SMALL-SCALE MODELLING OF THE FILLING-EMPTYING SYSTEM OF A NAVIGATION LOCK

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Abstract

In this study the authors introduce a small-scale model investigation for the filling-emptying operation of the longitudinal side culvert lock chamber.

The model is based on a navigation lock having been in operation for 13 years. The 92.8 m long, 12.1 m wide lock chamber with a total lift of 10.3 m and it's longitudinal side culvert filling-emptying system has been modeled in a scale of 1 : 36.67. By the variation of the filling-emptying ports (shape, size, location) and the width of the longitudinal culvert 48 series have been examined. The most important data of the series are shown in *Table 1.* The different arrangements of the series are shown in *Figures 1—5.*

By the development of each variation, the ain has been oet to reduce the filling-emptying period to achieve a smooth levelling up and down, a spreading of the filling jet, and to ensure conditions minimizing the dynamical effects acting on the wessels. The economic goal was to find the smallest cross-sectional, easily constructabe longitudinal side culvert and the optimal size and shape of the filling-emptying ports.

Result of the model investigation

a) The minimum cross-sectional area of the filling-emptying ports and their location along the lock chamber have been determined that ensures the shortest filling period at a given valve opening time and at a given longitudinal culvert size (Fig. 6.);

b) It has been proved that the shortest filling period can be ensured with a nearly quadratic shaped longitudinal culvert (Fig. 6);

c) It has been found that the discharge of the filling-emptying ports arranged uniformly along the lock chamber is — non uniform (Fig. 7);

d) By the application of 20 cm diameter filling-emptying ports the velocity extremes of the filling jets have been reduced by about 50 per cent and by this, the hydrodynamical forces acting on the vessel have been reduced by about 50 per cent and by this, the hydrodynamical forces acting on the vessel have been reduced as well as the longitudinal oscillation in the lock chamber (Fig. 8);

e) Near to the floor of the lock chamber, the hydraulically shaded areas have been reduced decreasing thereby the silting tendencies of the lock chamber as well.

