ON A PRAGMATIC FORCE CRITERION FOR THE DESIGN OF A NAVIGATION LOCK FILLING AND EMPTYING SYSTEM.

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SUMMARY
Prior to the design of the filling and emptying system for a new maritime lock in the harbour of Zeebrugge, a measuring campaign in a similar lock, the Vandamme lock, was carried out. During this campaign the variation of the water surface in the lock was measured. Consequently the end-to-end water surface slopes were calculated. Based on these data and based on the experience of the lock authorities that in the actual situation vessels similar to the design vessel of the new lock transit the Vandamme lock without encountering any problems, a pragmatic criterion for the maximum allowable force on the design vessel for the new lock is derived. This pragmatic criterion was adopted to verify the maximum longitudinal force on the design ship predicted with the numerical model during the preliminary design of the filling and emptying system of the new lock.

1. INTRODUCTION

During the filling and emptying of a navigation lock a ship is usually moored with mooring lines along the lock chamber walls. Consequently the forces acting on the ship generate forces in the mooring lines. This paper will elaborate on the hydrodynamic and hydrostatic forces on a ship during the filling and emptying of a lock. Unless stated otherwise, the forces in the mooring lines itself will not be considered in this paper.

The design of the filling and emptying system of a lock is usually a balance between the obtaining of an acceptable filling and emptying time of the lock and the maximum allowable force on the design ship. A faster filling and emptying of the lock results in generating higher, possibly unacceptable hydrostatic or hydrodynamic forces on the ship. On the other hand, to prevent damage of the mooring lines or damage of the ship(s) and lock infrastructure, a smooth variation of the water surface in the lock chamber and limited hydrodynamic forces on the moored ship(s) are aimed at. The latter usually requires a slower opening of the valves of the filling and emptying system.

The design of a filling and emptying system for a lock generally consists of the two following stages:

- The choice of type and dimensions of the filling and emptying system, usually based on common practice or guidelines and preliminary design formulae.
- Using a numerical or physical model, the forces acting on the design ship in the lock are predicted. It is then verified whether the predicted forces meet a criterion for the maximum allowable force on the ship.

In the past, only physical modelling could be relied upon as a verification tool. Nowadays, it is preferred to apply numerical modelling, especially during the preliminary design phase. A major issue for the verification phase concerns the definition of the criterion of the maximum allowable force on the ship. This paper describes a possible method to deal with the definition of the maximum allowable force on a ship for the numerical modelling during the preliminary design.

All examples described in this paper concern locks with filling or emptying through openings in the gates. Therefore only this type of filling and emptying system is considered.

Section 2 of this paper discusses the force on a ship during the levelling of the lock.

Section 3 discusses measuring of forces on a ship during lockage and measuring of the water surface slope in a lock. It will be explained that measuring the water surface slope in a lock chamber is a means to assess the hydrostatic force component on a ship. Based on a scale model test for the Zemst lock, it will be demonstrated that the hydrodynamic force on the ship and the water surface slope in the lock chamber are (often) well correlated and that the hydrostatic force is the dominant component.

Section 4 of the paper discusses the measurement campaign carried out in the Vandamme lock. The definition of the pragmatic criterion for the design of the filling emptying system for a new maritime lock in the harbour of Zeebrugge is described in section 5 of this paper.

Finally section 6 summarizes the conclusions of the paper.
2. FORCE ON A SHIP DURING FILLING AND EMPTYING OF A LOCK.

When filling a lock through openings in the gate the most important force is the longitudinal force on the ship. When filling a lock chamber through the gates, the following components of the longitudinal force on a ship can be discerned ([1] and [5]):

- Forces caused by translatory waves, generated by the (in time) varying discharge through the openings in the gate. These translatory waves result in ‘sloshing’ of the water surface, resulting in hydrostatic forces on a ship.
- Force caused by the decrease of momentum, resulting in a lowering of the fluid level above the openings in the gate and a sloping water surface along the lock chamber.
- Force from the concentrated filling jets against the bow of the ship, causing a force on the hull of the ship.
- Friction from the water flowing near the hull of the ship.
- Forces caused by differences in the density between the bow and the stern of the ship.

