

PIANC WORKING GROUP 155 “SHIP BEHAVIOUR IN LOCKS AND LOCK APPROACHES”

by

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ABSTRACT

The goal of PIANC Inland Commission (InCom) Working Group 155 “Ship behaviour in locks and lock approaches” is to give designers of locks and organizations that operate locks more insight into the troubles which vessels might encounter in the interaction with locks and what to do to avoid them. During the transit of a ship through a lock and even during normal navigation, ships can be significantly affected by the interaction with the processes induced by a lock. It is relevant to have an idea about the governing processes, as they have an impact both on the design and operation of navigation locks. In the report, it is pointed out which effects are important and how these combine with the experience from current and past lock projects. This paper presents an insight on the work of the group and on the main points covered in the report.

1 INTRODUCTION

PIANC has the goal of enhancing the exchange of knowledge between people that are engaged in waterborne transport. To achieve this, PIANC brings together international experts on the design, development and maintenance of ports, waterways and coastal areas. Many working groups (WG) are developing technical updates on shared best practices.

PIANC InCom WG 155 “Ship behaviour in locks and lock approaches” is a successor to InCom WG 29, which published the Report No. 106 “Innovations in navigation lock design” in 2009 (PIANC, 2009). During the preparation of that report, which focuses mainly on the design of locks, it became clear that it is necessary to give designers of locks and organizations that operate locks more insight into the troubles which vessels might encounter when operating locks and provide guidance on how to avoid them.

During the transit of a ship through a lock and even during normal navigation, ships can be significantly affected by the interaction with the processes induced by a lock. It is relevant to have an idea about the governing processes, as they have an impact both on design and operation of navigation locks.

The aim of the WG is to give designers and operators an idea as to why the effects of locks on vessels are important and to combine this with the experience from current lock projects. This paper presents an insight on the work of the group. WG 155 was set up in 2011 and currently has 14 senior and 4 young professional members from 9 countries (s. Figure 1).

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Figure 1: Group 155 in front of the hydraulic lab of Compagnie Nationale du Rhône (CNR) during the second full-blown meeting

2 WORKING GROUP MEETINGS

Introduction

After the inaugural kick-off meeting in New Orleans in September 2011 (attached to the PIANC Smart-Rivers Conference), further WG meetings in Delft, Lyon, Panama City and Maastricht followed. While the first meeting was a short kick-off meeting, the subsequent three meetings were full meetings that each followed roughly the same three day schedule: Each meeting had three half-day work sessions with two or three technical tours attached. This type of meeting structure is advantageous, as it enhances the discussions between the members.

Inaugural meeting in New Orleans

The group had its inaugural one-day meeting on September 12th, 2011 in New Orleans. An important part of the meeting was presentations of the different members about their background, i.e. the relevant parts of their CVs, the companies/institutions they are working for and important projects they have worked on. The group worked through and analysed the Terms of Reference (ToR), in order to develop a possible structure for a later report. It became clear that the ToR could not be directly used as a guideline on how to structure the report. The group developed two possible ways to structure the report.

The first approach was oriented on the point of view of the user of the infrastructure. It is based on a timeline of events for the vessel that transits through a lock, i.e. a separate chapter for leaving normal navigation, waiting in front of the entrance, entering the lock, the locking process, leaving the lock and returning to normal navigation.

Alternatively, a second approach was developed, which is more scientifically oriented. It was based on a chain of consequences. The chapters would explain ways to compute / estimate forces on the vessel, the reactions of the vessel, the handling of vessel, mooring, etc. by the crew, evaluation of safety levels based on vessel behaviour and equipment and finally the definition of guidelines from the processes analysed before.

It was decided to adopt the first approach, being of more practical value to users of the report.. As a major problem for both approaches, “possible duplication” was identified wherever the same physical principles are relevant in different stages of the transition through a lock.

First full meeting in Delft

In February 2012 the group met in Delft, the Netherlands. This meeting was hosted by Deltares. After a tour through the hydraulic laboratories of Deltares the group discussed a set of presentations, prepared by the members, covering the topics:

- Methods for experimental/numerical ship force evaluation during locking
- User experience about locking (equipment, problems, etc.)