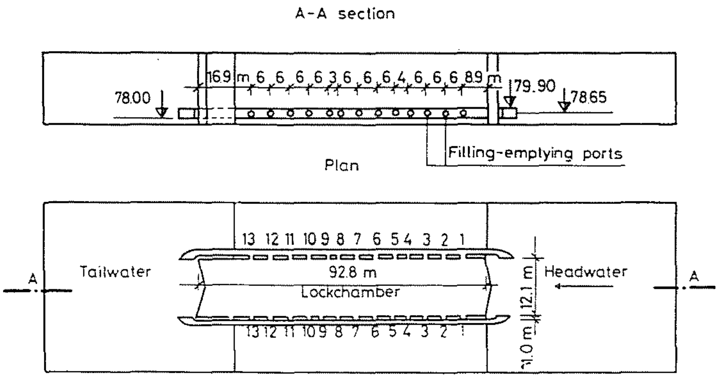

Fig. 1. Arrangement of series

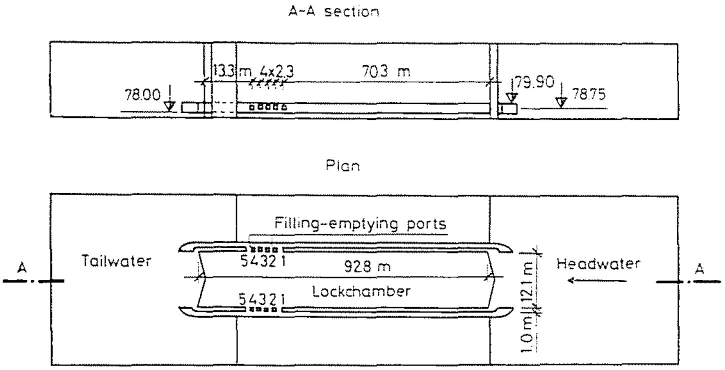

Fig. 2. Arrangement of series

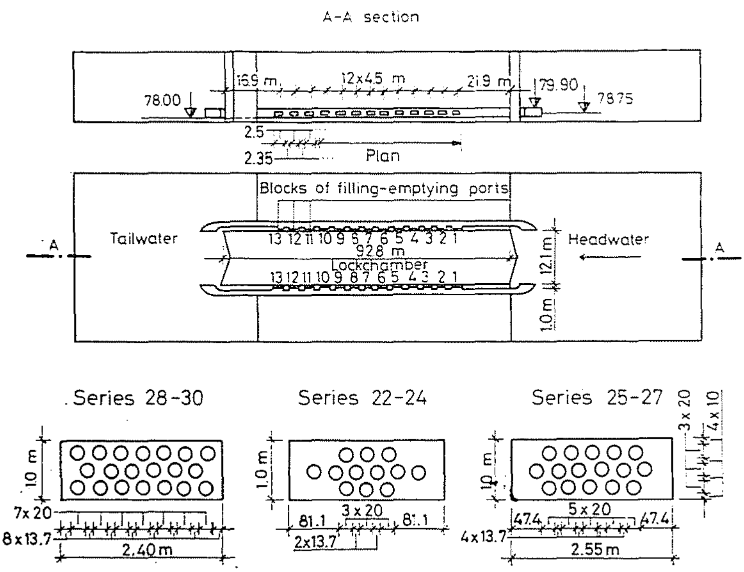

Fig. 3. Arrangement of series

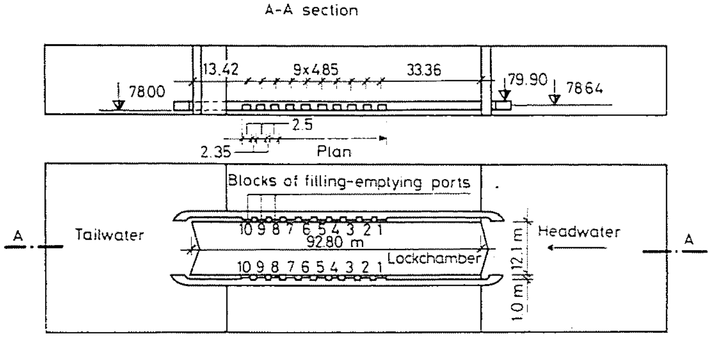

Fig. 4. Arrangement of series

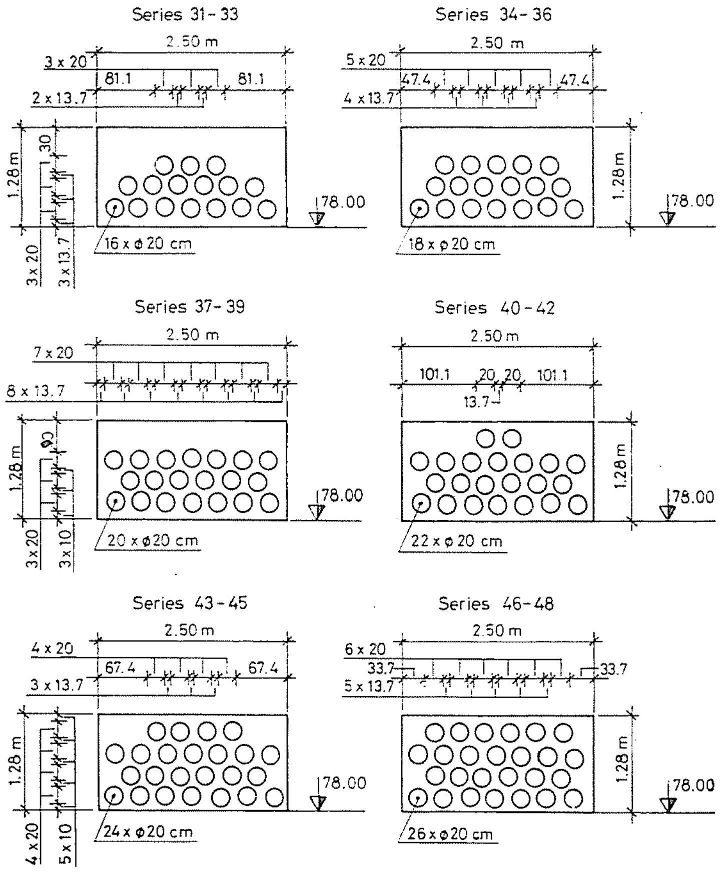

Fig. 5. The arrangement of the filling-emptying ports in series

With this new filling-emptying system, the filling-emptying time is reduced by about 1/3, the hydrodynamical forces acting on the vessels by about 1/2 and the silting tendencies of the lock chamber are also decreased.

