LOCKFILL

Introduction

In order to limit the delay for navigation it is of importance that the operation of a navigation lock progresses smoothly and within a minimum of time. Therefore, it is desired that the process of filling - and emptying of the lock chamber is executed at the highest possible pace. However, lock operation must also be safe from the shipping point of view; this requires that the hydraulic forces on the ships in the lock chamber, and in particular the longitudinal forces, remain acceptable during operation and that the rise or drop of the water level in the lock chamber occurs at a moderate rate. Because the latter demands are directly related to the layout of the filling - and emptying system and the way this system is operated, a carefully designed system is required.

The main engineering challenge in the hydraulic design of a shipping lock is thus to optimise the locking procedure under the constraints of a safe operation of the lock and a minimum of delay for navigation. To get insight into the hydraulic forces and the suitability of a proposed filling – and emptying system, the designer may feel the need to reliably simulate the locking process. Also operators of existing locks may require simulations of the locking process, e.g. to evaluate the effects of a different lock operation procedure.

Deltares (former WL|Delft Hydraulics) has developed the calculation program LOCKFILL, commisioned by the Dutch Ministry of Public Works. This program enables an accurate simulation of the locking process and it computes the hydraulic forces on a ship in the lock chamber. The user

source: Beeldbank Rijkswaterstaat

Figure 1 Aerial view of the Volkerak lock complex near Willemstad (NL).

can manipulate the operating programme of the lock or change the layout of the filling and emptying system in order to arrive at an optimal solution. Dynamic hawser forces can be determined in a subsequent calculation, making use of LOCKFILL output. LOCKFILL has extensively been validated with data of existing shipping locks in the Netherlands.

Application

The LOCKFILL program is suited to shipping locks with a filling - and emptying system in the heads of the lock. Prior to the execution of a LOCKFILL simulation the discharge characteristics of this system have to be established (they form a part of the input for the program). The discharge characteristics of 'standard designs' are known. For other designs data can sometimes be obtained from experience with similar systems.

When relevant data is missing, e.g. in the case of a new layout of the filling and emptying system or when the existing experience has to be extrapolated to more severe hydraulic conditions, the discharge characteristics can best be established by means of a scale model study or a study using three-dimensional CFD calculations. These can often be limited to one of the lock heads; the discharge coefficients can be derived from stationary flow tests. The combination of a limited scale model study or numerical study and LOCKFILL computations offers an excellent and cost-effective study approach in the design stage of a shipping lock.

LOCKFILL can as well be applied for existing locks, e.g. in the case that the fairway is upgraded to a higher shipping class and the operating programme of the lock has to be adapted. LOCKFILL is frequently used in the advice activities of Deltares.

Physical and mathematical background

The LOCKFILL program simulates the filling - and emptying process of a shipping lock. The lock is schematised as a lock head at the upstream or downstream side and a rectangular lock chamber with a horizontal floor. The lock chamber is filled or emptied through the lock head. Several options for filling - and emptying structures are available within LOCKFILL, such as openings in the gates of the lock provided with lifting gates, pipes through the lock gates with butterfly valves, flat lock gates which can slightly be lifted, and short culverts in the walls of the lock heads.

LOCKFILL computes the water level variation and water movement in the lock chamber as a function of time starting from an initial water- level difference across the lock head. Simultaneously, the time-dependent longitudinal force on the ship is derived from the hydraulic conditions in the lock chamber. During a simulation the vertical position of the ship is adapted to the mean water level in the lock chamber. The hydraulic computations in LOCKFILL are based on a one-dimensional approach, in which cross-sectional averaged quantities are applied. Shallow-water equations are applied in the computation of the translatory waves. At the beginning of filling or emptying of the lock chamber the water-level difference is maximum and the gates of the filling/emptying system have to be operated slowly and with care, in order to limit flow velocities and translatory waves in the lock chamber. After some time the gates can be further opened at a higher velocity. The operating schedule of the filling/emptying system has to be prescribed as a function of time in a LOCKFILL run as well as the dimensions and draught of the ship in the lock chamber.

Figure 2 Levelling through gate openings of the Zuidersluis in Nieuwegein (NL).

Figure 3 Levelling through culverts of the new lock at Panheel (NL).

LOCKFILL computes the longitudinal forces on the ship which are caused by translatory waves, momentum variation, skin friction, filling jet and density differences (the latter only in the case that the shipping lock is located at the transition of salt and fresh water). In many cases the force components caused by translatory waves and momentum variation are dominant, but density waves may also cause a considerable force component. In the case of a stilling chamber the energy of the filling jet is for the greater part dissipated and when the stilling chamber is designed well, the flow into the lock chamber is equally distributed (no jet force on the ship). Common practice is that the quality of the filling – and emptying system is evaluated taking into account criteria for the maximum longitudinal force on the ship (often expressed as a permillage of the ship weight) and vertical velocity of the water surface in the lock chamber.

Figure 4 View on the Zuidersluis (left) and Kleine Sluis (right) in IJmuiden (NL).

