Paper 99 - Design Guidelines versus Practices for the Upper-Seascheldt, the Inland Waterway Connection between Antwerp and Ghent

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ABSTRACT: Design guidelines for inland waterways are so far a national matter. PIANC InCom Working Group 141 "Design Guidelines for Inland Waterways" is nevertheless working on a report with a summary of existing guidelines and a methodology for the concept and detailed design of canals and rivers. For tidal rivers the design is a difficult process and an example is given through the accessibility of the Upper-Seascheldt for CEMT class IV and Va inland vessels between the port of Antwerp and the locks in Merelbeke. A combined evaluation based on concept design guidelines for canals, practices measured during a full-scale voyage and detailed design using ship handling simulators is discussed and illustrated.

1 INTRODUCTION

1.1 *Introduction*

Rivers are worldwide used as inland transportation axes between cities. So is the Upper-Seascheldt (Figure 1) the natural waterway for inland vessels between Antwerp and Ghent in Belgium. The entire river can nevertheless only be sailed by CEMT class IV (85 m) and smaller vessels as the river is too restrictive for higher classes in the section between Baasrode and the lock complex in Merelbeke. Additionally the Upper-Seascheldt is a tidal river with important currents and changing water levels that influence the manoeuvring behaviour of the vessels significantly. As part of the Trans European Network the TEN-T waterways should be accessible for class IV vessels (1350 ton) but an upgrade to classes Va (2250 ton) or Vb (4500 ton) should be considered in future. Also two-lane traffic of these classes in opposite directions should be possible. The upgrade of the Upper-Seascheldt for class Va (110 m), could improve the inland connection from Antwerp as these ship classes have now to reach Ghent by the Western Scheldt and the maritime canal Ghent-Terneuzen (Figure 1).

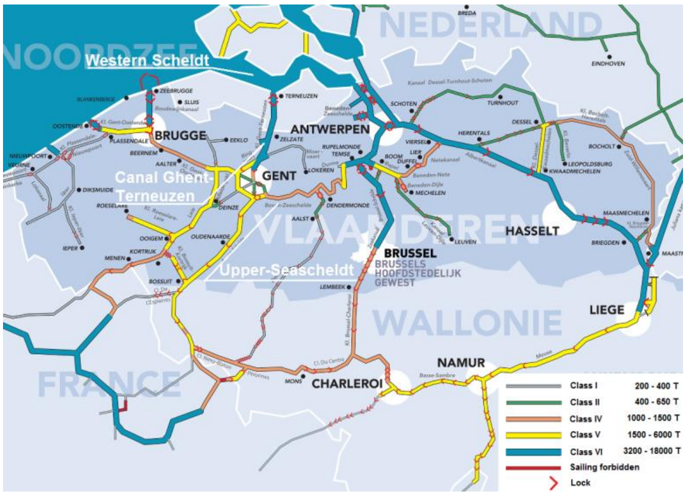

Figure 1: Inland waterways network in Flanders (www.binnenvaart.be)

There are so far no guidelines for the evaluation of the accessibility of a river for a prescribed design ship. The national guidelines available in certain European and other countries (USA and China) focus on design guidelines for canals and dammed rivers where the assumption is made that the current is minimal. PIANC InCom Working Group 141 is working on the “Design Guidelines for Inland Waterways” with the aim to provide values for the guidelines but also a methodology for designing inland waterways. The methodology makes use of a step by step approach divided into concept design using guidelines, best practices from existing waterways and detailed design through simulation.

1.2 *Overview*

For the Upper-Seascheldt an evaluation is made in the paper of the accessibility of the river:

- for class IV (85 m x 9.5 m):
  - best practice: a monitored inbound voyage of a 85 m vessel from Antwerp to Merelbeke. These full scale measurements provide the real path of a class IV vessel in the waterway. The path shows that even sharp bends can be taken at certain water levels and meetings are possible so that the river is mainly a two-lane class IV waterway;
  - concept design: an analysis of national guidelines for canals but applied to a tidal river. The guidelines are helping in designing the width, depth and overall lay-out of conjunctions of straight canal sections and bends and passages under bridges. The Upper-Seascheldt with its large number of natural bends is a good example of how design guidelines must be interpreted to be applicable to a river.
- for class Va (110 m x 11.45 m):
  - concept design: an analysis of national guidelines used for the tidal river with a comparison between the class IV en Va results;
  - detailed design: ship manoeuvring simulations on the inland simulator Lara of Flanders Hydraulics Research. The possibilities and limitations of the river for class Va for two-lane traffic are examined at the most difficult sections.

The evaluations are based on a study tendered by the Zeeschelde division of the waterway authority Waterwegen en Zeekanaal NV. International Marine and Dredging Consultants (IMDC) carried out the research in cooperation with Flanders Hydraulics Research (FHR). The subject is part of the knowledge gathered in the Knowledge Centre Manoeuvring in Shallow and Confined Water, a cooperation between Ghent University and FHR (www.shallowwater.be).

