SYNERGY BETWEEN THEORY AND PRACTICE FOR ULTRA LARGE CONTAINER SHIPS

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ABSTRACT

In 2003 an accessibility study based on real-time simulations for the S-class container ships of Maersk Sealand was performed at Flanders Hydraulics Research in cooperation with all involved parties (public and port authorities, pilots, tug and shipping company). The regulation for the upstream and downstream navigation on the Western Scheldt did not accept the arrival of a ship with length over all greater than 340 m.

The paper describes two main research studies executed to fill in the gap of knowledge about the manoeuvring behaviour of container ships in shallow and confined water: the accessibility of Ultra Large Container Ships with a maximum capacity of 14,000 TEU to the Western Scheldt and the accessibility of the Berendrecht Lock and Delwaide Dock located on the right bank of the port of Antwerp. An integrated simulation platform with mathematical models describing hydrodynamic (manoeuvrability, ship-bank and ship-ship interaction) and external (wind, current, tug assistance) forces and coupled ship manoeuvring simulators helped in evaluating the possibilities and limitations of head-on encounters, lock and turning manoeuvres.

The combination of research and training has finally led to the arrival of the MSC Beatrice in April 2009. After a validation period of more than half a year, characterised by a constant adaptation of negotiated restrictions, a new regulation for the upstream and downstream navigation is being prepared.

keywords: navigation for the future, ultra large container ship, accessibility, desk study, real-time simulation

1. INTRODUCTION

In 2003 an accessibility study based on real-time simulations for the S-class container ships of Maersk Sealand (see Table 1) sailing to the port of Antwerp was performed at Flanders Hydraulics Research (FHR, Antwerp) in cooperation with all involved parties (public and port authorities, pilots, tug and shipping company). The regulation for the upstream and downstream navigation on the Western Scheldt at that time did not accept the arrival of a ship with length over all greater than 340 m. This regulation was originally installed for bulk traffic but was meanwhile extended for all marginal ships. As the engine power and rudder capacity and thus manoeuvring behaviour of bulkers and container ships differ substantially a revision or re-interpretation of the regulation was necessary. At that time Ultra Large Container Ships (ULCS) were just being delivered and the knowledge of their behaviour and the experience in practice was scarce.

The Shipping Assistance Division of the Flemish Government and the Flemish Pilotage, both responsible for the safe navigation to the Flemish harbours, contacted all involved parties to be able to answer the question if the Western Scheldt was navigable for these 350 m container ships. Starting with mathematical manoeuvring models available in the FHR simulator database which were scaled to a look alike of an S-class container ship, the experiences of captains of Maersk Sealand, familiar with the ship, and of river pilots of the Flemish Pilotage, familiar with the Western Scheldt and the container terminals, were brought together. The modelled ship used during subsequent real-time simulations executed at the ship manoeuvring simulator of FHR was validated by the captains to be less manoeuvrable than the real S-class container ships so that the evaluation would be at the safe side. Since 2003, when the first S-class container ship sailed to the Europe Terminal, S-class ships were received on a regular base (Fig.1).

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Figure 1: S-class container ship leaving the Europe terminal

Since 2003 the ship dimensions of all shipping companies have been growing not only in length but also in width and the maximum draft exceeds the maximum allowable value for ships sailing in one tide to the port. The rather limited research for the accessibility of the S-class container ships was followed by a combination of extensive research and constant training to obtain enough background information to adjust the regulation for the upstream and downstream navigation. The main issue was the prevention of any accident with these ULCS. In this paper two main research studies are discussed, one concerning the evaluation of the accessibility of ULCS to the Western Scheldt and the other evaluating the accessibility of the Berendrecht Lock and Delwaide Dock.

The successful arrival of the ULCS MSC Beatrice in April 2009 can be considered as a first check of the preceding approach. Comprehensive research and training revealed new strategies to handle these ships in a confined environment as the Western Scheldt and the port of Antwerp. An evaluation period of approximately six months led to the adaptation and installation of a new regulation. Finally, thanks to the efforts and knowledge of all parties, existing infrastructure which was originally designed for ships with more modest dimensions, had been opened for ULCS with a maximum capacity of 14,000 TEU.

2. ACCESSIBILITY OF ULCS TO THE WESTERN SCHELDT

2.1 Background

In 2005, in order to gain an insight into the impact of the new generation of container ships on shipping traffic on the Western Scheldt, the Shipping Assistance Division of the Flemish Government has commissioned a study of the accessibility of the Scheldt for 8,400 and more TEU container vessels with a maximum draft of 145 dm. This study has been conducted by FHR in cooperation with Ghent University – Maritime Technology division.

When a vessel sails in open water with large water depth, the pressure distribution around the vessel will only be influenced by the vessel characteristics. However, a vessel sailing in a restricted environment or confined water will be influenced by different factors, whereby this modified pressure distribution at the hull will influence the forces acting on the vessel.

The impact of the environment can be broken down into, on the one hand into the influence of under keel clearance and, on the other hand the influence of banks that restrict the fairway in vertical and horizontal direction, respectively. Apart from permanent factors such as banks and bottom, the environment can also be temporarily influenced by the presence of other vessels. The interaction forces which these vessels exercise on each other may have an important impact on the vessel's manoeuvring behaviour. Except for the impact of the bathymetry of the waterway on the ship's behaviour, the impact of current and wind also needs to be modelled. Fig. 2 gives an overview of the factors influencing a vessel sailing in a restricted waterway.

Instead of applying internationally accepted design guidelines for the adaptation of the Western Scheldt for these Ultra Large Container Ships, the question arose if the existing river profile could be considered as acceptable or not, determining the limitations of this fairway for two-way traffic.

