Physical model research on breaking logs for through the gate filling of new Sint-Baafs-Vijve lock

by

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ABSTRACT

The lift height of most inland navigation locks in the Flemish region of Belgium is limited to 2-3 m. For these locks openings integrated in the lock gate sealed by vertical lift valves or butterfly valves are commonly used as lock levelling system. To improve the spreading and energy dissipation of the filling jets and hence reduce the hydrodynamic forces on the moored ships, breaking logs (also referred to as energy dissipation bars) might be mounted at the downstream side of the gate openings. Beem et al. (2000) provide some Dutch design guidelines. Since the shaping of a gate opening across the thickness of a steel gate and the integration of the valves are somewhat country-specific, it was decided to set up a generic physical model at Flanders Hydraulics Research (Antwerp, Belgium) aiming at determining the effect of breaking logs on the flow inside the lock chamber and optimization of the breaking log configurations adopted in Flanders (Verelst et al., 2016). In this contribution, an account will be given of the specific research carried out in this model during the design of the levelling system of the new lock of Sint-Baafs-Vijve (river Lys, Belgium). During the physical model research, 4 different configurations were tested. For reference purposes, the first configuration did not have any breaking logs. Next, three configurations with respectively 7, 5 and 3 breaking logs were tested. At first the discharge coefficients of the configurations were determined, for valve openings ranging between 20 % and 100 % of the total valve lift height. It turned out that the influence of the breaking logs on the discharge coefficient was negligible for valve openings below 50 % and limited for higher valve openings. Secondly, the effect of breaking logs on the energy dissipation was studied. When adding breaking logs, the spreading of the filling jet increased and the maximum velocity reduced to approximately 60 % of the velocity measured in the core of the jet compared to the configuration without breaking logs. The research revealed that the exact positioning of the breaking logs with respect to the gate opening at the upstream skin plate is more important for the spreading of the filling jets than the amount of blockage of the gate opening at the downstream skin plate. The lowest velocities were achieved with the configuration with 3 breaking logs, which is the configuration with the least blockage of the gate opening at the downstream skin plate.

1. INTRODUCTION

Navigation locks are key structures for navigation in canals and canalized rivers, as well as for the accessibility of ports. In Flanders, the northern part of Belgium, new CEMT class Vb locks are being built in the canalized river Lys, e.g. at Sint-Baafs-Vijve, in the framework of the Seine-Scheldt project. Also in other canalized rivers, like e.g. the Upper Scheldt river and the river Dendre, lock upgrading is on-going. The lift height of all these locks is limited to 2-3 m. For these inland navigation locks with a limited lift height, a leveling system with openings integrated in the lock gate, sealed by vertical lift valves or butterfly

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valves, is commonly used in Flanders. These leveling systems are characterized by concentrated filling jets entering the lock, generating relatively high forces on the ship in the lock chamber. Breaking logs (also referred to as energy dissipation bars) might be mounted at the downstream side of the gate openings, to enhance the spreading and energy dissipation of the filling jets, hence reducing the forces on the ship moored in the lock chamber. Beem *et al.* (2000) provide some Dutch design guidelines with respect to breaking logs. Since the shaping of a gate opening across the thickness of a steel gate and the integration of the valves are somewhat country-specific, it was decided to set up a generic physical model at Flanders Hydraulics Research (Antwerp, Belgium) aiming at determining the influence of breaking logs on the flow inside the lock chamber and optimization of the breaking log configurations adopted in Flanders (Verelst *et al.*, 2016). This paper will give an account of the specific research carried out in this physical model for the design of the new lock located at Sint-Baafs-Vijve on the river Lys. The major aim of the scale model research is to evaluate the influence of breaking logs on the flow pattern inside the lock chamber and to optimize the geometry of the breaking logs for this particular geometry of the gate opening. The secondary aim of the scale model research is to determine the discharge coefficient of the gate openings and the spreading rate of the jet immediately downstream of the opening, to use this information as input parameters of the software tool applied during the hydraulic design of the filling and emptying system.

The outline of this paper is as follows. Section 2 describes the new lock of Sint-Baafs-Vijve and the filing and emptying system of this lock. An overview of the physical model, the measurements techniques used and the tested configurations is presented in section 3. The influence of the breaking logs on the discharge through the gate opening is discussed in section 4. For analysing the effect of breaking logs on the flow pattern in the lock chamber both visualizations with dye and velocity measurements are performed. Section 5 describes the results of the visualization of the flow pattern with dye while section 6 presents the measured flow pattern downstream of the lock gate. The conclusions of this paper are provided in section 7.

2. **NEW LOCK OF SINT-BAAFS-VIJVE**

Within the frame work of the Seine-Scheldt project the river Lys is upgraded to CEMT class Vb. Therefore, the existing lock of Sint-Baafs-Vijve with a length of 152.5 m and a width of 16.0 m has to be replaced by a new lock with a length of 260.6 m and a width of 16.0 m. An planview of the new lock chamber is presented in Figure 1. The design lift height is 3.22 m, computed between an exceptional high level in the upstream reach and the reference level in the downstream reach of the river. The water depth in the lock chamber, with respect to the floor, ranges between 4.70 m (when leveled with the downstream reach) and 7.92 m (when leveled with the upstream reach). The lock gates are of the mitre gate type. Intermediate lock gates are present to enable levelling of smaller ships with a part of the lock chamber, in order to reduce water consumption. The upper, intermediate and downstream lock gates are identical, consequently only one spare set of mitre gates is needed.

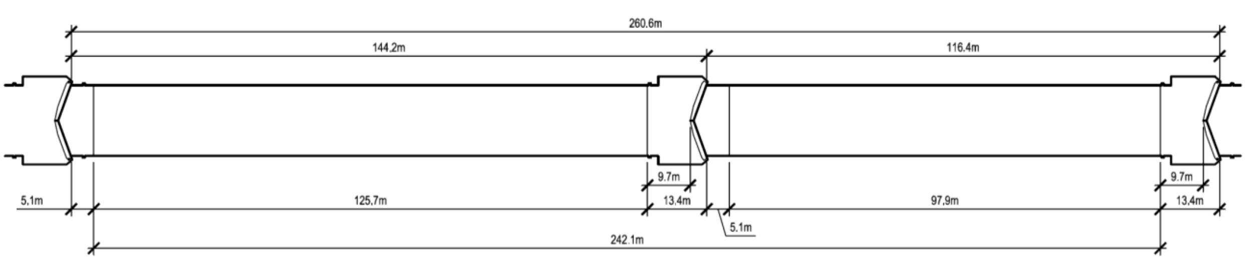


Figure 1: Planview lock chamber new lock Sint Baafs-Vijve

A frontal view from downstream, as well as a horizontal and vertical cross-section of the gate, are presented in Figure 2. The horizontal and vertical cross-section are situated at the center of the middle opening in the gate.

