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Feedback from 10 years of field measurement on navigation locks

Hydrolink

FEEDBACK FROM 10 YEARS OF FIELD MEASUREMENT ON NAVIGATION LOCKS

BY DIDIER BOUSMAR, CELINE SAVARY, CATHERINE SWARTENBROEKX & GIL ZORZAN

Navigation locks are the keystones of any waterway network. Design of modern locks and upgrade of existing ones rely on detailed hydraulic investigations. Besides numerical and physical modeling, field measurement is a must for existing lock diagnosis; new lock commissioning; and data collection for models validation. Such investigations necessitate specific methods considering the required accuracy of the measurements collected with non-permanent equipment in a harsh environment, while attempting to minimize traffic disturbance.

Locks and inland waterways

Navigation is an environment-friendly way of transporting goods. Its fuel consumption and related carbon emission per ton-kilometer are up to five times lower than for road transport. Navigation generates less noise than rail and road transport and has a much lower impact on natural sites and fauna. Moreover, in developed countries, waterways are usually less congested than railways and roads. As a result, inland waterways transport has an averaged share of 7% of freight in Europe and much higher share in countries with good waterways infrastructure. During the last 20 years, its growth rate rose to 25%.

Improved competitiveness of navigation is notably the result of the growth of inland vessels. Whereas 300 t and 600 t vessels were dominant fifty years ago, the European standard is nowadays a 2000 t vessel, sized 110 m x 11.40 m, for self-propelled units, and tows reaching 9000 t, sized 195 m x 22.80 m, or even more on the downstream part of the Rhine river. Larger vessels require larger locks, and the hydraulic design of these locks calls for more detailed analysis to optimize their performance. Their design has to address two concurrent objectives: (1) minimizing the transit duration, to increase the lock efficiency; and (2) reducing the perturbation generated in the lock chamber by the leveling waves, to limit the mooring forces and the risk of accidents during leveling (PIANC, 2015). Existing locks can also be re-engineered to improve their performance accordingly.

Figure 1. Measuring vessel position at Roselies lock

The constant progress of numerical and physical modeling methods supports such improved designs. Nevertheless, in many cases the field collection of hydraulic data on locks remains very valuable. Data collection may be required for improved understanding of the physical processes involved during lock leveling and/or as validation data for the improvement of the numerical modeling tools supporting lock design and operations. Data collection can confirm performances during a new lock commissioning. Lastly, data collection is also a convenient support tool for existing lock inspection, to possibly solve a reported problem or to improve its performance.

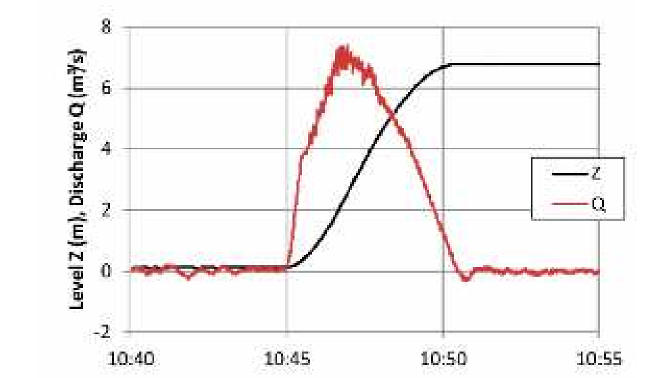

Figure 2. Filling curve for Thieu lock

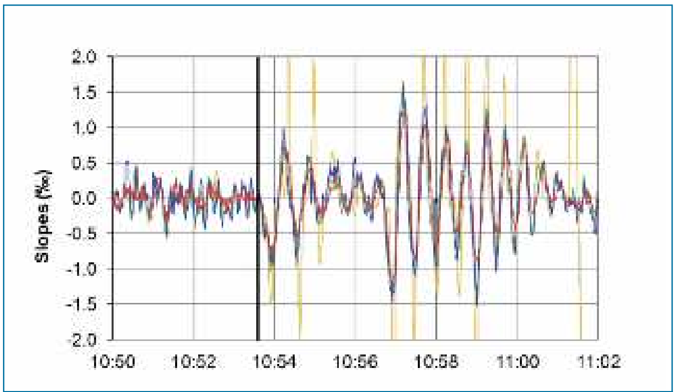

Figure 3. Filling at Roselies lock: water slope (red), vessel slope from total station (green), GPS (blue) and clinometer (yellow)

Lock instrumentation

Standard lock instrumentation is focused on the operation of the electro-mechanical system. It encompasses usually a single water level measurement in the lock chamber, one level in upstream and downstream reaches, gate and valves position, signaling, various electro-mechanic controls (oleo-hydraulic pressure, etc.) and safety equipments (CCTV, etc.). Data logging of these data is only available with recently installed controllers and, in most cases, data extraction for other purposes than electro-mechanical supervision is not easy. Specific data collection is therefore required for hydraulic investigation purposes. The necessary setup has to fulfill several requirements: (1) non-permanent use; (2) possibly harsh environment, with humidity and possible adverse meteorological conditions; (3) limited time available for measurement campaign, to limit impact on traffic; and (4) adequate accuracy regarding the investigated phenomena (Bousmar et al., 2017).