Introduction

In the Hydraulic Laboratory of the Water Resources Management and Hydraulic Engineering Institute of the Budapest Technical University investigations of small scale model have been carried out in a wide range on the navigation locks with longitudinal culverts and side ports filling emptying system.

This type of filling-emptying system is the most common in Hungary.

The necessity of model investigations was justified by unfavourable operational experiences. Namely, the filling-emptying ports at the head gate, the area of the mitre sill at tail gate and the tail bay of the lock chambers of the filling-emptying system with longitudinal culverts are silted within a relatively short period in alluvial water flows. The siltation of the filling-emptying ports hinders further the smooth filling operation, increasing thereby the longitudinal oscillation. The siltation of the sill area obstracts the movement (closing-opening) of the gates, while the siltation of the tail bay worsen the navigational conditions.

The small scale model was based on the Kisköre Barrage System Navigation Lock, having been in operation for 13 years.

During the tests we have varied the size, shape and location of the filling-emptying ports, and the width of the longitudinal culverts.

Our aim was to find a filling-emptying port system and width of longitudinal culvert which is economical, and from the point of view of construction and operation advantageous. With the application of this system the filling-emptying period is the shortest, the levelling up and down is smooth, the peak velocity of the filling jet is reduced, thus, the dynamical effects do not danger the vessels, at the same time the siltation of the hydrodynamically shaded area is reduced in the lock chamber as well as in the tail bay.

In the system, have been found as best out of 14 series, the time period of filling-emptying is reduced by 1/3; hydrodynamical forces acting on the vessels are reduced by 1/2 and the siltation tendencies in the lock chambers are reduced, too.

We note that we did not find studies with similar topics in the literature. In this study we present the results and experiences that should be advantageous in the practice, and also, for similar studies.

Experimental

The 1 : 36.67 scale model was based on the Kisköre lock having a size of 12.1 ×92.8 meters and total lift of 10.3 m. By the variation of the filling emptying side ports (size, shape, location) and the width of the longitudinal culverts we have tested 48 series. The serial numbers and the most important data are shown in Table 1. Series 1—6 are shown in Fig. 1, series 7—21 in Fig. 2,22—30 in Fig. 3 and series 31—48 in Figs 4 and 5. In the series 22—48 new type filling-emptying ports have been tested for the spreading of the filling jets. In series 22—30 ports of 20 cm diameter were placed in 13 blocks

Serial no.	Filling emptying ports'			The culvert's	
	number, shape, size, m	cross sectional area	arrangement	width	height
1				1.6	
2	13 pcs, ϕ 0.8	6.53		2.0	
3				2.4	
4			Fig. 1	1.6	
5	13 pcs, ϕ 0.8	6.53		2.0	
6				2.4	
7				1.6	
8	3 pcs 1.00 × 1.30	3.90		2.0	
9				2.4	
10				1.6	
11	4 pcs 1.00 × 1.30	5.20		2.0	
12				2.4	
13				1.6	1.9
14	5 pcs 1.00 × 1.30	6.50	Fig. 2	2.0	
15				2.4	
16				1.6	
17	6 pcs 1.00 × 1.30	7.80		2.0	
18				2.4	
19				1.6	
20	7 pcs 1.00 × 1.30	9.10		2.0	
21				2.4	
22	13 pcs			1.6	
23	1.00 × 2.50	4.90		2.0	
24	12 pcs; ϕ 0.2			2.4	
25	13 pcs			1.6	
26	1.00 × 2.50	6.53	Fig. 3	2.0	
27	16 pcs; ϕ 0.2			2.4	
28	13 pcs			1.6	
29	1.00 × 2.50	8.16		2.0	
30	20 pcs; ϕ 0.2			2.4	
31	10 pcs			1.6	
32	1.28 × 2.50	5.02		2.0	
33	16 pcs, ϕ 0.2			2.4	
34	10 pcs			1.6	
35	1.28 × 2.50	5.65		2.0	
36	18 pcs; ϕ 0.2			2.4	
37	10 pcs			1.6	
38	1.28 × 2.50	6.28		2.0	
39	20 pcs; ϕ 0.2			2.4	1.9
40	10 pcs		Fig. 4.	1.6	
41	1.28 × 2.50	6.91		2.0	
42	22 pcs, ϕ 0.2			2.4	
43	10 pcs			1.6	
44	1.28 × 2.50	7.54		2.0	
45	24 pcs, ϕ 0.2			2.4	
46	10 pcs			1.6	
47	1.28 × 2.50	8.20		2.0	
48	26 pcs; ϕ 0.2			2.4	