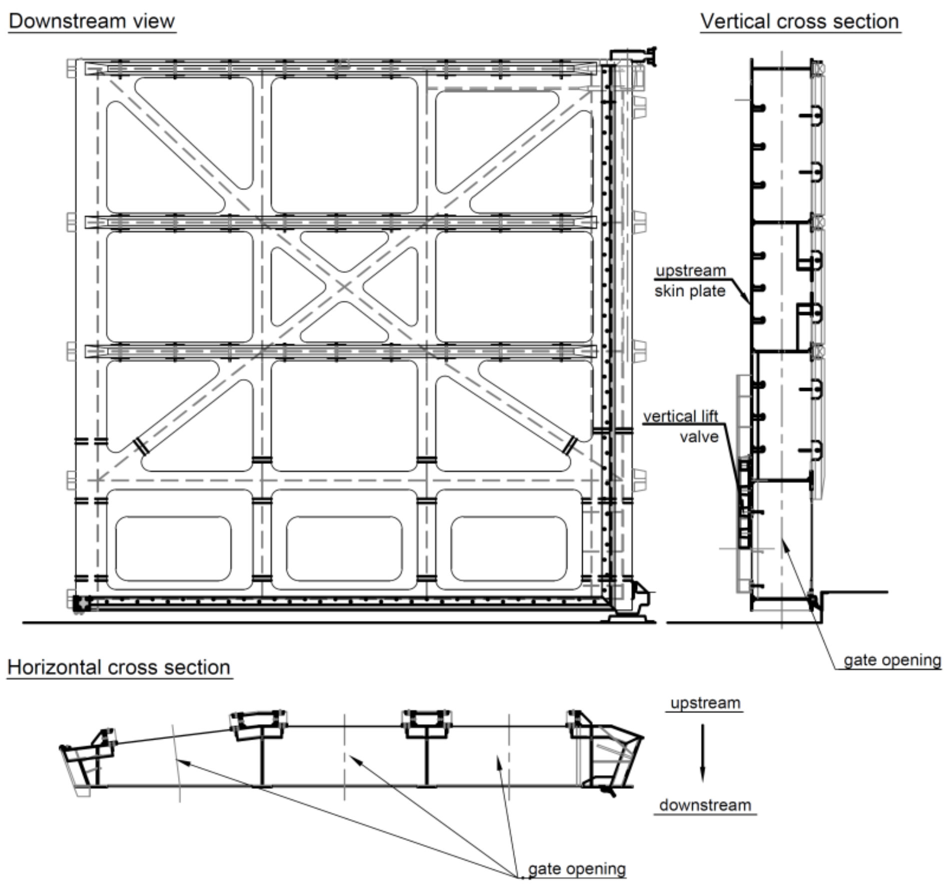


Figure 2: Mitre gate leaf with three leveling openings

The gate is constructed with both a vertical and a horizontal framing, as well as two diagonal struts. The thickness of the gate is 1.00 m. The gate is sealed at the upstream side with a closed skin plate. At the downstream side, a top plate is welded against the vertical, horizontal and diagonal girders. The leveling system is integrated in the mitre gates and consists of 3 rectangular openings in each mitre gate leaf placed at the bottom of the gate, hence 6 levelling openings per lock head are present. Each leveling opening is sealed with a vertical lift valve, mounted on top of the upstream skin plate. Each gate opening is delineated by the horizontal and vertical beams of the gate. These beams create a box with internal dimensions 2.69 m x 1.92 m (width x height). At the upstream side of the box, the gate opening has cross-sectional dimensions 1.89 m x 1.05 m (width x height), while the cross-sectional dimensions of the opening at the downstream side of the box are 2.40 m x 1.64 m (width x height).

During the physical model research, 4 different configurations of breaking logs are tested. The definition of the tested configurations was supervised by both hydraulic engineers and structural engineers involved in steel gate design, in order to be able to assess the hydraulic performance of a given configuration, as well as its (dis)advantages in terms of structural realization and maintenance of the gate.

For reference purposes, the first configuration (denoted C1) did not have any breaking logs. Next three configurations with breaking logs were tested: a configuration (denoted C2) with 7 breaking logs with section 0.15 m x 0.15 m and a distance between the breakings logs of 0.18 m, a configuration (denoted C3) with 5 breakings logs with section 0.15 m x 0.15 m and a distance between the breaking logs of 0.30 m and a configuration (denoted C4) of 3 somewhat larger breaking logs, section 0.20 m x 0.20 m, and a distance between the breaking logs of 0.30 m. For configuration C2 and C3 the upstream face of the breaking logs is positioned at 0.84 m with respect to the upstream face of the inlet opening. Due to structural reasons the breaking logs of configuration C4 are positioned 0.10 m more upstream then for the other configurations, i.e. the upstream face of the breaking logs is positioned at 0.74 m with respect to the upstream face of the inlet opening. The geometry of the four tested configurations is presented in Figure 3.

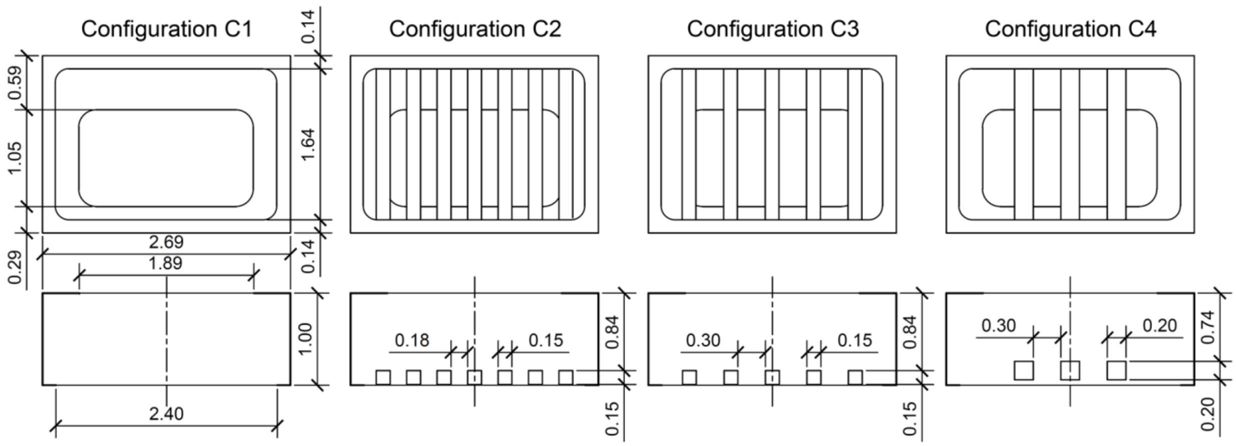


Figure 3: Tested configurations

With respect to energy dissipation bars (also referred to as breaking logs) the Dutch design manual (Beem *et al.*, 2000) presents the following three guidelines:

- Guideline 1: The blocking by the energy dissipating bars should be at least 50% of the downstream area of the opening without energy dissipating bars.
- Guideline 2: The total downstream opening, i.e. between the energy dissipating bars, should be larger than the total upstream opening in the lock gate. The largest flow velocity should occur in the gate and not outside the gate.
- Guideline 3: The smallest opening between the energy dissipating bars should be at least 0.30 m. Floating waste gets trapped in too narrow gaps.

