E = 0.60 m and 3.7 m/s at h_E = 1.5 m.

3. Important Views for the Construction of Boat Passages

In the following the observations gained from the model and the obtained correlations are described.

3.1 INLET OF THE BOAT PASSAGE

For functional reasons and for the purpose of traffic safety, the construction of the boat passage inlet should meet the following requirements:

a) The discharge should be continually accelerated taking the change of direction into account (flow change from flowing to rushing discharge).

b) The water level should gradually be transferred in a parallel fashion and without waves from the horizontal surface water level to the slope of the boat passage.

c) The construction method should be economically viable.

d) Low running and maintenance requirements in situ.

In the inlet structure, the cross-section is reduced by decreasing the discharge flume width and changing the height of the bottom. In areas where the water is very deep, it is advisable to contract the sides using side walls with bends, because in this section the discharge conditions are still definitely steadily flowing and not rushing. However, the nearer the depths come to the deepest point, the more steep the water level becomes within the transition structure and the tendency towards the formation of standing waves is growing.

In flume structures with a rushing discharge, the height of the standing waves can be reduced through a gradual change in the flow direction. Fundamentally, the narrow sections of flumes with an especially critical discharge should be:

- nozzle shaped,
- fan shaped,
- funnel shaped.

The path of the inlet of the boat passage (Figure 5) should run according to the equation

$$x = y^{1.85}/0.25 \qquad (4)$$

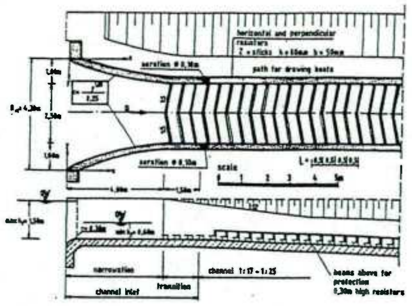

Figure 5
Proposal for the construction of a boat passage inlet

In the area of transition to the rushing discharge, the inlet contraction should be fan-shaped in an upstream direction. In the narrow section, no flow resistors should be placed on the bottom in the fan-shaped narrow section.

3.2 PASSAGE CLOSING CONSTRUCTION

The passage closing construction can be situated into the transition section (see Figure 6). When the passage is open, the shell plate should be in a horizontal position. Tests have shown that flow resistors should be arranged at a distance of 0.50 m from one another on the shell plate.

So that the water can flow out of the lock pit of the closure construction when the passage is opened, sluices, 0.15 x 0.30 m in size, are required on both sides. In addition, on both sides of the passage ventilation tubes should be provided. By means of the ventilation tubes, pressure compensation is possible under the closure construction, in order to prevent an increase of the elevation forces when the passage is closed.

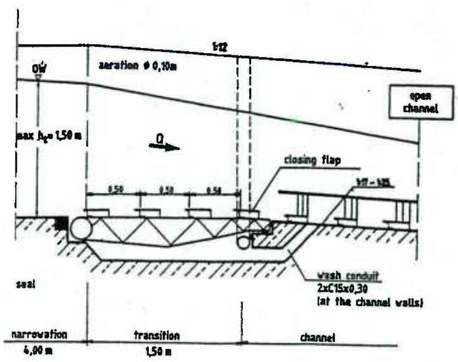

Figure 6
Layout and formation
of the passage closure construction

3.3 PASSAGE CHANNEL

In the passage channel the flow and shipping channel conditions can be influenced by the profile of the flow resistors, the position of the flow resistors in relation to the longitudinal axis of the passage, surface $A_\perp$ of the flow resistors projected perpendicular to the flow direction, the depth of the inlet water h_E, and the bottom slope of the boat passage channel J_s.

Both the energy loss ΔH and the coefficient of hydraulic friction c_w are dependent upon these influences.

3.3.1 ROWS OF FLOW RESISTORS

In order to ensure that there are stable flow and shipping channel conditions, as well as for the purpose of traffic safety, the flow velocity in the passage channel should meet the following two requirements:

a) The average amount of flow over the discharge cross-section should be close to the theoretically attainable minimum, when the inlet water depth h_E is constant. As a result the travelling speed of the sports boats can be kept low.

b) In the discharge cross section, a flow core with relatively higher velocities over the channel axis and, near the walls, a side flow with high velocity-gradients should form. So in the area of the highest flow velocities minimum pressures, and near the channel walls maximum pressures are generated. From this a pressure gradient of

$$\bar{p} = \frac{(\max\bar{v} - \min\bar{v})^2}{2}\rho \qquad (5)$$

must arise.

Thus the boat can be guided in the middle of the channel by forces coming from both sides, which result from the pressure gradients

$$F = L \cdot T \cdot \bar{p} \qquad (6)$$

where L = boat length and T = draught of the boat. So that the requirement in point b) can be met, the rows of flow resistors must be arranged opposite the longitudinal axis of the channel in the direction of the arrow against the direction of flow under 1 : 5 (Fig. 7).

The arrow formation of the flow resistors (Figure 7) leads to flow dimensions in the passage channel, which are shown in Figure 8. The velocity distribution (Figure 8) is advantageous for the stable guidance of the boats in the middle of the passage.

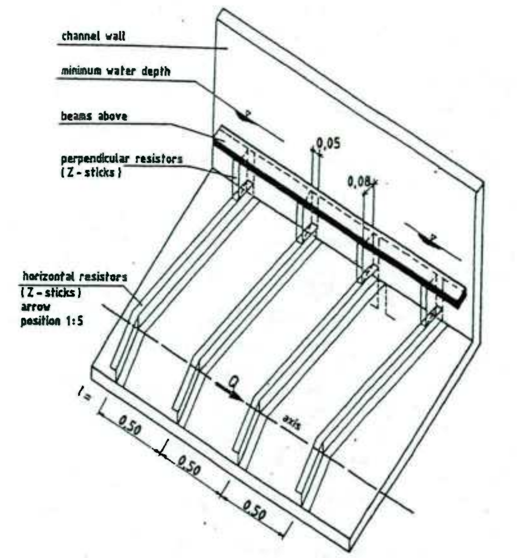

Figure 7
Layout of the rows of flow resistors made of Z-profile rods in arrow formation (proposal for construction)

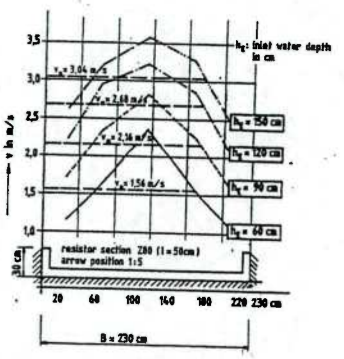

Figure 8
Average flow velocities related to the width of the channel for inlet water depths
0.60 m ≤ h_E ≤ 1.50 m
with flow resistors like in Figure 7

The rows of flow resistors should produce the following effects with the operational requirements to be met here:

1) great water depths in the steady reach of the boat passage channel h_G,

2) minimal flow velocities $\bar{v}$ at all inlet water depths h_E,

3) high local energy losses ΔH, and thus large coefficients of hydraulic friction c_w

The investigations themselves showed that with a flow resistor profile sloping towards the bottom and flow direction at an angle of less than 40° the greatest flow resistance can be generated (Fig. 3, see also [3]). This profile is however not commercially available.