- Chinese guidelines for ship force evaluation
- Importance of fenders
- Recreational vessels in locks
- Bollards (design, load assumptions etc.)
- Physical background of forces on moving ships

As a third alternative for the report structure, the idea of separating the report into two main topics “navigation” (horizontal movement) and “locking” (vertical movement) was suggested. But based on the presentations and the discussion of the report structure at the previous meetings, it was decided to keep the structure of the report “based on a timeline of events for the vessel”. The structure of chapters was set up during the meeting by two separate sub-groups (“out-of-the-lock”, “in-the-lock”). The next aim was to fill the developed framework with missing content. Thus, homework for contributions was distributed to the members. Up to that point, a significant amount of material had been collected and integrated into the report manuscript, but nevertheless a substantial amount of writing still needed to be done.



Figure 2: Fresh water tongue spreading over saltwater after opening the lock gate at IJmuiden, The Netherlands

A tour to the Volkerak and Krammer lock complexes and the IJmuiden locks completed the meeting. Here the members had the opportunity to see the very special flushing system of the Krammer locks, where saltwater intrusion is a specific problem. At the impressive sea-locks of IJmuiden the pilots gave an overview of their experience with density driven currents, which could also be observed at the locks. Fresh water streaming out of the lock, while underneath saltwater is streaming in, is shown in Figure 2. This situation is potentially dangerous, because “what you feel (as a vessel) is not what you see (as a captain)”.

Second full meeting in Lyon

In September 2012 the group had its third meeting in Lyon, France (Figure 1). The meeting was hosted by the Compagnie Nationale du Rhône (CNR). This offered the possibility to visit the physical model of the new Panama Canal locks, which was set up in the CNR’s hydraulic laboratories. During the meeting, the group reviewed the current status of the report, going through the report chapter by chapter. The previously decided structure was reason for discussion again, but was been accepted as “the lesser of two evils”. The report is intended to be an aggregation of knowledge about ship forces and resulting behaviour, that helps designers and operators to care for the most important effects around locks. To achieve this, several gaps in the framework of the report still had to be filled. Unfortunately, again some duplications were observed in different chapters which had to be cleared. In contrast to other reports, the group tried to find a “narrative” style introduction, to make it more readable. The meeting was rounded up by a tour to the Rhône Navigation Centre, a demonstration of bathymetric measurements on the Rhône and a visit of the lock of Châteauneuf. At the lock of Châteauneuf a vessel was observed that obviously had to fight the piston effect, which is explained in detail in the upcoming report. The exit of the vessel took nearly 15 min (Figure 3).

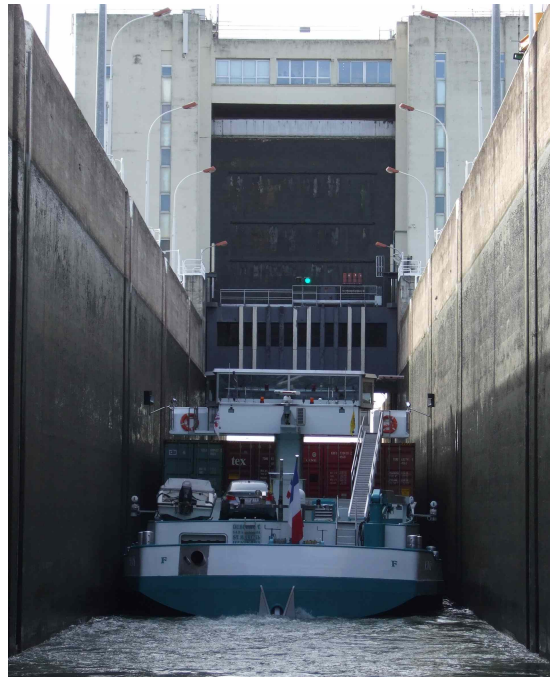


Figure 3: Vessel fighting with the piston effect when leaving the lock Châteauneuf

Third full meeting in Panama City

The meeting of the group in March 2013 in Panama was hosted by the Panama Canal Authority (ACP) and the International Maritime Pilots Association (IMPA). During the meeting, the group decided to present parts of its work in a workshop at the next Smart-Rivers 2013 conference. The workshop was planned to be a small symposium on the work of the group and other interesting topics concerning locks. Furthermore, during the meeting the new material provided for the WG (between sending out the last version of the report and the meeting) was reviewed and incorporated into the report. The meeting was finished with a brainstorming session on possible hazards while transiting a lock in order to prepare a hazard analysis (HAZOP). The accompanying technical tours gave an in-depth overview on both the Panama-Canal-Expansion-Program and the existing locks (s. Figure 4). Visiting the “Third Set of Locks” construction site and the technical tour to the dredging division at Gamboa and Culebra Cut gave an impressive overview of the enormous extent of the works to be done. This was accompanied by a visit of the marine traffic control center and the simulator facilities of ACP.