LOCKFILL offers the possibility to define a limit value for the longitudinal force on the ship. When the computed force differs more than 2% from the limit value, LOCKFILL automatically adapts the operating schedule of the filling/emptying system and restarts the computation. This process is repeated if necessary; usually the longitudinal force on the ship converges within a few cycles to the prescribed limit value.

Input and output

The input for a LOCKFILL computation consists of the following data:

- dimensions of approach harbour and lock chamber, roughness of bottom and walls, initial water levels, density of water
- dimensions, draught, mass, skin roughness and position of the ship in the lock chamber
- layout of filling/emptying system; operating schedule as a function of time discharge coefficients of filling/emptying system
- limit value for longitudinal force (optional)

The output of the LOCKFILL computations as a function of time consists of:

- water levels in approach harbour and lock chamber; vertical velocity of water surface in lock chamber
- filling/emptying discharge; gross flow opening
- components of the longitudinal force on the ship
- operating schedule of filling/emptying system (when adapted in the LOCKFILL run; optional)
- flow velocities near the bottom of the lock chamber (optional)

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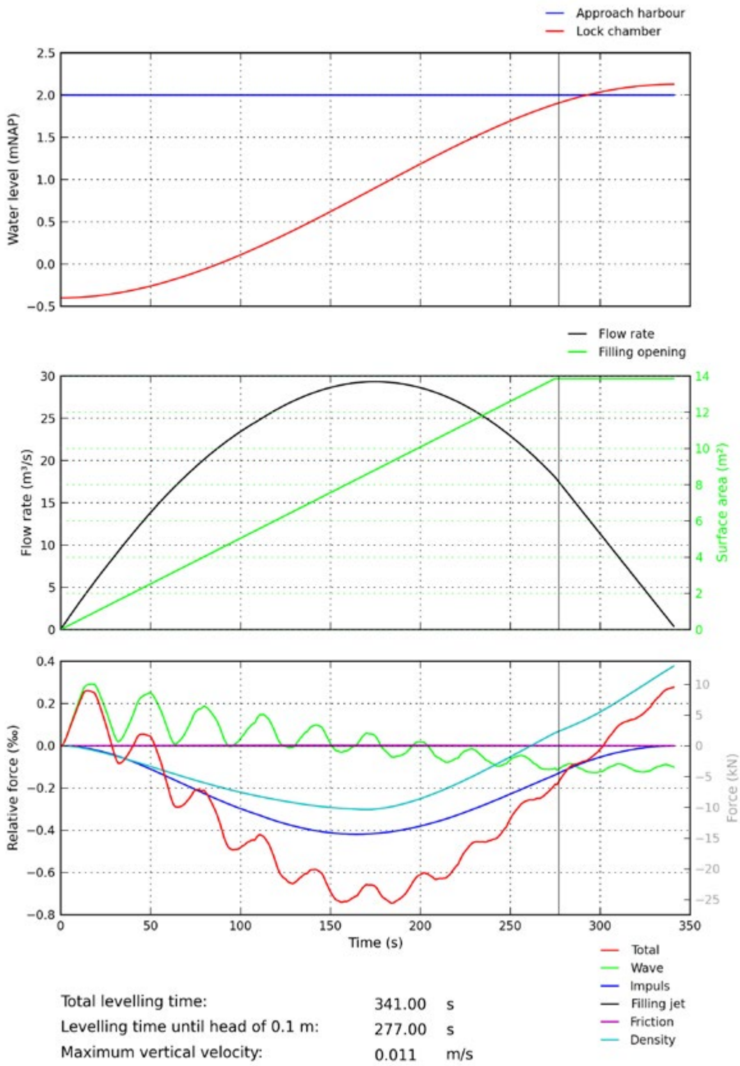
Example

The Zuidersluis navigation lock at the entrance to the Noordzeekanaal at IJmuiden (this canal connects the port of Amsterdam, Netherlands, with the North Sea) has been refurbished in the early 2000's. New mitre gates have been installed with filling/emptying openings. The design of these openings was checked with the help of the LOCKFILL program: several options were compared and the best suited in view of safety for navigation, dependability, ease of operation and structural design was selected. Design water levels at the seaside varied between +2.0 m and -1.5 m, while the canal water level was taken as -0.4 m (all water levels relative to NAP, mean sea level). A density difference of 20 kg/m^3 was taken into account. For design purposes two types of ships that regularly pass the lock were selected. The results of one of the LOCKFILL computations are shown in the graphs. The longitudinal force on the ship is expressed as a permillage of the ship weight and as a force in kN. The following data was applied in the computation:



Dimensions of sea lock		
Length	120.0	m
Width	21.5	m
Bottom	-8.5	mNAP

Dimensions of coaster in lock chamber		
Length	86	m
Width	12.05	m
Draught	4.0	m
Mass	3500	ton
Distance to lock gate	6	m

Water levels		
Sea	+2.0	m
Canal	-0.4	m

Rectangular filling openings with lifting gates.
Operating schedule; constant lifting speed of 0.004 m/s

Availability

Lockfill can be downloaded freely via

oss.deltares.nl

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