THE APPROACHES FOR THE NEW CLASS VIb LOCK AT IVOZ-RAMET, RIVER MEUSE, BELGIUM

by

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ABSTRACT

A new navigation lock, sized 225 m x 25 m will be built at Ivoz-Ramet, on River Meuse, Belgium. This new lock will significantly increase the traffic capacity of the existing weir and lock complex. Due to many existing restrictions on both river banks, the location of this new lock and of its upstream and downstream approach was difficult. This paper presents the different layouts that have been investigated and summarises the results of the composite modelling approach adopted to investigate their hydraulic and nautical characteristics.

1. INTRODUCTION

The Ivoz-Ramet river weir and lock complex is located on River Meuse, just upstream of the city of Liège, Belgium. In the last 20 years, the traffic through the lock has grown from 6 million to 12 million tons per year. As a result, the existing 136 m x 14 m lock is now near to saturation. Moreover, this lock dates from 1936 and suffers regular breakdowns, hindering navigation continuity. The Service Public de Wallonie (SPW) has, therefore, decided to build a new and larger lock, sized 225 m x 25 m, with a maximum water head of 4.5 m.

This project is part of a larger program of modernisation of the navigation on the River Meuse, aiming to provide class VIb locks from the city of Namur to the downstream border with the Netherlands. Indeed, the Meuse is the entrance gate for the Belgian waterways to the axis Rhine/Meuse-Main-Danube, which forms the priority corridor nr 18 in the Trans-European Transport Network.

Figure 1: Ivoz-Ramet weir and existing navigation locks (aerial view from downstream).

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The space available for this new lock was constrained by many restrictions, depicted on Fig. 1: road and railway on the right river bank, weir and hydropower station on the left bank, and important urban and economical developments in the surroundings. The only possible location was between the present 136 m x 14 m lock and the weir, dismantling the old 55 m x 7.5 m lock. This implied the design of new guide walls for the upstream and for the downstream approach, to create more space and better alignment for larger ships. On the other hand, the size of the upstream and downstream ports had to remain limited to avoid negative impact on the water run-off during floods.

2. COMPOSITE MODELLING APPROACH

Once the new navigation lock was drawn, the Hydraulic Research Laboratory of SPW conducted a composite modelling approach for the design of these new approaches. Several tools were used: (1) Field measurements of water profiles, velocity distributions and lock-levelling wave propagation, for calibration of the models; (2) One-dimensional numerical modelling of the water profiles in flood conditions, for estimation of the impact of the works on maximum water levels; (3) Two-dimensional numerical modelling (depth-averaged) of the flow, using Telemac2D, to investigate the flow conditions at the entrance of the approach ports and their influence on the navigation; (4) Physical modelling at scale 1/50 for validation of numerical results and investigation of 3D aspects; (5) Real-time manoeuvring simulations to investigate the safety and fluidity of navigation through the lock. These various models are described below, and the composite modelling approach will be illustrated in the next paragraph, presenting the layouts investigated.

2.1 Field measurements

Several field measurement campaigns were organised to collect data required for the calibration and validation of the models:

- a three-year water level measurement campaign, dedicated to the recording of flood levels, with temporary probes added to the existing hydrological measurement network;
- short-term level and velocity measurements, during a filling and an emptying manoeuvre of the lock, in order to identify existing locking waves (Bousmar et al. 2005);
- velocity profile measurements during a medium discharge event, using an ADCP probe.

2.2 Numerical modelling of water profile

The water profile in the Meuse was computed using a home-made numerical model, solving the 1D-steady-state energy equation with the standard step method. The model covered 25 km upstream and downstream of Ivoz-Ramet. The water level was fixed at the weir and lock downstream Ivoz-Ramet, and the flow resistance coefficients and the local head loss factor were calibrated using the water level records from selected locations during the centennial floods of 1993 and 1995 (ca 2250 m^3/s), together with the additional information collected specifically for this study (Bertrand & Hiver, 2009).