Figure 4: WG 155 and guests visiting the old Panama canal locks

Meeting and workshop in Liege/Maastricht

In September 2013 the group had its fifth meeting in Maastricht, the Netherlands. During the meeting, the group decided that the report had reached a status that could be called "near final". For the last steps, the separate chapters were given to some members of the group to manage the finishing steps for those chapters ("Chapter-Chairmen"). It was decided to wait for a few further contributions and to send then an early-review version to both a member from the US-side (as no US-member was actively working in the group) and to InCom. Due to illness and/or workload of some members the timetable was not achievable. Thus, an "even rougher" version of the report draft was sent out for review. Currently, the internal review by the Chapter-Chairmen is in progress. Probably no further meeting of the group will be needed for finalizing the report of WG 155.

The workshop on locks at the Smart-Rivers 2013 conference hosted by the group was clearly successful in promoting the work of the group. With nearly 40 participants, it stimulated the discussion between experts in the field (Figure 5).



Figure 5: Impressions from the workshop on locks during the Smart-Rivers Conference

3 IDENTIFIED RELEVANT IMPACTS ON THE VESSEL

3.1 Introduction

In the following, a short overview on the topics covered in the report is given. Obviously, only small parts of the report can be covered here.

3.2 During normal navigation

When filling a lock chamber, water is withdrawn from the upstream reach. This creates a negative surge in this reach. Similarly, when emptying a lock chamber, water is released in the downstream reach. This creates a positive surge in this reach. If these surges are too large, they may hinder navigation:

- Vessels may hit a bridge deck (positive surge) or touch the channel bottom (negative surge);
- Extra velocities are generated that may affect vessels, mostly when entering lock approaches or when stopping;
- Extra forces are generated between the barges of a tow train;

Apart from these effects, which are relevant for navigation, further side effects can occur:

- Adjacent hydraulic works can be affected: extra forces on lock gates, sudden level variation might irritate the control systems of weirs, extra load on the caisson of a ship lift;
- As the wave length of such surges is much longer than ship generated waves the submergence or emergence time of the banks increases. This may perturb bank ecosystems.

In the following chapters of the report we try to explain the relevant physics of a ship making way and the behaviour of translatory waves generated by the locking process. The sources for translatory waves are explained as well the propagation and transformation when travelling through the waterway. The resulting waves have to be within acceptable limits. Also guidelines for allowable wave heights from various countries are presented and an example for observed lock generated waves is presented.

Furthermore some advice is given on the interaction between the flow in the approaches resulting from adjacent river sections. Though not the main scope of the report, advice is given on the design of the approach in order to make the transit into the lock safe for the vessel.

3.3 In the lock approach

The lock approach can be considered as the connection between the navigation channel (river or canal) and the lock chamber. In this zone, a ship approaching the lock has to slow down to a speed suitable to enter the lock, which is much less than normal navigation speed. This requires reduced propeller action, which has an important consequence for manoeuvring and steering. Forces induced by the rudder are proportional to the square of the inflow velocity, which depends on both the ship's speed and the propeller action, which both are reduced in the lock approach. On the other hand, external forces due to wind, currents, interaction effects, etc. are more difficult to be compensated at low speed.

In these conditions it is often necessary to use other means to control the ship, either other control devices such as bow and stern thrusters, or external means of assistance such as tugs or moorings. Besides its function as a connection between the lock and the channel, the lock approach is also used as a waiting zone, where ships can be moored until the lock or the waterway is clear. Both functions and related issues are discussed in this chapter. The presence of moored ships in the lock approach is quite common, especially in inland navigation, but also near locks for sea-going vessels. Ships need have suitable infrastructure to wait in a safe way if they cannot proceed with their voyage and particularly if the lock is not ready or other ships have priority.

