NUMERICAL SIMULATIONS OF A LONGITUDINAL FILLING SYSTEM FOR THE NEW LOCK AT TERNEUZEN

by

T. O'Mahoney[1], A. Heinsbroek[1], A. de Loor[1], W. Kortlever[2] and K. Verelst[3]

ABSTRACT

The lock complex at Terneuzen in the Netherlands is the link between the Port of Ghent in Belgium and the Western Scheldt. The Flemish–Dutch Scheldt Commission (VNSC) is executing its plan to build a new large lock at this complex. As part of the research on the levelling system of the New Lock, Deltares has performed numerical calculations of a conceptual design, consisting of a longitudinal filling system, similar to the one present at the West lock in Terneuzen. For this conceptual design both detailed 3D CFD simulations of particular elements of the culvert system and 1D dynamic WANDA simulations of the entire system were carried out. The results of these simulations have been used to define contract requirements for the hydraulic design of the New Lock during the tender process.

1. INTRODUCTION

The canal from Ghent to Terneuzen forms the connection between the port of Ghent in Belgium and the Western Scheldt in The Netherlands. It is the only way for sea-going vessels to reach the port of Ghent. Since the water level in the Western Scheldt is dependent on the tide and the Ghent-Terneuzen canal has a fixed target level, a lock complex was built near Terneuzen.

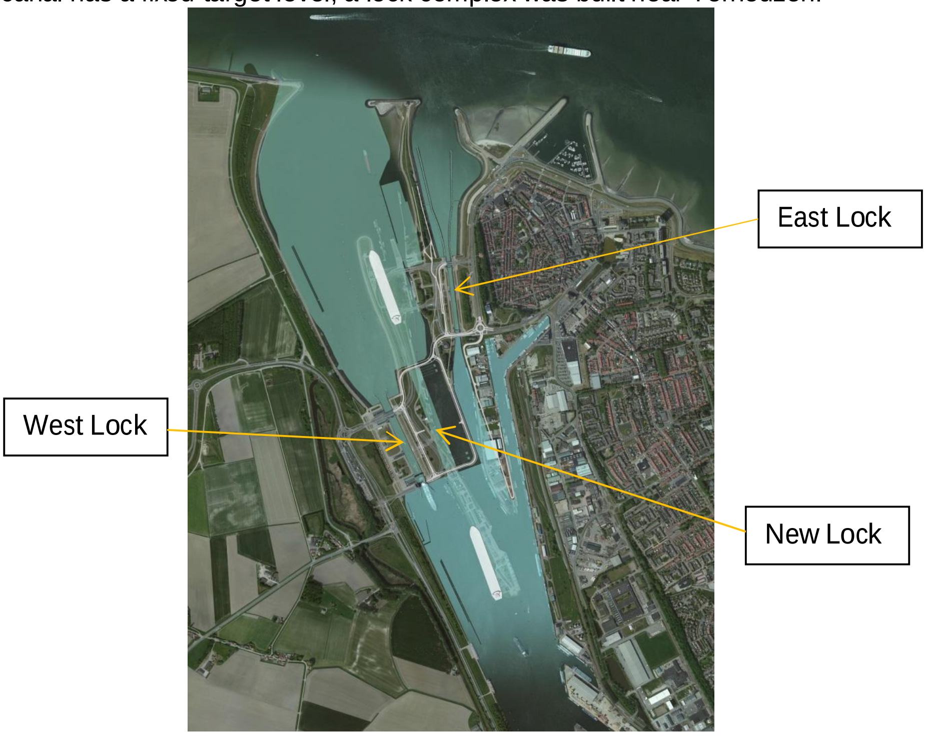

Figure 1: Layout of the new lock complex in Terneuzen (source: nieuwesluisterneuzen.eu)

[1] Deltares, Netherlands, tom.omahoney@deltares.nl
[2] Rijkswaterstaat, Netherlands
[2] Flanders Hydraulics Research, Belgium

The current lock complex consists of three locks: the Eastern Lock, the Middle lock and the West Lock. The West Lock is the largest and was constructed in the 1960s. It is sufficiently large to accommodate the Panamax class of sea-going vessels. The Flemish–Dutch Scheldt Commission (VNSC), a cooperation between the Dutch and the Belgian governments, is executing its plan to build a new larger lock at this complex, which will replace the Middle lock (Aerts et al. 2015). When completed, the New Lock will have two rolling gates at each head and a lock chamber with dimensions 55 m x 452 m between the outer doors at each head. This will rank it amongst the 10 largest locks in the world and will be sufficiently large to accommodate the Neo Panamax class of sea-going vessels. The water level of the canal is on average +2.13 mNAP (Amsterdam Ordnance Datum) and the lock operates between an extreme low tide of -2.69 mNAP (LAT) and a maximum lockage level of +4.60 mNAP on the Western Scheldt side. The largest head differences are therefore at low tide when the lock is filled from the canal or emptied to the Western Scheldt. The wish of the VNSC is that levelling can take place within 15 minutes for a head difference of 4 m, although the maximum allowed will be 20 minutes.

Recent hydraulic research at the scale model facility in Deltares, Delft, The Netherlands, on the levelling system of the New Lock of Terneuzen has shown that a system of openings in the rolling gate, as is being employed in the new sea lock of IJmuiden near Amsterdam (Kortlever et al. 2018), was not appropriate given the expected density differences across the New Lock and the desired levelling times. This conclusion is due to the large mooring forces caused by the density currents on the moored vessel during levelling (see Nogueira et al. (2018) and van der Hout (2018)). Consequently the choice was made for a longitudinal levelling system, similar to the one present at the West Lock in Terneuzen. The principle behind this choice is that density currents are generated at both bow and stern of the ship in the lock chamber and that the forces generated by these currents on the ship will partially cancel each other out leading to an overall reduction in the mooring forces. Decades of experience with the West Lock also give confidence that such a system will give acceptable levelling times even given the larger scale of the New Lock.

The final design of the lock is to be made by the contractor who will build the lock. Prior to the tender process of the New Lock, completed in the summer of 2017, additional hydraulic research was conducted at Deltares for VNSC to investigate the hydraulic dimensions of the longitudinal levelling system of the new lock. The preliminary scale model research with gate openings was completed only shortly before the start of the tender process. The additional research was conducted solely with numerical techniques in order to provide hydraulic information and requirements for the longitudinal levelling system in the tender process. A combination of 3D Computational Fluid Dynamics (CFD) of different components of the culvert system and dynamic 1D culvert simulations with WANDA (www.deltares.nl/en/software/wanda/) were used to simulate the levelling process. This approach cannot account for density flows in the lock chamber. The final design made by the contractor will partly be verified in a scale model where density differences can be accounted for.

The research regarded two alternatives for the longitudinal levelling system: One alternative where the lock is filled via bottom grids in the lock floor at ¼ and ¾ of the length of the lock chamber and one alternative where the lock is filled via openings in the wall at both sides of the lock and at both heads. The first system is similar to the levelling system of the current West Lock, the second system does not have direct antecedents, except a scale model investigation of the filling and emptying system of the Baalhoek Lock (WL Delft 1975), which was never constructed.