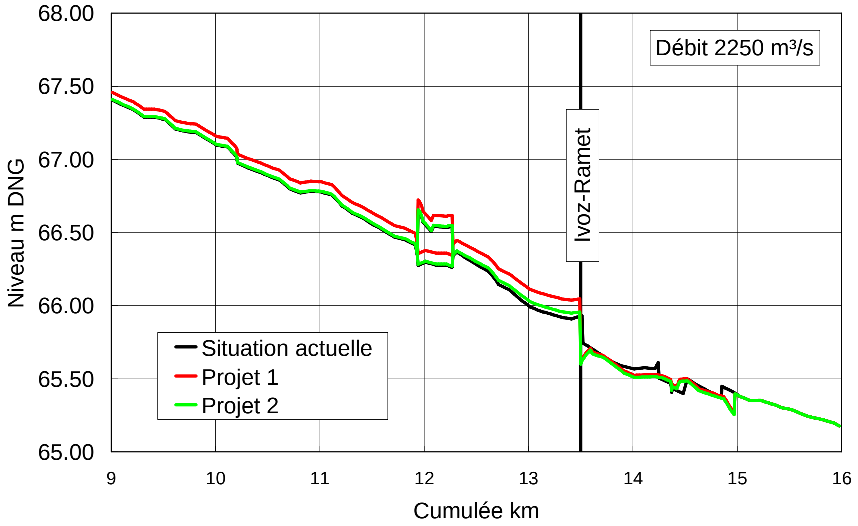

Figure 2: Water profile computed for 2 different layouts, compared to existing situation.

The propagation of the translatory wave from the locking process was performed with a second model, solving the transitory energy equation with the method of characteristics. However, thanks to the relatively large cross-section of the Meuse, no significant effect of the waves was observed, except on the flow pattern in the approaches of the locks.

2.3 Numerical modelling of the flow around the approaches of the lock

The two-dimensional (depth-averaged) finite element model Telemac2D was used to investigate the flow conditions at the entrance of the approach ports. An area of around 1.5 km upstream and 1.5 km downstream of the weir was modelled. The model was calibrated and validated using:

- the recorded translatory wave from the locking process;
- the field velocity measurements at a discharge $Q \approx 500$ m^3/s; and
- physical model measurements at discharges corresponding to Q = 400, 800, 1200 and 1600 m^3/s.

The choice and parameterisation of the turbulence model was particularly sensitive. Whereas, the global flow pattern, and also the eddies appearing during a locking manoeuvre, could be reproduced adequately; it was difficult to reproduce the stead-state circulations in the port. Moreover, it was very difficult to model the flow pattern emerging from the openings in the ends of the guide walls because no validation data was available.

The 2D numerical model was therefore only used for preliminary exploration of the flow patterns in layouts without openings in the guide wall; and also, together with the physical model, for investigating the flow pattern during the locking cycle.

2.4 Physical modelling of the flow around the approaches of the lock

A physical model, in Froude similitude at scale 1/50, was built in the facilities of the Hydraulic Research Laboratory, see Fig. 3. This model covered almost the same area as the 2D numerical model. The different layouts to be investigated were reproduced using wood models of the guide walls. Additionally, the exact design of the openings in these walls was systematically investigated, with various openings orientation, height and depth, number and distribution.

Two innovative techniques were used to measure the flow patterns: (1) water surface velocity recording through digital imagery and automated particle tracking; and (2) point measurement with traditional probes (ADV) moved by an automated frame (Bousmar & Hiver, 2009).

Figure 3: Physical model of the new lock of Ivoz-Ramet approaches.

2.5 Real-time navigation simulations

The latter simulations were performed by ALKYON Hydraulic Consultancy and Research (NL) on their SHIP-Navigator manoeuvring simulator. SHIP-Navigator is a tool capable of simulating ship manoeuvres in real-time. A model has been build that covers a total section of more than 5 km of the Meuse River including the approaches to the lock and the lock chamber. In the SHIP-Navigator simulations, the effects of the in time and space varying wind, currents and water depth are taken into account. In addition the effect of bank suction, fenders at the guiding structures and the lock chamber has been modelled for the upper and the lower approach. The flow field was based on the results of the physical and numerical modelling described before.