During the emptying of a lock the component of the longitudinal force caused by the concentrated jets against the bow of the ship is not present. The absence of the concentrated jets in the lock chamber decreases the component of the force caused by the decrease of momentum in comparison to the case of lock filling.

Concerning the force on a ship during the filling and emptying of a lock, the following remarks can be formulated:

- The description above treats only the longitudinal force on a ship. Besides longitudinal forces, also transversal forces and moments on a ship might be generated during the filling and emptying of a lock. In this paper, however, the transversal forces and moments are not considered.
- Similarly, this paper only considers hydrodynamic forces induced by the filling and emptying of a lock. Forces due to wind, propeller actions and other external forces are not discussed in this paper.

3. MEASURING FORCES AND WATER SURFACE SLOPES DURING FILLING AND EMPTYING OF A LOCK

In field measurements, the forces in the mooring lines can be measured directly by placing strain gauge force transducers between the mooring lines and the bollards. Few examples of prototype hawser force measurements have been reported, e.g. in Wilhemshaven ([2] and [4]) or in Jackson Lock, Alabama ([6] and [8]).

Nevertheless, it is far more practical to measure water surface slopes in field campaigns. In literature (e.g. [5]) the end-to-end water surface slope in a lock is considered as a proxy for the hydrostatic force on a ship. Especially when filling or emptying a lock through openings in the lock gates, the hydrostatic force is usually the dominant component of the total, hydrodynamic longitudinal force on a ship.

Ample evidence for the latter statement has been reported in literature. In the present paper, an additional illustration will be provided based on scale model tests for the Zemst lock, carried out by Flanders Hydraulics Research in 2007-2008.

The Zemst lock (Figure 1; total length: 250 m, width: 25 m) is situated in Belgium on the Sea Canal between the river Scheldt and Brussels. The upper lock head is equipped with a submersible drop gate, whereas mitre gates are present in the lower lock head. In both the upper and lower lock heads, short culverts are present for filling and emptying the lock. The water levels in the upstream and downstream reaches of the canal are situated around TAW + 13.30 m, respectively TAW + 4.40 m (TAW being the Belgian vertical reference level situated around low water), yielding an initial head for lock filling and emptying of about 8.9 m. The floor level of the lock chamber is at TAW – 3.10 m.

![Figure 1 : Lock of Zemst](image-url)
The Zemst lock also disposes of an intermediate lock head, equipped with mitre gates. The latter divide the total lock chamber into an upstream (length: ca. 120.2 m) and a downstream (length: ca. 129.8 m) lock chamber. For emptying the upstream lock chamber or filling the downstream lock chamber, in the actual situation, use is made of 4 small, circular openings in the mitre gates. Each opening is sealed by a butterfly valve with a diameter of 0.90 m. The initial head of 8.9 m in combination with the limited total area of the openings in the mitre gates results in a considerable filling time of the downstream lock chamber of ca. 48 min.

In 2006, the water agency Waterwegen en Zeekanaal nv decided to renovate the mitre gates in the intermediate lock head. This renovation also included the redesign of the filling emptying system. Therefore a scale model (scale: 1/25) of the downstream lock chamber was built at Flanders Hydraulics Research in 2006. The design ships were (one or two) push tow convoys of CEMT class Va, each convoy having a total length of 108.5 m, a width of 11.4 m and a draft of 4.1 m. During the scale model tests, the bow of the design ship was positioned between 1 m and 5 m (prototype dimensions) from the intermediate mitre gates. Besides the actual system, several alternative through-the-gate filling systems with a different size of the openings, sealed with either butterfly valves or vertical lifting gates, have been tested.

Besides the measurement of the filling and emptying time of the lock also the water level variation at the upstream and downstream end of the lock chamber and the longitudinal and transversal forces on the ship in the lock were measured.