For both alternative filling systems detailed flow patterns and hydraulic resistances of the various elements were calculated with 3D CFD simulations. Emptying and filling situations were considered owing to the asymmetry of the system. Consideration was also given to the flow patterns in the approach harbour for the design of the intake openings. Subsequently, the calculated hydraulic resistances were used in the 1D dynamic model to simulate the levelling process in the lock chamber. The water level slope in the lock chamber could be calculated during the simulation to provide a first estimate of mooring forces and achievable levelling times. This model was also used to assess the inertia effects of the large culvert system, such as overtravel and to assess the time-dependent asymmetry of the system. Due to overtravel, the water level in the lock chamber can overshoot the water level in the approach harbour and consequently influence the force on the gates during opening at the end of the levelling process. Unequal discharges through different branches of the culvert system can lead to large forces on the moored vessel in the lock chamber. The numerical simulations showed that both types of longitudinal filling systems were feasible for achieving the desired levelling times whilst maintaining a safe levelling process.

This paper only discusses the results of the numerical modelling for the system with bottom grids because the consortium which won the tender to build the New Lock (Sassevaart[1]) has chosen this type of system. The final design of the lock, including the design of the levelling system, is carried out by Sassevaart, who will follow a similar approach for the verification of the levelling system. Because this approach does not take into account density currents, the final verification of the levelling system of the New Lock, will be made in a physical scale model at the Deltares facility after the final design has been completed.

2. DESCRIPTION OF THE SYSTEM

The variant of a longitudinal filling system with culverts on one side of the lock chamber is based on the principle of the West Lock in Terneuzen (Philpott 1961), consisting of filling the lock chamber using two bottom grids (see Figure 2). These bottom grids are located at positions of ¼ and ¾ of the length of the lock chamber (here the length is considered between the two inner gates of the lock heads). This configuration allows for the filling of the lock chamber at two longitudinal locations whereby for the normative vessel a density current at both the bow and stern will develop.

The variant for this research shows some differences with the design for the West Lock, mostly owing to restrictions on space in the already existing lock complex. A first difference is that the culvert system is positioned along the lock chamber wall opposite the gate recesses whereas for the West lock the culverts are positioned around the gates recesses. Also the inlet ports of the culverts in the approach harbour are at the same level as the culverts along the lock chamber whereas for the West lock these ports exit at the bed level of the canal on both sides of the lock. Similarly, owing to considerations about the cost of the construction all elements of the culverts are to be located within 25 m of the lock chamber wall. Additionally, the West Lock has extra valves at the T-junctions to control the flow to each bottom grid. Owing to space restraints it is not possible to add such valves to the New Lock system.

[1] Sassevaart is a consortium consisting of BAM, DEME and Algemene Aannemingen Van Laere (Source: https://nieuwesluisterneuzen.eu/partners/sassevaart)

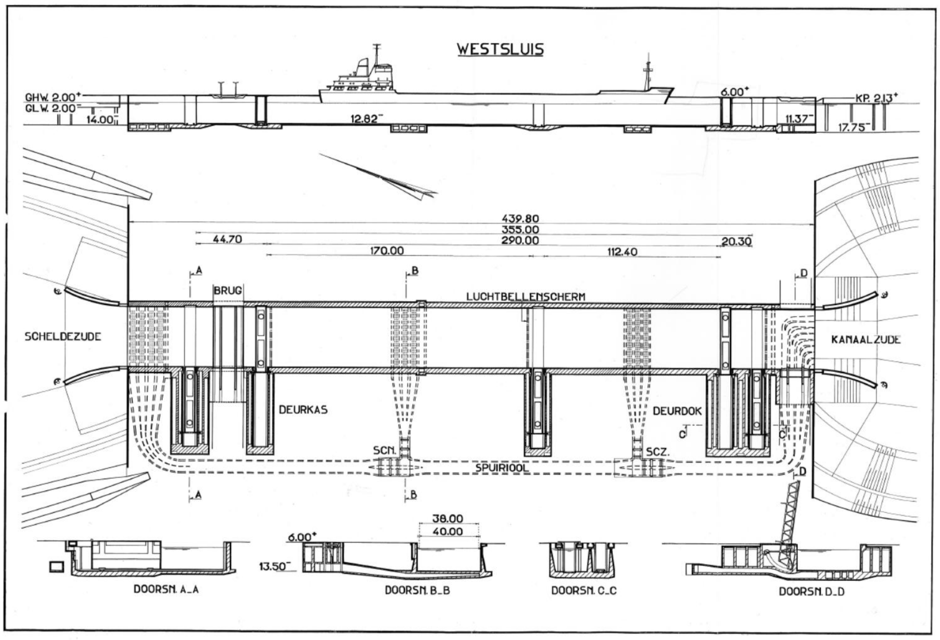

Figure 2: Summary view of the design of the West Lock

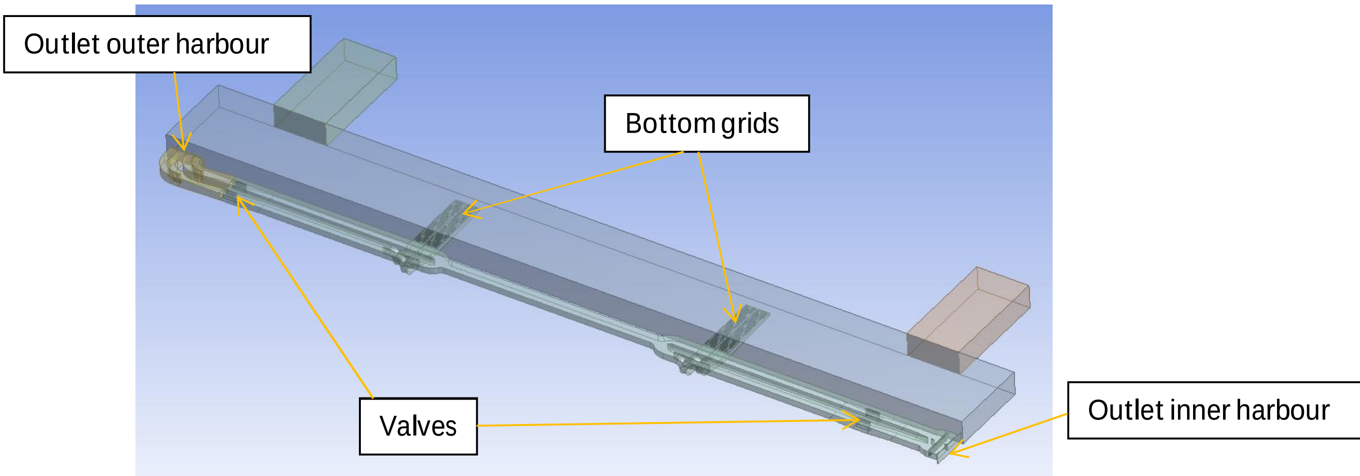

Figure 3: 3D CAD rendering of the culvert system studied for the New Lock.