Simulations have been carried out with Class Vb vessels (185 m x 11.4 m) with 2 x 800 kW main engines and a bow thruster of 400 kW. The vessel was fully loaded to a draft of 3.4 m or loaded with containers to a draft of only 2.0 m but with large wind area. Various lay-outs of the approaches have been tested both with and without current. The manoeuvres comprised:

- two initial layouts and one optimised layout for both approaches to the lock;
- entering the approach harbour and mooring at the guide wall before the lock;
- entering the approach and the lock chamber without waiting;
- entering the lock from the berth at the guide wall in the approach;
- departing from the lock chamber into the flowing river;
- without current and with river discharges of 800, 1200 and 1600 m^3/s;
- with and without vessel waiting at the berth at the guide wall in the approach.

The actual simulations were performed by an active inland-captain sailing a Class Vb vessel (Fig. 4). After each simulation a senior staff of Alkyon discussed the simulation with the captain to check his feelings about the safety and fluidity. The total test programme covered about 120 simulations. After completion of the simulations the numerical results were analysed:

- the track, distance to the bank, guide walls, moored vessels, lock chamber, etc;
- sailing velocity (head and drift);
- the rate of turn of the vessel;
- the use of the main engines, the rudder and the bow thruster.

Each simulation resulted in a brief report on the safety and fluidity of the manoeuvre and the safety of the approaches in a situation with high current velocities.

Figure 4: SHIP-Navigator with inland bridge.

3. LAYOUT OF THE APPROACH

3.1 General rules

The layout of the approach to the lock influences directly both safety and fluidity of traffic, and accordingly the total duration of the locking cycle. General rules recommend providing enough space in the approach area, in order to facilitate ship movements. A straight fairway from approach entrance to lock chamber should be available, with alignment on the lock axis. Guide walls, with an angle 1/6 to 1/4 to this axis, should help guiding the ship when entering the lock chamber. Depending on the traffic, one or several waiting berths should be available as close as possible to the lock chamber entrance (PIANC 1986, 2009).

When the waterway is a river, the approach port provides a tranquil area for ship manoeuvring to enter or leave the lock. Care has to be taken that eddies or cross currents are kept away from the areas where manoeuvring is complicated. To improve the situation upstream, it is possible to design a guard wall with openings. These openings draw a part of the river discharge in the approach port, and help to enlarge the cross-currents area, reducing their intensity. Stockstill et al. (2005) suggest that the optimal ratio between these openings area and the approach entrance area should be in the range 0.9 to 1.9, depending on the shape of the openings. Similar considerations should prevail in the downstream approach, to avoid eddy formation at the entrance of the approach area.

3.2 Initial layout A and B

Whereas the general rules quoted above can be applied easily to large rivers in non-urbanized area, with enough space available along the bank to design an optimal approach layout, the site constrains at Ivoz-Ramet made an ideal design impossible. So less ideal solutions had to be accepted for the approach of the new lock in the space available between existing banks, keeping enough width available for flood discharge. In a first stage, two draft layouts were drawn (Fig. 5). Layout A reproduces an enlarged version of the existing approach (see Fig. 1): the guide wall is slightly shifted towards riverside, but its gentle curvature along the river is maintained. The extremity of this guide wall can possibly be provided with openings. Layout B proposes much shorter guide walls that should enable easier access and an improved fluidity of navigation. In any case it was almost impossible to provide waiting areas for class VIb vessels. The berthing of class Vb vessels was possible in only few cases, and not always close to the lock head.

The flow patterns in both layout A and B were determined using the 2D numerical model and the physical model. Simulations were performed for discharges Q = 400, 800, 1200 and 1600 m^3/s. The latter are the maximum discharges for which downstream, respectively upstream, navigation is authorized. The return period for the 1200 m^3/s discharge is 5 days per year. Fig. 6 shows some typical results.

In both layout A and B, the cross currents at the entrance of the upstream approach are clearly depicted. Both numerical and physical models show a strong gradient bar that the ship has to cross entering the approach port. A significant flow contraction is observed on the river side, downstream the guide wall nose. This contraction could dramatically reduce the flood conveyance capacity. Lastly, the physical model indicates the existence of a large eddy in the approach port itself, rotating clockwise with velocities up to 0.40 m/s. This eddy could not be captured by the numerical model, due to a too large numerical diffusion. On the other hand, it was possible to reproduce a lock filling wave in the numerical model. This generates a significant axial current at the entrance of the port that could hinder ship stopping manoeuvre.

