MOORING FORCES AND VESSEL BEHAVIOUR IN LOCKS – EXPERIENCE IN BELGIUM –

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ABSTRACT: This paper presents the approach adopted in Belgium to assess the quality of the filling and emptying process in navigation locks. It is based on physical and numerical modeling, as well as in situ measurements.

1 INTRODUCTION

Belgium, though only 30000 km² large, has a number of maritime ports and a dense network of waterways. As a consequence, numerous maritime and inland navigation locks are operational, most of them having a low lift height (< 10m) and some an intermediate lift height (10 to 15m).

Here, a brief overview will be given of the role of mooring forces and vessel behaviour in the design of these locks.

2 MOORING FORCES

Traditionally, the concern of "smooth" filling and emptying during navigation lock design is translated into a so-called "hawser force criterion". This criterion imposes an upper limit (hereafter referred to as a threshold level) to the hydrodynamic force that the water exerts on a vessel in the lock chamber. Hence – contrary to what the name of the criterion suggests – the resulting forces in the hawsers (mooring lines) or other elements of the vessel-positioning system, are not explicitly used as a design criterion. This approach was meant to simplify the classical methodology for the verification of the criterion, i.e. a physical model of the lock, with a (centrally-positioned) vessel being attached to an (artificial) force measurement set-up, rather than to (a scaled version of) a realistic vessel-positioning system.

The threshold level is usually expressed as a fraction (in per mille) of the vessel's displacement weight. Most of the time, only threshold levels for the longitudinal component of the force are considered.

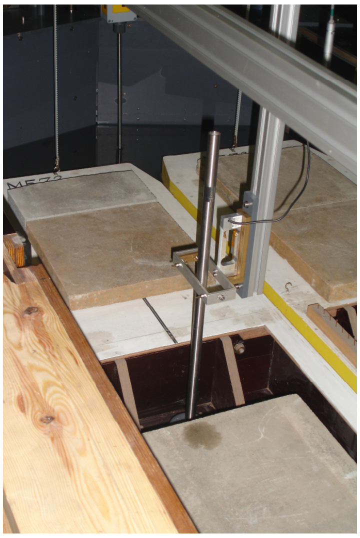

Figure 1: Measuring forces on push-tow combination in scale model

The values for the threshold level have evolved over the course of time. For quite some time, 1 ‰ was a popular value in Belgian designs. Since the nineteen eighties or so, values were adapted to evolutions in guidelines of neighbouring countries, in which the threshold level depends (somewhat) on the displacement weight of the vessel and on the characteristics of the mooring system (e.g. fixed vs. floating bollards).

Nowadays, not only physical models in the hydraulic laboratories of the Belgian regional Waterway Administrations – i.e. the "Waterbouwkundig Laboratorium" in Antwerp and the "Laboratoire de Recherches Hydrauliques" in Châtelet – are employed as verification tools (Figure 1), but also numerical models.

One type of numerical model is based on the shallow water equations to describe (in 1D or 2D) the water motion in the lock chamber in presence of vessels (modelled by artificial fields of atmospheric pressure). The time series of filling and emptying discharges that are (pre)calculated by hydraulic network models are used as boundary conditions. This type of model is applicable to (roughly) estimate the force on the vessel (Figure 2), when the longitudinal component of the hydrostatic force on a vessel (i.e. the slope of the water surface between bow and head of the vessel) is the dominant force component. Often (too often ?) this is assumed in literature.

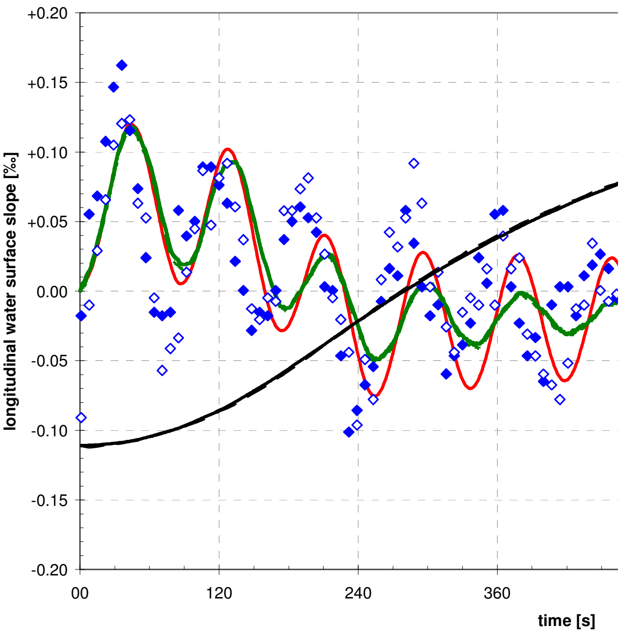

Figure 2: Comparison of numerically predicted (red line: LOCKSIM ; green line: DELFT3D) and in situ measured (blue markers) water surface slope

Since the nineteen eighties, a dedicated calculation programme for F/E systems with gate openings and slides has been developed in The Netherlands by Delft Hydraulics and Rijkswaterstaat. The so-called LOCKFILL programme allows e.g. to calculate the different longitudinal force components on a vessel. Based on the LOCKFILL literature, a similar in-house programme has recently been developed and validated at Flanders Hydraulics Research. During validation efforts, it turned out that the parameterization of the direct effect of the concentrated filling flow (jet) on the bow of a ship (which is moored relatively close to the filling gate) is afflicted with some uncertainty.