The selected distance between the rows of flow resistors should not be greater than 1 = 0.5 m. If the distances are greater, the flow becomes less calm and there are more waves on the water surface. In order to obtain an economically viable construction method, it is thus proposed that normal profiles of Z-rods, which are commercially available, should be used for construction.

3.3.2 BOTTOM SLOPE OF THE BOAT PASSAGE CHANNEL

Under the assumption that the peripheral conditions are the same, if the bottom slope of the boat passage channel is flatter,

- greater depths h_G,
- lower flow velocities $\bar{v}$, and
- increased safety for the user can be achieved.

The channel gradient 1:25 fulfills in sufficient approach the technical and economical optimum of the sport boat/boat channel system. This gradient should always be chosen when safe operation is to be guaranteed and inlet water depths fluctuate strongly. The channel gradient should not exceed 1:20 under any circumstances.

3.4 OUTLET OF THE BOAT PASSAGE

The passage outlet is a lateral channel enlargement with a rushing discharge. If the enlargement occurs too quickly, there are delays in the flow and thus an increase in the pressure, which in turn leads to flow separation. Below the cross-section, in which the point of separation lies, the width of the effective discharge would decrease as a result. As a side-effect, cross-waves, causing a constant disturbance, would arise.

When designing the boat passage outlet, it is thus important to find a configuration which makes it possible to avoid flow separation over as short a distance as possible. In this actual case, the outlet can be described as being optimal when the flow is widened as quickly as possible, avoiding separation, and afterwards is directed in a parallel direction again with as less disturbance as possible.

In the model, a configuration for the boat passage outlet was chosen, with which flow separation and the resulting

- cross waves and
- sudden deflections of the flow towards the bank can definitely be avoided.

So that the main flow cannot deflect laterally (Coanda effect), the wall of the boat passage outlet nearest the bank should be integrated into the bank slope at a gradient of at least 1 : 2 to the axis of the channel (Figure 9).

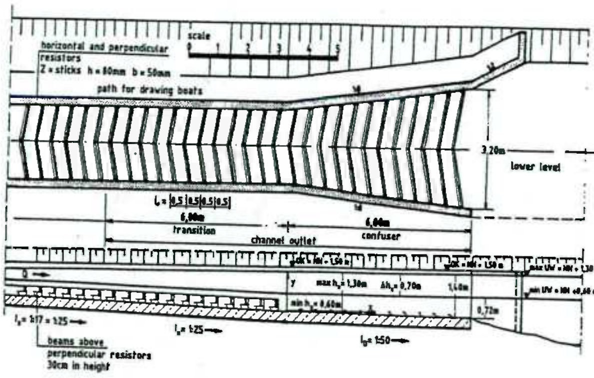

Figure 9

Proposal for the construction of the boat passage outlet

4. General Guiding Principles for Locks with Boats for Pleasure and Entertainment

Boat locks are built along river courses with drops, where:

I) a large number of small vessels and passenger boats are to be found,

II) the extent of commercial shipping excludes the use of large locks by small vessels,

III) the saving of water is important due to the small amount of water available, or due to the production of energy by means of run-of-the-river power plants and the drops should remain navigable throughout, due to the importance of the leisure amenities of the region.

An important basis for selecting the size of the lock chamber is to know the number and type of small vessels which would use the lock at the present time and in the future. Here, a categorisation in

a) rowing boats and canoes,

b) motor boats and sailing boats,

c) passenger boats with and without sleeping accommodation would be conceivable.

It should be taken into account here that experience has shown that the building of facilities, which are readily suitable for use, makes boating for pleasure and entertainment attractive.

According to experience up to now, the lock chamber should not exceed the following dimensions:

1. Usable length L_n = 20 - 25 m
   Usable width B = 4.0 - 4.5 m
   for the greater portion of the boats that are mentioned in points a) and b).
2. Usable length L_n = 25 - 40 m
   Usable width B = 6.5 - 7.5 m
   for all the boats mentioned in points a) to c) using the lock.

The following Table 2 shows the dimensions of several locks for boats for pleasure and entertainment, which have been built along the German inland waterways during the last 20 years.

Table 2
Dimensions of new German locks with boats for pleasure and entertainment

Lock/ Waterway	Width B (m)	Length m	Fall m	Year of constr.
Bad Abbach (Danube)	4	20	5,70	1975
Regensburg (Danube)	4	20	5,20	1977
Riedenburg (Altmühl)	4	20	8,40	1977
Mühlheim (Main)	4	20	3,77	1980
Krotzenburg (Main)	4	20	2,74	1983
Kehlheim (Altmühl)	4	20	8,40	1989
Wahnhausen (Fulda)	6,75	35	8,50	1980
Wilhelmshausen (Fulda)	7,50	35	2,44	1990
Bonaforth (Fulda)	7,50	35	2,41	1986
Kanzem (Saar)	6,75	40	11,75	1982
Serrig (Saar)	6,75	40	14,50	1985
Rehlingen (Saar)	6,75	40	8,00	1983
Mettlach (Saar)	6,75	40	11,00	1984
Bremen (Weser)	6,50	25	3,70 (average)	(1994-96 (planned)

Filling and emptying systems within locks should meet the following requirements:

- short filling and emptying time,
- steady positioning, i.e. the inlet water flows into the chamber with little or no turbulence or waves,
- the mooring ropes should not be put under too much strain,
- optimal construction and running costs.

