Conference Paper, Published Version

Kortlever, Wim C. D.; Van der Hout, Arne; De Loor, Alexander

Hydraulic Studies of the Levelling System for the New Sea Lock at IJmuiden

Hydraulic Studies of the Levelling System for the New Sea Lock at IJmuiden

Ir. Wim Kortlever, Rijkswaterstaat
Ir. Arne van der Hout, Deltares
Ir. Alexander de Loor, Deltares

Introduction

This paper describes the results of the hydraulic studies carried out to define the contract requirements in regard to the hydraulic design of the levelling system for the new sea lock of IJmuiden. First, in the next section, the lock lay-out and the hydraulic conditions are drawn up. In the following section the dimensions and the preliminary designs of two feasible levelling systems are presented. Then, an outline is given of the findings of the numerical models (3D-CFD) and the scale model. In the last sections first conclusions are drawn and other hydraulic aspects are indicated briefly.

Layout and Hydraulic Conditions

The preliminary layout of the new lock is shown in Figure 1. The entrance from the sea is on the west side, and the North Sea Canal to Amsterdam is on the east side. In this layout, the lock head at the sea side has two rolling gates, and the lock head at the canal side has one. The gate recess of the eastern gate in the western lock head is used as a maintenance dock.

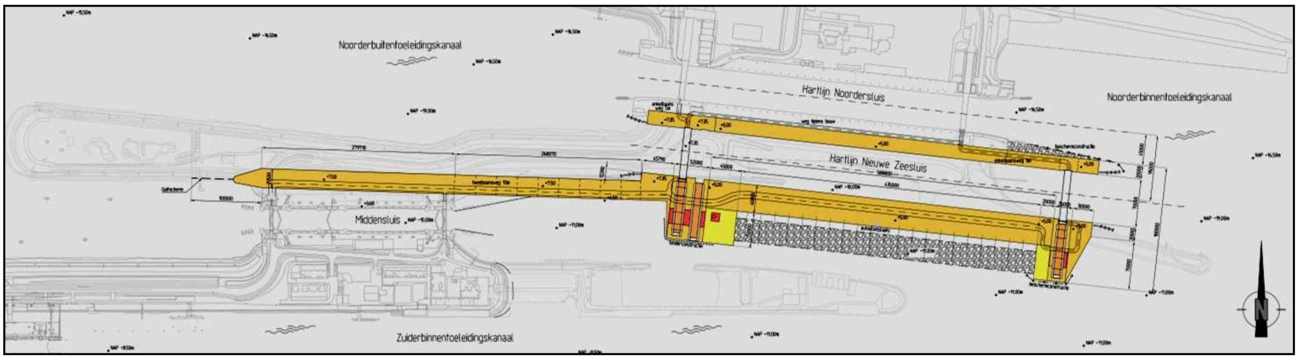

Figure 1: Preliminary layout

Approximately, the new lock will have the following dimensions: (1) overall lock length: 676 m, (2) chamber length between outer gates: 545 m, (3) overall chamber width: 70 m, (4) chamber width between floating fenders: 67 m, (5) sill level: NAP - 17.25 m, (6) chamber floor level: NAP - 17.75m (NAP: Amsterdam Ordnance Datum). The design vessels are a bulk carrier with Loa x B x T = 330m x 52 m x 19 m and a container vessel with Loa x B x T = 366 m x 52 m x 14.5 m. The maximum allowable vessel draft in salt water is 13.75 m, due to canal restrictions.

The mean spring tide corresponds to a high tide of NAP + 1.16 m and a low tide of NAP -0.72 m. The lock is closed for water levels above NAP + 3.90 m and below NAP - 1.65 m. The target water level of the canal is NAP - 0.40 m. The maximum head during levelling, with the sea at high water and the canal at low water, is 4.95 m and the minimum head, with the canal at high water and the sea at low water, is - 1.75 m. The maximum water density difference between the approach harbours is about 20 kg/m^3. The average density difference is estimated at 14 kg/m^3.

Dimensions of the Levelling System

Two types of levelling systems have been worked out: a system with a number of openings in the lock gates and a system with shorts culverts in the lock heads. The total cross-sectional area of the openings and the culverts has been determined by using the one-dimensional flow-force model LOCKFILL, which includes translatory waves, the effect of the jets and the force component due to the internal density waves (stratified flow). It has been assumed that the incoming flow from the levelling openings is well distributed over the width of the lock chamber. The flow curve and the levelling time are dependent on the chosen dimensions of the system and the valve opening program. On the basis of this flow curve, in LOCKFILL the longitudinal hydrodynamic force on the vessel is calculated, and the valve opening program (and the flow curve) is adjusted until the maximum hydrodynamic force meets the force criterion. This has resulted in an attainable maximum levelling time.