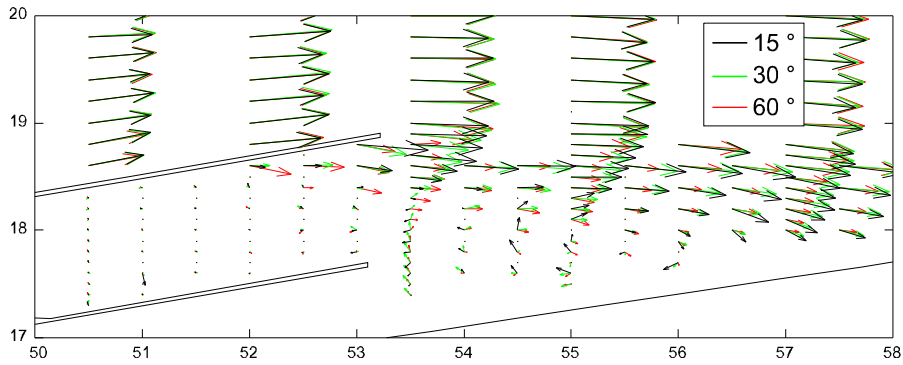


Figure 6: Effect of the openings in the sidewalls between lock approach and river

The necessary water depth in the approach is a most relevant factor for the maneuverability of the ships. Thus, some guideline values from different countries are provided. The vessels are also endangered by external currents. These can be very disturbing (or even dangerous) for ships traveling at low speed, i.e. directly before they enter the lock. Figure 6 shows the effect of openings in the sidewalls between lock approach and river, which can significantly change the flow field in the approach. Figure 7 shows the computed flow field from the emptying process of a lock, which has a negative impact on vessels that try to enter the other lock. Additionally, other possible sources for external forces like the discharge from hydro power plants (Figure 8) are explained and some relevant guideline values are given.

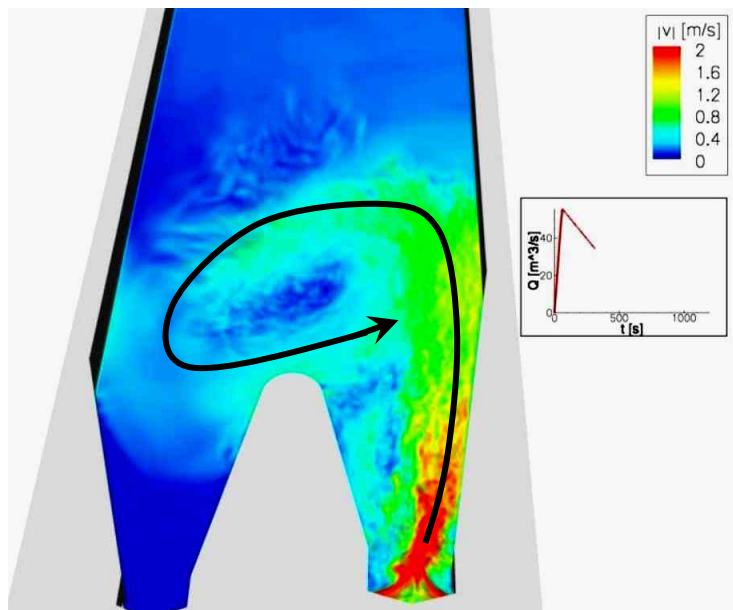


Figure 7: Vortex developing in the approach of a double lock

Another important factor is the interaction of the flow field generated by the moving vessel with the structures around it. The so-called bank-effect generates forces and moments on the vessel when it moves close to a wall. This effect is explained in detail with examples and possible remedies are presented.

When stopping the vessel in the lock approach, appropriate space must be available for the process. Stopping of small to medium size vessels generally poses no special problems; most of these vessels will often stop under their own power. Larger ships have to slow down using their own resources to a speed (about 5 to 6 knots) which is sufficiently low to allow the tugs to attach safely. Examples for the handling of larger vessels with tugs are given in the report.