The main dimensions of the conceptual design for the system of the New Lock (see Figure 3) are as follows:

- The culvert system consists of two culverts, each 4 m x 8 m. Between the two bottom grids the culverts converge. The total throughflow area in the culvert to each bottom grid is therefore 32 m^2,
- Each bottom grid is 45 m by 16.5 m. The throughflow area of each grid is 60 m^2 made up of 16x54 holes of 30 cm diameter each,
- The space beneath each bottom grid is split in two, separated by a central wall,

- Each culvert has a T-junction directed downwards which connects to a bottom grid. However, because the culverts converge between the bottom grids it is also possible for the flow to reverse itself at this convergence point and flow backwards towards the nearer bottom grid instead of onwards towards the farther bottom grid,

- The culvert valves are located at the location of the gates at each lock head and consist at each location of 4 separate valves of 5 m by 3 m, providing two valves per culvert. The smallest throughflow area in the system is located here, 30 m^2 per culvert,

- The outlet in the inner approach harbour, at the canal side, has dimensions 4 m by 22 m. The outflow direction follows the longitudinal axis of the culvert,

- The outlet in the outer approach harbor, at the Western Scheldt side, has dimensions 6 m by 22 m, being larger because of larger discharges for levelling in this direction. The outflow direction is perpendicular to the longitudinal axis of the culvert. This choice was made to generate a more favourable flow in the approach harbour for vessels entering the West Lock, whereby the flow from the new lock is directed away from the West Lock.

3. CFD MODEL OF CULVERT ELEMENTS

The culvert system was modelled using the commercial CFD software package Star-CCM+ (https://mdx.plm.automation.siemens.com/star-ccm-plus). The culvert system is divided into smaller elements and CFD models were made of each element to determine the flow patterns and resistance coefficients under steady boundary conditions. Both filling and emptying flow directions were considered. These CFD calculations cannot account for dynamic effects such as the inertia of the water, leading to overtravel in the lock chamber, or even the varying discharge in the culvert and water levels in the lock chamber. They are meant to provide the input of resistance coefficients to the 1D dynamic WANDA simulations. The resistance coefficients, ξ, were determined by the following formula:

$$\xi = 2A_{ref}^2 \, \Delta p/\rho Q^2 \qquad (1)$$

where A_{ref} is the reference flow area of the culverts [m^2] is, Δp is pressure drop across the element measured from the total pressure [Pa] (static pressure plus dynamic pressure), ρ is the density [kg/m^3] and Q is discharge [m^3/s]. A uniform density of 1000 kg/m^3 was used for these coefficients throughout this work.

The results of the CFD simulations are also judged based on flow uniformity through the bottom grids. Each bottom grid is split into sections as presented in Figure 4 and the proportion of the discharge through each section is analysed. The design is considered to be good on this aspect if the ratio of flow through each section of the bottom grid is close to 50/50 as this is expected to give lower forces on the vessels moored in the lock.

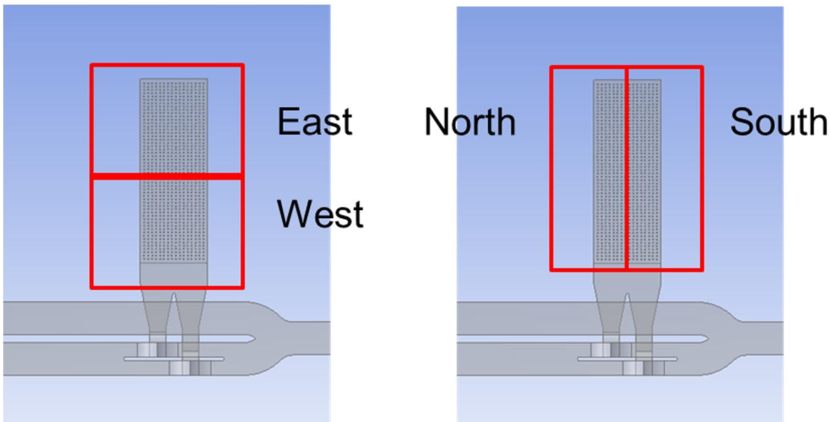

Figure 4: Plan view of the bottom grid showing the regions of interest for assessing flow uniformity

3.1 Geometry

Separate CFD models have been made for the outlet at the inner harbour, the outlet at the outer harbour and for the system of bends and T-junctions to the bottom grids including the outflow into the lock chamber. The model of the system of bends and T-junctions is for the analysis only split into sections (see Figure 5) to identify the areas of significant losses. The names of these sections are given in Table 1.

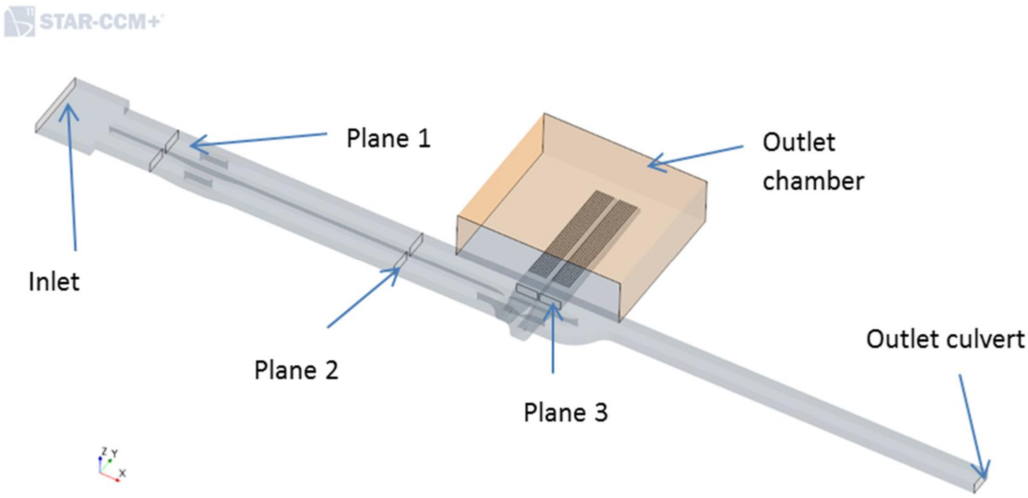

Figure 5: Isometric view of the CFD model of the culvert bends and bottom grid with locations of the planes between which the different elements are defined.

Element	Inlet plane	Outlet plane
Valves - chamber	Plane 1	Outlet chamber
Bend	Plane 2	Plane 3
Bottom grid	Plane 3	Outlet chamber
Valves – second culvert	Plane 1	Outlet culvert
T-junction	Plane 2	Outlet culvert

Table 1: Definitions of the elements in the CFD model

The intermediate planes 1, 2 and 3 are cross-sections of the culverts where the flow variables are calculated as averages over both culverts. The outlet chamber is an outlet volume, the width of the lock chamber and with approximately the lock depth. The outlet plane is a combination of the ends of the outlet chamber and the top, not including the walls of the lock chamber.

3.2 Mesh

The meshes for the simulations are made with the Star-CCM+ Trimmer mesh which uses hexahedral cells of mostly cube form. One exception is the mesh around the bottom grid which uses polyhedral cells. The grid for each of the final simulations is refined locally such that there is sufficient mesh refinement at the areas of the smallest cross-section, giving at least 20 cells between the dividing beams of the outflow port and at least 10 cells in each opening of the bottom grid. A prism layer is added at the walls of the culvert system to allow the boundary layer to be modelled with wall functions. The y^+ value is generally between the required $30 < y^+ < 300$ value for the validity of the wall functions and is no greater than 500 in the entire domain. The total number of cells for each geometry is then in the order of 13 million cells. Figure 6 gives an impression of the level of refinement in the models.