Various parameters should be collected on the lock. Water level is definitively the most important: (1) Direct measurement of the water level in the lock chamber provides the leveling curve and the locking duration; (2) Derivation of the leveling curve gives the total instantaneous filling/emptying discharge; (3) Measuring water level at several places in the lock chamber enables water slope computation; and (4) Level measurement with all gates and valves closed enables accurate estimation of gate leakage. Depending on the study objectives, single or multi-point measurements may be required. Sensors accuracy, time-resolution and synchronization are of particular importance, notably when water surface slope is investigated. Other relevant parameters that can be collected, depending on the measurement campaign purpose, are: pressure in the lock culverts; valves and/or gates position; vibration and/or noise level, notably for cavitation detection; vessel position and trim angle.

Several examples will be illustrated in this article, based on studies performed by the Hydraulic Research Laboratory of the Service Public de Wallonie, Belgium.

Data collection for model validation

Ten years ago, Wallonia initiated a large investment program on its waterway network, involving the building of several new locks. As support to this program and to the development and the validation of the numerical models used for the new locks design, the Hydraulic Research Laboratory conducted a data acquisition campaign on two locks: Thieu (Canal du Centre historique, 41 m x 5.20 m x drop 6.80 m) and Roselies (Sambre river, 112 m x 12.50 m x drop 3.60 m).

The Thieu lock is mainly devoted to recreational navigation, in such a way that almost no vessel uses this lock between November and March. Test measurements were thus done at this lock to validate the methodology for water surface slope measurement. First level measurements were collected using autonomous pressure probes with integrated data loggers. The leveling discharge $Q = A\,dZ/dt$ could easily be deduced by derivation of the so-recorded leveling curve $Z(t)$, where A is the lock chamber horizontal area (Figure 2). Due to inaccuracies in the time synchronization of the probes, the water surface slope computed from the level difference between two sensors was significantly biased: the difference due to the vertical filling velocity dZ/dt was found to be significantly higher than the actual water slope dZ/dx. Further measurements with other probes, cable-connected to a centralized data acquisition system, solved the synchronization problem and enabled adequate water surface slope estimation.

Further improvements of the measurements techniques were tested at the Roselies Lock with notably the objective to track vessel position and trim angle during leveling. The vessel position measurement equipment had to be versatile and easy to install as no specific vessel was hired for the measurement campaign: only the vessels constituting the normal traffic were instrumented. First tests were conducted with video tracking of two targets located at the bow and the stern of the vessels. As no stereoscopic system was used at the time, the lateral movements of the vessels jeopardized the analysis of the video. Further tests were conducted with clinometers and with topographic equipment (Figures 1 and 3). The clinometers did not deliver satisfactory results as a significant overshoot was observed at each peak, with also some slight phase shift at the beginning of the filling sequence. The topographic equipment provided very good results with the use of a pair of automated total stations that tracked in x, y and z two target prisms located at bow and stern, in parallel with a pair of GPS receivers. Although one total station suffered a temporary loss of its target prism due to a black cloud of smoke released by an old vessel engine, both measurements delivered consistent results. The collected observations confirmed that the vessel follows almost exactly the water slope. The analysis also highlighted the influence of the vessel obstruction on the Eigen frequencies of the waves oscillating in the lock chamber.

New lock commissioning

The new locks of Ivoz-Ramet (Meuse river, 225 m x 25 m x drop 4.45 m) and Lanaye (Canal Albert, 225 m x 25 m x drop 14 m) were commissioned in 2016. The measurement

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techniques developed previously were used to verify that the lock performances were in agreement with prescriptions and studies predictions. The following aspects were notably checked: filling time and discharge, water slope in chamber, and leveling waves (Savary et al. 2016).

In both cases, up to 25 temporary sensors were installed for a few days measurement campaign (Figure 4). In order to insure proper synchronization, most of the probes were cable-connected to data acquisition devices connected to laptops and dispatched at 3 or 4 locations. A cable loop was then installed between all acquisition devices. At the beginning of each measurement sequence, a step signal was sent on the loop and recorded by all laptops, enabling to post-synchronize all recording with an accuracy of 0.05 s. This solution was tedious to install, with large lengths of cables (e.g. at Lanaye lock, 3,300 m of temporary cables were installed) and the need of appropriate shelters, but it enabled proper measurements of all required parameters.

At Ivoz-Ramet, several filling and emptying operations were recorded, in normal and in asymmetric mode. Asymmetric mode means that one valve remains closed, which may happen during a maintenance period. All results were found conform to hydraulic design studies. Additionally, an emergency stop of the lock was tested. Filling valves were quickly closed at the peak discharge time. Large additional waves were generated by the abrupt discharge gradient, but maximum slope remained acceptable.