These requirements contradict themselves and can therefore only be fulfilled by finding an achievable compromise as a solution. Short filling times demand a fast inflow per second and fast rising of the water in the chamber. However, it is an important fact here that filling systems where the inflow comes from the head gate (filling via the lock gate or via short culverts beside the gate) have been shown to have a limited capacity with regard to the filling time and the height of the drop. If the height of the slope exceeds a certain limit, the size of which ought to be around 4 m in up-to-date locks for boats for pleasure and entertainment, then the required filling time leads to a change in the filling system. As a rule, the lateral culverts are constructed as branch channels which run through the cross-section of the chamber walls or of the chamber bottom.

The advantage of these filling systems lies in the fact that the gush of filling water is greatly reduced and that flow and wave movements are avoided.

The rise in the level of the water in the chamber is more even without any noticeable lateral sloping. The most important result is that the filling time can be distinctly shortened, while calculating with the same hawswer stresses.

4.1 FILLING AND EMPTYING SYSTEMS

When chosing an economically viable filling and emptying system, depending on the local peripheral conditions, fundamentally the following possibilities are available for locks for boats for pleasure and sports:

1a) Filling directly through the upper gate (turning stop gate) or through lock gates (mitre gate, segment gate).

1b) Filling via sidewall or bottom laterals with additional filling sluices at the head and a large number of ports (like the Tennessee Valley Authority's multiport system).

2a) Discharge through lock gates (mitre gate, segment gate) with sluices.

2b) Discharge via laterals with additional emptying sluices and ports (analogous to filling).

By means of these filling and emptying systems constructional savings can partly be made, since the foundations are of no great depth, if the chamber walls are so constructed that the laterals can be integrated.

4.2 CALCULATION OF THE FILLING AND EMPTYING PROCESSES

When calculating the filling process, it is necessary to know when the water level of the chamber has reached the height of the inlet opening, i.e. the upper edge of the lock sill. The inflow at the point in time t can be calculated according to the commonly known equ. (7).

$$Q_t = \mu\,(a_0 + nt)\,\sqrt{2g}\cdot\sqrt{H_t} \tag{7}$$

In order to ascertain the height of pressure H_t at the point in time t, it should be determined whether the cross-section of the filling is lower or higher than the downstream water. (Filling with a low or high lock sill: Figures 10 and 11).

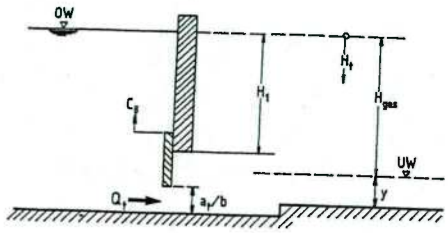

Figure 10
Inflow during the first filling phase with a low lock sill

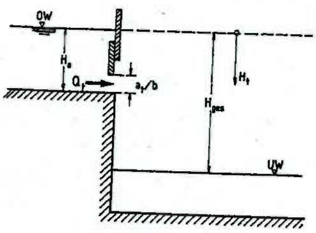

Figure 11
Inflow during the first filling phase with a high lock sill

The calculation of the filling curves can then be made according to the commonly known equations.

Fundamentally the same facilities can be used for the emptying of the chamber as for the filling; however, the opening of the emptying cross section can be carried out considerably faster, since on the one hand, due to the high water level, the boat lies more calmly in the water at the beginning, and on the other hand the energy dissipation takes place outside the chamber. More details on the hydraulics of the filling or emptying processes can be found in extensive publications (e.g. [4]).

4.3 INFLOW AND DISCHARGE WATER QUANTITIES

The total force acting on boats during the filling process depends on

- the filling system (see section 4.1),
- the quantity of the water inflow (Q_t),
- the increase in the water inflow into the lock chamber per second (dQ/dt).

In order to determine the maximum inflow quantity max. $Q_{(t)}$, it is thus necessary to know the stress limits of small boats. Operational experience with locks with boats for pleasure and entertainment, which is shown in a Table in section 4, can give indications and information on these limits, which indeed should be set higher.

For the purpose of further examination, two prototypes with a large and small drop, i.e. the Saar lock at Serrig (elevation H_{Ges} = 14.5 m; filling system via laterals and ports) and the Main lock at Mühlheim (elevation H_{Ges} = 3.47 m; filling system at the head), will be taken. Both locks have been available for use 12 and 7 years ago, respectively. Complaints about excessive forces or occurrences of strong turbulence during operation are not known or have not been observed.

a) SAAR LOCK AT SERRIG

H_{Ges} = 14.5 m; A = 51.7 • 6.75 = 349 m^2
t_{Ges} = 12 min. = 720 s; V = 5060 m^3
Q_{Mittel} = 5060/720 = 7.03 m^3/s;
a_1 = 2 x 0.80 x 1.0 = 1.6 m^2; $c_ö$ = 2.0 mm/s
t_1 = 1000/2 = 500 s; n = 0.0032 m^2/s
Average filling coefficient:

$$\mu_m = \frac{2A\cdot\sqrt{H_{Ges}}}{\sqrt{2g}\,a_1\,(t_{Ges}-t_1/2)} \approx 0.80 \tag{8}$$

Period of time until Q_{max} is reached:

$$t_{max} = \sqrt{\frac{4A\sqrt{H_{Ges}}}{3\mu n\cdot\sqrt{2g}}} = 395.45\,\text{s} < 500\ \text{s} \tag{9}$$

Q_{max} before the sluices are opened:

$$Q_{max} = \sqrt{16/27\mu\cdot\sqrt{2g}\ n\cdot AH^{1.5}_{Ges}} = 11.36\ \text{m}^3/\text{s} \tag{10}$$

so that the speed of the rising water level in the chamber:

$$v_{max} = \frac{Q_{max}}{A} = 1.95\ \text{m/(min)}\ ;\ v_{Mittel} = 1.20\,\text{m/min} \tag{11}$$

With a lifting speed of the lock sluices (2 x 0.8 x 1.0 = 1.6 m^2) of $c_ö$ = 2.0 mm/s a filling or emptying time of 12 min. = 720 s results. The elevation and inflow quantity curve during the filling of the lock chamber at Serrig via 20 ports per side of the laterals are shown in the graph in Figure 12