For the downstream approach in layout A and B, the numerical and physical models showed significant cross currents, with a gradient smoother than in the upstream approach. Again, a large eddy develops in the approach port near the entrance, driven by the shearing generated by the river flow from the weir. In this case, the numerical model was able to reproduce this eddy, but the calibration process was tricky and necessitated actual data from the scale model.

After a first expert analysis of the layout and of the flow pattern, a large program of real-time navigation simulations was executed. This programme covered simulations with zero river discharge, in order to investigate traffic fluidity, and simulations with flood discharge, more focusing on navigation safety. The simulations focused on class Vb vessels (bulk-carrier and container): whereas the lock can accommodate class VIb tows, mainly Vb traffic is expected, due to downstream river conditions (presence of bridge piles, etc.). Various manoeuvres were investigated, upstream and downstream: entering the lock, leaving the lock, entering the approach and mooring at a waiting berth (see e.g.

Fig. 7). These manoeuvres were tested with or without a ship already present at the waiting area, and with or without lateral wind (Alkyon 2007, 2008a).

The analysis of the simulation led to the following conclusions for the upstream approach: none of the two investigated layouts offer sufficient safety conditions. In layout A, the stopping distance is sufficient, but the entrance of the approach port is too small, so that significant bank suction affects the ship track. In layout B, the entrance is wide enough, but the stopping distance is too short. Regarding traffic fluidity, both layout A and B offer poor waiting berth location, increasing the duration of the locking cycle. Moreover, for layout B, the waiting berth has to be free as soon as the discharge increases slightly, in order to ensure minimum safety conditions.