At Lanaye, some concerns were raised during lock building about possible cavitation risk at the valves. Accordingly, modified valve opening schedules were investigated to reduce the cavitation duration. Cavitation risk was estimated from pressure measurements in culverts and computation of the cavitation number, which expresses the ratio between the absolute pressure downstream the valve and the headloss through the valve. Noise and vibration measurements were also used in an attempt to quantify the actual cavitation level. Large high frequency vibrations were observed during the first stages of valve opening, when cavitation number is the smallest. In-situ valves inspection conducted after 12 months of service however confirmed that no cavitation damage had occurred yet.

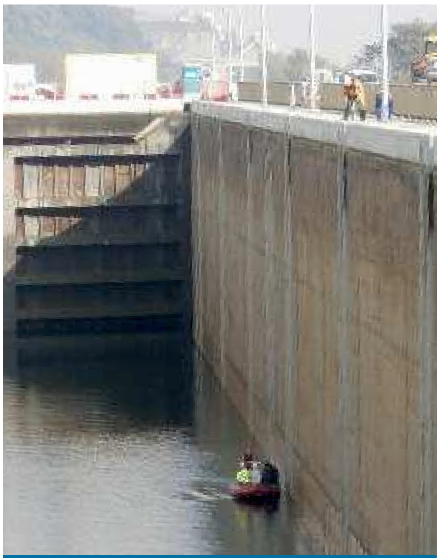

Figure 4. Installing a pressure probe in Lanaye lock chamber

Existing lock diagnosis

The measurement techniques depicted above were also applied to existing locks with the purpose of maintenance planning or performance optimization. A first example of a simple application of water level measurement in lock chamber is the estimation of leakage discharge at gate seals. Such information is relevant for maintenance work planning, for work acceptance, but also in water resource planning studies. Bousmar & Zorzan (2015) give a detailed presentation of the method. The water level is recorded in the lock chamber during periods with no navigation, e.g. during nights. All gates and valves being closed, water losses or gains are only due to leakage at the downstream or upstream gates and valves. The leakage discharge is then estimated from the time derivate of the level. A modeled leakage equation can then be fitted to the field data.

Another application of water level measurement is the evaluation of leveling surge waves propagation on the Canal Charleroi-Bruxelles (Swartenbroekx et al., 2014). Each lock emptying or filling generates waves in the adjacent reach. A too large amplitude of those waves may hinder navigation. In particular, the reach between Viesville and Gosselies locks (both 86 m x 11.50 m x drop 7.20 m and 7.50 m) is only 2.5 km long so that many wave reflections and superpositions can be observed. Measurements were conducted during night after two days of navigation interruption (during a week-end) so that only limited residual waves were present on the canal. It should be noted that a first measurement campaign did not produced accurate results due to adverse

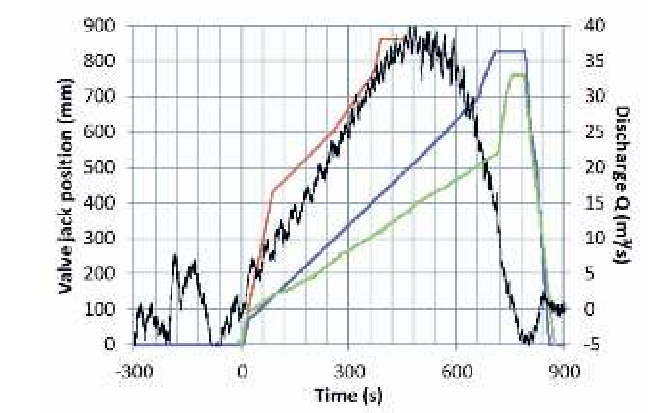

Figure 5. Valve schedule at Havré lock (red = theory, green and blue = actual left and right valve, black = discharge)

weather conditions: storms and strong wind generated too much waves at the canal surface. Several autonomous pressure sensors were installed along the canal and the locks to record the wave propagation, reflection, and damping. These results were then used to validate a numerical model to be used during the design of a second lock to be built in parallel with the existing one.

Leveling curve measurement is also useful when reworking a valve opening schedule. On the Havré lock (Canal du Centre, 124 m x 12.50 m x drop 10 m), valve schedule and filling curves were recorded when planning replacement of the whole electro-mechanical equipment of the lock. The actual valve opening schedule was found to be very different from the theoretical schedule found in original study reports (Figure 5). As a consequence, the whole filling process had to be re-studied. Recorded filling curves were then used as validation data for the numerical model. The re-engineered opening schedule enabled a gain of more than 2 minutes on the lock filling duration.

Summary

Field measurements on navigation locks are useful to support the hydraulic diagnosis of these works and to improve their performance in support of waterways transport development. As any field measurement, equipment and methodology has to be adapted to guarantee proper accuracy, with a non-permanent installation in a harsh environment. Moreover, disturbances to navigation have to be minimized. Nevertheless, properly conducted measurements proved to be valuable for data collection in support of model development and validation. Such measurements were also helpful during lock commissioning to control and optimize lock performance. When applied on existing locks, these measurement methodologies provided relevant information for maintenance planning and/or for re-engineering studies. ■

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