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WATER FLOW INERTIA IN LONG BY-PASS FILLING SYSTEMS OF NAVIGATION CHAMBERS

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ABSTRACT

The time taken to fill and empty lock chambers is an important factor of the operation and economic parameters of waterways. It directly affects the transport capacity of waterways and can affect navigational safety at navigation locks, as well. The computations performed and terrain measurement results prove that the filling time of lock chambers is due to water flow inertia in the chamber filling system over 10% shorter compared to the results of theoretical computations, which do not take the flow inertia into account.

KEY WORDS

- navigation chambers,
- long by-pass filling system,
- water flow inertia

INTRODUCTION

Inland waterway transport is one of the oldest means of transport in continental Europe. Over the course of its historical development throughout centuries it has overcome periods of prosperity, stagnation and depression. Nowadays it is an important part of the traffic infrastructure in most industrially developed countries as well as in many developing countries. The importance of inland waterway transport was underestimated during the process of the economic transformation in Slovakia for no objective reasons whatsoever. The waterway transport of raw material and products in Slovakia has been oscillating around constant figures during a longer period of time, although as implied by the results of several studies, its importance will presumably rise in the future. This is mainly due to the fact

that the costs are relatively low, thus creating an advantage when compared to road and railway transport with the constant rise in the cost of propellants and electricity in addition to the open political and economic support of the European Union. In January 2006, an integrated action programme for the complex support of inland waterway transport in Europe *Navigation and Inland Waterway Action and Development in Europe* (NAIADES) was declared by the European Committee. This program is supposed to be carried out between 2006 to 2013. The main goal of the action programme is to balance the system of freight in the European Union, which is unilaterally oriented mainly towards road transport.

The main theme of the article relates to the chief goals of the integrated action programme of the European Union, specifically to the support of the complex innovation of technical equipment

in inland waterway transport. The European Committee in the report analyzing the NAIADES programme points out that the competitiveness of waterway transport compared to road or railway transport lowers the “narrow spots” such as insufficient navigational depth, the width of a navigation lane, the low height of bridges or the inadequate capacities of navigation chambers or ports. The article submitted deals with one of the aspects which may contribute to an increase in the competitiveness of waterway transport, i.e., the enlargement of the transport capacity of navigation chambers by a reduction in their filling time.

As to the technical practice, it is important that it is possible to design an optimal filling system when constructing new navigation chambers and choose an appropriate system for their filling which enable the use of water flow inertia in order to reduce the filling time without affecting the rules of craft safety. With regard to navigation chambers that are already, this inertia effect can be used to reduce the filling time of navigation chambers by its appropriate manipulation, for example, by already starting to open the upper gate when the water in the navigation chamber (NC) reaches the level of the upper water for the first time.

The effect of water flow inertia during the NC filling has been disregarded when projecting filling systems of navigation chambers with long bypasses and their hydraulic construction. It is necessary to focus on this phenomenon and examine it in order to reduce the filling time of navigation chambers, while maintaining the ultimate conditions of their filling, namely, the speed, safety and economy of filling, thus maintaining the former two conditions while keeping the investment and capital costs as low as possible.

EFFECT OF WATER FLOW INERTIA ON THE COURSE AND TIME OF FILLING A NAVIGATION CHAMBER

The effect of water flow inertia can be seen as the water in the bypass prevents itself from setting into motion by its inertia as the filling of the chamber starts; moreover, at the end of the filling, this is evident as the inertia is still keeping the water in motion. If the process of the actual rise in the water level in the chamber is compared to the calculated process without considering the inertia effect, it is obvious that in reality the water level in the chamber rises up more slowly in the beginning and faster later on; thus at the end of the chamber is filling, the levels of water in the chamber and in the upper reservoir do not reach a balance but exceeds the level of the upper water to a certain value ΔH . The period of time from the first opening of the seal until the balance of the water levels is reached for the first time is considered to be the time period of the filling of the chamber T^* . If compared to the time period

T calculated for the filling of the chamber without the effect of inertia, the actual time period T^* is 8 to 12% shorter. The longer and bigger the bypasses are and the faster the water circulation is, the stronger the effect of the water flow inertia is. The effect of inertia occurs in chambers with direct filling as well, but only with a minor course of the wave, which moves on the chamber from the upper to the lower gate, rebounds from it and comes back until it ceases to exist. As to long bypasses, this phenomenon is not as apparent as in chambers with direct filling and depends on the arrangement of the outflows.