The allowable maximum hydrodynamic force on the vessel has been defined on the basis of static hawser force calculations, using the SCHAT model, while the elasticity and the slack of the hawsers has been taken into account. For a minimum hawser configuration, i.e. one hawser (angle of 45 degrees) and one spring at the bow and one hawser (angle of 45 degrees) and one spring at the stern, the criterion for the longitudinal hydrodynamic force is fixed at 0.2 ‰ of the weight of the actual water displacement of the vessel. The total transverse hydrodynamic force and the yawing moment have been converted into one force at the bow perpendicular and one force at the stern perpendicular. The criterion for the transverse force at the bow and the transverse force at the stern is fixed at 0.12 ‰.

For both gate openings and short culverts the initial LOCKFILL-calculations have resulted in a total cross-sectional area of 80 m^2: twelve gate openings of b x h = 2.2 m x 3 m or four culverts (two on the south side, two on the north side) of b x h = 4 m x 5 m (Jongeling, 2014).

The IJmuiden locks maintain the transition between the fresh (brackish) water in the North Sea Canal and the salt water in the outer port. It is assumed that, at the end of the levelling, the gate is opened when the pressure difference at the level of the gate openings or between the inlets and the outlets of the culverts is below a certain threshold. The result is an initial water level difference between the lock approach and the chamber that is mainly determined by the density difference and the levels of the inlets and outlets of the levelling system. This is illustrated by Figure 2 in which the situation at equilibrium (no flow) is shown.

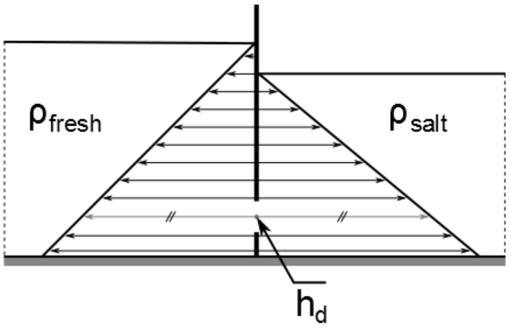

Figure 2: Water level difference due to density difference in case of equilibrium (no flow) between hydrostatic pressures at level of gate openings (h_d)

That initial water level is contributory to the residual moment and horizontal force on the gate at the time that the gate opening starts, and can also cause an external translatory wave which can exert a high short-lasting force on the moored vessel in the chamber. It can be shown that the residual horizontal force on the gate and external wave will be minimal if the level of the openings or culvert in-/outlets is halfway the water depth at the end of levelling. Therefore, it has been decided to put the openings and in-/outlets near NAP - 8.5 m, halfway the mean water column of 17 m. Point of interest is the force on the vessel due to the relatively high level of the incoming jets when the vessel is moored close to the active gate.

Hydraulic Design

Given the dimensions of the levelling systems, a number of alternatives for the layout of the culvert system have been considered. At the sea side head, it is impossible to build the south side culverts around the gate recesses, due to a lack of space. Passing below these gate recesses is regarded as not feasible, because of the soil conditions. Consequently, all four culverts pass the gate on the north side of the gate (Figure 3). Two culverts come out into the chamber through the north wall, and two culverts cross below the chamber floor and come out into the chamber through the south wall. At the canal side head, two culverts pass the gate on the north side of the gate, and two culverts pass through the gate recess, comparable to the existing North Lock (Figure 4).

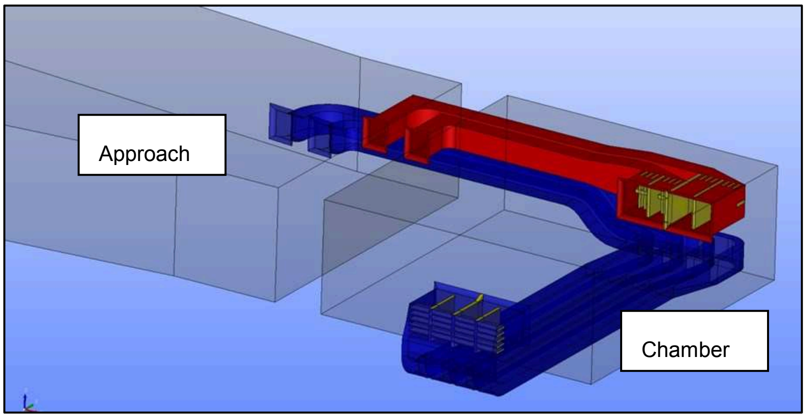

Figure 3: Sea side, lock head, two short culverts (red), two long culverts (blue)