Table 1 analyses how the different tested configurations of breaking logs meet the guidelines presented in the Dutch design manual (Beem *et al.*, 2000).

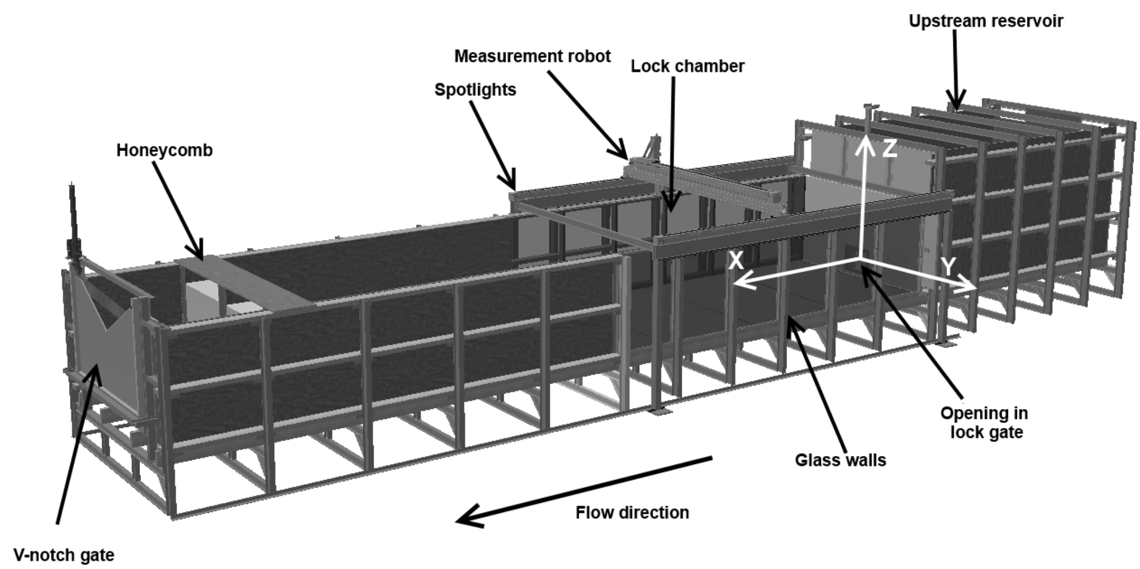
		Configuration			
		C1	C2	C3	C4
Cross-section upstream side of gate opening	[m^2]	1.98	1.98	1.98	1.98
Width of breaking logs	[m]	/	0.15	0.15	0.20
Number of breaking logs	[-]	0	7	5	3
Cross-section breaking logs	[m^2]	0.00	1.72	1.23	0.98
Cross-section between the breaking logs at downstream side of gate opening	[m^2]	3.94	2.21	2.71	2.95
$\frac{\text{Cross-section breaking logs}}{\text{Cross-section downstream side of gate opening}}$	[-]	1.00	0.44	0.31	0.25
$\frac{\text{Cross-section between the breaking logs at downstream side of gate opening}}{\text{Cross-section upstream side of gate opening}}$	[-]	1.98	1.12	1.36	1.49
Distance between breaking logs	[m]	/	0.18	0.30	0.30
Guideline met? (Beem *et al.*, 2000)	Guideline 1	/	No	No	No
	Guideline 2	/	Yes	Yes	Yes
	Guideline 3	/	No	Yes	Yes

Table 1: Characteristics tested breaking logs configurations

The blockage of the breaking logs ranges from 25 % to 44 %. Note that neither of the three tested configurations meets the first guideline, e.g. the blockage of the downstream side of the gate opening by the energy dissipation bars has to be at least 50 %. The three tested configurations with breaking logs meet the second guideline, i.e. the cross-section of opening at the downstream side of the gate between the breaking logs has to exceed the cross-section of the upstream side of the gate opening. Configuration C3 (5 breaking logs) and configuration C4 (3 breaking logs) meet guideline 3, i.e. the distance between the breaking logs is 0.30 m or larger, while configuration C2 does not.

3. **PHYSICAL MODEL**

The research was performed in a dedicated physical model for studying the influence of breaking logs on a lock levelling system with openings in the lock gate (Verelst et al., 2016, Ramos et al., 2016). A 3D sketch of this scale model is presented in Figure 4. The local reference system used in this paper is also indicated in white in this figure. The origin of this local reference system is situated at the center of the opening at the downstream side of the gate.



The local reference system used in this paper is indicated in white

Figure 4: Physical model

The physical model represents a part of the upstream reach and a part of the lock chamber with in between the lock gate. To reduce the complexity of the model, only a gate perpendicular to the lock chamber and only one gate opening in the lock gate is considered. Consequently only one filling jet is entering the lock chamber. Also no vessels are present in the lock chamber. The width of the scale model is 2.0 m, the length of the measurement section in the lock chamber is 3.75 m and the gate has a thickness of 0.12 m. At 7.9 m downstream of the gate a honeycomb structure is present, to smoothen the water surface in the downstream reach. The water level of the upstream reach is regulated by adjusting the supply discharge, while the water level in the downstream reach is regulated by an adjustable V-notch gate. To enhance flexibility of the set-up, the leveling opening in the model can be readily exchanged. For a certain opening in the lock gate a variety of breaking logs configurations can easily be installed.

During the physical model tests, the water level in the upstream reach and the water level in the lock chamber is measured using micropulse tranducers (from Balluff). The discharge feeding the upstream reach is measured by an electromagnetic flow meter (from Krohne), mounted on the supply pipe. The V-notch gate at the downstream end of the model is used as a complementary discharge measurement. Flow velocity measurements (see section 6) were carried out by means of an ADV velocity meter (Vectrino Profiler, from Nortek), making only use of the measurements in the “sweet spots” (in order not to suffer from the bias problems reported and explained in Thomas *et al.*, 2017). The specifications of the Vectrino Profiler give a maximum range of +/- 3.0 m/s. This range is not exceeded by the theoretical maximum velocity of 2.7 m/s. During tests, however, it was noticed that (due to fluctuations in the measured signal) higher velocities occur, but these are cut of at 2.8 m/s. For measured velocities above 2.8 m/s aliasing occurs, resulting in negative velocities. To correct this, a de-aliasing script is applied (Thomas et al., 2017). By attaching the Vectrino Profiler to an automated traverse system a dense grid of point velocities was measured. For visualizing the flow pattern, dye (Potassium Permanganate) is injected upstream of the inlet opening using simultaneously a horizontal and vertical half circular dye injector. With an underwater camera it was controlled that also the outer streamlines of the flow through the gate opening contain dye. A system equipped with 4 cameras (IDS UI-5420 RE), a power supply, data storage and 2 computers for data acquisition, is used to obtain sequential photos of the dye spreading. To provide a proper illumination of the measurement area 14 halogen spotlights with 90 W each are used, from which 12 spotligths are placed behind the left glass wall and 2 are used above the water surface.

Taking into account the available space in the physical model, a geometrical scale factor of 1:8.5 was used to scale the four tested configurations presented in Figure 3. Compared to the gate in prototype, the opening in the gate in the physical model is situated 0.049 m (in scale model dimensions or 0.417 m in prototype dimensions) too high above the floor of the physical model.