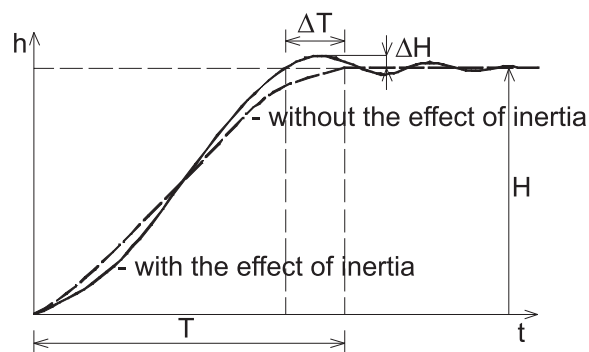


Figure 1: Effect of water flow inertia on the course and time of filling a navigation chamber.

If the effect of the water flow inertia on the time and course of the filling of the chamber is considered, the dynamic equation of the constant water circulation in the bypasses is as follows:

$$v_t = \mu_s \cdot \sqrt{2 \cdot g \cdot \left(H_t - \frac{\lambda}{g} \cdot \frac{dv}{dt} \right)} \quad (1)$$

where

v_t is the speed of the water in the bypass in time t and

component $\frac{\lambda}{g} \cdot \frac{dv}{dt}$ expresses the effect of the inertia,

λ is the virtual length of the bypasses

H_t is the head at the beginning of the interval dt ,

$\frac{dv}{dt}$ is the acceleration of the water in the bypasses

μ_s is the average coefficient of the filling

The calculation of the virtual length of a bypass λ is based on the presumption of n slots and even the outflow of the water from the filling slots into the chamber provided by the gradual increase in the distance of the outflow slots with the constant size of the outflow slots. Thus the outflow through the filling slot is:



$$Q_i = \frac{Q}{n} \quad (2)$$

Virtual length λ_i of the i – section is:

$$\lambda_i = \frac{Q-i \cdot Q_i}{Q} \cdot l_i = \frac{Q-i \cdot \frac{Q}{n}}{Q} \cdot l_i \quad (3)$$

After editing:

$$\lambda = \sum_{i=1}^n \left(1 - \frac{i}{n}\right) \cdot l_i \quad (4)$$

The behaviour of the chamber filling can be determined from the following differential equation:

$$dV = F \cdot dh = \mu_s \cdot f_i \cdot \sqrt{2 \cdot g \cdot \left(H_i - \frac{\lambda}{g} \cdot \frac{dv}{dt}\right)} \cdot dt \quad (5)$$

For the practical use of this equation, finite values Δh , Δv a Δt are used.

After further editing, it is transformed into the form of $fm = \varphi_3(t)$ with the linear course of the seal opening.

$$\left[\frac{2 \cdot F \cdot \Delta h_i \cdot t_i}{\mu_s \cdot f \cdot \Delta t_i \cdot (2 \cdot t_i + \Delta t_i)} \right]^2 - 2g \left(\left(H_i - \frac{\Delta h_i}{2} \right) - \frac{\lambda}{g} \cdot \frac{F}{f \cdot \Delta t_i} \cdot \left(\frac{\Delta h_i}{\Delta t_i} - \frac{\Delta h_{i-1}}{\Delta t_{i-1}} \right) \right) = 0 \quad (6)$$

where F is the ground area of the navigation chamber
 Δh_i is the increase of the water level in the time interval Δt_i
 Δt_i is the time interval corresponding to the water level increase Δh_i

At the time when the surface of the bypass f_m reaches the overall surface of the filling slot, it is considered $f_m = f = const$.

$$\left[\frac{F \cdot \Delta h_i}{\mu_s \cdot f \cdot \Delta t_i} \right]^2 - 2g \left(\left(H_i - \frac{\Delta h_i}{2} \right) - \frac{\lambda}{g} \cdot \frac{F}{f \cdot \Delta t_i} \cdot \left(\frac{\Delta h_i}{\Delta t_i} - \frac{\Delta h_{i-1}}{\Delta t_{i-1}} \right) \right) = 0 \quad (7)$$

As stated in these equations (6, 7), there are four variables to be found: Δh_i , Δh_{i-1} , Δt_i , Δt_{i-1} . The examined course of the filling can be calculated by using the previously chosen interval Δh_i , and counting up Δt_i thereafter or vice versa. The lower the values used in the respective components of the equation, the more accurate the calculation of the course of the filling of the NC is.