with sizes of 2.5 ×1.0 meter (see. Fig. 3), and in the series 31—48 in 10 blocks with sizes of 2.5 ×1.28 meter (see. Figs 4—5). The cross-sections of blocks were rectangular, and the wall thickness was 33 cm. For strength's sake in the walls of the lock chambers concrete piers were built in between the blocks with 2 m length; and in series 31—48 2.35 m length, 1 m width and 1 m height. That is why in series the lock chambers became 67 cm wider along the blocks 22—48, than along the piers.

Summary of model experiments

In this part we present an economical and hydraulical evaluation of the results.

We note that during the tests, each measurement has been repeated 3 times. As a result, the mathematical mean value is applied. Considering that the hydrodynamical effects and the hydrodynamically shaded areas are greater during the filling period, in the following, only the results of the filling operation will be presented.

Filling time

The filling time (T) is given as a function of the period of valve opening (t_0) and that of the series.

The extreme filling times are:

Duration of valve opening t_0/min	$T_{minimum}$	$T_{maximum}$
5	6'30" (series 41)	9'35" (series 19)
6	7'04" (series 41)	9'49" (series 19)
7	7'30" (series 21)	10'27" (series 1)

The maximum filling time period at all the three valve openings belongs to the smallest width longitudinal culvert (1.6 m), while at the minimum $t_0 = 5$ and 6 min valve opening to 2.0 m width, at $t_0 = 7$ min belong to the 2.4 m width longitudinal culvert. However, the difference between minimum and maximum filling time period is 3'57" (3 min 57 s) Further variation of the filling time period should be made only by the variation of the filling-emptying system (as further changes in the cross section, size location, etc.).

Relation of the filling time period and cross sectional area, shape and location of the filling-emptying system

The relation of the measured filling time period and the cross sectional area (with the variation of the filling-emptying ports) is shown in Fig. 6. Here the variables are the filling time period (T), the cross sectional area of the filling-emptying ports (A), the auxiliary variables are the valve opening (t_0), the cross section and the width of the longitudinal culvert, and the location of the blocks of the filling-emptying ports.

The following conclusions may be drawn from the Figure:

a) To each cross section of the longitudinal culvert belongs one filling-emptying port area where the filling time period is minimum. The practical essence of the curves is, that they give the corresponding optimal cross sectional area of the filling-emptying ports and the longitudinal culvert for the minimized filling period. We have learned from our measurements, that for a filling-emptying port greater than the optimal size, a longer filling period belongs. The reason is most probably the increase of hydraulical resistances (contraction) but that should be proved more exactly on a greater scale (1 : 5; 1 : 10) models.

b) Figure 6 illustrates that the filling period is not only a function of valve opening time, cross sectional area of the longitudinal culvert and the filling-emptying ports and of their hydraulical losses, but it is greatly influenced also by the location of the filling-emptying ports. Thus in the arrangement of the filling-emptying ports (shown in Fig. 4) in 10 blocks near to the tail gate a considerably shorter filling period belongs (curves with continuous line) than to those arranged in 13 blocks (Fig. 3) uniformly along the lock chamber (curves with broken line). For example, when the $A = 7$ m² filling-