The hydraulic design, i.e. the shaping and streamlining of especially the culvert system, has been done on the basis of flow models in CFD, with STAR-CCM+ (De Loor and O'Mahoney, 2014). To make it possible to study a large number of variants, all calculations were carried out for situations with a constant flow, and without a free water surface. Certain calculations were carried out with a density difference. The models consisted of the levelling system and parts of the lock approach and the chamber. A vessel was not included. Attention has been given to the flow conditions in the culverts or the gate openings, the detachment points of the flow and the distribution of the incoming flow over the cross section of the chamber. The loss coefficients of all specific parts of the systems have been determined. The design of the north side culverts was adapted to decrease the difference in loss coefficients between the short north side culverts and the longer south side culverts.

The culvert inlets in the lock chamber were enlarged to reduce the flow velocities and improve the flow distribution at the foremost position of the bow of the vessel. The openings between the beams and columns in the chamber inlets on the sea side have a cross-sectional area of about 80 m^2 (north) or 103 m^2 (south), and on the canal side a cross-sectional area of about 56 m^2 on both sides.

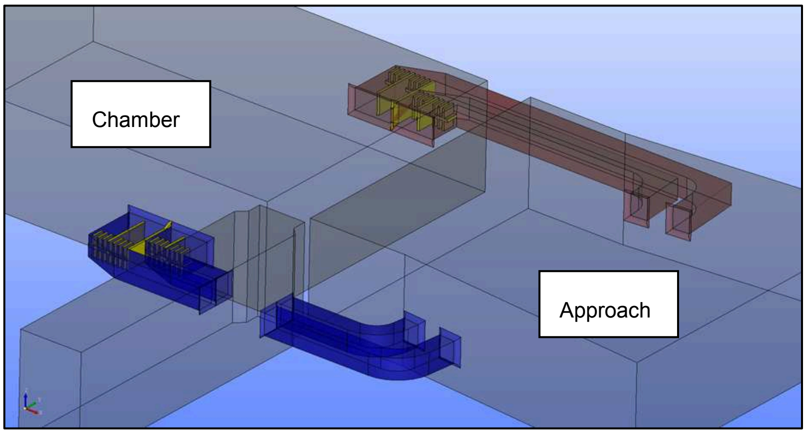

Figure 4: Canal side, lock head, south culverts connected to the gate recess

With regard to the gate openings, dissipating bars have been placed at the end of all openings in the sea side gate, to improve the distribution of the inflow into the chamber when the valves are not fully open. At the same time the number of openings has been increased from 12 to 14.

Scale Model

After the dimensions and the layout of the levelling systems had been determined with the numerical models, a scale model of the lock has been built, on a scale of 40 to 1, including both systems. This physical model serves for the validation of the hydraulic design, because, contrary to the numerical models, it includes all hydraulic phenomena. Given a scale of 40 to 1, scale effects will be limited, when compared to the prototype. The scale model is shown in Figure 5.