It should be noted that in the remainder of this paper all results will be presented in a dimensionless format.

4. DISCHARGE COEFFICIENTS

For the hydraulic design of a navigation lock the discharge coefficient is used to calculate the discharge through the opening in the lock gate in function of the water levels and the relative valve opening. The discharge through the gate openings is calculated using following formula:

$$Q = \mu A\sqrt{2g\Delta h} \qquad (1)$$

where Q = discharge [m³/s]; μ = discharge coefficient [-]; A = is the cross-sectional area of the opening under the valve [m^2], g = the gravitational acceleration [m/s²] and Δh = the head [m].

The discharge coefficient expresses the efficiency of the levelling opening. The theoretical maximum value of the discharge coefficient is equal to one, indicating that no contraction and energy losses are present. Due to contraction and energy losses the actual discharge coefficient will be less.

During the physical model research, the discharge coefficient is (steady state) measured for different positions of the vertical lift valve, yielding a relative opening ranging between 20 % till 100 % (with a step size of 10 %). After the flow reached perfectly steady state conditions, the discharge, upstream water level, and downstream water level were recorded during a period of 360 s. For each test, the value of the discharge coefficient is computed as a time-average of the instantaneous values during this recording period. Figure 5 and Table 2 present the variation of the computed discharge coefficient for the four tested configurations in function of the relative valve opening. Note that the discharge coefficient is determined by using the discharge measured with the electromagnetic flow meter mounted on the supply tube, as well as by using the discharge determined from the overflow height over the downstream V-notch gate. The difference between the discharge coefficient calculated with the electromagnetic flow meter and the V-notch gate is for most of the measurements limited to +/- 1 %. For 3 measurements, however, the difference is somewhat higher and amounts up to -4 %.

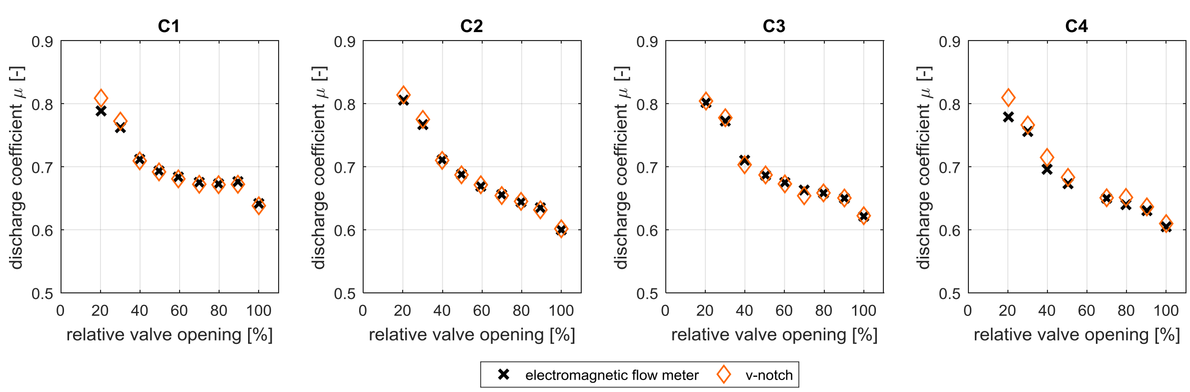


Figure 5: Discharge coefficient in function of relative valve opening

Relative valve opening [%]	Discharge coefficients											
	C1			C2			C3			C4		
	flow meter	V-notch gate	Δ [%]	flow meter	V-notch gate	Δ] [%]	flow meter	V-notch gate	Δ [%]	flow meter	V-notch gate	Δ [%]
20	0.79	0.81	-3	0.81	0.81	-1	0.80	0.80	0	0.78	0.81	-4
30	0.76	0.77	-1	0.77	0.78	-1	0.77	0.78	-1	0.76	0.77	-1
40	0.71	0.71	0	0.71	0.71	0	0.71	0.70	1	0.70	0.71	-3
50	0.69	0.69	0	0.69	0.69	0	0.69	0.69	0	0.67	0.68	-1
60	0.68	0.68	0	0.67	0.67	0	0.67	0.67	0	0.66[1]	0.67[1]	-1
70	0.68	0.67	0	0.66	0.65	0	0.66	0.65	1	0.65	0.65	0
80	0.67	0.67	0	0.64	0.65	0	0.66	0.66	0	0.64	0.65	-2
90	0.68	0.67	1	0.63	0.63	1	0.65	0.65	0	0.63	0.64	-1
100	0.64	0.64	1	0.60	0.60	0	0.62	0.62	0	0.60	0.61	-1

[1] Interpolated value.

Table 2: Discharge coefficient in function of relative valve opening

The discharge coefficient decreases with an increasing valve opening. Table 3 presents the influence of breaking logs on the discharge coefficient. The influence of the breaking logs on the discharge coefficient is negligible for relative valve openings below 50 %, i.e. the maximum difference is 2 %. For the lowest measured relative valve opening (20%) the discharge coefficient equals 0.80 (+/-0.02) for the four tested configurations. For relative valve openings above 50 % breaking logs result in a reduction of the discharge coefficient between 1 % and 7 %. For the vertical lift valve fully opened the discharge coefficient for the configuration without breaking logs amounts 0.64, while for the configurations with breakings logs a discharge coefficient of 0.60 is obtained for the configuration with 7 breaking logs (C2) and the configuration with 3 breaking logs (C4) and a discharge coefficient of 0.62 is measured for the configuration with 5 breaking logs (C3).

Relative valve opening [%]	Relative difference Δ compared to C1		
	C2 [%]	C3 [%]	C4 [%]
20	2	2	-1
30	1	1	-1
40	0	0	-2
50	-1	-1	-3
60	-2	-1	-3
70	-3	-2	-4
80	-4	-2	-5
90	-6	-4	-7
100	-6	-3	-6

Table 3: Influence of breaking logs on the discharge coefficiënt (based on the electromagnetic flow meter)

Prior to the tests for a rectangular opening a circular opening based on a previous design for the new lock at Sint-Baafs-Vijve was tested in the FHR physical model (Ramos *et al.*, 2016). During these tests the discharge coefficient was measured for relative valve openings from 10 % till 100 % for a configuration without breaking logs and for a configuration with three breaking logs placed inside or outside the gate opening. Van der Ven *et al.* (2015) compared CFD simulations and physical model tests for a geometry with two rectangular openings placed side by side in a flume with and without breaking logs. In the physical model tests the discharge coefficient is determined for relative valve openings 10 % till 100 %. Figure 6 compares the discharge coefficient presented in Figure 5 and Table 2 (based on the electromagnetic flow meter) with the results for the circular opening of Sint-Baafs-Vijve and the physical model tests described in Van der Ven *et al.* (2015).