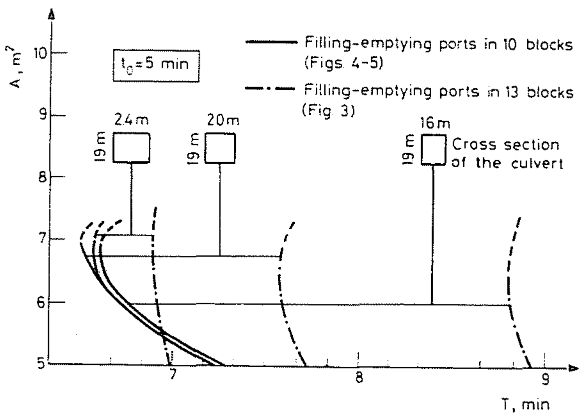

Fig. 6. Relation of the filling period and the cross sectional area of the filling-emptying system

emptying ports are arranged near to the tail gate according to Fig. 4, for the 1.6 m wide longitudinal culvert 6′37″ filling time belongs and for the 2.0 m wide longitudinal culvert 6′33″ filling time, while for the same size filling-emptying ports that are arranged in 13 blocks uniformly along the lock chamber according to Fig. 3, filling periods are 8′49″; 7′36″ and 6′35″, respectively, varied according to the width of the longitudinal culvert. As is seen in the Figure, the greater the cross sectional area of the longitudinal culvert, the shorter the filling time is.

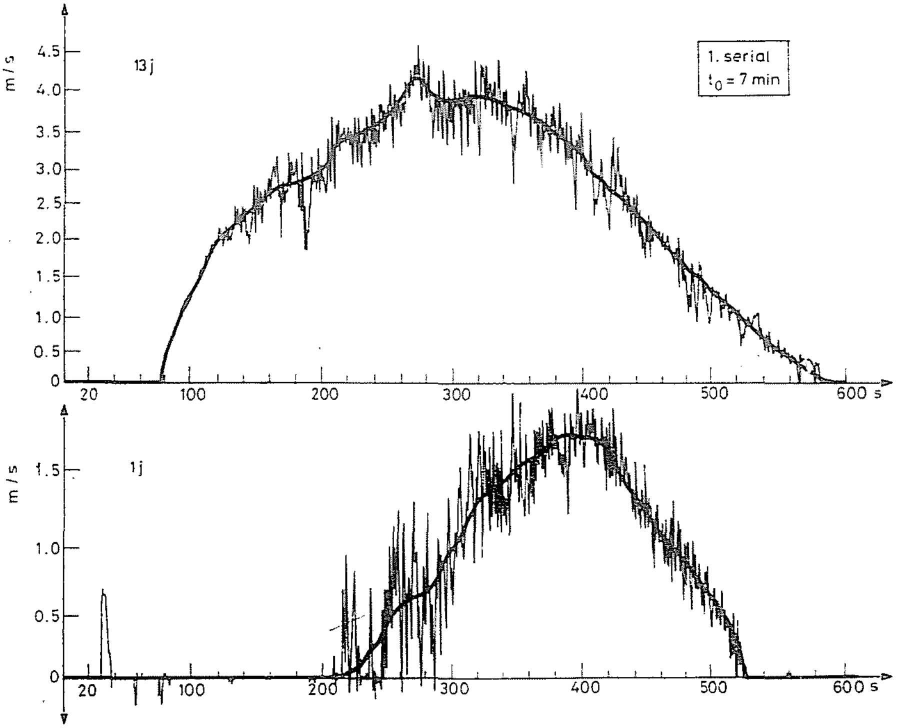

Fig. 7. Velocity time plots in series 1

c) The shortest filling time $T = 6'30''$ in Fig. 6 is obtained for a 2.0×1.9 m cross sectional culvert with $A = 6.59$ m^2 filling-emptying ports arranged in 10 blocks as is shown in Fig. 4.

d) For the arrangement shown in Fig. 4 (In 10 blocks for series 31—48), the shortest filling period belongs to the nearly quadratic (1.9×2.0 m) longitudinal culvert.

e) At the area and total lift of the lock chamber investigated the shortest filling time can be ensured by the following area ratio: $A_{zs}/A_0 = 1123/3.8 = 296$ $A/A_0 = 6.95/3.8 = 1.38$