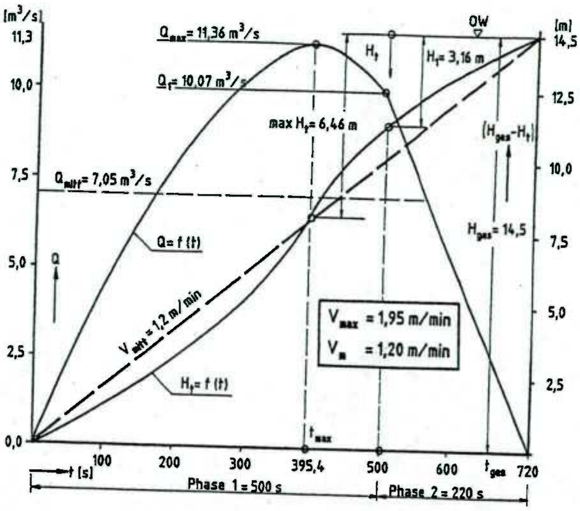

Figure 12
Elevation and inflow quantity curve during the filling of the lock chamber at Serrig (filling with a low lock sill)

With the dimensions of the Saar lock at Serrig
Q_{max} ≈ 11.36 m^3/s, μ_m = 0.80
the following formulations for calculations for other drops in height at locks can be determined:

1. Time in seconds until opening of the filling cross section

$$n = \frac{Q_{max}^2}{16/27\mu\sqrt{2g}AH_{Ges}^{1.5}}\ [m^2/s] \tag{12}$$

2. Opening speed of the lock sluice during filling

$$C_ö = n/b\,[m/s] \tag{13}$$

3. Opening time

$$t_1 = n/a_1\,[s] \tag{14}$$

4. Time period t_{max} until the inflow peak according to equ. (9) has been reached
5. Filling time of the lock chamber

$$t_{Ges} = \frac{2A\sqrt{H_{ges}}}{\mu\sqrt{2g}\cdot a_1} + t_{1/2} \tag{15}$$

6. Height of pressure at the time of the maximum inflow

a) $t_{max} < t_1$

$$\sqrt{H_t} = \sqrt{H_{Ges}} - \frac{\mu\cdot n\sqrt{2g}}{4A}\cdot t_{max}^2 \tag{16}$$

b) $t_{max} > t_1$ then $t_{max} = t_1$

$$\sqrt{H_1} = \sqrt{H_{ges}} - \frac{\mu\cdot\sqrt{2g}a_1}{4A}\cdot t_1 \tag{17}$$

The calculated dimensions are listed in the following Table.

Table 3
Dimensions for the filling of small locks taking the fall in height into consideration

H_{Ges}	n	$c_ö$	t_1	t_{max}	H_t	t_{Ges}	
m	m²/s	mm/s	s	s	m	s	min.
5	0,0148	9,2	108	108	3,23	329	5,48
6	0,0112	7,0	142	142	3,50	373	6,2
7	0,0089	5,6	179	179	3,68	415	6,9
8	0,0073	4,6	217	217	3,79	457	7,6
9	0,0061	3,8	263	254	4,00	500	8,34
10	0,0052	3,3	303	283	4,43	541	9,01
11	0,0045	2,8	357	311	4,97	587	9,78
12	0,0040	2,5	400	337	5,42	626	10,44
13	0,0035	2,2	454	368	5,85	670	11,2
14	0,0032	2,00	500	392	6,31	710	11,84
15	0,0028	1,8	555	426	6,77	754	12,57
16	0,0026	1,6	625	450	7,20	804	13,40
Surface area of the lock chamber A = 349 m²							

The increase of the water flow per second into the lock chamber via 20 ports type laterals on each side is of no significance. This is due to the fact that the laterals with relatively large cross-sections along the length of the chamber almost completely prevent high pressure changes and therefore slopes of the water level in a lateral direction.

The maximum inflow into the lock Q_{max} and the area of the chamber A are in a ratio to one another as defined in equ. (18)

$$\frac{Q_{max}}{\sqrt{A}} = \sqrt{\frac{16}{27}\mu\cdot\sqrt{2gn}\cdot H_{Ges}^{1.5}} \tag{18}$$

For the lock with small boats at Serrig the following results:

$$Q_{max}/\sqrt{A} = 0.61\ [m^2/s]$$

and from this

$Q_{max} = 0.61 \sqrt{A}$

The maximum inflow into a small lock Q_{max} taking the chamber area A into consideration can be taken from the following Table 4:

Table 4
Standard values for maximum inflows in dependence of the area of the small lock chamber A

A [m²]	350	300	250	200	150	100
Q_{max} [m³/s]	11.36	10.57	9.65	8.63	7.47	6.10

b) RIVER MAIN LOCK AT MÜHLHEIM

H_{Ges} = 3.77 m; A = 30.7 x 4.0 = 122.8 m²
t_{Ges} = 6.5 min. = 390 s; v = 463 m³
Q_{Mittel} = 463/390 = 1.19 m³/s; q_{Mittel} = 0.30 [m³/s]/m
a_1 = 2.2 x 0.3 = 0.66 m²; $c_ö$ = 2.2 mm/s
t_1 = 300/2.2 = 137 s; n = 0.66/137 = 0.0048 m²/s
H_o = 2.30 m, H_{Ges} - H_o = 1.47 m
Average filling coefficient

$$\mu m = \frac{A(H_{Ges}+H_o)}{\sqrt{2g}\cdot a_1\sqrt{H_0}(t_{Ges}-t_1/2)} = 0.523 \qquad (19)$$

Time period until the filling-gap at the lock sill is stemmed:

$$t_D = \frac{A(H_{Ges}-H_o)}{\mu\cdot\sqrt{2g}\cdot a_1\cdot\sqrt{H_o}} + \frac{t_1}{2} = 146.3\text{ s} \qquad (20)$$

Largest quantity of inflow:

$$Q_{max} = \mu\cdot\sqrt{2g}\cdot\sqrt{H_o}\cdot a_1 = 2.32\,m^3/s \qquad (21)$$

Height of pressure after the filling-gap has been completely opened:

$$H_1 = H_{Ges} - \frac{\mu\cdot\sqrt{2g}\cdot\sqrt{H_o}\cdot a_1 t_1}{2A} = 2.47\,m \qquad (22)$$

Speeds at which the level of the water in the chamber rise :
v_{max} = $Q_{max/A}$ = 1.13 m/min., v_{Mittel} = 0.58 m/min.