In the scale model set-up, the mooring lines to moor the ship in the lock chamber were not modelled. To measure the hydrodynamic forces on the ship, vertical beams were fixed to the ship’s hull. The movement of these beams (hence of the ship), was restrained (in one direction) by two parallel steel wires connected to a load cell (see Figure 2). For each convoy, one longitudinal force component and two transversal force components (near the bow respectively the stern) were measured.

Figure 2: Push tow convoys in the lock chamber with equipment for measuring longitudinal and transversal forces (top figure); detail of force measurement set-up (bottom figure).

Figure 3 presents a comparison between the measured longitudinal force on the ship and the measured end-to-end water surface slopes in the lock chamber both for the case of two push tow convoys as for the case of one push tow convoy in the lock chamber. Note that a negative value in Figure 3 corresponds to a movement of the ship towards the filling gate.

The graphs in Figure 3 contain all results of the present and the alternative through-the-gate configurations that were investigated. Note that those results correspond to different types or sizes of valves, valve opening laws and distances of the ship’s bow to the filling gate. This explains the rather high measured forces on the ship of approximately 7 % (expressed as a fraction of the ship’s displacement weight).
4. PROTOTYPE MEASUREMENT OF WATER SURFACE SLOPES

4.1 GENERAL

Prior to the design of the filling and emptying system for a new maritime lock in the harbour of Zeebrugge, a measurement campaign (reported in [9]) of the water surface variation in a similar lock, the Vandamme lock, was carried out (on July 17th and July 18th 2012).

The Vandamme lock is situated between the (non-tidal) inner harbour and the (tidal) outer harbour of Zeebrugge (Figure 4) along the Belgian North Sea coast. The lock is operational since 1985. The lock is equipped with 4 rolling gates. The lock chamber length between the outer rolling gates (indicated with N° 1 and N° 4 in Figure 4) is 500 m. The width of the lock is 57 m. The sill of the lock is situated at TAW – 15.00 m.

Since the end-to-end water surface slope is a measure of the hydrostatic force on a ship (provided that the ship’s length is only slightly smaller than the lock chamber length), the Zemst lock results, with a ship’s length of 108.5 m and a lock chamber length of 129.8 m, illustrate that the hydrostatic force on the ship is the dominant component of the total longitudinal force on the ship.

From the trend lines in Figure 3 it can be concluded that for this lock and these ships in the lock chamber, the maximum value of the end-to-end water surface slope amounts to about 70% in case of one ship in the lock chamber, respectively 73% in case of two ships in the lock chamber, of the maximum value of the longitudinal force on the ship.

The tide in the outer harbour varies between TAW + 0.56 m at low water and TAW + 4.21 m at high water during a mean tide. The mean water level in the inner harbour is TAW + 3.50 m.
For filling and emptying of the lock, each rolling gate is equipped with five openings of diameter 1.90 m, sealed with butterfly valves. It should be noted that in the actual situation the filling time is approximately 50 min. when the outer rolling gates are used and the initial head assumes a maximum value. During the future renovation of rolling gates number 1 and 4, four extra openings of diameter 1.90 m, sealed with butterfly valves will be installed, in order to reduce the filling and emptying time (to approximately 30 min).

To measure the water level variation in the lock chamber, a number of (synchronously logging) pressure sensors were mounted in some ladder recesses (see Figure 5) along the lock chamber walls.

The measurement campaign was carried out during mean tide conditions, with a maximum head between the inner and the outer harbour of approximately 2.9 m.

During the measurement campaign rolling gate N° 3 was out of service, for renovation purposes. Consequently the gate recess of the latter rolling gate was sealed with a bulkhead.

4.2 MEASURED WATER SURFACE SLOPES

From the measured (instantaneous) water level data, (instantaneous) water surface slopes can be calculated. The latter will be further referred to as “measured” slopes, in order to simplify the wording in this paper.

The slopes will be denoted as “Hij” (i and j being integers) when the water surface slope is calculated between water level sensors “Di” and “Dj”, as indicated in Figure 6. If the sensors near the extremities of the lock chamber are used, the corresponding slopes (e.g. H14 and H58) are referred to as the “end-to-end” slope. Similarly, “end-to-middle” slopes (e.g. H13 and H68) are based on a sensor near one of the extremities of the lock chamber and a sensor near the middle of lock chamber.