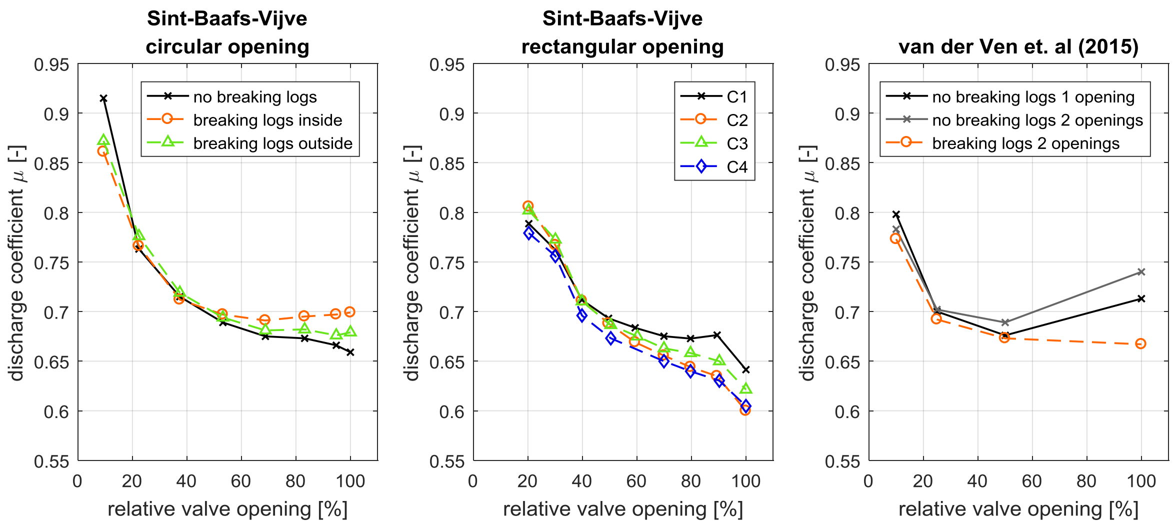


Figure 6: Comparison discharge coefficient for different physical model tests

Based on the comparison of the different physical model tests its concluded that for relative valve openings below 50 % the discharge coefficient increases. The effect of breaking logs on the discharge coefficient is negligible for relative valve openings below 50 %. At relative valve openings above 50 % the trends between the different physical model tests differ somewhat. For the circular opening with breaking logs the discharge coefficient is more or less constant for relative valve openings superior to 50 %. Without breaking logs the discharge coefficient decreases with an increase of the relative valve opening. When the valve is fully opened the discharge coefficient increases with 3 % when breaking logs are placed inside the gate opening and with 6 % when breaking logs are placed outside the gate opening. The tests described in van der Ven et al. (2015) show a contrary behavior for valve openings superior to 50 %, i.e. the discharge coefficient for tests without breaking logs increases with increasing valve opening. Note that when using 1 opening instead of 2 openings the discharge coefficient decreases with 4 % for the situation with fully opened valves. Adding breaking logs reduces the discharge coefficient with 10 % (for a fully opened valve and 2 openings present).

The manual of the software Lockfill (Deltares, 2015) recommends the use of values between 0.60 and 0.90 for the discharge coefficient. The discharge coefficients obtained from the present physical model tests are well within this range. The value 0.90 corresponds to the lower relative valve openings and the value 0.60 to the higher ones.

5. VISUALIZATION OF FLOW PATTERN IN LOCK CHAMBER

The jet in the lock chamber is visualized by injecting dye upstream of the gate opening. A top view and a side view of the flow pattern in the lock chamber is presented in Figure 7 for the experiments with the vertical lift valve fully opened and in Figure 8 for the experiments with the vertical lift valve half opened. During the different experiments with dye, both the color and the transparency of the water in the physical model varied. The contrast and color of each individual picture was adapted by a Matlab post processing script.

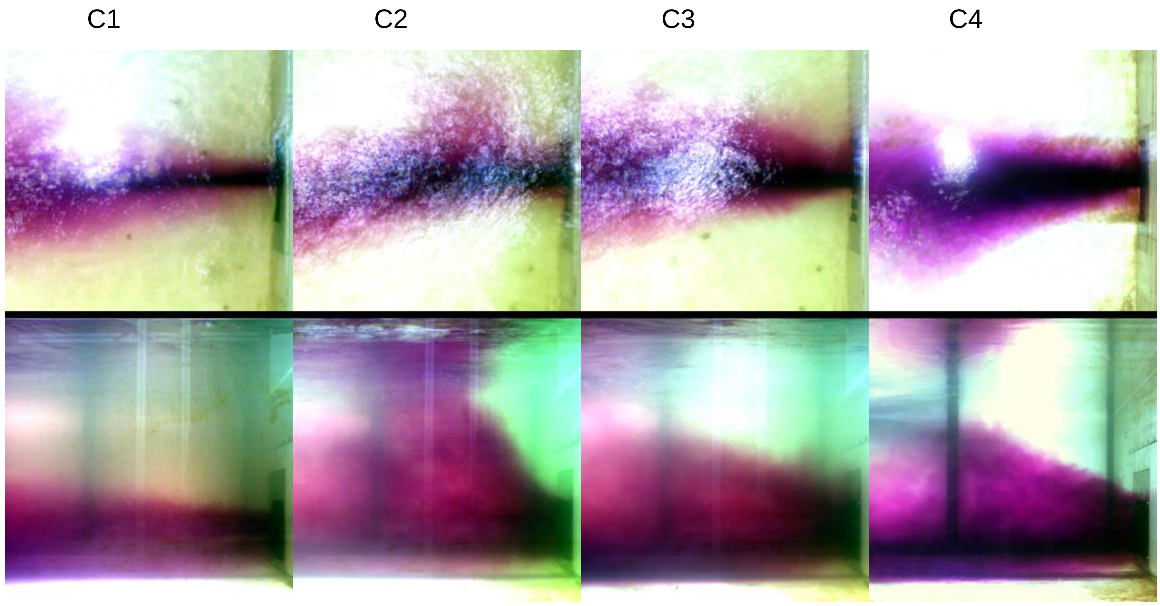


Figure 7: Visualized flow pattern vertical lift valve fully opened; above: top view; below: side view