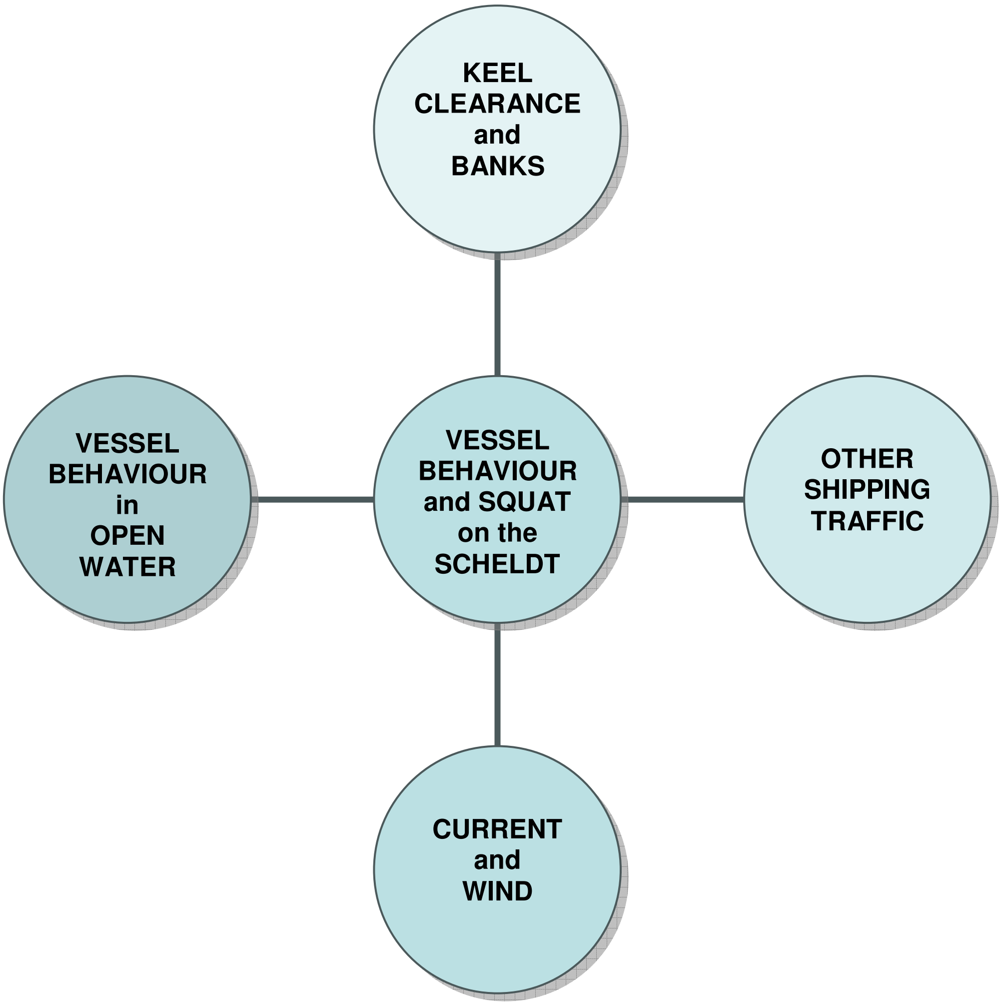

Figure 2: Overview of influence factors

During this extensive research two methods have been used to evaluate the inherent safety of navigation on the Western Scheldt. The first method was based on a desk study comparing the control forces of the ship with the forces required to compensate for disturbing forces or to perform a given trajectory. For the second method captive model test results from the Towing Tank for Manoeuvres in Shallow Water (Fig. 3, cooperation FHR – Ghent University) have been implemented into a fully integrated simulation model for the evaluation of meetings of ULCS on the Western Scheldt. A decade of model tests has been used to build mathematical prediction models for ship behaviour, bank effects, ship-ship interaction and squat evaluation. Real-time simulations at two coupled ship manoeuvring simulators revealed the possibilities and restrictions.

Figure 3: 8,000 TEU ship model tested in the Towing Tank for Manoeuvres in Shallow Water

2.2 Development of mathematical models

Considering the aforementioned elements, the study was broken down into five sub-studies.

- Squat
- Manoeuvring behaviour in open water
- Bank effects
- Interaction between vessels
- Assessment of upstream and downstream navigation through desk-studies and real-time simulation studies.

The first four sub-studies pertained to the modelling of the influence factors. In the last sub-study the results of this modelling were applied to assess the behaviour of the studied container vessels.

The mathematical modelling of ship behaviour on the Western Scheldt has been based on tank tests with a scale model of an 8,000 TEU container ship with a length over all of 4.36 m (see Table 1). By applying different scale factors, the test results for this scale model have been scaled up to ultra large container ships brought into service by different shipping companies since 2003. Taking into account the ship's beam value of existing ULCS an additional correction for the beam B has been executed after geometrically scaling (see values in italic in Table 1). The design drafts of these ULCS vary between 13.0 and 16.0 m.

	Ship model U	Maersk S-class	CMA-CGM	MSC	Maersk E-class
Scale	**1**	**80.8**	**85.1**	**88.3**	**91.6**
TEU	-	8,400	11,400	13,230	14,000
L_{OA} (m)	4.36	352.0	365.5	381.0	397.6
B (m)	0.53	42.8	*48.4*	*51.0*	*56.4*

Table 1: Dimensions based on scaling of ship model U

2.3 Desk studies

The desk study method described in ELOOT, K. et al. (2007) uses a methodology for evaluating the controllability of a ship navigating in a restricted channel by means of a hydrodynamic force analysis. The available control forces are compared with the hydrodynamic forces that have to be counteracted. In general, both types of forces can be expressed as functions of a large number of parameters. In the case of a ship taking a bend in a river with longitudinal current (e.g. the bend of Bath on the Western Scheldt), following non-exhaustive distinction can be made:

- ship dependent characteristics such as draft, geometric dimensions (scale factor), and manoeuvring behaviour;
- environmental parameters such as water depth variations, current and tide;
- channel characteristics such as bank geometry, water depth and bend radius;
- operational parameters such as propeller rate, ship speed and bank clearance.

The hydrodynamic force analysis only takes yawing moments into consideration and has been applied to the locations along the Western Scheldt shown on Fig. 4. The evaluation of the controllability of an ULCS sailing along the bend of Bath nearby buoy 75 using this desk study method is shown in Fig. 5. For instance, the figure allows to conclude that for the considered tidal level (MLLWS and an ebb current of 0.95 knots) at a speed through the water of 12 knots a distance of at least one ship beam should be available between the ship's side and the buoy to ensure sufficient (no more than 100%) rudder capacity to counteract the hydrodynamic forces.

Hydrodynamic forces due to other shipping traffic (e.g. head-on encounters between large container ships) and wind effect have not been considered during the desk studies. As not only the manoeuvrability of the ship itself is important, but also the availability of channel or river sections where head-on encounters can safely and smoothly be performed, an additional evaluation method based on simulation techniques had been applied.