Figure 13 shows the elevation and the inflow quantity curve during the filling of the chamber of the boat lock at Mühlheim/Main via a sluice in the door gate (a_1 = 2.2 x 0.30 = 0.66 m²), which is opened linearly with $c_ö$ = 2.2 mm/s. The maximum elevation speed of the water level of the chamber v_{max} = 1.13 m/min should be coordinated with the maximum quantity of water inflow Q_{max} = 2.32 m³/s.

At the beginning of the filling process of the chamber from the head gate, there is a water level slope towards the downstream direction of the lock. A sloping force

$$F_w = G_s \cdot I_w \qquad (23)$$

is exerted on the boats in the chamber.

The extent of the lateral slope of the water level (slope of the wave front of the gush of the filling water) at the beginning of the lock process fundamentally depends on the increase per second of the quantity of the inflow dQ/dt. The greatest acceptable increase per second in the water inflow into the lock chamber can be determined using equation (24).

$$\left(\frac{dQ}{dt}\right)_{max} = \left(\frac{dQ}{dt}\right)_{t=0} = \mu_m\cdot n\cdot\sqrt{2g}\sqrt{H_o} \qquad (24)$$

$$I_w = \frac{1000}{g\cdot B\cdot y_o}\frac{dQ}{dt}\text{‰} \qquad (25)$$

where :

B = chamber width and

y_o = depth of water in the lock at the beginning of the filling process.

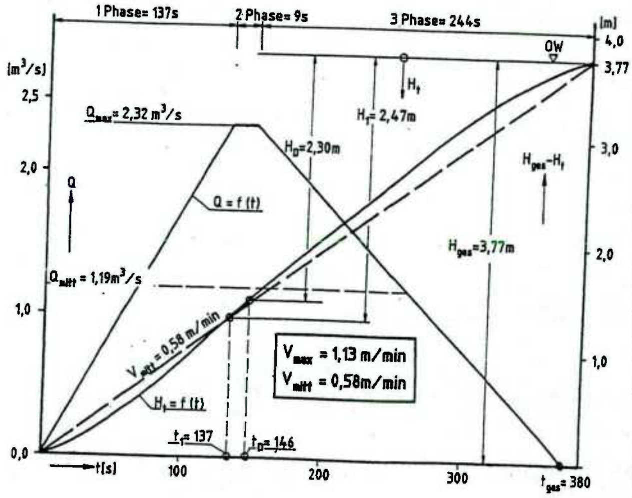

Figure 13
Elevation and inflow quantity curves during the filling of the boat lo at Mühlheim/Main (filling with a high lock sill)

For the lock Mühlheim with y_o = 1.8 m; B = 4.0 m; n = 0.005 m^2/s; and H_{ges} = 3.77 m

I_w = 0.25 ‰ can be calculated.

With the help of value I_w = 0.00025 an acceptable increase per second of the water inflow into a small lock of this kind can generally be given as a standard value (equ. 22).

$$\frac{dQ}{dt} = 0.0025 \cdot B \cdot y_o \qquad (26)$$

The maximum inflow with a head filling system should, according to experience, be limited, so that the elevation speeds of the water level in the chamber do not exceed 0.60 m/min.

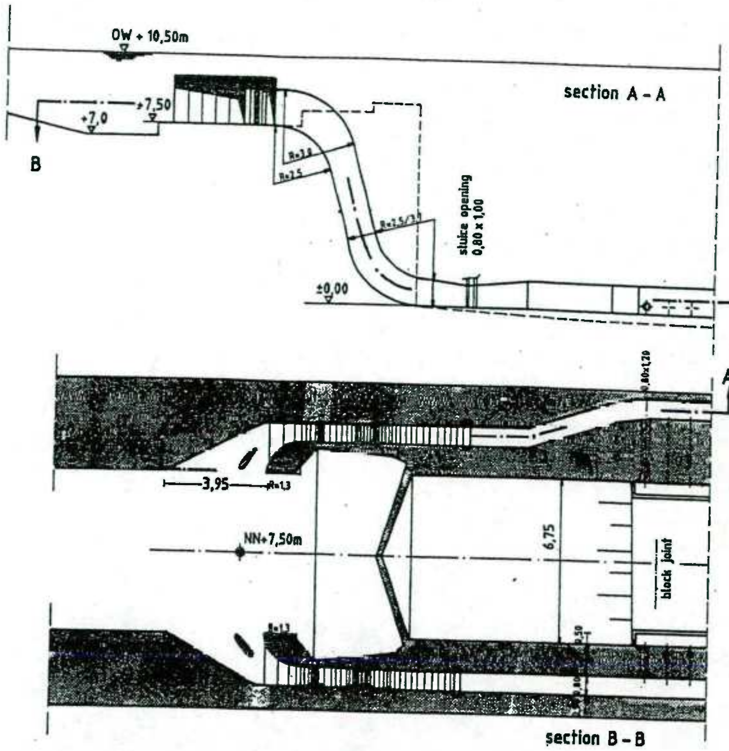

Figure 14
Design of the filling system at the head according to [5]

5. Important Views for the Design of Locks with Boats for Pleasure and Entertainment

The flowing processes in the lock chamber can be considerably influenced by the design of the filling and emptying installations. In addition to the economic aspects, when solving constructional problems, questions regarding the safety demands for using small locks should therefore be taken into consideration.

In consequence, at all locks installations for energy dissipation are necessary, which guarantee as calm positioning as possible for small vessels during the whole filling and emptying process.

5.1 FILLING SYSTEMS

As already stated in section 4, it is necessary to differentiate between filling via the laterals and filling from the head.

A) FILLING VIA LATERALS

The following constructional elements should be measured and designed for the water inflow:

- Inlet structures at the entrance of the lock.
- Downpipe with elbows leading down to the lock sluice cross sections.
- Laterals with relatively large cross-sections for reducing the pressure changes.
- Filling parts according to number and size of the section.
- Rebounding wall in front of the mouths of ports, especially when filling takes place via one channel only.

Each of the stations through which the water passes was examined and optimised in the Federal Waterways Engineering and Research Institute (BAW) using a hydraulic model with a scale of 1 : 7.5 (see [5]). The design of the inlet has to prevent the formation of eddies and the intake of air. For this purpose, a long trumpet inlet at the required water depth with an ogee curve at the upper edge of the inlet was developed in the model (Figures 14 and 15).

For laterals with ports leading to the chamber, the largest cross-section possible must be selected in relation to the small cross-sections of the ports, in order to counteract fluctuations in the admission of the water (Figs. 16 and 17).