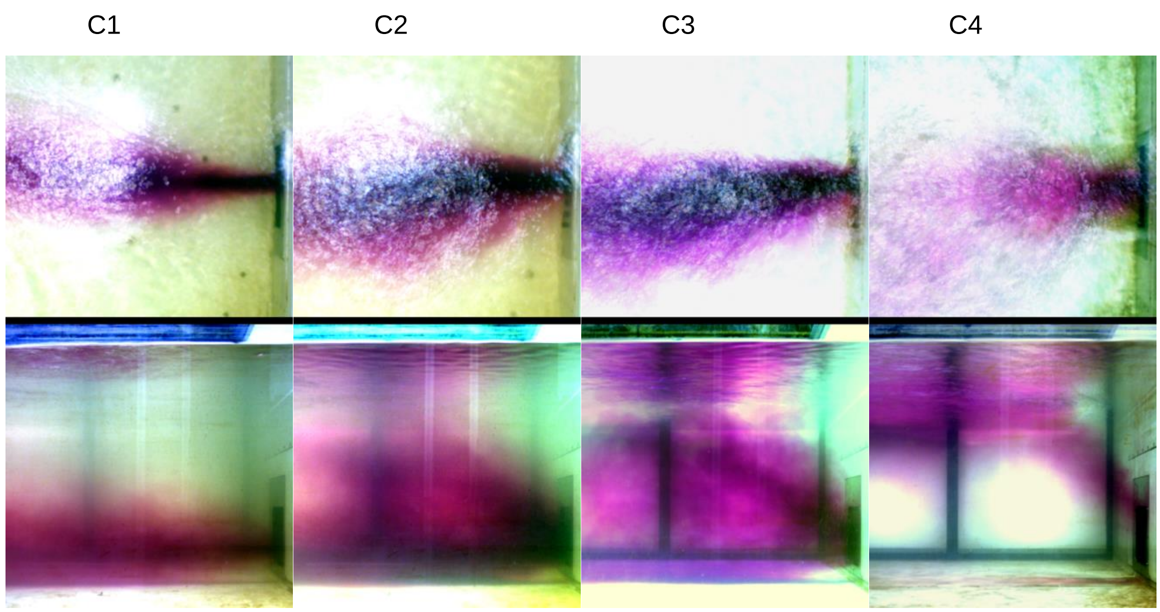


Figure 8: Visualized flow pattern vertical lift valve half opened; above: top view; below: side view

The figures illustrate that the (horizontal) breaking logs enhance the spreading of the jet in vertical direction. Although less apparent, also an increase of spreading in the width of the jet can be noticed when adding breaking logs. In the top view visualizations the color in the central part of the outflow is fully saturated. This central part is surrounded with a less saturated zone that makes the transition with the surrounding non colored water. The less saturated zone indicates the entrainment of ambient fluid with the fluid in the jet. Although both the top view picture and the side view picture are taken at the same time, a clear transition between a fully saturated and a less saturated zone is not detectable in the side view. The top view of the configuration with 7 breaking logs (C2) and the configuration with 5 breaking logs (C3) show that, both for the fully opened and the half opened valve, the filling jet is not passing the outer breaking logs. Therefore, a new configuration with 3 somewhat wider breaking logs was defined (C4). For the fully opened valve, the configuration with 3 breaking logs (C4) is comparable to the configuration with 5 breaking logs (C3), both in terms of spreading in the horizontal direction and in the vertical direction. The configuration with 7 breaking logs (C2) results for the fully opened valve in an increased spreading in vertical direction, i.e. towards the water surface, as compared to the other configurations with breaking logs. For the configuration with 3 breaking logs (C4) and the half opened valve, the lack of dye in the lower part of the water column is probably caused by a malfunctioning of the dye injection system. For the configuration with 3 breaking logs (C4) the spreading of the jet in the vertical direction to the water surface with the vertical lift valve half opened is comparable as for the configuration with 5 breaking logs (C3). Compared to the fully opened valve, the configuration with 5 breaking logs (C3) and the configuration with 3 breaking logs (C4) show a higher spreading in vertical direction, i.e. towards the water surface.

6. **VELOCITY FIELDS**

One of the main goals of the physical model research is to determine the effect of breaking logs on the velocity field downstream of the gate opening. Therefore, velocity measurements were performed in a dense grid of points in the lock chamber downstream of the gate opening. A first series of grid points is situated in a vertical plane at x = 1.7 m downstream of the gate opening (for reasons of comparison with previous research for a different gate opening geometry). A second series of grid points is situated in the vertical symmetry plane of the physical model.

During leveling of a lock the vertical lift valves are gradually opened. From the hydraulic design of the levelling system follows that the vertical lift valve is not fully opened at the moment of the maximum force on the ships in the lock chamber. Therefore, the velocity measurements are both carried out for the fully opened valve and for the half opened valve. Earlier velocity measurements in the physical model indicated a meandering behavior of the filling jet with a period of approximately 60 s (Verelst *et al.*, 2016) and an off-centerline excursion increasing with the distance from the gate opening. As a compromise between accuracy and available time, a measurement duration of 180 s (equal to approximately 3 periods of the low-frequency oscillations of this cyclic behavior of the jet) is considered for the velocity measurements.

For the visualization of the measured velocities in Figure 9 to Figure 11, the x-, y- and z-coordinates are presented in dimensionless form. As a length scale for the x- and z-coordinates, the height H (=1.05 m) of the (fully opened) opening at the upstream side of the gate is used, whereas the width W (=1.89 m) of the opening at the upstream side of the gate is chosen as the length scale for the y-coordinates.

Also the velocities are presented in dimensionless form, using the cross-sectionally averaged velocity U_0 in the opening (below the lower edge of the vertical lift valve) at the upstream side of the gate as the velocity scale.

Since $U_0 = Q/A$, from equation (1) follows:

$$U_0 = \mu \sqrt{2g\Delta h} = \mu \ V_{max} \tag{2}$$

where V_{max} denotes the theoretical maximum (cross-sectionally averaged) velocity [m/s] in the opening, if contraction and energy losses were absent. Note that the dimensionless value of V_{max} is given by:

$$\frac{V_{max}}{U_0} = \frac{1}{\mu} \tag{3}$$

which yields a value of about 1.56 for a discharge coefficient of 0.64 (section 3).

The measured velocities in the vertical plane downstream of the opening are presented in Figure 9, whereas the measured velocities along the vertical symmetry plane of the model are presented in Figure 10. Both figures present the velocities for the fully opened valve, as well as for the half opened valve. To reduce the number of measurements, at the elevations z/H = -0.65, z/H = -0.41 and z/H = +0.41 velocity measurements are only carried out for half of the model domain.