Unfortunately it is common practices for smaller inland vessels to stop using their mooring lines. This procedure is potentially dangerous and should be avoided, as the loads on the mooring lines can be very high.

Moored ships in the approach can be endangered in several ways by the wave loads generated from the locking process or by passing ships:

- Touching the ground due to excessive vertical movement;
- Touching the berth or dolphins, mainly due to rolling;
- Breaking of lines due to horizontal movement.

The allowable limits for the ship's movements to ensure safe conditions always depend on the vessel, the fendering and the mooring system in use. The slope of the lock generated waves and the resulting flow velocities are typically generating the highest forces, as passing ships are moving slowly in the approaches. The equations to calculate the forces from translatory waves are given in the report as well as the requirements in different countries for the mooring equipment of vessels.

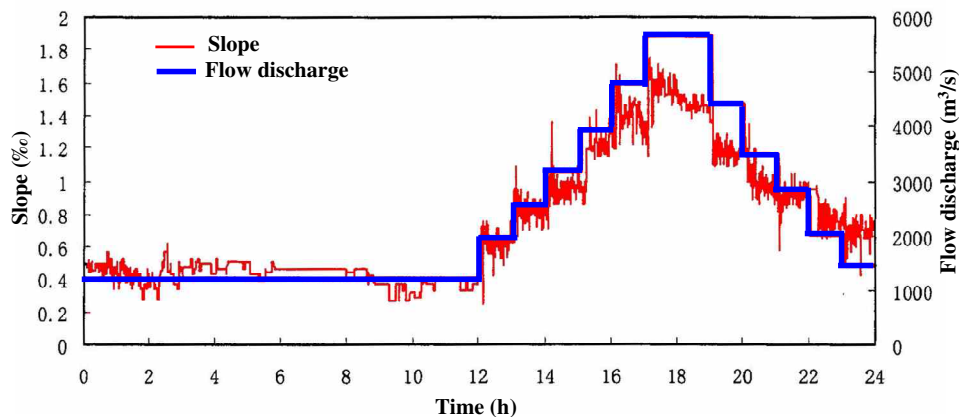


Figure 8: Measured discharge of hydro power plant and resulting water slopes

3.4 Entering the lock

Several factors determine the safety when entering a lock. The effects of density currents on entering can be significant, mainly considering deep sea locks at the transition from salt to fresh water, where the density differences can induce significant density currents (compare Figure 2). The density currents are characterized by a fresh water flow at the surface, and a salt water flow below (in the opposite direction to the fresh water flow). The density currents are caused by the discharge of the levelling system in the approach, the strength of which depends on the head difference, and by the opening of the lock gate. These density currents can exert important forces and moments on the manoeuvring ship and the assisting tugs, when approaching and entering the lock. Also the effects of the ship speed on the entering manoeuvre are important. In order to be safe this speed should not be too high. The entering speed is often higher for unloaded ships and/or wider locks. When a ship enters a lock, it generates translatory waves which reflect against the closed gate(s) at the other lock head, and, in consequence of the high return flow velocities next to the ship in the lock, the water level alongside the ship lowers. As a result of this lowering the sinkage (squat) of the ship may increase, with the risk of hitting the sill. The forward speed of the ship is restricted by the high resistance in the constraint profile. All these effects of the water motion due to the ship are strongly dependent on the sailing speed, the blockage of the lock cross section by the ship and the ratio between the ship draft and the water depth. Different approaches on how to evaluate these effects are presented.

3.5 In the lock with the gates open

When ships have entered the lock and are in the process of mooring, they can be vulnerable to hydrodynamic loads originating from translatory waves entering the lock from the approach, from the closing of the lock gates or from other vessels. The main sources of translatory waves in the lock chamber are explained in the report and formulae are presented to estimate the loads on the vessel. Although the height of the translatory waves in the chamber is often small, the effects on the ship can become quite large.

Waves in the approaches enter the lock chamber and can move the ships moored in the chamber. These waves can be significant, especially if the funnel shape of the lock entrance is a solid wall and guiding the waves into the chamber and is thus amplifying the height of the waves.

When the ship enters the chamber, it produces a wave in front of the ship. If the closing of the gate and the mooring process start before the waves have deadened, these waves can generate significant mooring forces. Furthermore, if there is already a ship in the chamber, the wave that is generated by a second ship, which enters the lock or approach harbour can endanger the prior ship, as the generated wave pushes the first ship forward.

