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Title:
Performance of a lock with vertical lift gates after renovation; case study including measurements and optimisation of levelling system

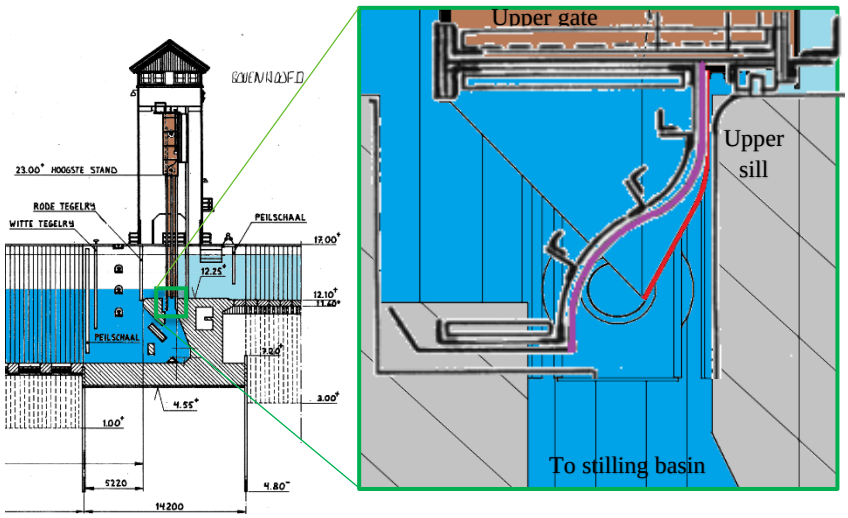
Abstract:

Lock Delden, an 80-year-old lock in the Twentekanaal (a channel in the eastern part of The Netherlands) was renovated in 2018. The renovation of the lock included additional safety measures to support a bigger class of vessel ("Class Va"), see also Veldman (2018). The levelling system with slowly opening lift gates remained unchanged. Despite the original gate lifting schedule was re-implemented, skippers noticed an increase in lock-levelling time, and thus in lock-cycle time after the renovation.

This paper describes the analyses of the levelling system after the renovation and the proposed improvements. The reengineering of the gate-lifting schedule of the renovated lock looked promising. The computed levelling of lock Delden is even faster than before the renovation. The optimised gate-lifting schedule has been implementation on 12 September 2019. Results of validation measurement are satisfactory.

Introduction to lock Delden

The lock chamber is 140 m long (between the gates), 12 m wide, and has a lift height of 6 m. Levelling is provided by controlled lifting of the lift gate in the lock head. The water flows through the horizontal slit between the lock gate and the upper sill through the stilling basin into the lock (see figure with upper lock head and detail).



The slit below the upper gate has a special shape that controls the discharge. At the bottom of the upper gate a 1 m high flow guiding sheet is fitted, that guides the flow down to the stilling basin.
The present guiding sheet (see red line) origins from 1994, when the gate was replaced. However, the original drawings from the lock (1933) indicate a different S-shaped guiding sheet (see overlay with purple line).

The original S-shaped flow guiding sheet has been designed to slowly increase the slit and the discharge in the first minutes of the gate lifting. In an introduction to the Twenthe-kanaal, Wentholt(1932) explains that the original system was developed and tested on a 1:30 scale at the Waterloopkundig Laboratorium in Delft (now Deltares). The advantage at that time was, that it allows a low (0.005 m/s) but constant gate-lifting speed while at the same time the tranquillity in the lock chamber remains acceptable. Disadvantage is that the sheet at the bottom of the gate develops a huge upward hydraulic pressure on the gate during the lifting. This upward force must be accounted in the counterbalance of the gate lifting system.

The gate in the lower lock head is lifted from a sill in the horizontal floor of the lock head. This results in a linear increase of the slit with the height the gate is lifted. The vertical lifting of the gates follows the gate lifting schedules.

Increase of levelling time after renovation

In spring 2017, about a year before the renovation of the lock, prototype measurements were carried out in lock Delden to investigate the effect of larger vessels on the locking process (Veldman,2018). The measurement included the position of the vessel and the water level in the canal and in the lock. The analyses of the measurements indicated that the filling of the lock took about 13.5 min and the emptying 9.5 min till the gate was completely lifted and the vessel could leave the lock (Aktis,2017).

The gut feelings of the skippers on an increase of the levelling time was confirmed from a video registration in July 2018, few weeks after the completion of the renovation. The video indicated that the filling took 14.5 min (=1 min extra) and the emptying 12.5 min (=3 min extra) till the gate was completely lifted and the vessel could leave the lock (Aktis,2019a). According to the conditions for the renovation, an increase of levelling time was not allowed. Bousmar(2018) showed that that for some locks, the reengineering of the valve opening law (or gate lifting schedule) can be applied successfully to optimise the levelling. For lock Delden, Rijkswaterstaat decided to reengineer the gate-lifting schedule to reduce the levelling time to the original duration or less.

Analyses of levelling process

The renovation of the lock included also the mechanical parts for the lifting of the lock gates. The requirement was to maintain the levelling time. It was decided to reproduce the original gate lifting schedule. In addition is was decided to start the final lifting of the gate already when the remaining head difference over the gate is less than 0.1 m. For this purpose, the levels of the gates and the water levels in the lock chamber and the outer harbours are permanently measured and stored by the lock operation system.

Registration of the gate level indicated, that, despite the exact reproduction of the gate lifting schedule, the time required for locking increased. Detailed analyses of 5 lock cycles indicated that the lifting schedules are indeed reproduced accurately. Nevertheless, the time from the start of levelling up to the gates being completely lifted varied from 14 to 19 min for the filling of the lock and from 13 to 17 min for the emptying of the lock. Both levelling times are significantly longer than before the renovation.