MEASUREMENT AT NC KRÁĽOVÁ NAD VÁHOM

It is possible to verify the calculation on the water flow inertia in the filling bypasses of an NC by measuring the actual course of the water elevation in an NC at an operated NC. By comparing the calculated figures to the measured ones, the rate of correspondence between the results of the calculations and measurements can be determined; thus the validity and applicability of the methodology and the theoretical apparatus can be verified. If the comparison between the calculations and measurements is relevant, the input parameters must be equivalent and the values of the filling coefficient used must be identical to the coefficient determined by the measurement as well.

The navigation chamber at the Kráľová nad Váhom water structure is projected for waterway class E 21-350, with an effective length of 110 m, a free width of 24 m and the depth of the water above the lock gate sill 4 m. The filling of the chamber is accomplished through long bypasses with dimensions of 2.0 x 3.0 m. The navigation chamber is emptied by short bypasses with a transverse profile with dimensions of 3.0 x 3.0 m. The opening time of the seal of the upper filling bypasses is 3 min. 50 s., and the closing of the seals takes 4 min. 50 s. The time period of the seal opening of the lower emptying bypasses is 5 min. 40 s with a closing time period of 6 min. 40 s. The measurements were executed by using probes which measure the position of the water level based on the water pressures intensity. Thus, the acquired data had to be converted in an apposite output file to complete the course of the NC's filling.

While the measurements were being taken, the upper water level reached 123.61 m (AMSL) at the elevation point and the lower water level was 111.42 m (AMSL); thus the head value was 12.19 m. The navigation chamber was filled through both bypasses. The slot opening speed of the filling system bypasses was $t = 3$ min. 44 s or $t = 224$ s.

COMPARISON BETWEEN THE THEORETICAL CALCULATIONS AND MEASUREMENTS AT THE OPERATING KRÁĽOVÁ NAD VÁHOM NAVIGATION CHAMBER

In order to compare the course of the filling chamber, two calculations were made, namely, a calculation disregarding the effect of the water flow inertia and a calculation considering its effect. Both were compared to the actual course of NC filling as measured in the Kráľová nad Váhom navigation chamber.



Table 1 Input data for calculating the filling time of the NC without the inertia effect T

Table of input data			
L (m)	148.90	H (m)	12.19
B (m)	24.00	F (m ²)	3573.60
K_1 (mn.m.)	123.61	μ_s	0.65
K_2 (mn.m.)	111.42	f (m ²)	12.00
t_z (s)	224.00	T (s)	834.26

The basic input parameters used in the course of the NC filling calculations were taken from the operating manual of the Kráľová nad Váhom water structure.

Difference between the NC filling time calculations not considering water flow inertia and considering it

$$\Delta T = T - T^* = 834.26 - 736.88 = 97.38 \text{ s} = 1 \text{ min } 38 \text{ s}$$

The difference is 11, 67% of the total filling time calculated.

The filling time measured directly in the NC is $T' = 20 \text{ min.}$, when the water level was balanced on the upper water level and the oscillation was smaller than $\Delta H = 5 \text{ cm}$.

Table 2 Input data for the filling time calculation of NC with the inertia effect T^*

Input parameters	
F (m ²)	3573.60
μ_s	0.65
g	9.81
t_z (s)	224.00
f (m ²)	12.00
H (m)	12.19
λ/g	21.00

If the curves of the course of the water level elevation are compared, it is evident that when the upper water level is reached for the first time as stated by measuring the actual course of the water level rise and calculating it while considering the water flow inertia effect, they are almost identical, thus in agreement with the actual water level elevation values. If the filling course curve is analyzed in detail, a minor difference between the calculated and measured figures of the water level course with the effect of the water inertia can be seen, which is caused by the use of the average coefficient of filling μ_s .