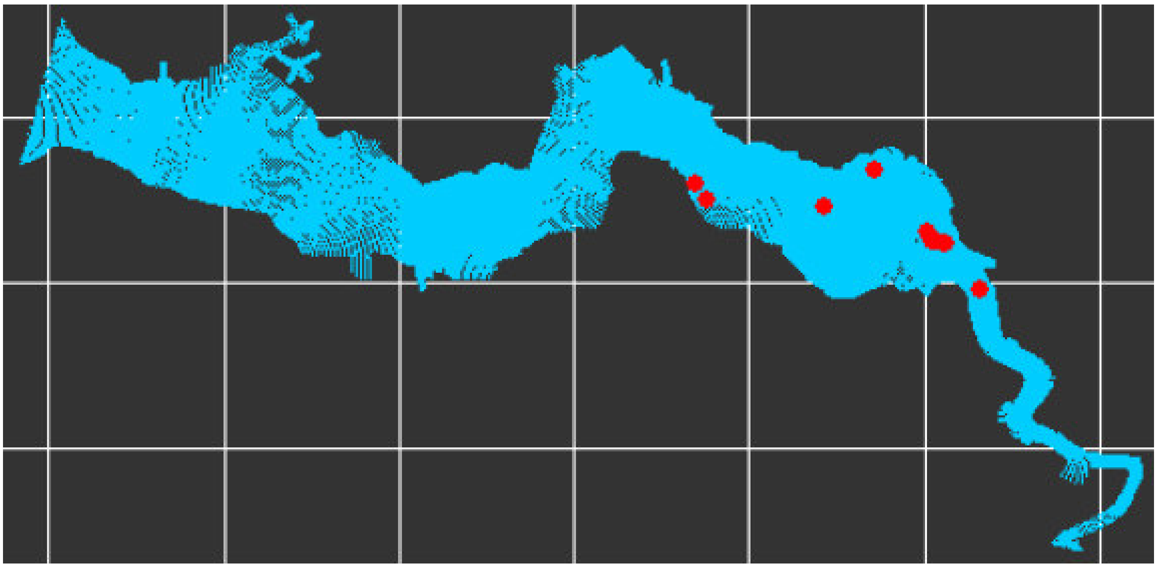

Figure 4: Examined locations (red dots) along the Western Scheldt

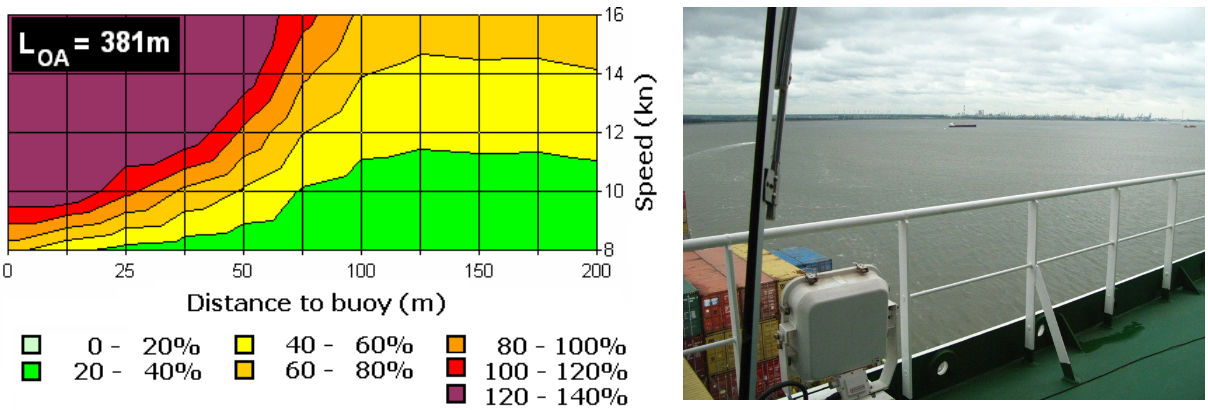

Figure 5: Required rudder capacity in % at Harbour Full ahead nearby buoy 75 at Bath

2.4 Real-time simulation studies

Two series of real-time simulation studies, executed with a time interval of approximately one year, have shown the importance of the realism of each component of the simulation model. During the first study one ULCS was steered by the pilots of the Flemish Pilotage on one full mission ship manoeuvring simulator. The other ship encountered during the simulated meetings was simplified to a target ship that only follows a prescribed trajectory at a chosen speed over ground. Although preliminary conclusions about the acceptability of meeting locations on the river could already be derived from this first study, the necessity of a fully integrated simulation approach with coupled ship manoeuvring simulators became clear. Indeed, a realistic meeting manoeuvre can only be simulated if the hydrodynamic behaviour of both ships is described by a full mathematical model, if both ships are controlled in a professional way, and if both pilots can communicate with each other before and during the manoeuvre.

During the second simulation study 224 simulation runs (112 exercises with two manned simulators) have been performed at three critical locations along the Western Scheldt at maximum flood or ebb current and a WSW 5 Beaufort wind. The aim was to examine whether encounters at these locations were feasible or advisable. The three locations were (Fig. 6):