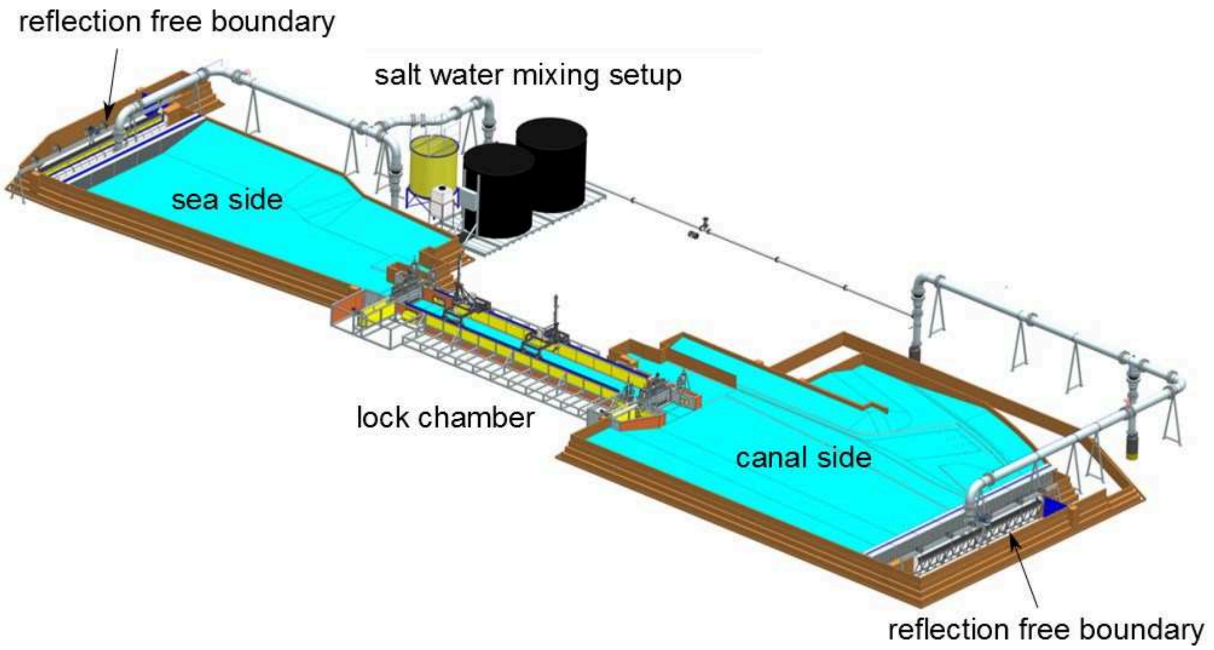

Figure 5: Scale model design, 40 to 1

The zigzag weirs at the beginning of the lock approaches are used to adjust the water levels in the lock approaches. To avoid reflections of the translatory waves a constant flow is maintained over the weirs by using a suitable pipe system. The approaches in the model have been made approximately 600 m long, to avoid that the reflections of the internal density waves interfere with the measurements. To bring about a density difference over the lock, the density of the water in the outer approach can be increased by mixing the fresh water with brine.

Important parameters which were measured during the model tests: (1) water level; during levelling the water slopes in the chamber are a measure for the forces on the vessel, (2) water density; the density forces on the vessel are mainly determined by the density distribution over the verticals on both sides of the vessel (bow and stern, port and starboard), (3) pressure; the pressures in the culverts are measured to assess the energy losses along the culverts, essential to validate the flow resistances which have been assumed in the numerical models, (4) force; the longitudinal force and the transverse forces on the bow and the stern of the vessel are measured, and the yawing moment can be derived from the transverse forces. Vessel displacements in the horizontal plane are prevented.

First, tests were carried out with a stationary flow through both levelling systems to determine the system loss coefficients. Then, levelling tests were performed without and with the main bulk carrier, still in fresh water. After that, levelling tests were carried out for a maximum density difference of 20 kg/m^3, with and without the same vessel. In the levelling tests, both the levelling times and the hydrodynamic forces were measured. For a number of density tests, at the end of the levelling process, the lock gate was opened, followed by a lock exchange. These are some of the findings of the model tests (Van der Hout et al., 2015):

- The loss coefficients of the culvert system in the scale model were higher than in the numerical model, mainly caused by the underestimation of the effect of the valves on the total flow losses. After the loss coefficients in LOCKFILL had been adjusted, the calculated filling curves corresponded well with the measured ones.
- When levelling through the gate openings in the scale model, the incline of the flow curve at the beginning of the levelling process was very steep. This high flow increase led to a higher longitudinal force on the vessel due to the first translatory wave, exceeding the force criterion. This high flow increase can be explained by the leakage around and over the valves when these are opened. Therefore, for the final design of the valves, special attention has to be given to the leakage of the valves.
- It showed that the damping of the translatory waves in the chamber is less in the case of levelling through the gate openings than levelling through the culverts.
- The maximum force in the longitudinal direction at the moment of high flow rate was higher in the scale model. To fit the measurements, the momentum force in LOCKFILL has been increased by adjusting the size of the jet, and the jet forces at the bow have been reduced.
- In the density tests, it showed that both the longitudinal and the transverse forces on the vessel in some cases exceeded the criterion as a result of the extra density component.
  The influence of the density differences on the forces is considerable and even larger than the influence of the translatory waves. The coefficients concerning the density flow in LOCKFILL had to be adjusted, especially the coefficient with respect to the mixing of the jets with the surrounding water. An example of the longitudinally measured force is given in Figure 6.
- The higher forces in the scale model tests showed that the opening speeds of the valves had to be reduced.