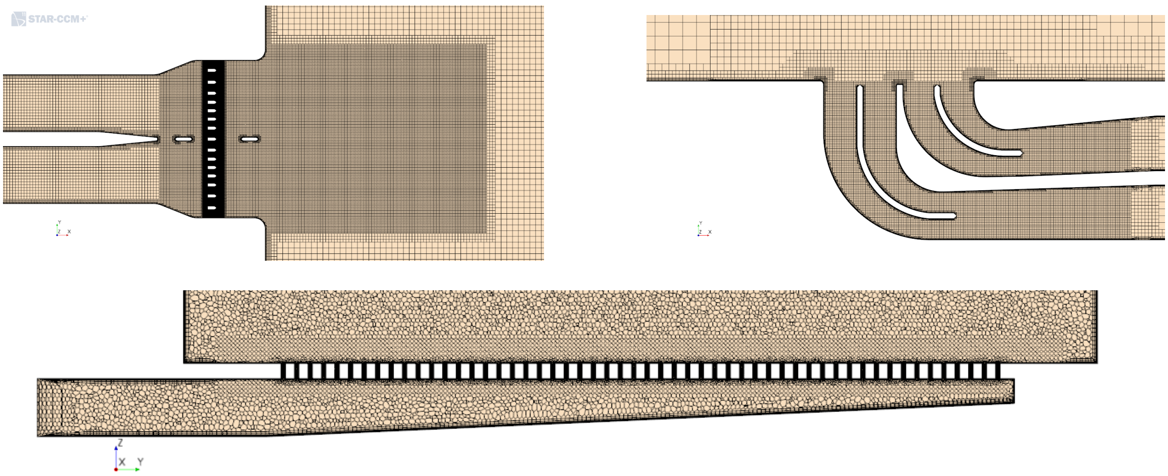

Figure 6: Detailed views of the areas of local mesh refinement for the models of the outlet at the inner harbor (top left),the outlet at the outer harbor (top right), and, the chamber below the bottom grid and the bottom grid (below)

3.3 Numerical settings

The numerical settings of the simulations can be summarised as follows

- Steady boundary conditions with an unsteady solver,
- First order implicit scheme for temporal discretisation,
- Second order scheme for spatial gradients,
- Segregated solver for pressure and fluxes,
- 10 internal iterations per time step,

- The time step used in the simulations varies between 0.5 s and 1.0 s,

- The realizable k-ε turbulence model is used, except for the simulations of outlet in the outer harbour where the k-ω SST model is used because it is known to be more effective for the prediction of separation points in curved bends,

- Constant discharge inlet boundary conditions are used of 100 m^3/s. For the simulations of the system of bends and T-junctions to the bottom grids a distribution between outlet chamber and outlet culvert of 50/50 is specified through a boundary condition of -50 m3/s volume flux at the outlet culvert boundary,

- A roughness of 2 mm is used for all concrete walls in the domain,

- No water surface is modelled. The outlet planes in the harbours and lock chamber are modelled as pressure boundaries. The focus of the work here is on the flow in the culverts so this is considered to be a reasonable approximation.

3.3 CFD results

The CFD simulations were run to investigate design differences for certain elements. The outlets to the approach harbours were assessed based on uniformity of the flow with low velocity, predominantly for the emptying direction, and on a loss coefficient which was not too high. The low velocity in the harbour is to minimize the hindrance to vessels moored or sailing in the harbour. The low loss coefficient allows the total discharge capacity of the entire levelling system to be high enough to achieve the required levelling times. To assess whether the losses were acceptable the complete levelling system was modelled in the one-dimensional WANDA model (see section 4 of this paper). After some iterations of the design for the inner approach harbour an outlet has been selected in which the flow is distributed over a wider area by a row of columns, perpendicular to the flow. The total outflow area was chosen such that the average velocity for the largest expected discharge during levelling was less than 2 m/s. The rack of beams was then designed to distribute the flow over this total outflow area. In Figure 7 the final result can be seen. The flow velocities between the beams are of course higher than 2 m/s but the flow is well distributed downstream of the beams and at the outlet t.

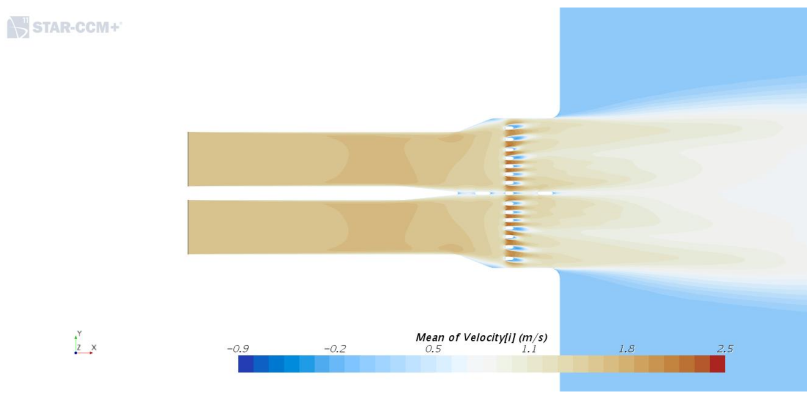

Figure 7: Top view of mean velocity field for the outflow at the inner harbor when emptying the lock

For the outer approach harbour a different solution has been chosen, namely an outlet which directs the flow away from the entrance of the adjacent lock (the West Lock). This, it is expected, will prevent unwanted high currents from emptying of the New Lock reaching the fairway of the entrance to the older West Lock and should enable the operation of both locks to continue relatively independently of each other. At the outer head the emptying discharges are higher than at the inner head because the head difference at low tide (emptying into the outer harbour) is higher than the head difference at high tide (emptying into the inner harbour). Furthermore emptying into the outer harbour will cause a surface current due to density differences between lock and approach harbour.

Figure 8 shows the final solution for this outlet with 90 degree bend. Guide vanes are added into the culvert at the bend to steer the flow and a nearly perpendicular flow is achieved in this simplified outlet. The flow manages to take the bend without high concentration of flow in the outer bend.