Another source for waves can be the movement of the lock gates. Due to the larger cross section, the waves produced are normally not relevant for the approaches but only for the lock chamber itself. There are many different types of gates for navigation locks. These are described in detail in the PIANC reports on locks (PIANC 1986 and PIANC 2009). Some of these gates move only very small amounts of water during their operation (sector gates, lift gates) while mitre gates induce a more significant movement. This results in an instantaneous flow that is sustained only for a short time, as water starts to flow through the opening gate, too. For larger vessels the generated wave is lasting too short to set them significantly in motion, but for smaller vessels with a high blockage an unexpected motion can occur.

As the ship is being moored typically while the gates are still open, the design guidelines for bollard spacing and design loads are explained in this chapter. Also the choice between fixed and floating bollards is highlighted together with some experiences from mooring practice (Figure 9).



Figure 9: Synthetic lines used on inland navigation vessels

3.6 Lockage

The locking process itself is probably the most relevant interaction between the vessel and the lock. Thus, the relevant processes are described in the report in detail.

Once the ship is moored in the lock chamber and lock gates are closed, the lock levelling process itself can start. The lock chamber is filled or emptied by gravity, either through the head (Figure 10) or through a more complex system of culverts and valves. Therefore an overview of the major filling system types is given. As the discharge resulting from this levelling will induce waves and forces on the ship present in the chamber, the system must be carefully chosen and the flow must be limited to acceptable values. The resulting forces have to remain small enough for a comfortable and safe operation.

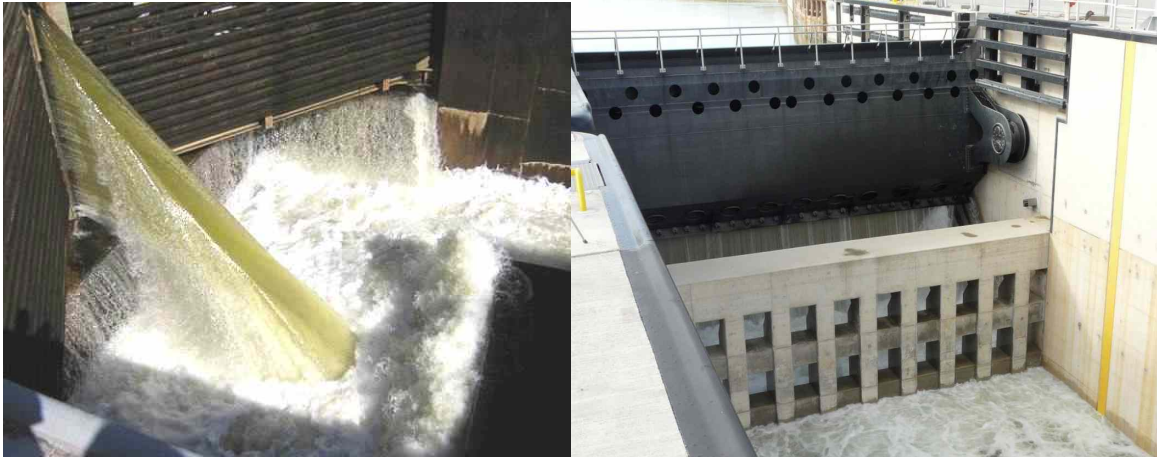


Figure 10: Most simple and more sophisticated through the head filling system

Different ways to define forces occurring during levelling are listed, together with acceptance criteria for comfortable and safe operation. The force components and associated physical processes are then analysed. The effects of different valve schedules are explained in the report, as they quite often result in problems during the operation of a lock. Figure 11 shows an example, where a stepwise opening of a valve leads to large waves in the chamber due to superpositioning of the waves.