Figure 7 shows the time variation of the measured end-to-end water surface slope during filling of the lock through rolling gate N° 2. For this lockage rolling gates N°2 and N° 4 were used to close the lock chamber.

The highest end-to-end water surface slopes were measured shortly after the beginning of the filling of the lock chamber, though somewhat later than the butterfly valve opening time of 35 s.

The oscillating variation of the end-to-end water surface slopes is due to the translatory waves induced by the filling of the lock chamber. During filling a (in absolute value) maximum end-to-end water surface slope of about 0.46 ‰ is measured.
Figure 7: Variation in time of end-to-end water level slope during filling of the Vandamme lock through rolling gate N° 2 with rolling gates N° 2 and N° 4 closed

Figure 8: Variation of the (in absolute value) maximum value of the end-to-end water surface slopes (figure left) and the end-to-middle water surface slopes (figure right) as a function of the initial head during lockage of the Vandamme lock

Figure 8 presents for every lockage during the measurement campaign the variation of the (in absolute value) maximum value of the measured end-to-end water surface slopes and the measured end-to-middle water surface slopes as a function of the initial head of the lockage. It should be noted that as well as for filling as for emptying the lock, the levelling of the lock takes place using the openings in the upstream as well as in the downstream rolling gate.

From Figure 8 the following general conclusions can be drawn:

- The maximum values of the end-to-end and end-to-middle water surface slope are an increasing function of the initial head, though the increase is less pronounced for emptying as compared to filling.
• For a given initial head, the maximum water slopes are lower in case of emptying than in case of filling. This holds both for the end-to-end as the end-to-middle slopes. As mentioned in section 2, during emptying of the lock the component of the force caused by the concentrated jets is absent and the component of the force caused by the decrease of momentum is lower than during filling the lock.

• During filling of the lock with the maximum initial head of 2.9 m, a maximum value of the end-to-middle water surface slope of 0.46 ‰ is measured. With this head a maximum value of the end-to-middle water surface slope of 0.65 ‰ is measured. During emptying of the lock chamber with the maximum initial head of 2.9 m, a maximum value of the end-to-end water surface slope of 0.22 ‰ and a maximum value of the end-to-middle water surface slope of 0.32 ‰ is measured.

• For a given initial head a rather wide range of end-to-end and end-to-middle water surface slopes are measured.

It should be noted that the slope values are based on the water level measurements, hence an uncertainty estimate of the calculated slopes can be derived based upon the intrinsic accuracy of the pressure sensors and the stability of the internal clock in the self-logging devices.

Based on the data provided by the pressure sensor supplier and the duration of the measurement campaign, a total error of 0.05 ‰ on the end-to-end water surface slope and 0.09 ‰ on the end-to-middle water surface slope is estimated.

5. DEFINITION OF A PRAGMATIC CRITERION FOR FORCE ON THE SHIP IN THE LOCK

5.1 GENERAL

Similarly to the Vandamme lock, the new maritime lock in the harbour of Zeebrugge (location indicated in Figure 4) will be equipped with a pair of rolling gates in both the outer and inner lock heads. The length of the new lock will be 390 m between the outer rolling gates and 340 m between the inner rolling gates. The width of the lock will be 45 m and the sill level will be situated at TAW – 12.5 m. Similarly to the Vandamme lock, a through-the-gate filling and emptying system is selected for the new lock.

During the preliminary design phase, numerical modelling was carried out with the Car Carrier Wallenius Wilhelmsen TOMAR (length: 200.0 m, width: 32.26 m and draft: 11.0 m) as the design ship. Besides the design ship, also an “exceptional” ship, the Car Carrier Wallenius Wilhelmsen TONSBERG (length: 265.0 m, width: 32.26 m and draft: 12.30 m) and a fishing boat (length: 30.0 m, width: 7.0 m and draft: 5.0 m) were considered for the numerical modelling.