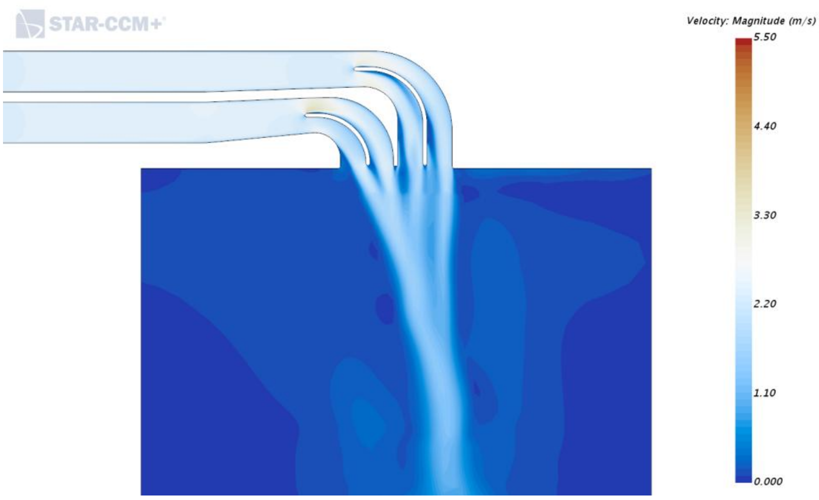

Figure 8: Top view of velocity field for the outflow at the outer harbor when emptying the lock

For the bottom grids, similarly, the criterion of flow homogeneity was used to judge different designs. The sections of the bottom grid as shown in Figure 4 were used to define discharge ratios which should not deviate too much from 50/50. This criterion is to provide a uniform filling of the lock and to prevent asymmetric flow patterns in the lock during levelling, which can lead to high forces on the moored vessels.

A bottom grid with a throughflow area two times the area of the culverts is used in the conceptual design. Handbooks for internal flows (Miller 1978) claim that in order to have a uniform flow manifolds such as this bottom grid should not have a throughflow area larger than the throughflow area of the incoming duct or culvert. However, the West Lock has a ratio of throughflow area between bottom grid and culvert of 2 and a sloped floor underneath the grid which distributes the flow more evenly. This sloped floor has also been adopted in the conceptual design of the New Lock (see Figure 6 where this is visible in cross section). CFD simulations with a smaller throughflow area of the bottom grid were also conducted but these resulted in a large loss coefficient. Figure 9 shows another example of a design iteration which was conducted with the CFD. The two simulations shown are both with the larger bottom grid throughflow area. In the first simulation, the chamber underneath the grid is combined in one single chamber. Owing to the sharp turn that the flow makes from the culvert into this chamber a circulating pattern is formed which leads to a non-uniform flow out of the grid. This is improved by dividing the chamber into two separate parts, each fed from one branch of the culvert. The resulting flow out of the grid is not perfectly uniform but the ratio of flow through the different sections stays between the ratios 45/55 and 55/45 (see Table 2).

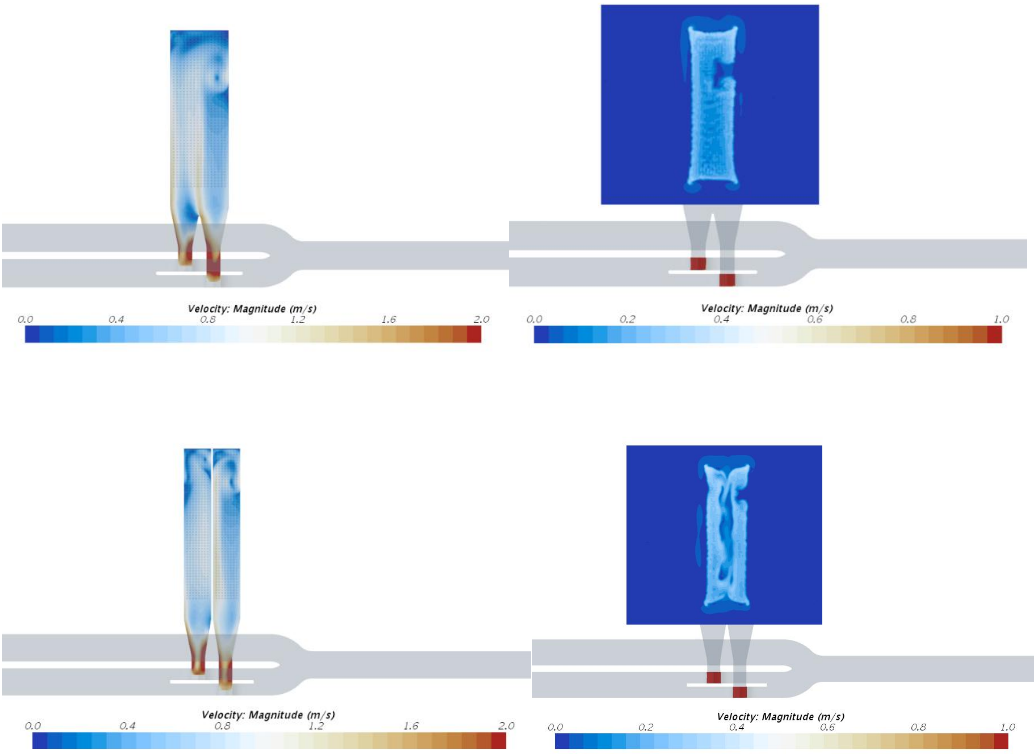

Figure 9: Top view of velocity field for the bottom grids, left in the chamber below the grids and right in the lock chamber above the grids. The top two figures are for a bottom grid with a single spacechamber and the bottom figures are for a bottom grid with two separate spaces under the gridlower chambers.

Figure 10 shows the velocity field above the bottom grid for an emptying scenario. The flow is almost symmetrical between the North and South sectors (see Figure 4 for definitions) but far from symmetrical between the East and West sectors. It is considered that for emptying this lack of symmetry is less important as the forces on the vessels in the lock tend to be more favourable for emptying scenarios. The distribution of flow within the bottom grid for the final simulations is given in Table 2.

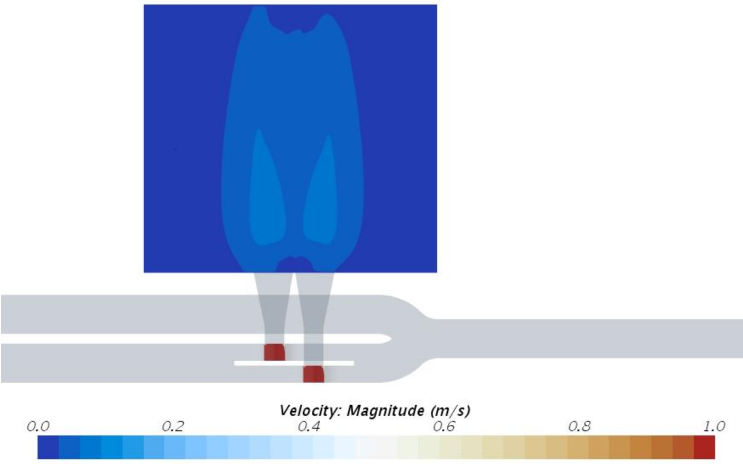

Figure 10: Top view of velocity field above the bottom grid by emptying

Simulation	East/West [%/%]	North/South [%,%]
Filling	54/46	52/48
Emptying	39/61	51/49

Table 2: Results of the flow distribution within the bottom grid

In Table 3 the summary of all loss coefficients for the different elements based on the final simulations is given as well as the totals for the trajectory to the northern grid (R1) and the southern grid (R2) for each scenario. The totals are deduced from the sum of the appropriate elements and are not the result of a single calculation in each case. The final total loss coefficients are then converted to a net throughflow area of the system by means of the discharge coefficient $\mu = 1/\sqrt{\xi}$. The reference throughflow area A is the throughflow area of the culverts at the valves (30 m^2) in all cases.