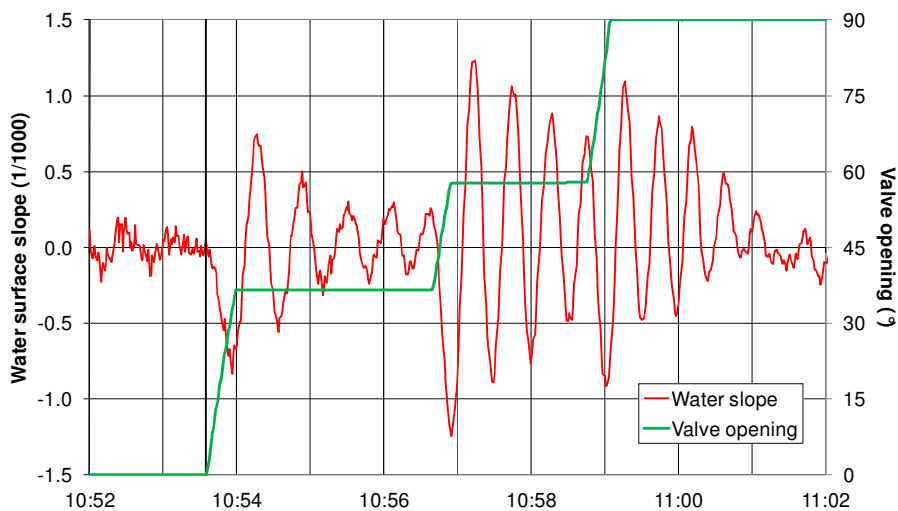


Figure 11: Impact of a discontinuous valve opening schedule on the water surface slope

Lastly, the advantages and weaknesses of the possible investigation methods for levelling modelling are summarized (numerical, physical, field measurement). Together with the guidelines from different countries this gives an overview of the forces acting on the ship during the levelling process and the possibilities of evaluating the safety of the process.

3.7 Leaving the lock

After the levelling has finished, the gates will be opened. Normally the opening will start when sensors show a water level difference below a certain threshold between inside and outside the chamber. As this is never exactly the case, a transitory wave will be started. This effect is less pronounced if the gates are opened slowly. This is explained in the report together with rule-of-thumb approximations for allowable water level differences.

The filling of the lock can over- or undershoot, especially if the filling system has long culverts. In that case the fluid in the culverts has so much momentum, that the water level in the chamber can exceed the upstream level or fall beneath the downstream level. The valve operation procedure should be carefully adjusted, so that the overshooting is limited. This can be achieved by beginning to close the

valves before the filling/emptying process has ended. Otherwise the levelling can take much longer (until the water oscillation has stopped) or the ship forces can be big (if the gate is opened at the wrong moment, i.e. at the maximum overshoot).

When a ship starts to leave the lock, it accelerates slowly and is lowered slowly (development of squat) due to the large resistance of the narrow cross section of the lock. The water which is pushed away by the bow flows easily to the open end of the lock and with difficulty to the stern as a result of the narrow profile. During the exiting process, grounding can be a problem. Some experience values are given in order to estimate the speed that exiting vessels can safely reach (compare Figure 3).

As a special practice, the “hydraulic assist” procedure can be used to let the vessels exit the lock faster to downstream: The upstream valves are opened slightly, so that the vessel is pushed out of the lock. This procedure is used for maritime vessels with very high blockage ratio at the Panama canal. It was also investigated for inland navigation vessels in Germany, but is not in use currently. The advantages and drawbacks are explained in the report.

3.8 Other aspects

Several aspects that do not fit into sequence of chapters in the report are assembled in this chapter. These topics are security considerations (a HAZOP analysis for lock transits), the usage of fenders and the question how to treat pleasure craft.

4 CONCLUSION

The work of WG 155 already resulted in substantial benefit, as the different points of view of the experts on the selected topics significantly broadened the scope for all participating members. In addition, the public has been involved by arranging a workshop on locks during the Smart-Rivers Conference 2013. This workshop showed the broad range of topics covered by the group and gave the public opportunity for interaction with the group.

During the work meetings of the group (and working on it in the time in between) it was possible to develop a suitable structure for the report and fill it with significant content. It became obvious that a “perfect” structure will not be an achievable goal, but that instead the result should be a structure and content that are digestible for non-expert readers. The final goal of the report is to point out the troubles which vessels might encounter when operating locks and what to do to avoid them. The report is supposed to give designers of locks and organizations that operate locks more insight into the relevant physical principles and best-practice experience to avoid problems.

At the time given, the report comprises about 120 pages and completion of the report is expected for 2014.

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