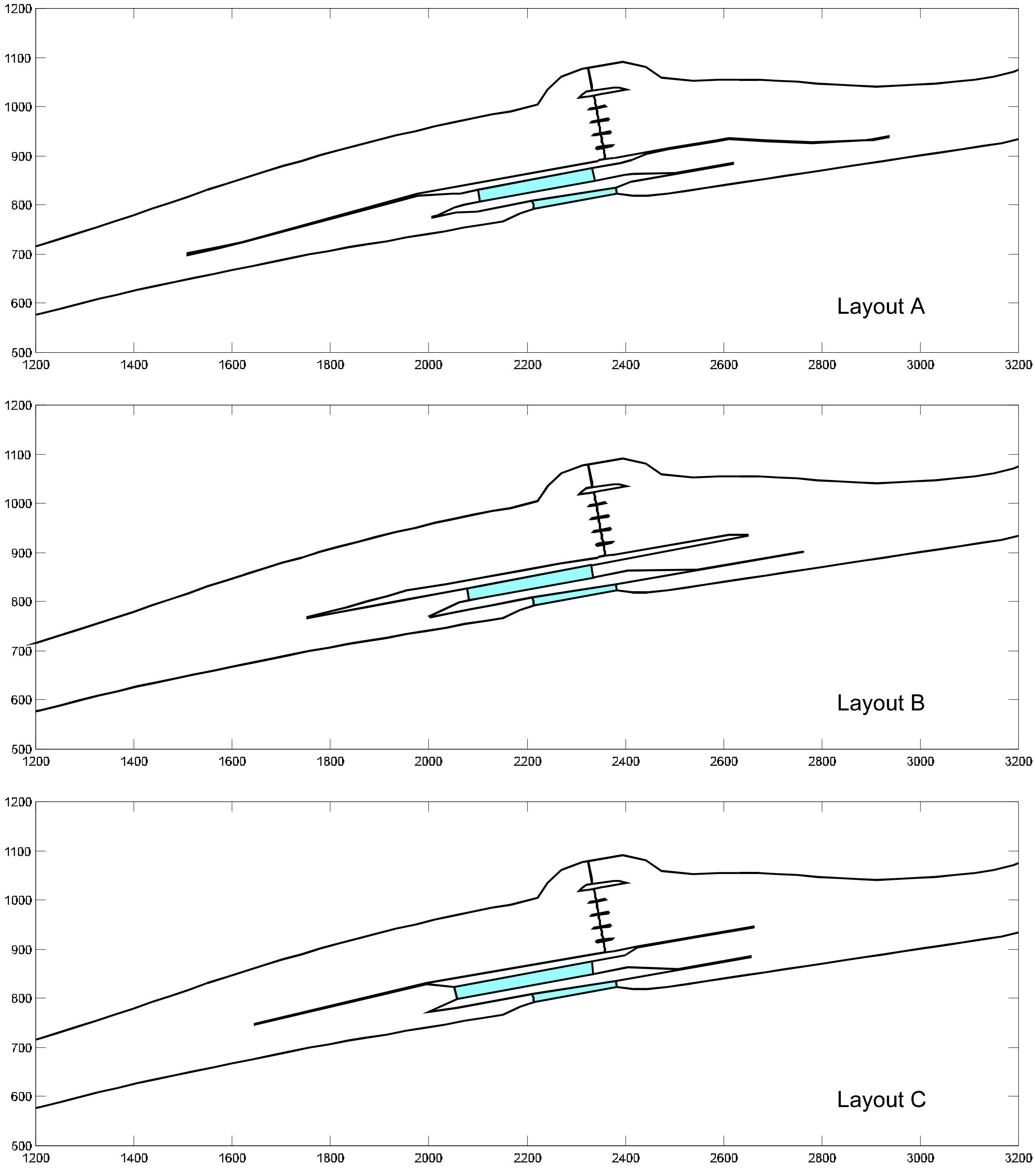

Figure 5: Layouts approach A, B and C

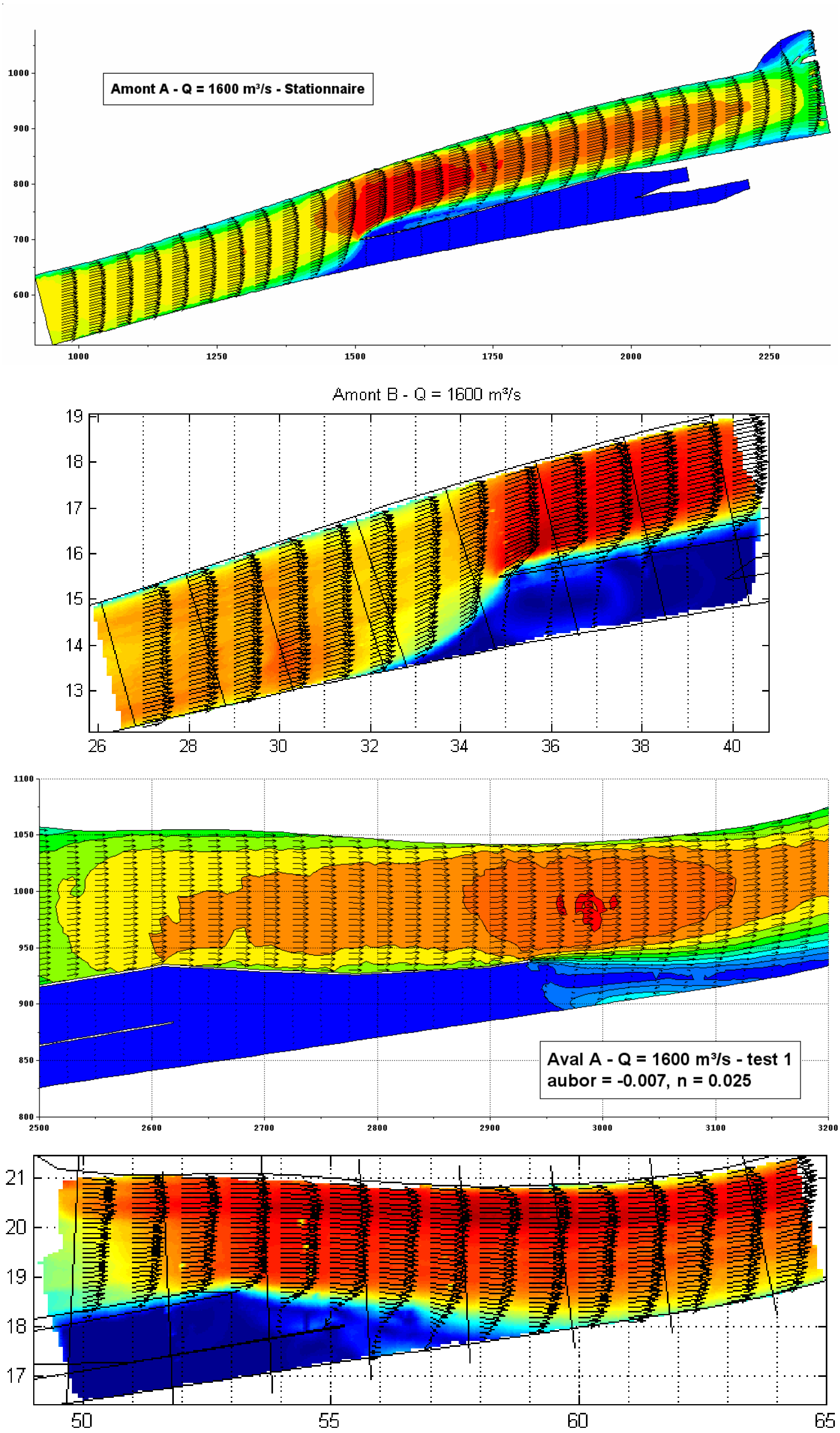

Figure 6: Velocity distribution at Q = 1600 m^3/s: (a, c) layouts A, numerical model; and (b, d) layout B, physical model.

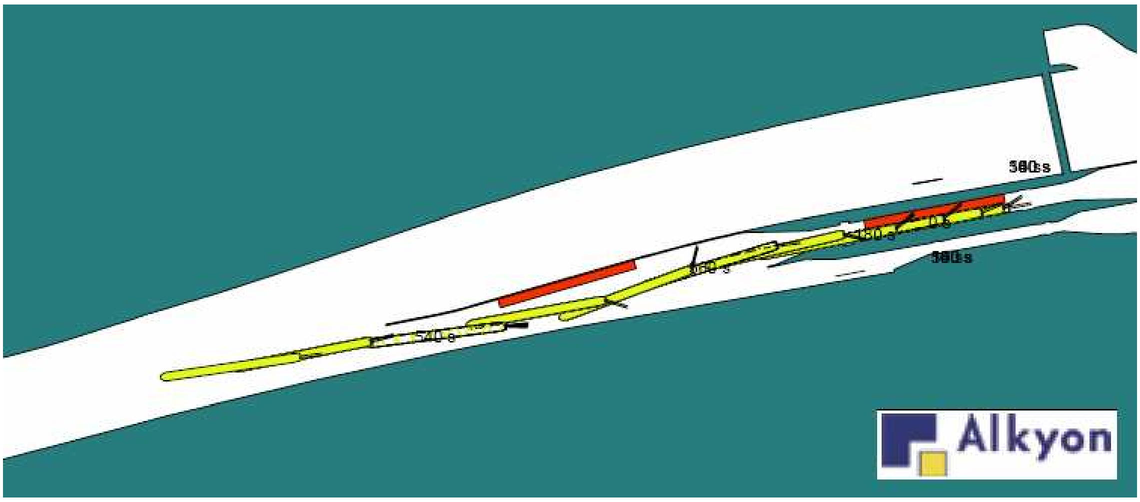

Figure 7: Layout A, upstream approach, no discharge: real-time simulation of a ship leaving the lock.

Regarding the downstream approach, layout A was already discarded on the basis of calm flow conditions: it imposes a zigzag track to the ship in a narrow section, in such a way that the security is moderate and that the fluidity is very poor. Layout B offered adequate conditions regarding fluidity. When the discharge increased, it was found that the security level decreased, due to too short length of the approach port and to the too narrow distance between the outer side wall and the separation wall between the existing and new lock. Indeed, when crossing the eddy that develop in the entrance area, the ship, that is already sailing with a deflection angle to face the cross-currents effect, undergoes a rotating force that pushes its bow to the outer wall and its stern to the separation wall.

3.3 Optimisation of upstream approach layout

Based on the conclusions of the nautical study of layout A and B, a new layout C was designed for the upstream approach. This layout offers a longer stopping distance than layout B and a wider entrance than layout A. By making the guard wall of layout B slimmer, it was even possible to manage a waiting berth along this guide wall. However, layout C is also not ideal: it is a compromise between navigation consideration and flood capacity preservation. On one hand, the fairway is not correctly aligned with the lock axis; and, on the other hand, the width of the river is reduced as compared to the existing situation.