The system which was chosen to act as a reference system and which is simulated in the WANDA model of the next section therefore has at least a net throughflow area of 34.5 m^2 for filling and 33.0 m^2 for emptying.

Element	ξ [-]			
	Filling from Scheldt	**Emptying to Scheldt**	**Filling from Canal**	**Emptying to Canal**
Valves – chamber	1.95	1.72	1.95	1.72
Valves – outlet culvert	0.94	1.50	0.94	1.50
Bend	0.95	0.82	0.95	0.82
Bottom grid	0.71	0.57	0.71	0.57
Outflow	0.67	0.96	0.35	0.92
T-junction	0.34	0.21	0.34	0.21
Total (R1/R2)	2.62/3.61	2.69/4.06	2.30/3.28	2.64/4.02
μA [m^2]	34.5	33.0	36.5	33.5

Table 3: Values of the loss coefficients and net throughflow areas

3.3 Conclusions CFD

The conclusions of the CFD can be summarized as follows:

- A variant of the longitudinal levelling system with bottom grids is designed such that the discharge capacity of the system has at least 33 m^2 of net throughflow area for emptying and a net throughflow area of 34.5 m^2 for filling, assuming an equal discharge through both bottom grids,

- A bottom grid with 60 m^2 of throughflow area and well distributed holes, together with a chamber below with an appropriately sloping floor can achieve a good distribution of the flow into the lock chamber such that the proportion of discharge through each half of the each bottom grid stays within percentages 45/55 and 55/45 for filling. For emptying this distribution is not achievable but also not necessary,

- The outlets in inner and outer harbour as simulated provide an acceptably uniform flow into the approach harbour, which should minimize the hindrance to the vessels entering the West Lock, given the spatial constraints on the location and size of these outlet constructions.

4. WANDA MODEL OF LEVELLING SYSTEM

4.1 Model setup WANDA

WANDA is a 1D dynamic flow solver for pipeline systems which can be used for free-surface flows in locks with valve and culvert components. The following aspects are accounted for:

- Wall friction of culverts using the Darcy-Weisbach formulation,

- Inertia of the water in the culverts, using Newton's second law,

- Local loss coefficients,

- Discharge dependent loss coefficients for T- and Y-junctions,

- Lifting programme of culvert valves,

- Valve position dependent loss coefficients,

- Surge waves (translatory waves) in the lock chamber and water level slopes in the lock chamber, including the reduced cross sectional effects due to the presence of the ship cross section,

- Solution of Saint-Venant equations for computation of the water level variation in the lock chamber.

The effects of density differences cannot be taken into account

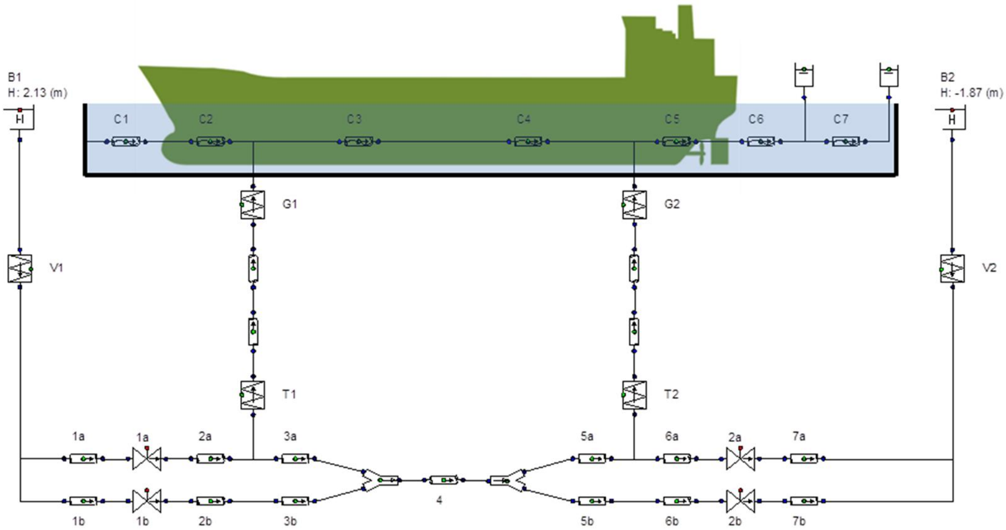

Figure 11: Schematic view of the WANDA model

A schematisation of the WANDA model for the levelling system is given in Figure 11. Elements 1a, 1b, 2a, 2b are valves representing the lifting valves in the culverts. The water level in the approach harbours is defined by elements B1 and B2, the water level in the lock chamber is represented by the C elements. All other elements represent resistance and pipe elements of the culvert system. The vessel is accounted for in the lock by means of a reduced throughflow area of the lock chamber elements C2-C5. This gives a more accurate estimate of the water level slopes in the lock chamber and consequently the levelling forces on the vessel in the lock chamber can be assessed. Table 4 summarizes the conditions of the selected simulations. The water levels considered are the normative water levels. The simulations were conducted for a lock chamber of 427 m length which corresponds to the situation where at one head an outer gate is used and at the other head an inner gate. The volume of the gate recesses which are in connection with the lock chamber are also accounted for.

Sim.	Condition	Lockhead	Scenario	Waterlevel harbor [NAP +m]	Waterlevel lock [NAP + m]	Head [m]	Lifting time valve a [s]	Lifting time valve b [s]
1	Filling	Inner	Scheldt low	2.13	-1.87	4.00	780	780
2	Filling	Outer	Scheldt high	4.60	2.13	2.47	780	780
3	Emptying	Outer	Scheldt low	-1.87	2.13	-4.00	320	320
4	Emptying	Inner	Scheldt high	2.13	4.60	-2.47	320	320
5	Filling	Inner	Scheldt low	2.13	-1.87	4.00	730	880
6	Emptying	Outer	Scheldt low	-1.87	2.13	-4.00	400	270

Table 4: Summary of the conducted simulations

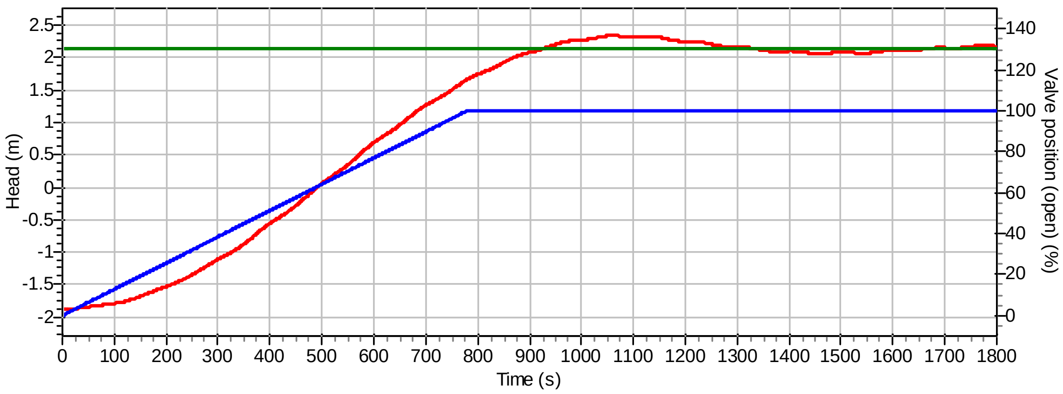

Figure 12: Water levels (red and green lines, left axis) and valve position (blue line, right axis) for Sim 1

Figure 12 shows the water levels of the harbour (green line) and lock chamber (red line) during levelling as well as the valve position (blue line) for a single simulation (Sim 1). It shows that equal water level is reached for the first time at 900 s, the required levelling time of 15 minutes. The overtravel is also visible as the water level in the lock chamber rises above the harbour water level, reaching a peak at approximately 1050 s. A summary of these results can be found in Table 5.