- the bend of Bath
- buoy 78 at Ballast Plate
- buoy 91 at Europe Terminal

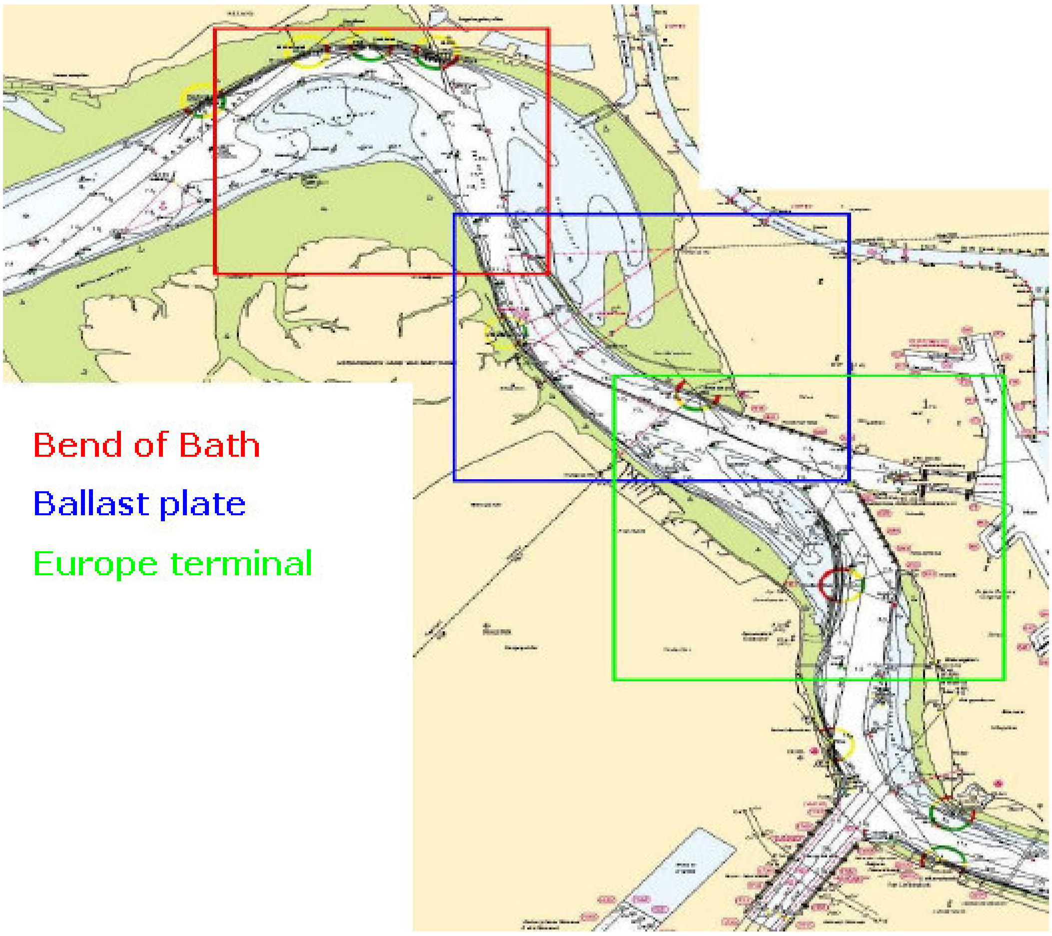

Figure 6: Critical locations examined during real-time simulations

Three different Ultra Large Container Ships were used with length varying between 366 and 397 m (see Table 1) and two draft values of:

- 13.1 m: tide-independent draft after the third deepening of the Western Scheldt
- 14.5 m: an approximate maximum draft for containerships sailing to the port of Antwerp.

Due to the enormous length of these container ships the position of the ship's bridge is moved forward so that each ULCS simulation model has additionally a typical longitudinal ship's bridge location (Fig. 7):

- conventional position for a L_{OA} 366 m ship (80 m aft of midship)
- forward position for a L_{OA} 381 m ship (40 m fore of midship)
- central position for a L_{OA} 397 m ship (30 m aft of midship)

Thanks to the coupling of the two ship manoeuvring simulators at FHR the simulations could be executed as realistically as possible. Besides of the two ULCS other target ships with more moderate dimensions were added to the simulation run to ensure a dense but realistic traffic scenario avoiding the ULCS to occupy the full river width before and after the encounter with the other ULCS.

For each location and each current condition the head on encounters have been evaluated based on:

- the lateral distance between the vessels,
- the minimum distance to the buoys,
- the wave generated at the Europe Terminal, which depends on the passing vessel's speed and lateral distance.

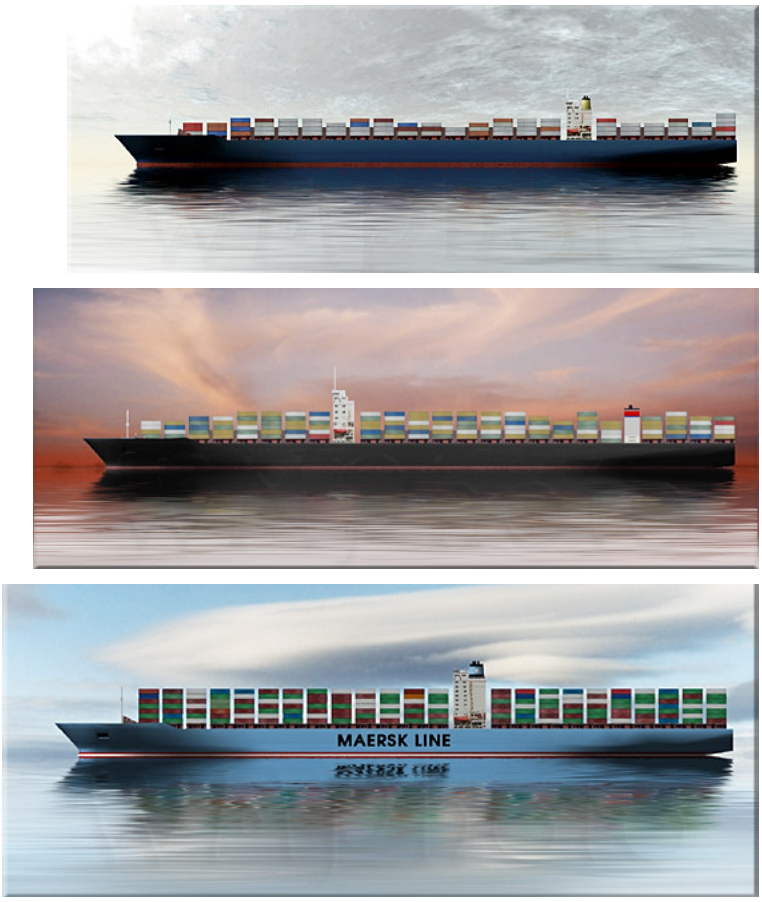

Figure 7: Ultra Large Container Ships of 366, 381 and 397 m L_{OA}

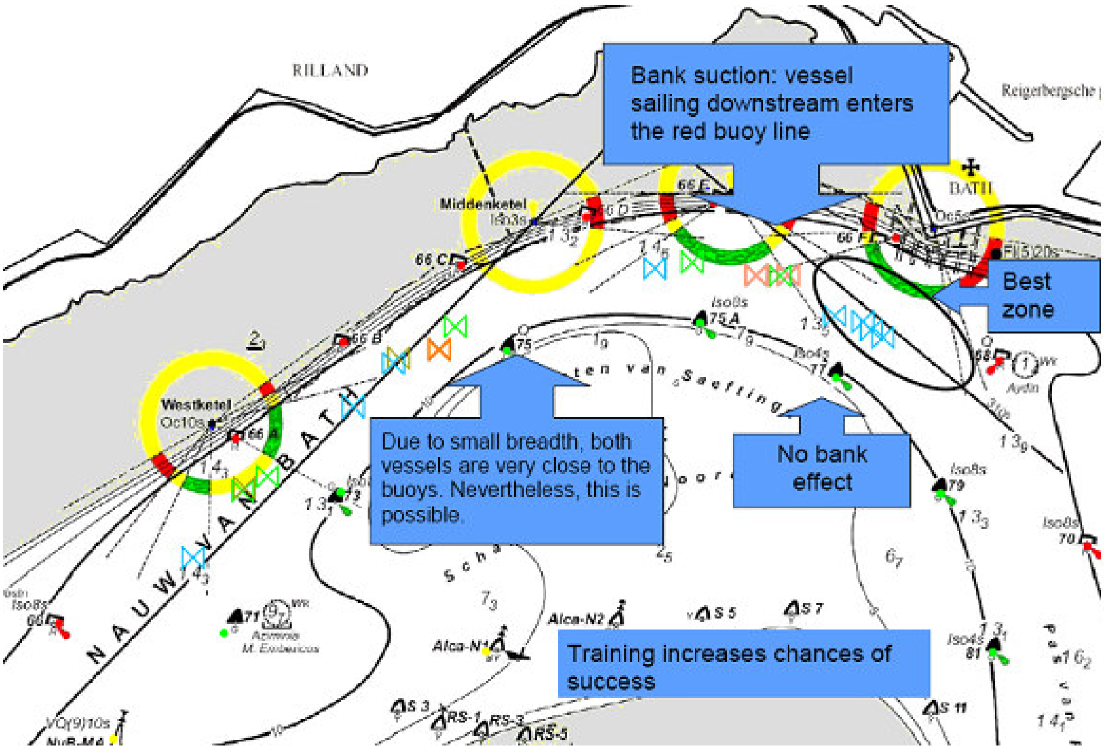

Figure 8: Evaluation of the encounter locations for the Bend of Bath at maximum ebb current

An additional evaluation is performed based on squat predictions. A mathematical model for squat at bow and stern, taking account of all hydrodynamic effects including forward speed, drift, yaw, ship-bank and ship-ship interaction has been developed, ELOOT, K. et al. (2008), so that the margin for bottom touch can be assessed during each simulation run. Given that a voyage plan must be made for each tide-dependent ship, the generally applied deterministic method for determining the tidal window can be assessed in this way.