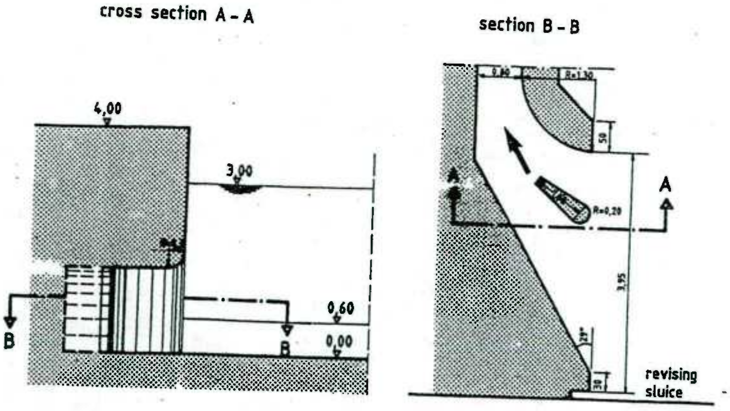

Figure 15
Inlet of the laterals at the head
(proposal for design according to [5])

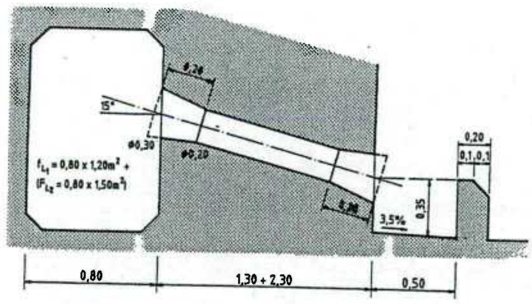

Figure 16
Lateral cross-section with port and rebounding wall
(proposal for design according to [5])

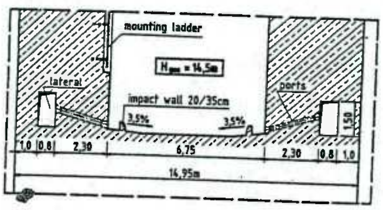

Figure 17
Laterals and ports in a cross-section of the chamber
(current drawing of the Saar lock at Serrig)

The laterals should be at least high enough for walking along. Due to the hydraulic over-dimensional size of the laterals, the cross-section of the lock gates can be made narrower (0.8×1.0 m^2). The narrowing of the culverts in the area of the sluice gates should be carried out on the bottom with a gradient of 1 : 10. Information regarding the elevation speed of the sluices can be taken from Table 3. Due to the inertia of the water column in the laterals, more water is admitted through the ports nearest the head at the start of filling and, towards the end, less water and, under certain circumstances, there is a negative admission. These negative occurrences can largely be avoided by the large number of small ports 1.0 m apart (Fig. 18).

In the chamber in the area of ports the rebounding walls are effective, since the sprays from the ports can thus be dispersed into many small turbulences. This leads to a speedy dissipation of energy and thus to an extremely calm water surface in the chamber, especially when only one lateral is in operation.

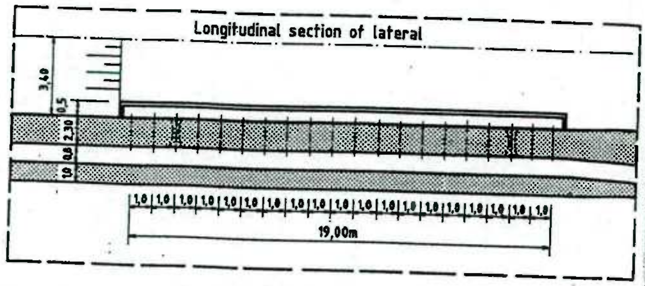

Figure 18
Distribution of the ports in the chamber in a longitudinal directi
(current drawing of the Saar locks)

B) FILLING FROM THE UPPER HEAD

At the head an energy dissipation is necessary, to provide as smooth a positioning as possible for small vessels during the whole lockage.

The inlet flow must therefore be influenced in the area near the gate, in such a way that under all discharge conditions large centres of turbulence and an uneven distribution of speeds are avoided.

Figure 19 shows the arrangement of the energy dissipation at the boat lock at Mühlheim/Main. Alternatively, the installation for energy dissipation, which was developed for the construction of the Mosel locks in the model on a scale of 1: 25, can be recommended as an example (see also [6] (Figure 20)).

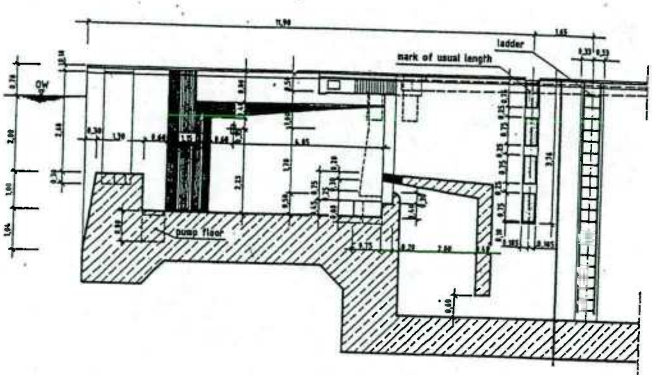

Figure 19
Energy dissipation at the boat lock at Mühlheim/Main
(current drawing)

Energy dissipation takes place in a stilling chamber, which is guarded by a cut-off bluff (Figure 19). Its effectiveness can be increased by means of a distributor beam (Figure 20). This is due to the fact that the outflowing mixture of water and air is partly directed upwards via the distributor beam. Here the air is given off and at the same time the speed of flow is reduced in a longitudinal direction.