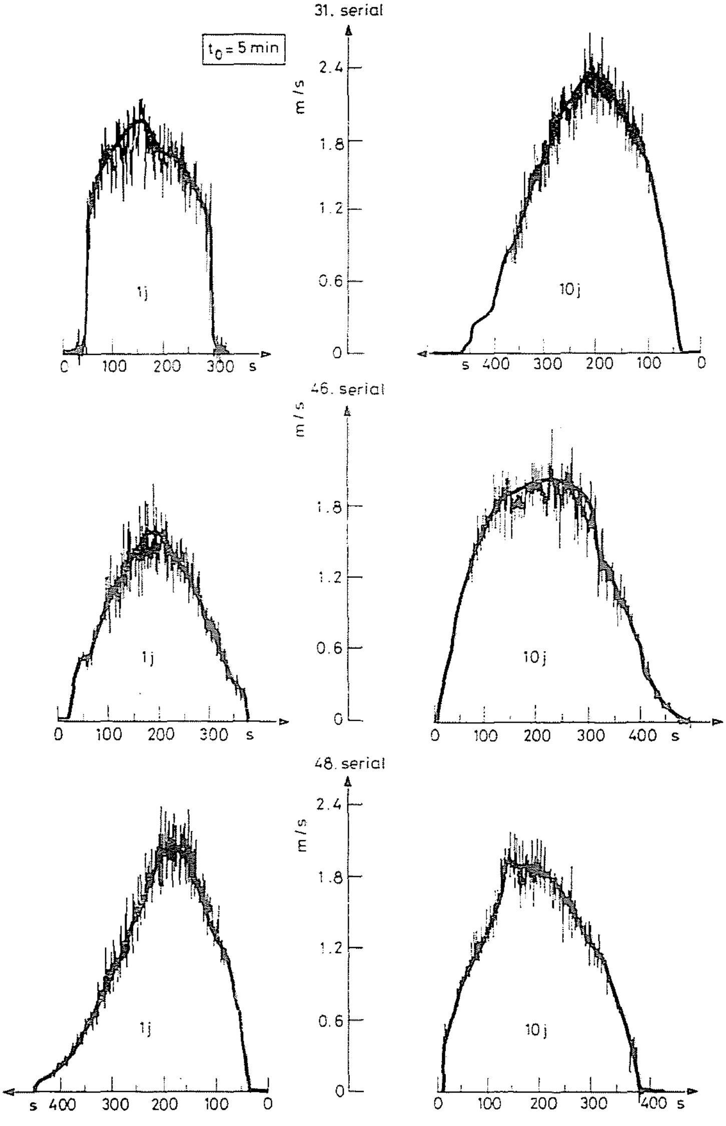

Fig. 8. Velocity-time recordings

where: A_{zs} = the area of the lock chamber

A_0 = the cross sectional area of the longitudinal culvert (at one side of the lock chamber)

A = the cross sectional area of the filling-emptying port (at one side of the lock chamber)

Hydrodynamical characteristics

For the description of the hydraulical phenomena, the variation in time of the local velocity components perpendicular to the longitudinal axis of the lock chamber, and the variation in time of the water level elevation, have been measured. We have observed a horizontal spreadings of the filling jet, the prevailing directions of the velocities on the surface, as well as the longitudinal and crossversal oscillation.

The recordings of Fig. 7 verify our assumption that the filling-emptying ports near to the head gate are unconnected later to the filling operation, and that smaller local velocities are prevailing here. As a result of this, the discharge of the ports near to the head gate is smaller then that near to the tail gate. To gain uniform discharge, in series 31—48 the blocks are arranged in the lower part — about 2/3 — of the lock chamber. The improved results are shown in Fig. 8. This shows that the upper (marked 1 j) and lower (marked 10 j) blocks have nearly equal discharges and the peaks of the local velocities are reduced by about 50 per cent, and according to this, the hydrodynamical effects on the vessels are reduced as well. The variation of the water level elevation is corresponding to the values found in the literature. It varies between 1.08—1.74 m/min for filling and emptying operation, as well. At emptying operation, we could not detect any longitudinal current.

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