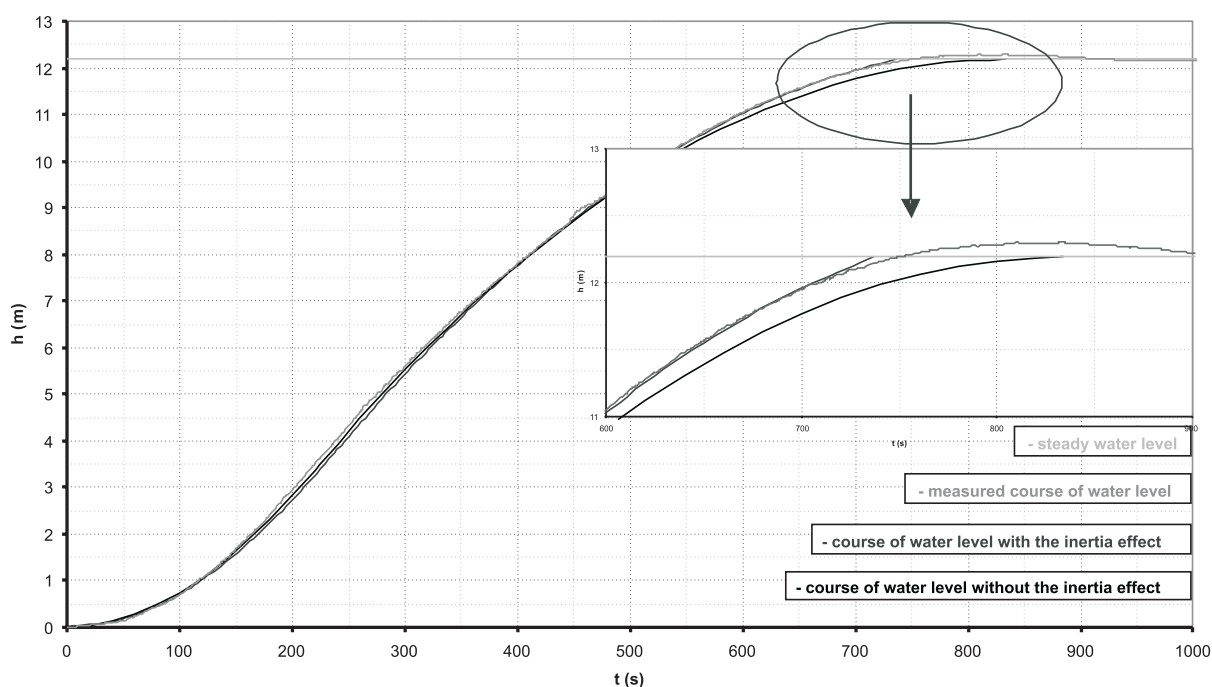


Figure 2 Kráľová nad Váhom, functionality $h = f(t)$, calculations and measurements



CONCLUSION

The time of filling and emptying a navigation chamber is an important factor in the operational and economic characteristics of waterways. It directly affects the traffic capacity of a waterway and may affect the navigational safety in the area of water structures.

Based on the calculations and measurements performed, the following conclusions may be drawn:

- It has been proved that the water flow inertia effect causes the time of filling an NC in a bypass filling system to be more than 10% shorter if compared to the results of theoretical calculations not considering it
- Based on the results of the measurements in an existing NC, it is evident that the water flow inertia effect directly depends on the type of NC filling system; thus its effect is stronger (the water level oscillation around a steady water level in an NC) if the surface of the cross-sectional profile of the filling system's bypass is longer and larger and if the water flows faster due to the value of the head
- the calculation of an NC filling course considering the water inertia effect can be automated if an appropriate programming tool is used
- Based on the mentioned relations, it is possible to choose the optimal course of chamber filling in the phase of designing a new chamber and designing an effective filling system with respect to technology, which enables the use of water flow inertia in the course of filling and reduces the sailing time
- Concerning Slovak waterways, it is possible to use the water flow inertia effect to reduce the sailing time of a vessel through a navigation chamber, e.g., WS Kráľová nad Váhom if the upper gate is opened when the level of the upper water is reached for the first time
- If this phenomenon is to be further exploited, it is necessary to analyze the utilization of various possibilities of the water flow inertia effect for NC filling with different possible combinations of upper gate filling as well as its effect on the safety of moored vessels when sailing through a navigation chamber
- The use of combined filling of an NC reduces the filling time without worsening the safety conditions of a sailing vessel. In planning and assessment stage of a filling system and a filling course, it is possible to find optimal parameters of filling slots, bypasses and gates as well as their manipulation times. Thus, it is possible to considerably reduce total sailing time through navigation chambers and increase the traffic capacity of a navigation chamber and thus an entire waterway.

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