Summarizing figures show the major difficulties for each critical location. Examples are given in Fig. 8 and 9 with the sandglass symbol showing the encountering locations of the two midship's sections. The colour of the symbol gives an appreciation of the head-on encounter based on the three evaluation parameters mentioned above, varying between blue for comfortable distances to the buoys and between the encountering vessels, and dark red for unacceptable situations.

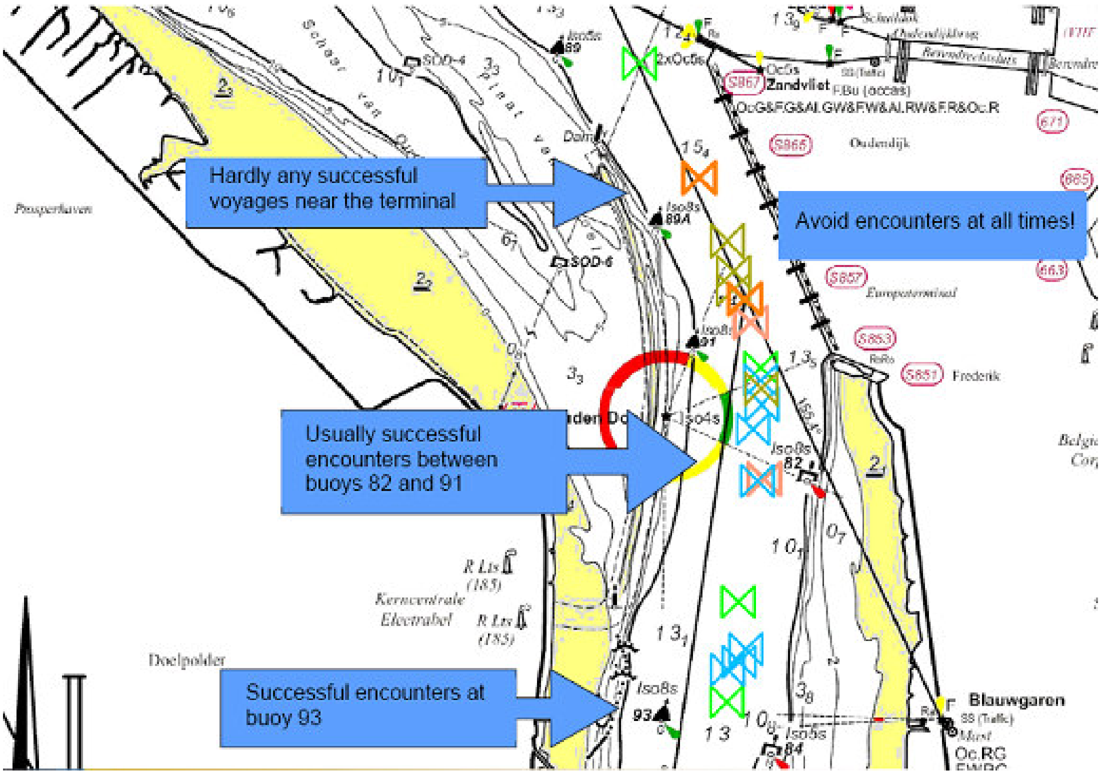

Figure 9: Evaluation of the encounter locations for the Europe Terminal at maximum flood current

2.5 General conclusions

The conclusions of the real-time simulation study for the accessibility of ULCS to the Western Scheldt can be formulated as follows:

- The impact of the ship's dimensions and of the increase in scale of vessels from 366 m till 400 m L_{OA} on the results of the simulations does not appear to be significant. Also the desk study showed the limited impact of the ship's dimensions on the control of the vessel. Consequently one can presume that within the studies range the ship's dimensions have little impact on the actual manoeuvres. However, the manoeuvrability of the ship (resulting from the ship's hull, the characteristics of the propeller and rudder, the conformity of the engine-room telegraph and the number of propeller revolutions) is of great importance.
- A well-founded updated version of the upstream and downstream navigation rules for container traffic to the port of Antwerp should be drawn up in accordance with the present situation. This regulation – which is the responsibility of the Common Nautical Authority (Gemeenschappelijke Nautische Autoriteit – GNA) representing the Flemish and Dutch authorities – should be redrafted after the deepening of the river Scheldt.
- Intensive traffic guidance on all levels is required to manage the interactions and crossing of vessels at specific critical locations, or to avoid them, if tidal conditions should require so. Training of Flemish and Dutch river pilots on the ship manoeuvring simulators will give

a valuable contribution in combination with "know-how on the job". Further research and training on the simulators will make it possible to evaluate less extreme (and thus more frequent) situations under better tidal conditions and less wind.

- As an additional precondition, a number of requirements have to be met. In a so-called "chain approach", all parties involved in the arrival or departure of ULCS and other marginal ships hold responsibility for their part of the chain, which implies that accessibility also depends on, e.g., presence of sufficient tugboats, availability of berth and/or locks, boatmen. Also the manoeuvrability of the vessels has to meet certain standards.

3. ACCESSIBILITY OF ULCS TO BERENDRECHT LOCK AND DELWAIDE DOCK

The accessibility of ULCS to the container terminals of the Mediterranean Shipping Company in the Delwaide Dock introduced some additional challenges. The Delwaide Dock is situated on the right bank of the Western Scheldt (Fig. 10) and is accessible for ULCS through the Berendrecht Lock. Based on the horizontal dimensions the Berendrecht Lock is in 2010 still the largest lock in the world with a length between the lock doors of 500 m and a width of 68 m. Nevertheless, the water depth in the lock is restricted to TAW -13.5 m which consequently increases the blockage when entering the lock with ULCS. A simulation study was executed to examine:

- the accessibility of the Berendrecht Lock for a 381 m container ship at varying wind and current conditions with a special focus on the contact forces with the wheel fenders
- the accessibility of the Delwaide Dock for a 381 and a 397 m container ship at varying wind forces.