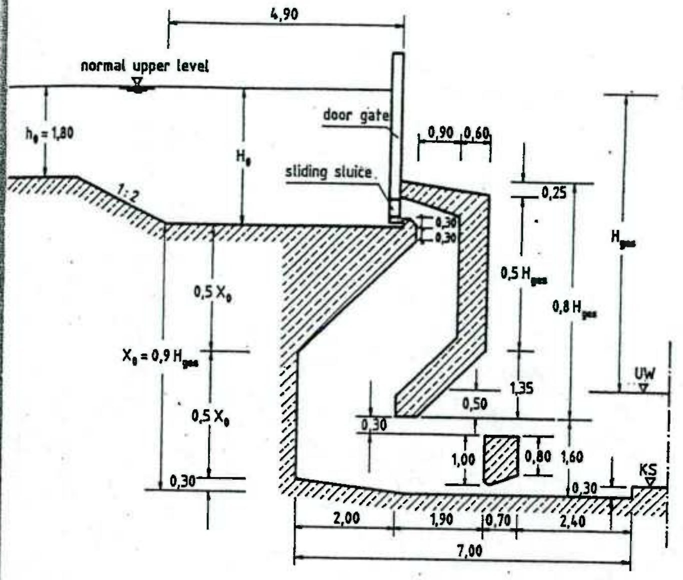

Figure 20

Recommendation for the design of a more extensive energy dissipation during filling from the head with sliding sluices (principle of the Mosel locks)

With the stabilizing installation used in the Mosel locks, an advantageous effect between the distributor beam and the flow is achieved.

5.2 EMPTYING SYSTEMS

By means of emptying systems the outflow should be kept down to a low degree of turbulence and should be passed into the lower outer bay without any gushing waves. Analogously to the filling systems, it is necessary to differentiate between the discharge via the laterals and the discharge immediately at the downstream end of the lock.

A) EMPTYING VIA LATERALS

The water being discharged flows through the ports back into the laterals, it then passes the lower head by sluice openings and is then directed into the stilling basin, where the energy is dissipated (Figure 21).

In order to increase the capacity of the discharge system, the jets' cross-sections can be widened towards the ends, since, if the edges are too sharp, unnecessary constrictions and in consequence losses of energy are produced (Figure 16). However, simple tubes with a correspondingly larger diameter have also proved themselves during practical operation.

The outlet has to effect even distribution of the water spray coming from the laterals into the stilling basin. This is above all of significance when there is an operational disturbance (failure of a lateral for the emptying) (Figure 21). In front of each outlet in the stilling basin, there is an energy dissipator and in the longitudinal axis a spur should be attached (Figure 22).

As a result, a steady steep front can be produced in the centre of the stilling basin, even when there is an operational disturbance, and, despite the asymmetrical admission of the water in the stilling basin, an even outflow can be produced.

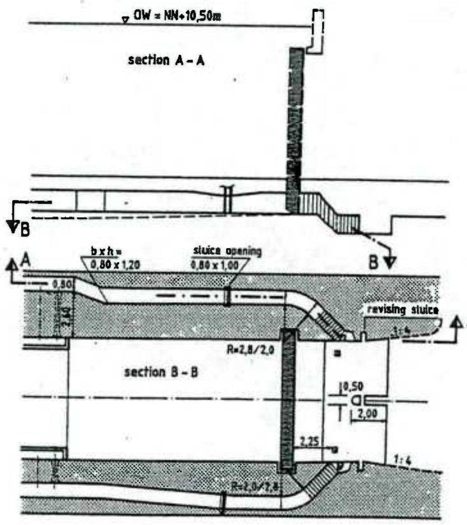

Figure 21

Proposal for the design of the emptying system according to [5]

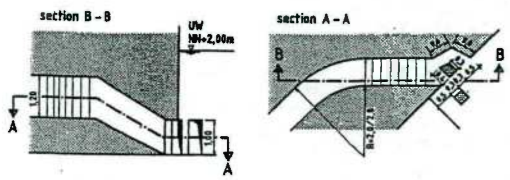

Figure 22

Outlet of the lateral at the lower head of the lock (proposal for design according to [5])

During the emptying of the lock chamber via laterals, there are practically no gushing movements in the chamber and, consequently, hardly any effects of forces acting on the boats.

B) EMPTYING OF THE CHAMBER VIA SLUICES IN THE LOWER GATE

During the emptying of the chamber via sluice openings in the lock gate, initially the water surface slopes down towards the downstream end of the lock. Thus a longitudinal force is exerted on small vessels. Due to the larger water cushion in the chamber, the removal of the water out of the chamber has less effect than during a comparable filling process, although the peripheral conditions are identical.

In Figure 23 the outlet structure of the boat lock at Mühlheim/Main is shown as an example for construction.

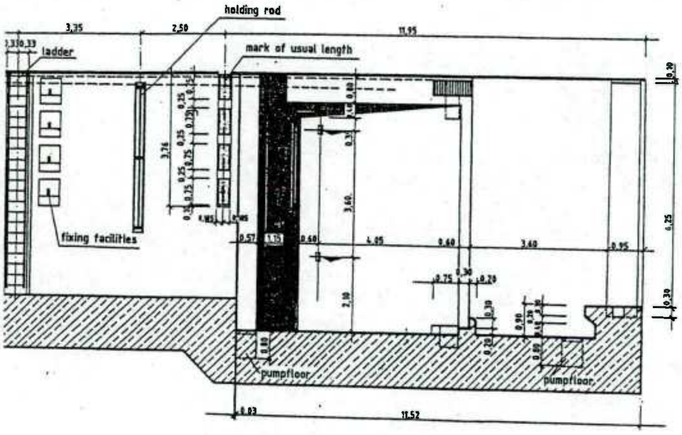

Figure 23
let structure at the boat lock at Mühlheim/Main (current drawing)

5.3 OUTER BAYS OF THE LOCKS

The boat lock can only achieve the required operability if the outer bays and approaches have a friendly design for users.

Respectively cross-flows, high waves and backflow effects must be avoided right up to the highest water level allowed for sports traffic. Backflow effects can lead to deposits of washed-up matter, of suspended matter, as well as of the bedload, and as a result can severely restrict the function of the structure or even make it completely unusable at times.

Dimensions of two types influence the design of the outer bays:

a) Design dimensions, which are set in advance by the flow mechanics, i.e.

- cross flows,
- wave heights,
- backflow effects.

b) The basis of the planning from practical experience, which, with the so-called permissible limiting values, are necessary for the tasks and functions of the structure, i.e.

- length and width of the outer bays,
- dimensions of the mooring points,
- berth widths and safety distances.

From operational experience, it is known that the dimensions of a lock chamber and those of the outer bays must be related to one another (see also [1]).

Consequently, the width of the outer bay (Figure 24) is determined by the

- width of the fairway (determined by a rowing boat): $b_F = 7.50$ m
- width of the berth = minimum width of the lock: $b_L = 4.00$ m ÷ 7.50 m
- safety distance: s = 0.50 m.