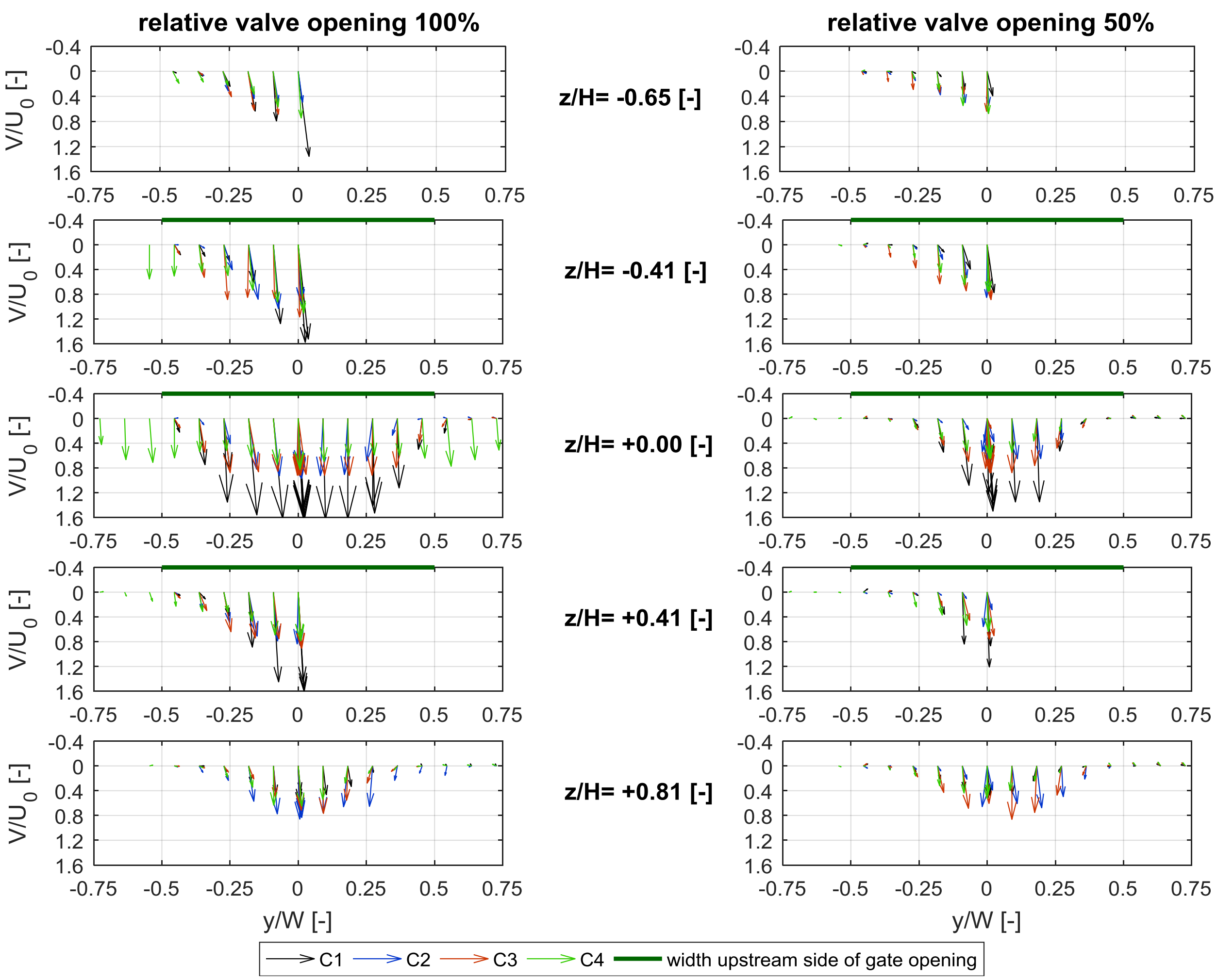


Figure 9: Horizontal velocity patterns at a distance x/H = 1.6 downstream of the opening and at different vertical elevations

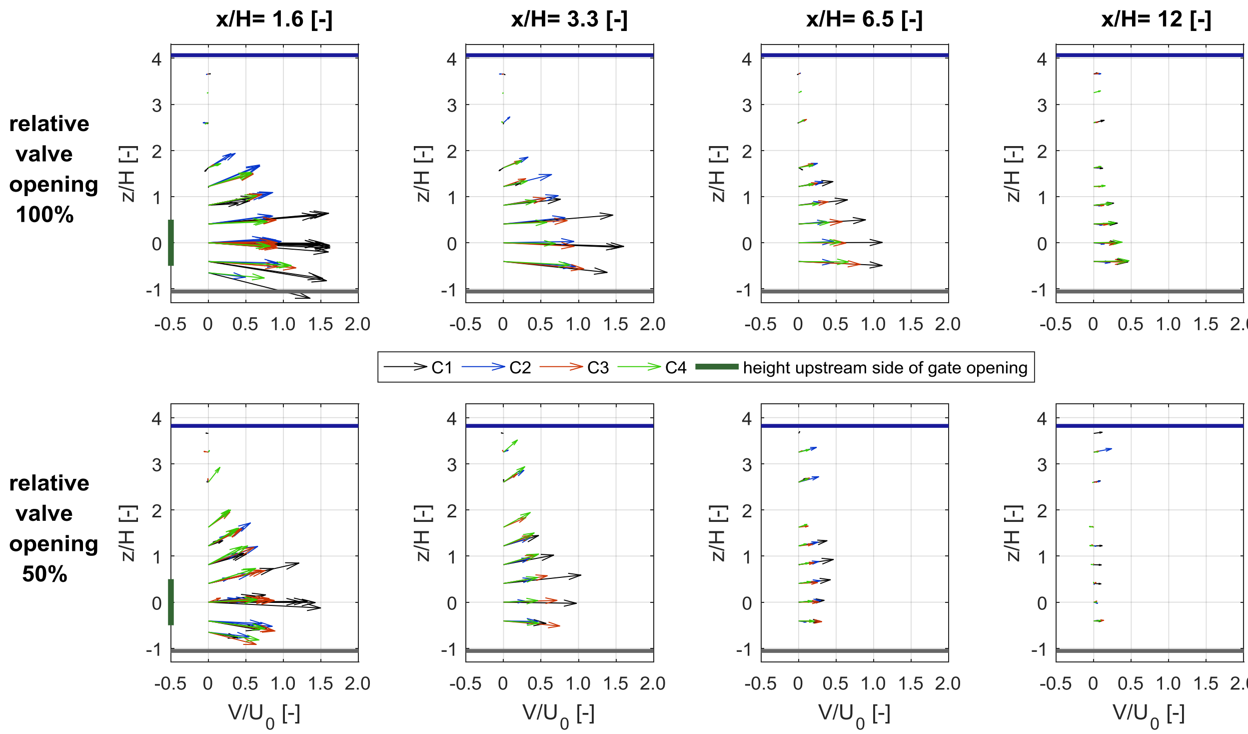


Figure 10: Vertical velocity patterns in the model's symmetry plane (y/W = 0)

Figure 9 and Figure 10 show that for the configuration without breaking logs (C1) the highest velocities are measured in the center of the gate opening. For locations near the center of the gate opening, significantly lower velocities are measured. For the configuration with 7 breaking logs (C2) and the configuration with 5 breaking logs (C3) the spreading of the jet in the vertical direction increases both for the fully opened and the half opened valve. The increased spreading of the jet in the horizontal direction is limited compared to the configuration without breaking logs. For the configuration with 3 breaking logs (C4), there is a difference in the flow pattern for the fully opened and the half opened valve. For the fully opened valve, the spreading of the jet in the horizontal direction increases and at x/H=1.6 three regions with higher velocities can be noticed at the centerline of the opening (z/H =0.0). For the half opened valve, however, the velocity pattern for the configuration with 3 breaking logs (C4) is similar to the velocity patterns of the other configurations with breaking logs. The conclusions on the spreading in vertical direction based on the dye visualizations (section 5) are retrieved in the results of the velocity measurements. For the configuration with 7 breaking logs (C2) and the fully opened valve there is an increased spreading in vertical direction towards the water surface, compared to the other two geometries with breaking logs. For the half opened valve, the spreading in vertical direction towards the water surface is the highest for the configuration with 3 breaking logs (C4).

The decay of the velocity in the lock chamber along the centerline of the opening (i.e. the x-axis) is presented in Figure 11.