Analysis of the water-level registration from the lock-operation system questioned the reliability of the registration. Measurements of the water level in the lock and the outer harbours confirmed several imperfections in the water level registration of the lock-operation system. Moreover, the system produces only a moving average over 100 s, with a time-lag of 50 s.

These findings indicate that the water level registration by the lock operation system is not a reliable data source for controlling the opening of the lock gate. The inaccurate water level registration is most probably one of the reasons for the increase of the lock-levelling time, especially, since the final opening of the gate is related to the (measured) water head over the lock gate being less than 0.10 m.

Options to reduce the lock levelling time

The options to reduce the time for the levelling of the lock till the gate is fully lifted are:

1. Improve the accuracy of the water level registration by the lock operation system;
2. Reengineering of the gate-lifting schedules.

The accuracy of the water level registration is included in the lock renovation programme. The present work concentrates on the reengineering of the gate lifting schedules for filling and emptying.
Important aspects are:

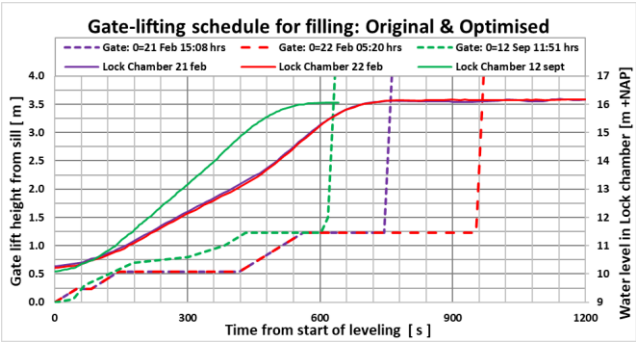
- The levelling-discharge gradient to reduce wave amplitude in the lock chamber (PIANC,2015);
- The upward hydraulic pressure on the flow guiding sheet under the upper gate (<50 kN);

The gate lifting scheme has been optimised in several steps by try and error. For each try the force on the vessel in the lock chamber was checked with LockFill Version 5.1 (Deltares,2016). Finally, the following measures have been implemented in the optimised gate lifting schedule that improve the levelling:

- Variation of the gate lifting speed;
- Reduce the number of stops during the gate lifting to one (prior to final opening); and
- Final opening of the lock gate on fixed time from start of levelling (not on measured water levels).

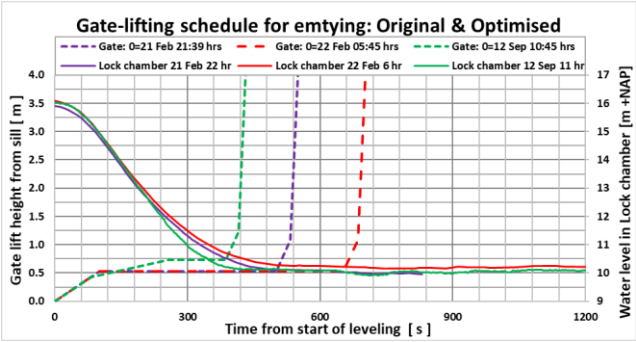
The original and the optimised gate-lifting schedules are presented in the figures below. The dashed lines indicate the gate lifting schedule, the solid lines the water level in the lock chamber. The purple and red lines present measurements (21 and 22 February 2019) with the original gate-lifting schedules. The green lines represent the optimised gate-lift schedules implemented on 12 September 2019.

The upper-gate was lifted in three steps with three stops in between: lifting up to 0.2 m, a 30 s stop, lifting up to 0,5 m, a 270 s stop, lifting up to 1.2 m and a stop till the remaining head is less than 0.1 m before the gate was lifted at higher speed for the final opening. The solid lines indicate that the filling of the lock was completed after about 12 min. However, for yet unknown reasons, the total time for the levelling and opening of the gate varied from 13.9 to 17.7 min.



The green lines show that filling has been accelerated. The total time for filling and opening of the gate has been reduced to 11.9 min.

The lower gate was lifted in one step and one stop: lifting to 0.5 m and a stop till the remaining head was less than 0.1 m before the gate was lifted at higher speed for the final opening.
The solid lines indicate that the emptying of the lock was completed after about 9 min. The total time for the levelling and opening of the gate varied from 10.4 to 13.3 min.



The green lines show that emptying has been accelerated. The total time for emptying and opening of the gate has been reduced to 8.5 min.

LockFill simulations for the optimised gate-lifting schedules indicate that the maximum longitudinal forces exerted on the vessel is reduced to 0.9‰ of the displacement (from 1.3‰).

Conclusion:

After the renovation of the mechanical and electronic part for the lifting of the lock gates the original gate lifting schedule was reproduced, but the levelling time was increased. The reengineering of the lock levelling system and the implementation of an adapted lifting schedule accelerated the lock levelling and improved the tranquillity in the lock. The main adaptations in the gate lifting schedule are:

- Remove the stops (the initial lifting schedule comprised various stops);
- Vary the gate lifting velocity (the initial lifting schedule was based on one fixed lifting velocity);
- Accelerate the procedure for the determination of the remaining head over the gate for the final opening of the gate (the moving average period was reduced and the head at final opening increased).

The reengineering of the gate-lifting schedules reduces both the filling and the emptying with at about 2 min or even more, while the longitudinal forces exerted on the vessel have been reduced to near the criterion for a Class Va lock. The lock-cycle time has been reduced with at least 10%.

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