The filling and emptying of the lock chamber with these ships in the lock chamber was simulated using an in-house developed program, called “VUL_SLUIS.m”. This program computes the variations of the water level in the lock chamber, the end-to-end water surface slope and the (longitudinal) force on a ship moored in the lock chamber. The program “VUL_SLUIS.m” is very similar to LOCKFILL, a code developed in the Netherlands by Deltares and Rijkswaterstaat.

As mentioned in section 1, the definition of the criterion for the maximum allowable force on the ship is a major issue. This section will only elaborate on the definition of the verification criterion for the maximum allowable force on the ship. A detailed description of the used numerical model as well as any results of the design of the filling emptying system (reported in [10]) will not be discussed in this section.

5.2 LITERATURE

First, criteria for the maximum allowable longitudinal force on the TOMAR and TONSBERG vessels were searched for in literature.

For ocean going ships, maximum allowable values for the longitudinal (and transversal) force(s) on a ship in a lock were derived in [11], based on a rational but simplified methodology, taking into account the number of mooring lines and the mooring line and winch characteristics. It should be noted that in [11] the mooring line configuration of Figure 9 is considered.

![Figure 9: Mooring line configuration considered for definition of mooring force criteria in [11]](image-url)
Applying the criteria defined in [11] to the new maritime lock in Zeebrugge, results in a maximum allowable longitudinal force between 0.19 % and 0.36 % for the design ship TOMAR and 0.14 % and 0.26 % for the exceptional ship TONSBERG, depending on the pretension in the hawser and the type of the used mooring lines.

Another source of information in literature is [7], where a maximum allowable longitudinal force of 10 ton is advocated for ships with a deadweight up to 50,000 ton. Applying this value to the new maritime lock in Zeebrugge, yields a maximum longitudinal force of 0.25 % for the design ship TOMAR and 0.13 % for the exceptional ship TONSBERG. Note that these values are situated in the aforementioned ranges based on [11].

In the first step of the design of the filling and emptying system for the new lock, the dimensioning of the openings in the gate has been based on the preliminary design formulas published in [1], adopting the lower bound of the aforementioned ranges derived for the design ship according to [11].

5.3 DEFINITION OF THE PRAGMATIC CRITERION

During the field campaign in the Vandamme lock (see section 4.2) a maximum end-to-end water surface slope of 0.46 % (with an estimated accuracy of +/- 0.05 %) was measured. During the field campaign a ship with a similar length, width and draft as the design ship transited the Vandamme lock.

Section 3 illustrated (for a particular lock and particular configurations of ships in the lock) that for filling and emptying through openings in the gates; the end-to-end water surface slope, being a proxy for the hydrostatic force on a ship, represents the major component of the total longitudinal (hydrodynamic) force on a ship. Based on the latter statement - and taking into account that ships similar to the design ship already transit the Vandamme lock without any problems - it can be expected that the maximum longitudinal (hydrodynamic) force on the design ship in the Vandamme lock, with a maximum measured end-to-end water level slope of 0.46 %, will be higher than this measured value, even when the uncertainty of the measurements is accounted for.

To predict the maximum longitudinal force acting on the ship, some numerical model simulations for the filling of the Vandamme Lock either with the design vessel TOMAR or with the exceptional vessel TONSBERG in the lock chamber were carried out. For these simulations, the lock chamber between the outer rolling gates (N° 1 and N°4) is considered, corresponding to the maximum lock chamber length of 500 m. Similarly, the maximum value of the initial head (being 3.5 m) was adopted. For the butterfly valves, the valve opening law was specified based on the measured opening time and the angular velocities provided by the lock authority. Several distances from the ship’s bow to the filling gate were considered. For these numerical model simulations, only filling of the lock chamber was considered. From the measurements carried out in the Vandamme lock, it followed that during filling of the lock significantly higher end-to-end water surface slopes were measured. Consequently the predicted longitudinal (hydrodynamic) force on the ship will be higher during filling the lock chamber than during emptying.

During the measurement campaign in the Vandamme lock water density differences were considered to be negligible. Therefore, forces caused by density currents were not taken into account during the numerical modelling of the filling of the Vandamme lock.