With respect to design of F/E systems for navigation locks where also recreational craft might be present in the lock chamber, the use of numerical models is somewhat limited so far. The reason is not only the lack of a proper validation of predicted "hawser forces", but neither is it obvious how to (additionally) assess the sensitivity to "turbulence" that is stated in literature for these small crafts. Moreover, recreational vessels might be moored close to the filling gate (i.e. ahead of professional vessels in the lock chamber, in order to avoid the effects of the propeller wash of the latter), where the impact of local flow phenomena is larger.

3 VESSEL BEHAVIOUR

In the framework of the conceptual design of the new Panama Canal locks, a reflection has been made on the specification of "hawser force criteria" for the associated numerical and physical modelling work (De Mulder, 2007 and 2009). Inspired by the work of (Partenscky, 1986) and (Vrijburcht, 1994), criteria for the maximum allowable force on the design vessel have been sought which take into account characteristics of the vessel-positioning system.

Additional to these efforts, a full dynamic analysis has been made of the vessel motion and the forces in the mooring lines (Vantorre, 2008; Roux et al, 2010), under the action of the hydrodynamic forces during lock-filling, which were (previously) predicted by numerical models and/or measured in the physical model. The purpose of this analysis was to assess whether these hydrodynamic forces could be considered as acceptable. Eventually, a mooring configuration making use of the ship's own winches and lines (four springs and four breast lines) was considered, controlled by a very simple algorithm that could potentially be used during manual control, to keep the ship more or less centred in the lock chamber by means of line forces that are within 20% of the minimum breaking load. Criteria for the magnitude of the horizontal forces could be formulated; for the lateral force and yawing moment, which showed significant oscillations, it was concluded that the importance of the peak values was rather limited, and that a running average over, in this particular case, 25 s could be applied without affecting the controllability of the design vessel.

So far, the abovementioned efforts that were triggered by the conceptual design of the new Panama locks, have not yet been applied subsequently in the design of new Belgian locks, for which still more "classical" approaches are adopted.

Nevertheless, the issue of mooring forces and vessel behaviour is still an active research topic in Belgium. Frequently, in situ measurements of the water surface slopes during lock filling/emptying – which are a measure of the hydrostatic forces on vessels moored in the lock chamber – have been carried out (see e.g. De Mulder et al., 2010). More recently, both the hydraulic research laboratories in Antwerp (Figure 3) and in Châtelet (Bousmar, 2011) attempt to measure the associated vessel motion during lock-filling.

All these research efforts are not only meant to collect validation data for models, but – more importantly – aim at getting more insight into the phenomena and (eventually) better-founded design criteria, which are not overly conservative while still assuring safe and comfortable lock transits. In this respect, it is felt that also sufficient weight should be given to "testing at prototype scale" of e.g. alternative valve opening schedules.

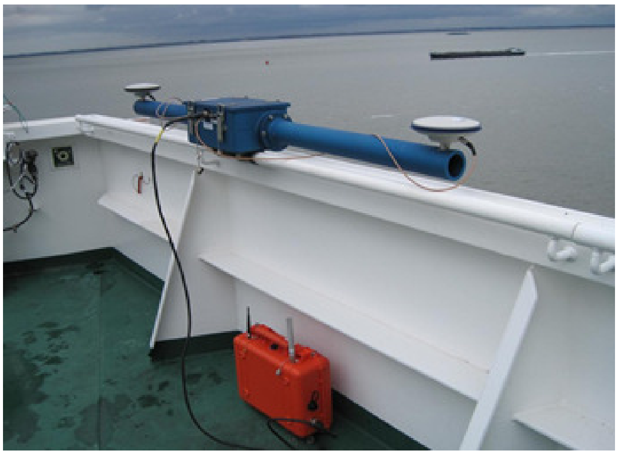

Figure 3: In situ measurement of vessel motion

4 REFERENCES

De Mulder, T. (2009). Mooring forces and ship behaviour in navigation locks. Paper 7 in International Workshop on "Innovations in Navigation Lock Design", PIANC-Brussels-Belgium, 15-17 Oct. 2009.

De Mulder, T., Verelst, K., Vercruysse, J., De Cock, W. & Haegeman, M. (2010). On hawser force criteria for navigation lock design: Case study of maritime locks in Port of Antwerp. Paper 290 in PIANC MMX Congress, Liverpool-UK, 10-14 May 2010.

De Mulder, T. (2007). Specification of hawser force criteria. Report TO1-Task 1.2.4-CNR-FHR-R013 of Consorcio Pos-Panamax, commissioned by the Autoridad del Canal de Panama.

Partenscky, H.-W. (1986). Binnenverkehrs-wasserbau – Schleusenanlagen. Springer-Verlag, Berlin.

Vrijburcht, A. (1994). Troskrachtcriteria in schutsluizen, report Q1443, Delft Hydraulics.

Vantorre, M. (2008). Mooring layout for lock filling/emptying. Annex 3-22 in report TO5-Task5.1-CNR-R002 of Consorcio Pos-Panamax, commissioned by the Autoridad del Canal de Panama.

Roux, S.; Roumieu, P.; De Mulder, T.; Vantorre, M.; De Regge, J.; Wong, J. (2010). Determination of hawser forces using numerical and physical models for the third set of Panama locks studies. PIANC MMX Congress, Liverpool, UK, May 2010.

Bousmar, D. (2011). In-situ measurements of vessel behavior during lock operation. Proceedings of Smart Rivers 2011 Conference, New Orleans-USA, 13-14 Sep. 2011.

Schohl, G.A. (1998). User's Manual for LOCKSIM – Hydraulic simulation of navigation lock filling and emptying systems, Tennessee Valley Authority, August 1998.