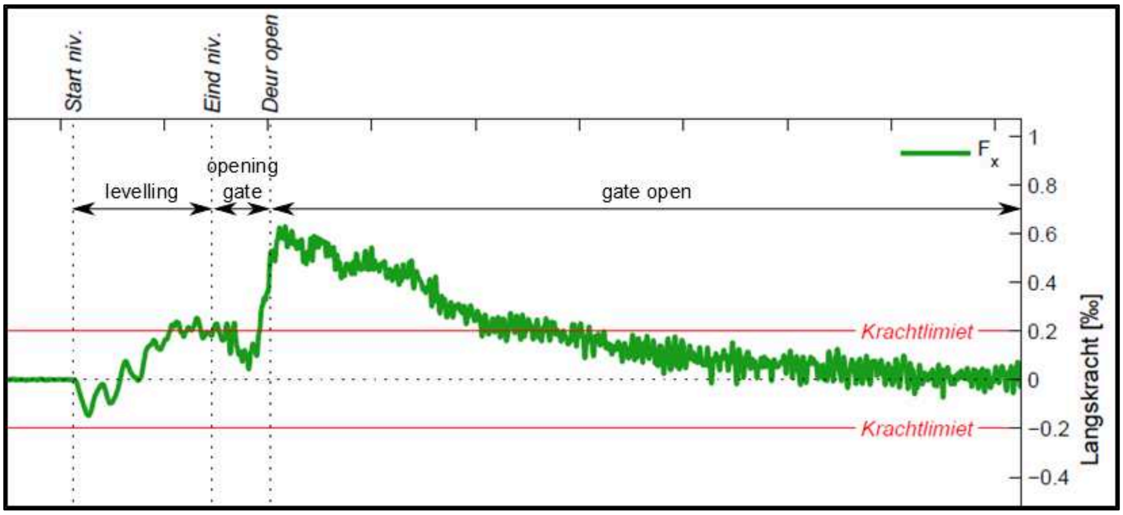

Figure 6: Test 5.02: filling through the culverts in the outer lock head, initial head 1,55 m, longitudinal force from beginning to end of levelling and after opening of the gate

Conclusion

After the calibration of the model in LOCKFILL, this numerical model has been used to determine the maximum levelling times, allowing for the inaccuracy of the model (De Loor et al., 2015). It proved that these required levelling times are longer in case of levelling through the system with gate openings, when compared with levelling through the culvert system. When the water level in the outer harbour is higher than on the canal, which is the predominant condition, the required filling times at the outer lock head are longer than the emptying times at the inner head. Due to the density difference the transverse forces during levelling may be higher than the criterion. The transverse forces are higher for the gate system than for the culvert system.

Other Hydraulic Aspects

After levelling, when the gate is opened, the lock exchange flow, given the high density difference, brings about very high forces on the vessel, directed towards the side with the higher density. Both longitudinal and transverse forces are much higher than the criteria (e.g. Figure 6). These high forces are independent of the type of levelling system. In the coming period, measures will be studied, meant either to reduce the forces, e.g. installation of air bubble screens near the lock heads, or to raise the force criteria, e.g. by applying extra hawsers or tug assistance.

At times, in the outer harbour of IJmuiden 'seiches' occur. These are standing oscillations in the closed harbour basin which are caused by atmospheric phenomena on the North Sea. The seiche amplitude may be about 0.5 m and the period, which corresponds to the basin length, is 33 min. Additional tests have been carried out in the scale model to assess the effect of seiches on the vessel moored in the lock. It showed that the forces on this vessel can rise above the criterion. In the event of seiches lock operations may be restricted.

References

Jongeling, T.H.G. (2014): Zeetoegang IJmond Nieuwe Zeesluis, Analyse van het nivelleringssysteem met behulp van rekenprogramma LOCKFILL. Rijkswaterstaat Grote Projecten en Onderhoud.

De Loor, A., O'Mahoney, T. (2014): Hydraulische vormgeving nivelleersysteem zeesluis IJmuiden. Deltares. By order of Rijkswaterstaat.

Van der Hout, A.J., Van der Ven, P.P.D., Dos Santos Nogueira, H. (2015): Resultaten schaalmodelproeven (Serie 1 t/m Serie 6). Deltares. By order of Rijkswaterstaat.

De Loor, A., O'Mahoney, T., Weiler, O. (2015): Nieuwe Zeesluis van IJmuiden, Maatgevende nivelleertijden. Deltares. By order of Rijkswaterstaat.