The computed (in absolute value) maximum values for the end-to-end water surface slope and the longitudinal forces on the both ships for the simulations for filling the Vandamme lock (in the actual situation) are presented in Figure 10.

![Figure 10: Variation of end-to-end water surface slope and the longitudinal force on the TOMAR vessel and the TONSBERG vessel with the distance to the filling gate for filling the Vandamme Lock in the actual situation.](image)

Figure 10 allows to conclude that longitudinal forces on the TOMAR vessel between 0.89 % and 1.03 % are computed. For the TONSBERG vessel, longitudinal forces between 0.56 % and 0.68 % are computed. The end-to-end water surface slope varies between 0.27 % and 0.30 %.
With an initial head of 3.5 m, being higher than the maximum head during the measuring campaign, the numerical model computes end-to-end water surface slopes of approximately 0.30 ‰. Compared with the measured end-to-end water surface slope of 0.46 ‰, the end-to-end water surface slope clearly seems to be underestimated by the numerical model. It should be noted that the lock gate configuration for the numerical modelling (i.e. the outer rolling gates with N° 1 and 4 are used) and the lock gate configuration during the measurement campaign (rolling gates with N° 2 and 4 were used) are not identical. This complicates the comparison of the measured and computed end-to-end water surface slopes.

Computing the ratio between the computed end-to-end water surface slopes and the computed longitudinal forces on the ship results in a ratio of approximately 0.33 for the TOMAR vessel and approximately 0.50 for the TONSBERG vessel. These ratios are significantly lower than the in section 3 presented value of approximately 0.70 for the scale model tests of Zemst lock. It should be noted that the length of both ships (200.0 m and 265.0 m) is almost half the length of the lock chamber (i.e. 500 m). The ratio of ship length to lock length for the Vandamme lock (0.40 à 0.53) is considerably lower than for the Zemst lock (0.84). During the measurement campaign in the Vandamme lock a maximum value of the end-to-middle water surface slope of 0.65 ‰ (with an estimated accuracy of +/- 0.09 ‰) was measured. For the end-to-middle water surface slope, the distance between the water level sensors was about 200 m, being of the same order as the length of the considered design ship. Computing the ratio between the measured end-to-middle water surface slope and the computed longitudinal forces for the design vessel TOMAR results into values between 0.63 and 0.73, being of the same order as the value of 0.70 that was presented in section 3 based on the scale model tests for Zemst lock.

When the computed longitudinal forces on both ships are compared with the criteria for the longitudinal force on the ship suggested in literature (section 5.2), one can conclude that the filling and emptying system for the Vandamme lock in the present situation does not meet the criteria appearing in literature. Nevertheless, similar ships as the design ship pass the Vandamme lock in the present situation, without encountering any problems. This leads to the conclusion that the criteria suggested in literature, seem to be very conservative. A similar conclusion was formulated in [3], based on field measurements carried out in the Zandvliet and Berendrecht locks.

To incorporate these findings in the preliminary design, a more pragmatic criterion for the longitudinal force on a ship was defined as follows.

For the actual situation of the Vandamme lock the numerical model simulations with the filling and emptying system were carried out for the worst situation (i.e. filling of the lock, using rolling gates N° 1 and N° 4, maximum initial head) and with either the design ship TOMAR or the exceptional ship TONSBERG in the lock chamber. From these numerical model simulations, maximum values can be derived for the longitudinal force that is exerted on these ships: a value of 1.03 ‰ for the design vessel TOMAR and a value of 0.68 ‰ for the exceptional vessel TONSBERG. These values can be adopted as a pragmatic criterion for the maximum longitudinal force on these ships during the subsequent simulations with the designed filling and emptying system for the new maritime lock.

The pragmatic criterion can be summarized as follows. The longitudinal force - computed with a given numerical model - on the design ship in the lock chamber of the new lock should be lower than the maximum values of the longitudinal force on the same ship, computed with the same numerical model in the reference lock – i.e. the Vandamme lock in the present situation – with a maximum head of 3.5 m.