In the outer bay itself, there should be a minimum water depth of 1.8 m. The minimum length of the berth should amount to 1.5 times the usable length of the lock chamber. Locks with boats for pleasure and entertainment are mostly designed for self-service.

The users must, therefore, be able to find a mooring in the outer bay, where they can get out. The mooring should consist of a mooring platform with steps leading to it.

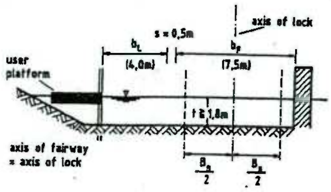

Figure 24
Cross-section of an outer basin for boats according to [1]

6. Conclusions

In the future, the increase in the use of boats for pleasure activities, which can now already be recognized, will increase even further. At the same time, the safety requirements will gain in importance. Measures taken to rationalise the course of the traffic must take these developments into account. It is possible for people performing water sports to be able to overcome a drop almost unimpeded, since the journey through the lane with crew and luggage takes place within a short space of time.

Locks with boats for pleasure and entertainment should be built along river courses with heavy traffic consisting of sports boats and passenger boats.

The design of a lock is judged inter alia by the so-called "permissible hawswer stress". Those stresses should, however, not be regarded as being the characteristic of particular constructional solutions, but more as a value which lies within certain limits, because it is influenced by the kind of handling and the attentiveness of the operating personnel.

As a result, a particular "permissible limit" can only be determined under conditional circumstances. This is due to the fact that many users of locks with boats for pleasure and entertainment have no professional experience. At locks with a drop $H_{Ges} > 4.0$ m, laterals with ports should for this reason be constructed for the filling and emptying of the lock chamber. By means of this system, the water surface remains so calm during the lock process that practically no forces are exerted on the various small vessels. At locks with a drop $H_{Ges} \leq 4.0$ m filling can take place via the head (turning segment gate or sluice in the door gate) and the emptying can take place via the sluices integrated into the mitre gate or door gate.

The function of the boat locks and boat passages is, however, only completely guaranteed if cross flows, waves and backflow effects are already avoided in the outer bay.

7. Literature references

[1] Der Bundesminster für Verkehr: "Empfehlungen für die Gestaltung von Wassersportanlagen an Binnenstraßen", Verkehrsblatt Heft 12/1979, Bestell-Nr. 3079

[2] Naudascher, E.: "Hydraulik der Gerinne und Gerinnebauwerke", Springer-Verlag 1987

[3] Grünagel, E.: "Kantenwiderstand von Schaufelreihen", Forschung Band 9/Heft 4, Juli/August 1939, 187-196

[4] Partenscky, H.W.: "Binnenverkehrswasserbau Schleusenanlagen", Springer Verlag 1986

[5] BAW (1974): "Gutachten über die hydraulischen Einrichtungen der Kleinschiffahrtsschleuse Wahnhausen (Fulda)", BAW-Nr. W 335 (unveröffentlicht)

[6] BAW (1964): "Untersuchungsergebnisse für die Moselschleusen auf grund von Modelluntersuchungen im Maßstab 1:25", Hauptbericht BAW-Nr. 103 (unveröffentlicht)

8. Symbols and Abbreviations

ΔH	local energy loss [m]
c_w	coefficient of hydraulic friction [-]
$A_\perp$	projected surface of the flow resistors perpendicular to the flow direction [m²]
l	distance between the flow resistors
A_1	$B \cdot y$ area of the cross section through which the flow passes in the undisturbed area, with B: width of the passage [m], y: water depth [m]
$\bar{v}$	area flow velocity in the passage channel [m/s]
h_G	water depth in the passage channel [m]
Q	discharge in the passage [m³/s]
h_E	inlet water depth in the boat passage [m]
I_s	slope of the channel [-]
s	length of the acceleration reach [m]
p	pressure gradient between the channel axis - channel wall [kg/m · s²]
F	opposing forces from both sides, which guide the boat in the passage channel [N = m · kg/s²]
L	length of boat [m]
T	draught of boat [m]
A	surface of lock chamber [m²]
a_o	cross-section of filling at the beginning of the filling process [m²]
a_D	cross-section of filling at the point in time when the level of the water in the chamber has reached the height of the sill [m²]
a_t	cross-section of filling at point in time t [s]
b	total width of filling cross-section [m]
$c_{\ddot{o}}$	opening speed of the filling sluice [m/s]
H_{Ges}	height of elevation of the lock [m]

H_o	initial height of pressure [m]
H_t	height of pressure at point in time t [m]
Q_t	inflow at point in time t [m^3/s]
$V = A \cdot H_{Ges}$	volume of water filling of lock [m^3]
μ	inflow coefficient [-]
t	running time [s]
t_1	time [s] until the filling cross-section a_1 is completely opened
$n = c_\delta \cdot b$	opening of the filling cross-section per second [m^2/s]
H_1	height of pressure at point in time t_1
$v_{max}=Q_{max}/A$	maximum elevation or lowering speed of the water level in the chamber [m/min]
v_m	average elevation or lowering speed of the water level in the chamber [m/min]
I_w	slope of water level in the lock chamber
G_s	gross weight of small vessel [t]
B	chamber width [m]
y_o	depth of water in the lock at the beginning of the filling process [m]

RESUME

La conception et le dimensionnement de passages pour bateaux et d'écluses pour bateaux de sport et de plaisance

Cet article expose les problèmes de conception de chenaux pour bateaux de sport et de plaisance, ainsi que les raisons pour lesquelles des recherches sur modèle hydraulique ont été conduites.

Les résultats de la mesure de différents paramètres importants ont permis d'avancer des suggestions et des propositions garantissant l'exploitation en toute sécurité. Celles-ci portent notamment sur la conception des bouches d'entrées et de sortie, le système de fermeture du passage, les rangées de résistances au courant spécialement conçues, et la pente aval.

Les principes généraux de conception et d'exploitation d'écluses pour petits bateaux sont également décrits. La validité des dispositifs de remplissage et de vidange proposés a été démontrée par des tests sur modèle ainsi que des mesures sur le terrain. Deux versions normalisées dont la performance est une fonction de la hauteur de chute, sont proposées aux ingénieurs.

Le calcul des processus de remplissage et de vidange est rendu possible par l'utilisation des paramètres-limite importants d'écluses dont le bon fonctionnement a été démontré par des tests sur modèle ainsi que par des mesures sur le terrain.