All real-time simulations were realised by the river pilots of the Flemish Pilotage and the BRABO pilots of the port of Antwerp. A preceding research for a new lock at the left bank planned at the southern end of the Deurganck Dock with identical horizontal dimensions as the Berendrecht Lock but with a much larger depth of TAW –17.8 m showed that the design of the wheel fenders is of major importance for the evaluation of the accessibility of this 68 m wide lock for ships with beams up to 56.4 m. Contact with the wheel fenders while entering and leaving the lock is indeed possible, especially at larger wind forces and wind directions perpendicular to the lock orientation, so that besides of the determination of essential tug assistance and entrance and departure strategy, an approximate estimation of the contact characteristics (dent dimensions, contact position at the ship profile, ship velocities during contact) will help in deciding the pros and cons of installing new lock infrastructure.

3.1 Accessibility of the Berendrecht lock

The mathematical manoeuvring models described in chapter 2 were used although some additional influences related to lock manoeuvres were modelled:

- longitudinal waves propagating in the lock (longitudinal force)
- increase of the return flow due to the increased blockage (lateral force and yawing moment)
- cushion effect due to the lateral displacement of the ship towards the lock wall (lateral force and yawing moment).

Real-time simulations were executed with wind forces varying between 3 and 7 Beaufort (a mean synoptic wind speed between respectively 4.3 and 15.4 m/s).

In Fig. 11 an entrance manoeuvre is shown from the river side at a southern wind of 6 Beaufort. In spite of the wind direction perpendicular to the lock orientation, no contact with the wheel fenders occurred during this run.

Two fore tugs of 45 ton bollard pull (BP) each were used and two aft tugs of 60 ton BP. A histogram of tug assistance clearly shows that the aft tugs pull with more than half power (or 30 ton) for more than 90% of the time. This is partly explained by the high dead slow speed of the MSC container ships corresponding with a dead slow telegraph of 30 to 35 rpm. The aft tugs reduce the speed while propeller and rudder can be operated to align the ship while entering the lock. The fore tugs have more reserve with the starboard (SB) tug pulling with more than 15 ton during 50% of the time. Due to the wind impact both tugs operating at starboard side are loaded more compared to the tugs at port (P) side.

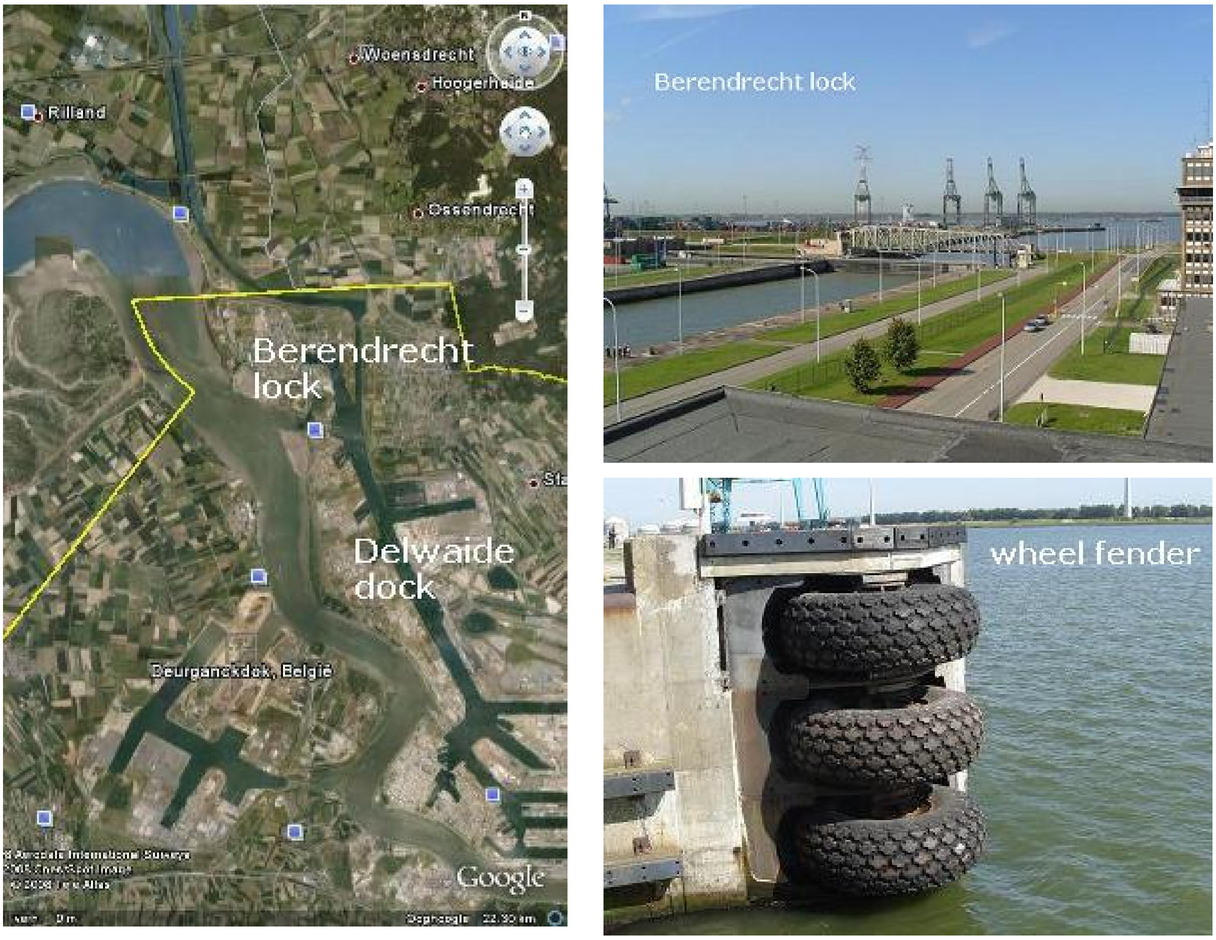

Figure 10: Berendrecht Lock and Delwaide Dock at right bank

In Fig. 12 an entrance manoeuvre of the same lock is shown starting from the dock side at an identical wind condition of S 6Bf. Tug assistance, proposed by the pilots and based on the available tug types, is decreased to two tugs of 55 ton BP each. Taking into account the large lateral wind area of ULCS this combined tug power is insufficient to ensure a safe and balanced entrance manoeuvre. An additional aft tug with 22 ton BP had been added while simulating but did not prevent the ship of hitting the three wheel fenders (P4 to P6, Fig. 12, right down), placed above each other at the starboard side of the lock. The contact point on the ship was located in the forward part at 69.4 m from the midship section and the maximum dent was 0.96 m. At a dent of 1.16 m the ship hits the wheel house resulting into damage of both the wheel fender and the ship's hull.