Further investigations were thus required to design openings in the end of the guide wall. Several tests were performed on the physical model, modifying the openings section and distribution. These tests showed that the velocity gradient bar is mainly governed by the upstream flow field and not by the downstream conditions: modifying the openings distribution only switch the gradient bar upstream or downstream (Fig. 8). This result, in apparent contradiction with previous results by Stockstill et al. (2005), can be explained by the high ratio between the approach port entrance width and the total river width (ca 0.38). Nevertheless, a correct design of the openings helped in reducing the flow contraction in the river channel, thanks to a jet effect along the wall. This enabled to restore the flood capacity, as verified through water profile computations.

The final layout adopted for the wall openings is shown on Fig. 9. The openings present a converging shape across the wall, in order to produce on the river side the pursued jet effect. The adopted distribution did not affect the velocity gradient bar shape, but reduced eddy formation in the approach to the lock. Real-time navigation simulations were performed, similarly to layout A and B. The analysis of the results showed that the safety conditions were significantly increased compared to A and B. The recommendation to free the waiting area in conditions with a river discharge larger than $Q = 1200\ m^3/s$ (5 days/year) was maintained (Alkyon, 2008b).

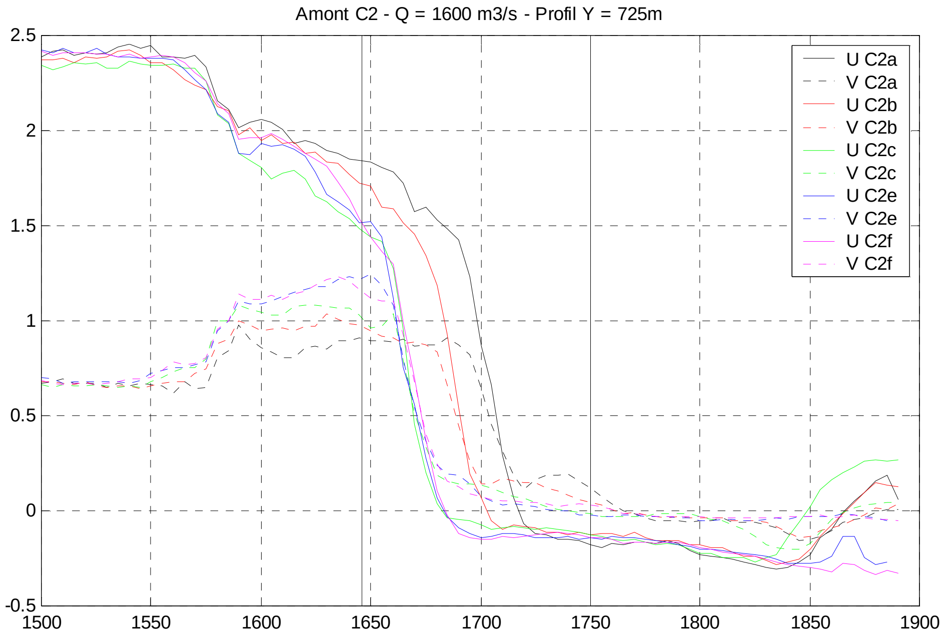

Figure 8: Layout C, upstream: longitudinal and transverse velocity distribution along an idealised ship track, for different wall openings distributions.

Figure 9: Layout C, upstream: final layout of the openings, seen on the scale model.

3.4 Optimisation of downstream approach layout

Similarly to upstream, a new layout C was drawn for downstream approach, based on the nautical analysis of layout A and B. This layout C was mainly based on layout B, where the outer guide wall is slightly extended and made slimmer at his origin, while the inner separation wall is significantly shortened. Again, the end of the outer guide wall was fitted with openings in order to reduce cross currents and eddy formation.

Physical modelling of various openings size, orientation and distribution showed that it was possible to eliminate almost all eddies and to significantly reduce cross currents. First tests investigated the orientation of the openings, relative to the guide wall axis. Orientation closer to normal to the wall (60°) resulted in better flow pattern than orientation almost tangent (30°): the discharge enters the approach port, resulting in decreased downstream cross currents, but the water looses its momentum due to the change in direction, and does not drive any significant eddy (Fig. 10).