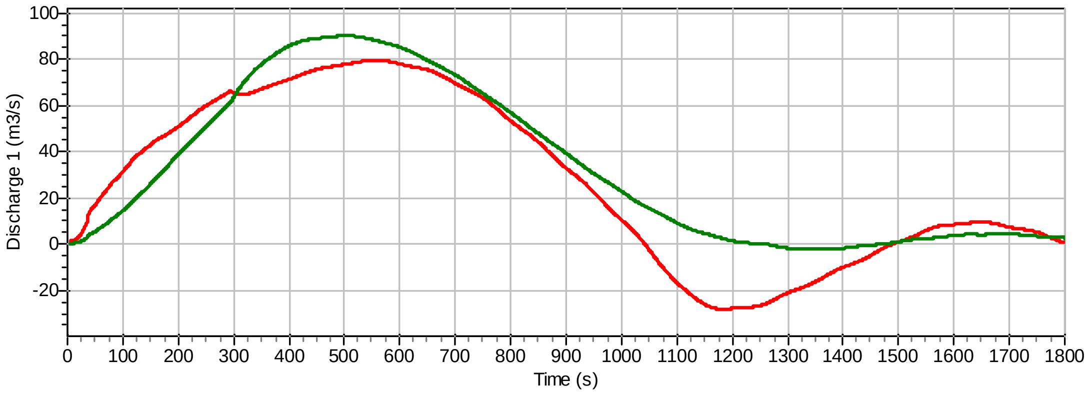

Figure 13: Discharge through the two grids during levelling for Sim 1

Figure 13 shows the discharge through the two bottom grids with the red line grid 1, closest to the active head and the green line grid 2, farthest away. The flow through the nearest grid rises quicker than through the other but the maximum discharge is higher in the farther grid. This behaviour is very dependent on what occurs at the Y-junction. Figure 14 shows the behaviour of discharge distribution in time around the Y-junction. In Figure 14 the red line shows the flow along the branch between grid 1 and the Y-junction (3a in Figure 11). A negative value indicates that the flow is from the Y-junction to grid 1. This occurs at the beginning of levelling as some of the flow from the outer culvert (3b in Figure 11) takes the shorter route to the lock chamber via grid 1. Later in the levelling process the direction of the flow in the branch 3a is reversed as some of the flow from the inner culvert (2a in Figure 11) bypasses the first grid and travels to the second grid. The complexity of this element makes it difficult to determine the expected behaviour with accuracy and it is therefore a source of uncertainty in the numerical model approach described in this paper.

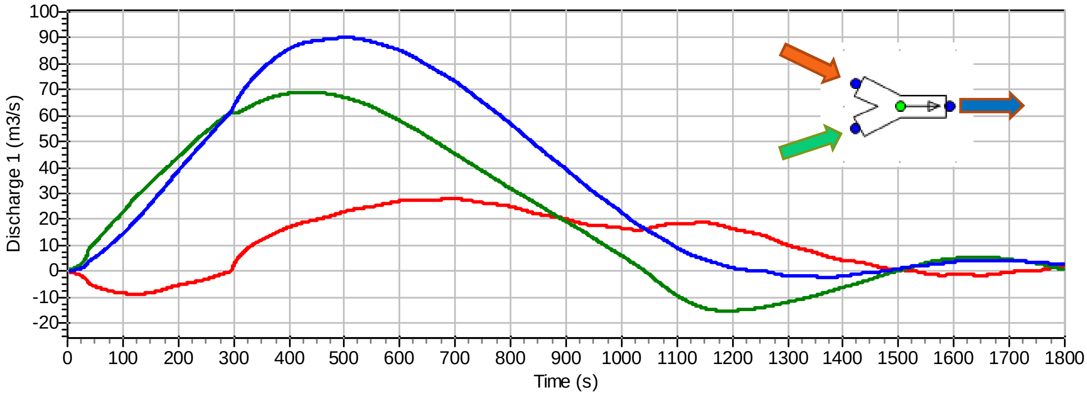

Figure 14: Discharge through different culvert elements adjacent to the Y-junction during levelling for Sim 1. The definitions of the positive sense of discharges (the red, green and blue lines) is depicted with the corresponding coloured arrows around the Y-junction in the graph

The results of the simulations with the levelling system are assessed based on the variation in time of the ratio of the discharges through each bottom grid. Clearly the ratio cannot be close to 50/50 throughout the entirety of the levelling process as there are occasions when the flow through one grid is very small whilst there is still flow through the other. Of importance to a safe levelling process is that this discharge is evenly distributed between the two grids when the discharges are high (near the moment of maximum discharge). This will reduce the water level slope along the ship in the lock chamber and also, although this cannot be modelled here, ensure that a density current of almost equal strength is initiated at both bow and stern of the ship. Figure 15 shows the time evolution of the ratio of the discharges through the bottom grids to the total discharge for Sim 1. The vertical solid black line in the middle of the Figure is the moment of maximum total discharge. The shaded area is the period ±25 % of the total levelling time around the moment of maximum discharge. The Figure shows that the ratio of discharges stays between 45/55 and 55/45 within the shaded area.

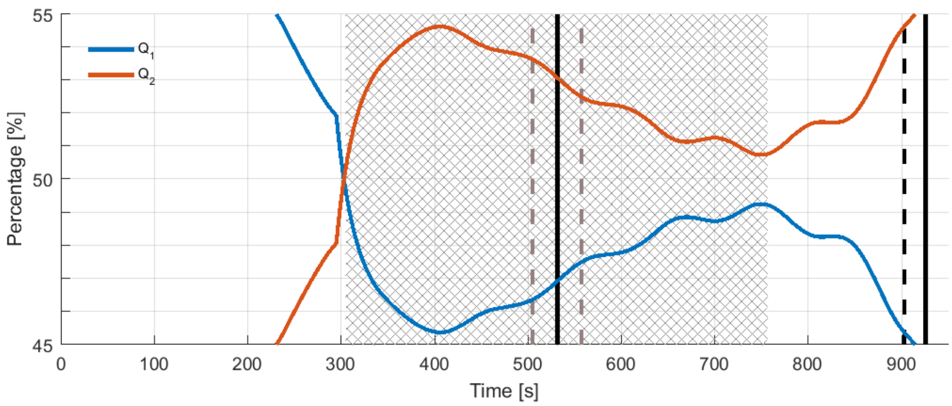

Figure 15: Discharge through different bottom grids during levelling for Sim 1 as a percentage of the total discharge. The vertical solid black line is the moment of maximum total discharge. The shaded area is the period ±25 % of the total levelling time around the moment of maximum discharge

Figure 16 shows the same scenario as Sim 1 but with an adjusted valve lifting programme (Sim 5 in Table 4). This lifting programme uses different lifting speeds for the valves in the two culverts. The Figure shows that by using the valves an improvement in the ratio of discharges between the bottom grids can be achieved.