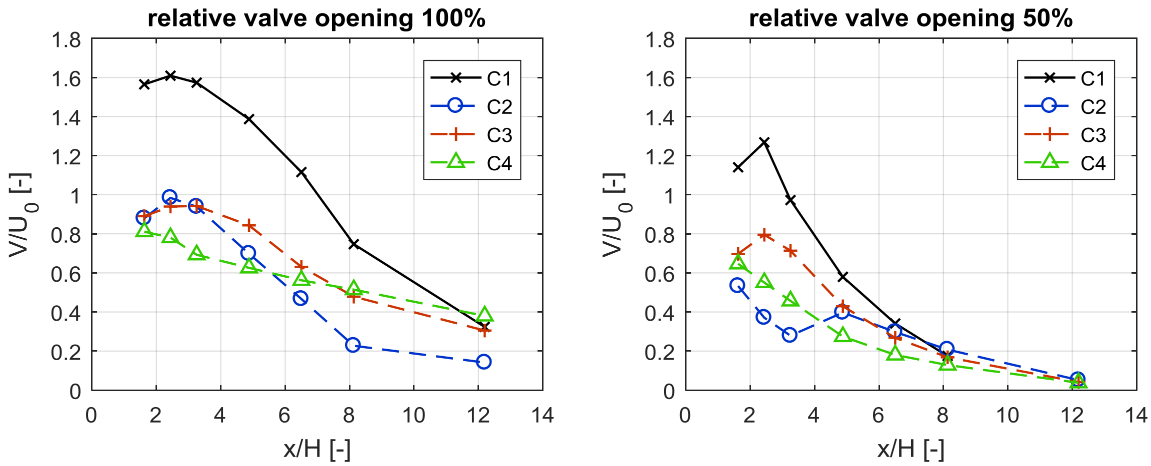


Figure 11: Velocity decay along the centerline of the opening (y=0 and z=0)

For the configuration without breaking logs and the fully opened valve, the maximum dimensionless velocity of 1.6 is measured at x/H=2.45. Note that the value of 1.6 corresponds well to the theoretical value of 1.56 (=1/0.64) derived above. Beyond x/H=2.45 the velocity on the centerline shows a continuous decay with an increase in distance. At x/H=12 the dimensionless velocity is reduced to 0.3. For the measurements without breaking logs and the half opened valve, a maximum dimensionless velocity of 1.3 is measured at x/H = 2.45. Note that the value of 1.3 is somewhat lower than the theoretical value of 1.43 (=1/0.69). It should be emphasized that for the half opened valve, the velocities are also measured at the centerline of the fully-opened opening. Due to contraction of the flow it is to be expected that for the measurement with the half opened valve the velocity is measured above the core of the jet. This is a plausible explanation for the velocity increase from x/H = 1.6 to x/H = 2.45. The decay in velocity with an increase in distance is higher for the measurements with the half opened valve compared to the measurements with the fully opened valve. This can be, partially, explained by the use of the full lift height H to scale the distance in x-direction both for the fully opened and the half opened valve. Adding breaking logs reduces the velocity. For the other configurations, the velocity on the centerline of the opening, for the measurements with the fully opened valve, is reduced with approx. 40 % (=1-1.0/1.6) for the configuration with 7 breaking logs (C2) and for the configuration with 5 breakings logs (C3). For the configuration with 3 breaking logs (C4), a reduction of approx. 50 % (=1-0.8/1.6) is observed. Note that in Figure 9 and Figure 10 for the configuration with 5 breaking logs (C3) and for the configuration with 3 breaking logs (C4) somewhat higher velocities are measured at z/H=-0.41 and y/W = 0.00, i.e. a dimensionless velocity 1.2 for the configuration with 5 breakings logs (C3) and a value of 1.1 for the configuration with 3 breaking logs (C4). At this point, the reduction of the velocity due to the breaking logs equals 25 % for the configuration with 5 breaking logs (C3) and 31 % for the configuration with 3 breaking logs (C4). For the configuration with 7 breaking logs (C2) and the configuration with 5 breakings logs (C3) and the fully opened valve, the velocity increases from x/H = 1.6 to x/H = 2.45. Beyond this point there is a continuous decay till the last velocity measurement at x/H = 12. For the configuration with 3 breaking logs (C4) and the fully opened valve, there is a continuous decay till the last velocity measurement at x/H = 12. At x/H =12 the velocity for the configuration with 5 breakings logs (C3) and the configuration with 3 breaking logs (C4) is in the same range of the velocity for the configuration without breaking logs, while for the configuration with 7 breaking logs the velocity is about half. The reduction of the velocity for the configuration with 7 breaking logs (C2) is most probably linked to the increase in vertical spreading, as observed both in the dye visualizations and the velocity patterns. For the measurements with breaking logs and the half open valve, the configuration with three breaking logs shows a continuous decay of the velocity, while for the configuration with 7 breaking logs (C2) an increase in velocity is noticed from x/H = 3.3 to x/H = 4.8 and for the configuration with 5 breaking logs (C3) an increase in velocity is noticed from x/H =1.6 to x/H =2.45. At x/H =12, the velocity for the configuration with breaking logs and the half opened valve ranges from 0.03 to 0.04.

7. CONCLUSIONS

For a lock leveling system with openings through the gates, mounting of breaking logs (also referred to as energy dissipation bars) at the downstream side of the gate openings is recommended to reduce the forces on the ships moored in the lock chamber. Since the shaping of a gate opening across the thickness of a steel gate and the integration of the valves are somewhat country-specific, it was decided to set up a generic physical model at Flanders Hydraulics Research (Antwerp, Belgium) aiming at determining the effect of breaking logs on the flow inside the lock chamber and optimization of the breaking log configurations adopted in Flanders (Verelst *et al.*, 2016). In this paper an account is given of the specific research carried out in this physical model for the rectangular gate openings of the new lock of Sint-Baafs-Vijve on the river Lys.

Four different configurations have been tested: one without breaking logs (denoted C1) and three configurations with breaking logs (denoted C2 to C4). The configurations with breaking logs differ in number of logs, spacing between the logs and (as far as C4 is concerned) width of the logs and positioning with respect to the upstream gate opening.

First, the discharge coefficients of the configurations were determined for relative valve openings ranging between 20 % and 100 %. It turned out that the influence of the breaking logs on the discharge coefficient was negligible for relative valve openings lower than 50 % and limited for higher relative valve openings.

Secondly, the effect of breaking logs on the spreading of a filling jet was studied. To this end, the velocity fields associated to a filling jet were measured by means of a dense grid of pointwise velocities, using an ADV device attached to an automated traverse system. In addition to the velocity measurements, flow patterns in the lock chamber were also visualized by means of dye injection. When adding breaking logs, the spreading of the filling jet in the vertical direction increased and the maximum velocity on the centerline of the inlet opening is reduced with 40 to 50 %, depending on the geometry of the breaking logs. The lowest velocities were achieved with the configuration with the least blockage of the gate opening at the downstream skin plate, i.e. the configuration with three breaking logs. The research revealed that the exact positioning of the breaking logs is more important for the spreading of the filling jets than the amount of blockage of the opening.

8. REFERENCES

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