Based on the simulations and the analysis of tug histograms and contact characteristics the realism and acceptance of the manoeuvres could be evaluated by the pilots and the load of tugs could be identified so that depending on the wind influence best strategies with minimum tug assistance could be determined. These recommendations have been part of the validation period for the new regulation for ULCS (see chapter 4).

3.2 Accessiblity of the Delwaide dock

With the arrival of the S-class containerships the B2 Canal Dock, connecting the Delwaide Dock with the Berendrecht Lock, had been adjusted with a vertical wall instead of a flooded bank opposite the entrance of the Delwaide Dock (Fig. 13). This adaptation gives the tugs sufficient space to assist while the ship is entering the dock astern. The largest ULCS tested during the real-time simulations had a length over all of 397 m which is approximating the width of the Delwaide Dock so that no dredging was necessary on the condition that instead of aligning the ship with the bow nearby the southern corner of the Delwaide Dock sufficient distance between the ship's side and the dock entrance is kept while turning the ship.

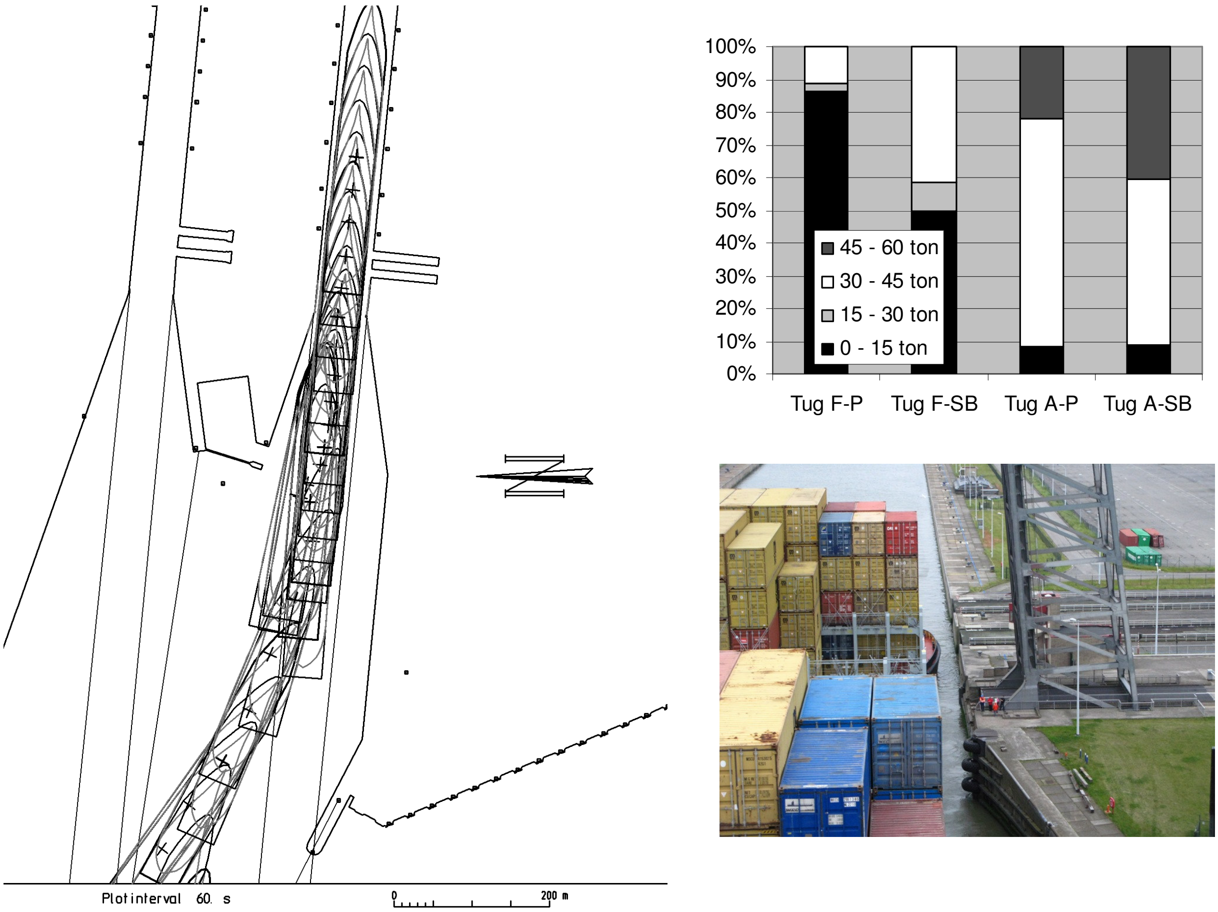

Figure 11: Simulation: entrance to Berendrecht Lock from river side at S6 Bf

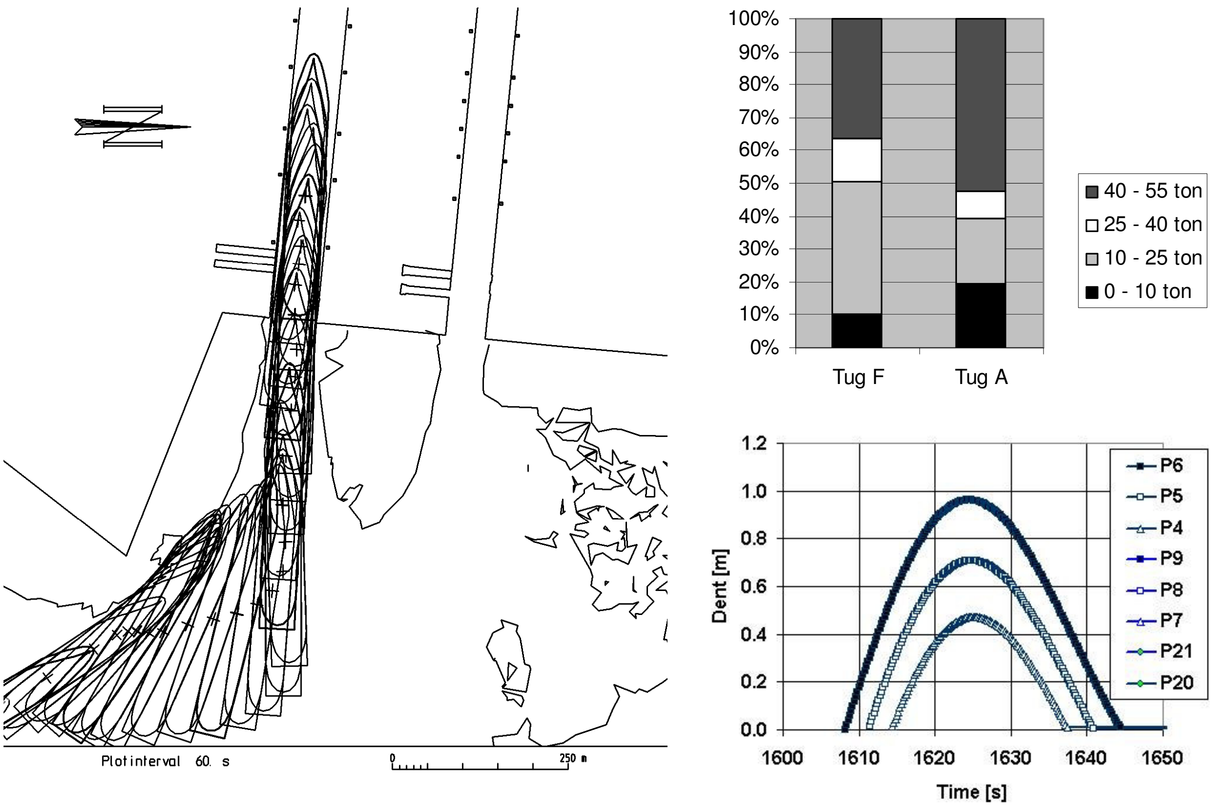

Figure 12: Simulation: entrance to Berendrecht Lock from dock side at S6 Bf

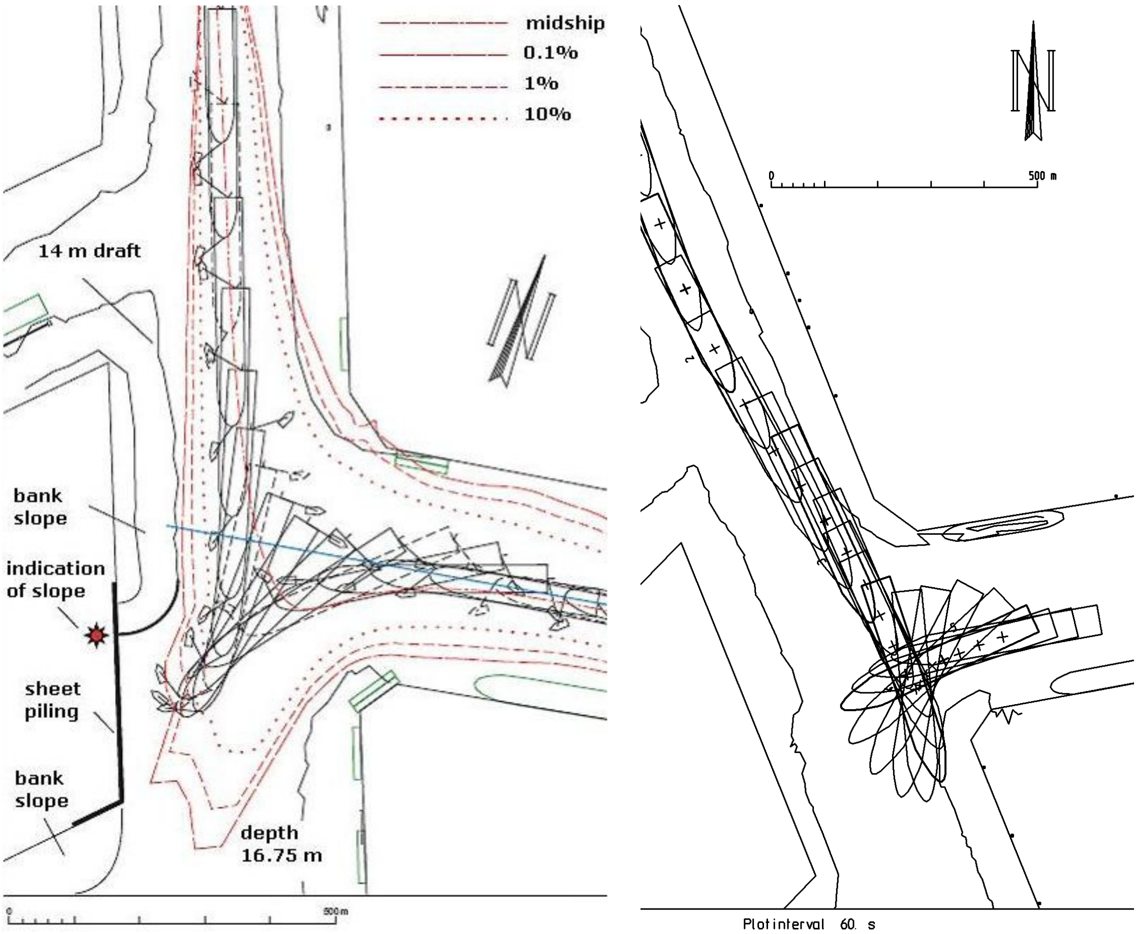

Figure 13: Adaptation of the B2 canal for the accessibility of ULCS and simulation run

4. VALIDATION BASED ON FULL SCALE VOYAGES