For emptying the distribution is worse. Figure 17 shows an emptying scenario, Sim 6. In this Figure, even though the valve programme has been improved the discharge ratio does not stay within 45/55 and 55/45 within the shaded area. Instead the discharge ratio stays within 45/55 en 55/45 for a period of ±10% or ±15% of the levelling time around the moment of maximum discharge.

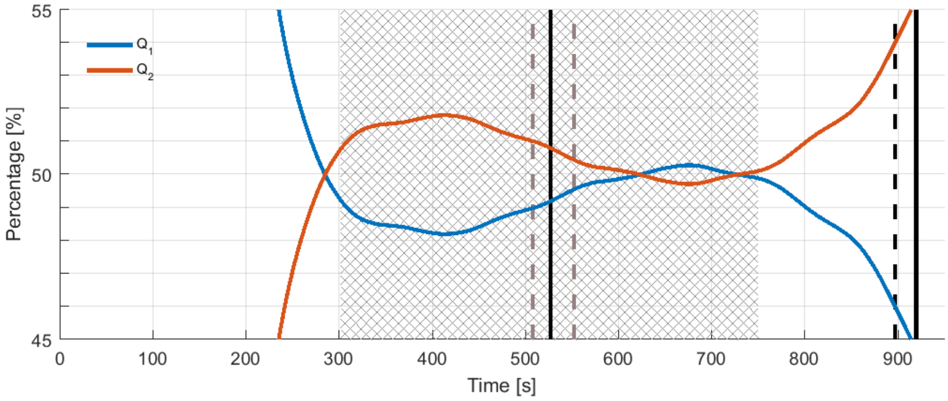

Figure 16: Discharge through different bottom grids during levelling for Sim 5 as a percentage. The vertical solid black line is the moment of maximum total discharge. The shaded area is the period ±25 % of the total levelling time around the moment of maximum discharge

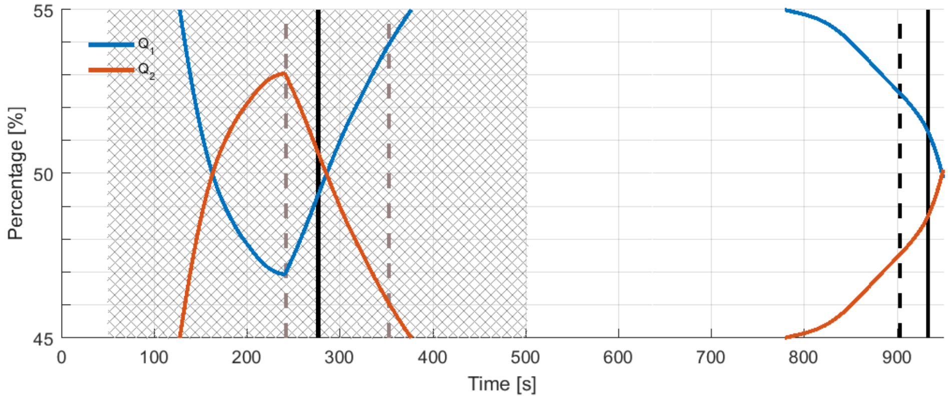

Figure 17: Discharge through different bottom grids during levelling for Sim 6 as a percentage of the total discharge. The vertical solid black line is the moment of maximum total discharge. The shaded area is the period ±25 % of the total levelling time around the moment of maximum discharge

Table 5 shows the summary of the levelling time, calculated force on the ship, maximum discharge for both bottom grids, discharge ratio and maximum value of overtravel for the six simulations of Table 4. The levelling times are always sufficiently fast to be acceptable (approximately 15 minutes or faster). The maximum force shown in the table accounts only for the modelled water level slope in the lock chamber and not for any additional forces owing to density currents and therefore no comparison is made here between this value and the allowable mooring forces. In addition, the force is only in the longitudinal direction and does not account for transverse forces. Finally it can be concluded that the overtravel in the lock will be no more than 21 cm. The design of the lock gate should take this into account although again density differences are not accounted for in these simulations.

Sim.	Levelling time [s /min]	Max. force [‰]	Max. discharge R1 [m^3/s]	Max. discharge R2 [m^3/s]	Discharge ratio at max. discharge [% / %]	Max. overtravel [cm]
1	902 / 15.0	0.104	79.6	90.1	46.9 / 53.1	20.6
2	821 / 13.7	0.053	51.6	60.4	46.1 / 53.9	14.8
3	896 / 14.9	0.109	-102.4	-81.2	55.8 / 44.2	-11.6
4	684 / 11.4	0.034	-77.3	-61.8	55.6 / 44.4	-11.5
5	897 / 15.0	0.078	84.5	87.2	49.2 / 50.8	20.0
6	902 / 15.0	0.104	-91.7	-92.3	49.8 / 50.2	-11.2

Table 5: Results of the WANDA simulations for the variant with bottom grids

3.3 Conclusions WANDA

The conclusions of the WANDA simulations can be summarized as follows:

- The designed variant of the longitudinal filling system with bottom grids shows computed levelling times of 15 minutes
- Where needed, by adjusting the valves, the discharges through the two bottom grids can only be made to be within the ratio 45/55 and 55/45 during a time period concentrated around the middle of the levelling process owing to inertial effects. This period is defined here as the moment of maximum discharge ±25% of the total levelling time for filling. For emptying this period should be reduced to the moment of maximum discharge ±15% of the total levelling time,
- The maximum computed overtravel of the system is about 20 cm,
- The largest uncertainty in the results comes from the modelling of the Y-junctions as the resistances of these elements will be dependent on the discharge ratios through each branch and in this research only one ratio per element has been calculated. It is recommended to study these elements in more detail for similar systems.

5. CONCLUSIONS

As a conceptual design, a longitudinal levelling system with two bottom grids is designed for the New Lock of Terneuzen. This levelling system achieves levelling times of 15 minutes or less for a 4 m head without large forces on the moored vessel if the following hydraulic conditions are met:

- a discharge capacity of the system with at least 33 m^2 of net throughflow area for emptying and a net throughflow area of 34.5 m^2 for filling,
- When performing a stationary CFD simulation of the flow in the system, the flow into the lock chamber through each half of the each bottom grid stays within percentages 45/55 and 55/45 for filling,
- The discharges through the two bottom grids are within percentages 45/55 and 55/45 during a time period concentrated around the moment of maximum discharge ±25% of the total levelling time for filling. For emptying this period should be reduced to the moment of maximum discharge ±15% of the total levelling time.

The final design of the lock, including the design of the levelling system, will be carried out the contractor selected for building the lock. This final design will follow a similar approach as described in this paper for the verification of the levelling system. Because this approach does not take into account density currents the final design of the levelling system is to be verified in a scale model because the effects of density currents will be dominant for the forces on the moored vessel and as of yet no numerical tools are available to study this with sufficient accuracy.

6. REFERENCES

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