The definition and use of this pragmatic criterion is schematically presented in Figure 11.

![Figure 11: Schematic presentation of the defined pragmatic criterion.](image)

By defining the pragmatic criterion in this way, the uncertainty on the numerical model predictions of the longitudinal force that is exerted on the ship, is taken into account. Consequently, this pragmatic criterion can only be adopted in combination with the numerical model that was used to define the criterion. It is emphasized that the
computed “maximum values” for the force on the design ship (computed for the “reference lock”) should not be compared with results from physical models, neither with those of prototype measurements (if available), or results computed with other numerical models.

It is clear that the use of this pragmatic criterion is only possible if a “reference” lock with a similar filling and emptying system and a similar head is available. Another major constraint in the general use of this pragmatic criterion is the fact that in the actual situation similar ships as the design ship for the new lock should already transit the existing “reference” lock.

During the preliminary design of the filling and emptying system of the new lock in Zeebrugge, this pragmatic criterion was adopted. With a suitable valve opening law of the openings in the gate, the computed maximum longitudinal force on the ship can be shown to be lower than the threshold value specified by this pragmatic criterion, while the resulting filling time is still acceptable.

For comparison purposes, also a (much) slower valve opening law of the openings in the lock gate is considered during the preliminary design, i.e. a law that gives rise to maximum forces on the design ship that meet the (more conservative) criteria according to literature (see section 5.2). Due to the slower opening of the valves, the corresponding filling time is considerably higher than when adopting the aforementioned pragmatic force criterion.

The conservative criteria in literature can only be met if the valves are opened very slowly, yielding considerably high values of the lock filling and emptying time.

In this paper a pragmatic method is proposed to deal with the problem of the force criterion specification, while still allowing acceptable filling and emptying times. The approach is illustrated for a particular case, i.e. the design of a new maritime lock in the harbour of Zeebrugge.

This pragmatic method requires the availability of a similar lock – the so called “reference lock” – for which the lock authorities ascertain that ships similar to the design ships of the new lock transit in safe and comfortable conditions. In the Zeebrugge case, the Vandamme lock is such a suitable reference lock.

Using an available numerical model (validated for through-the-gate systems), the transit of the design vessel in the reference lock is simulated. The associated maximum value for the longitudinal force on the design vessel is then defined as a pragmatic force criterion for the subsequent numerical simulations of the design vessel in the new lock.

It should be emphasized that this pragmatic approach leads to a quantitative force criterion that should only be used in combination with the given numerical model that was applied to define the criterion. It cannot be extrapolated as a suitable criterion for other means (like e.g. scale modelling, field measurements or other numerical models) with which a designer might want to verify that the filling and emptying system does not give rise to unacceptable forces on the ship and water motion in the lock chamber.

It is good practice to optimize on site the valve opening laws before a new lock becomes operational. Especially if the pragmatic approach described above is relied upon, this advice should not be overlooked.

Finally, it is clear that the proposed pragmatic force criterion does not provide a workable solution to the force criterion specification problem when no reference lock is available.

For this and other reasons (e.g. lack of criteria for transversal forces; mismatch between vessel positioning in physical and numerical models as compared to the situation in the field; need to quantify comfort as a substitute to solely focusing on safety; lack of attention to recreational vessels; etc.) the force criterion specification will for quite some time remain an important research issue.

6. CONCLUSION

During the preliminary design of a filling and emptying system for a lock, nowadays usually only numerical modelling is relied upon to verify whether the (hydrostatic or hydrodynamic) forces on the design ship do not exceed a maximum allowable threshold value. Prior to the numerical modelling, the definition of such a force criterion is still a major issue.

The few criteria that have been proposed in literature for ocean-going ships, turn out to be very conservative. The latter assertion is mostly based on the outcome of field measurements, in which water surface slopes are measured as a proxy for the hydrostatic force on a vessel. This component turns out to be the dominant one in the total hydrodynamic force on a vessel, as is illustrated in scale model tests (of through-the-gate systems).
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AUTHORS BIOGRAPHY

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