Since the arrival of the MSC Beatrice on April 7th 2009 (366 m x 51.2 m) at the MSC terminal in the Delwaide Dock ("a déjà-vu" according to the river pilots) a validation period has been started divided in three phases (April – June, June – September, September – November). During each validation period an agreement was formulated by all involved parties (Flemish and Dutch authorities, pilotages, tug companies, port authority, …) that summarised the conditions to be met (operational, environmental, …) for a safe and smooth voyage from the North Sea to the terminal in the Delwaide Dock. After each phase an evaluation was made and the restrictions added to the "Gezamenlijke bekendmaking 02-2005" (admittance policy for marginal ships) were if possible adjusted. These agreements published as a notification can be downloaded from the Belgian Bulletin of Acts, Orders and Decrees (see references).

All voyages were positively evaluated and a new regulation for the upstream and downstream navigation on the Western Scheldt is being prepared.

Additional monitoring of the ship behaviour during some voyages has been ordered to be able to validate the real-time simulations and collect data for the evaluation of squat prediction formulae.

5. CONCLUSION

Opening existing fairways for ever growing vessels requires a combination of scientific research or theory and practice. The described studies show clearly that a profound examination of all bottlenecks helps in evaluating the accessibility of the Ultra Large Container Ships for especially the port of Antwerp. Desk study methodologies and simulation techniques have been used for the evaluation of the upstream and downstream navigation on the Western Scheldt and the accessibility of the Berendrecht Lock and the Delwaide Dock.

If design guidelines can not be fulfilled, the use of an integrated simulation platform based on mathematical models predicting all involved hydrodynamic and external forces helps in evaluating the dimensions of the fairway and locks and deciding whether additional dredging is necessary or not.

6. AKNOWLEDGEMENT

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