Additional tests showed that one should not reduce the height of the openings: when the openings top level was limited below the ship hull, this resulted in a concentration of momentum and a jet effect, generating a significant eddy in the approach port. On the other hand, it was necessary to install a defence to prevent ship bow to hit the openings edges. It was finally decided to install a 1 m thick floor just above the normal water level (Fig. 11).

Again, real-time navigation simulations were performed, similarly to layout A and B. These simulations demonstrated that layout C offers very good safety conditions for navigation, even at the larger discharge of Q = 1600 m^3/s (Alkyon, 2008b).

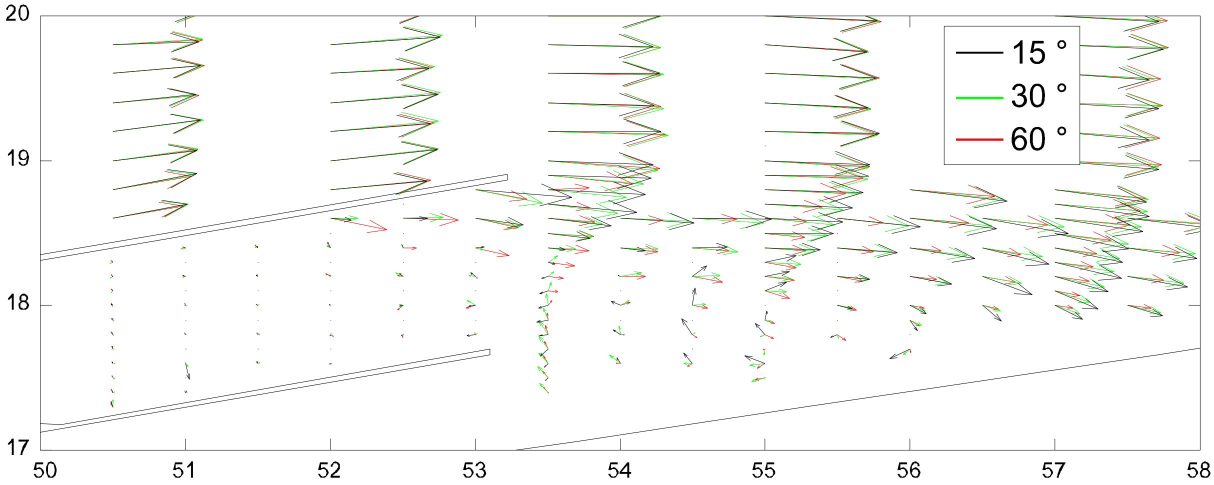

Figure 10: Layout C, downstream: flow pattern for different opening orientations.

Figure 11: Layout C, downstream: final layout of the openings, seen on the scale model.

4. CONCLUSIONS

A new navigation lock, sized 225 m x 25 m, will be built alongside the smaller existing one at Ivoz-Ramet, on the River Meuse, Belgium, to face the traffic growth and to improve the connection of the Belgian waterways with the Rhine/Meuse-Main-Danube corridor.

Due to the limited space available for building this new lock, standard rules are not applicable for designing the modified approach to the lock. A composite modelling approach was therefore adopted, combining physical and numerical modelling of the flow, together with real-time navigation simulation. Analysis of the two first draft layouts showed severe shortcomings in terms of traffic fluidity and/or navigation safety that might not have been identified without the navigation simulations. An improved layout was therefore sketched, with adapted guard walls. The design of the openings in these guard walls was optimised using the physical model.

The final solution, validated through further navigation simulations, offers good traffic fluidity and a safety level ranging from good in the upstream approach to very good in the downstream approach to the lock. Only the cross currents at the entrance of the upstream approach port could not be fully mitigated, due to the very large ratio between this entrance width and the total width of the river. Nevertheless, the design of the openings eliminates flow recirculation along the wall in the river channel, so that the flood conveyance capacity is not reduced by contraction affects

The building licence for the new lock at Ivoz-Ramet has been delivered on April 30, 2009. Building is expected to start in 2010, with a co-funding by the European Commission, Trans-European Network of Transport program (TEN-T). The new lock should be in operation in 2014.

5. ACKNOWLEDGEMENT

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