2 DESIGN GUIDELINES FOR CLASS IV AND VA

2.1 *Design guidelines worldwide*

As no European national guidelines are available for rivers, the evaluation of the bottlenecks for the accessibility of class IV and Va vessels will start using the design guidelines for canals. The Dutch and French guidelines distinguish a maximal (normal) profile and a minimal (narrow) profile based on the traffic density. A narrow profile will accept a lower ease value which means that safe navigation must always be taken as starting point but restrictions in smoothness of the traffic are considered.

The Chinese guidelines are the only guidelines that consider the design of the width and depth of natural and canalized rivers for one-lane and two-lane traffic. For the latter a distinction is made between the upbound (U) and downbound (D) sailing ship in the determination of the swept path. The Chinese fleet differs considerably from the European fleet with a class number I for the largest convoys and class VII for the smallest. The Chinese class IV corresponds to CEMT class IV, Va and Vb with respect ot the horizontal dimensions, but has a very small design draft of 1.6 m. For a vessel with a beam of 10.8 m the width of a single lane river should be 30 m and of a double lane river should be 50 m.

2.2 *Bottlenecks for ship manoeuvring*

The bottlenecks for ship manoeuvring on the Upper-Seascheldt are related to:

- the waterway profile in straight sections and bends for two-lane traffic;
- the minimum bend radii for taking the bends;
- the passage of bridges with minimum height and width related to tidal elevation and current.

Waterway profile in straight sections and bends

The definition of the waterway profile of a river is not straightforward. The profile depends indeed on the chosen reference water level as the water level depends on the tidal cycle. For a canal or dammed river a more or less constant water level can be considered.

To judge the tidal influence on the available water profile for the Upper-Seascheldt a period was chosen according to the 50 percentile lowest low waters (LW) and highest high waters (HW). The tidal range between LW and HW is only 2.5 m in Merelbeke and more than 5.0 m in Antwerp.

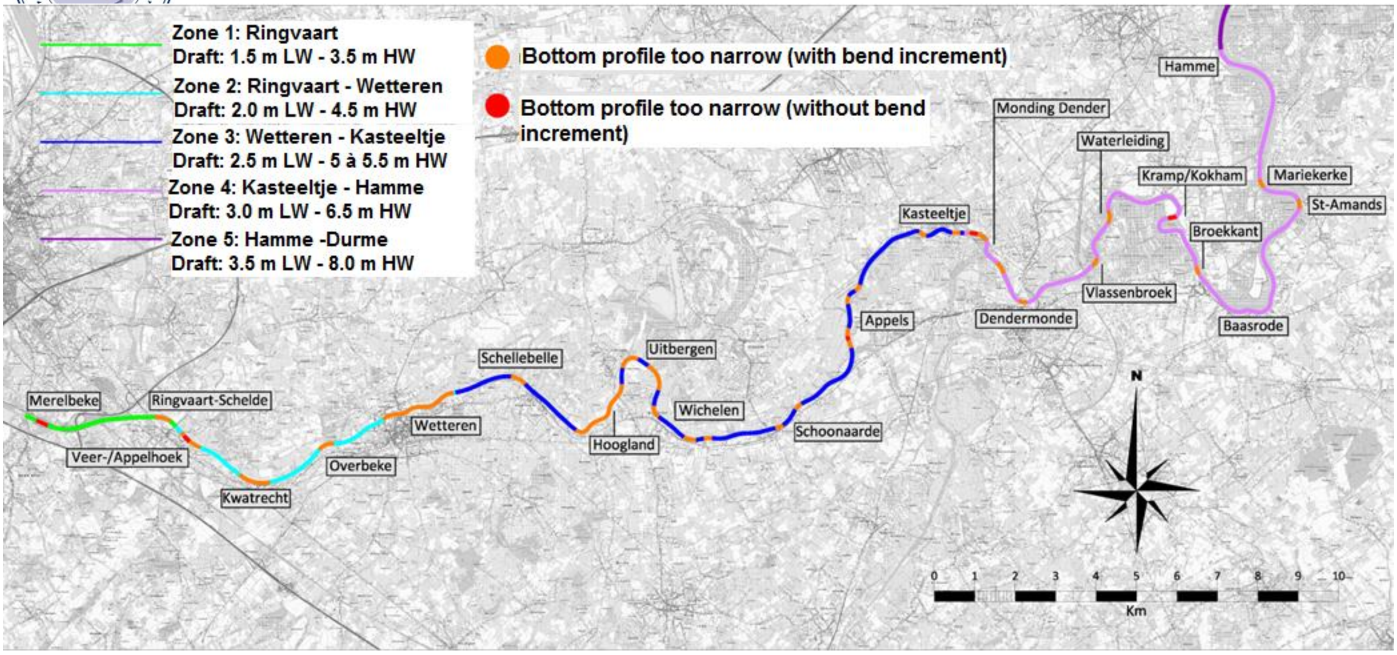

Figure 2: Evaluation of the available draft and bottom profile for class Va (Adams, 2011)

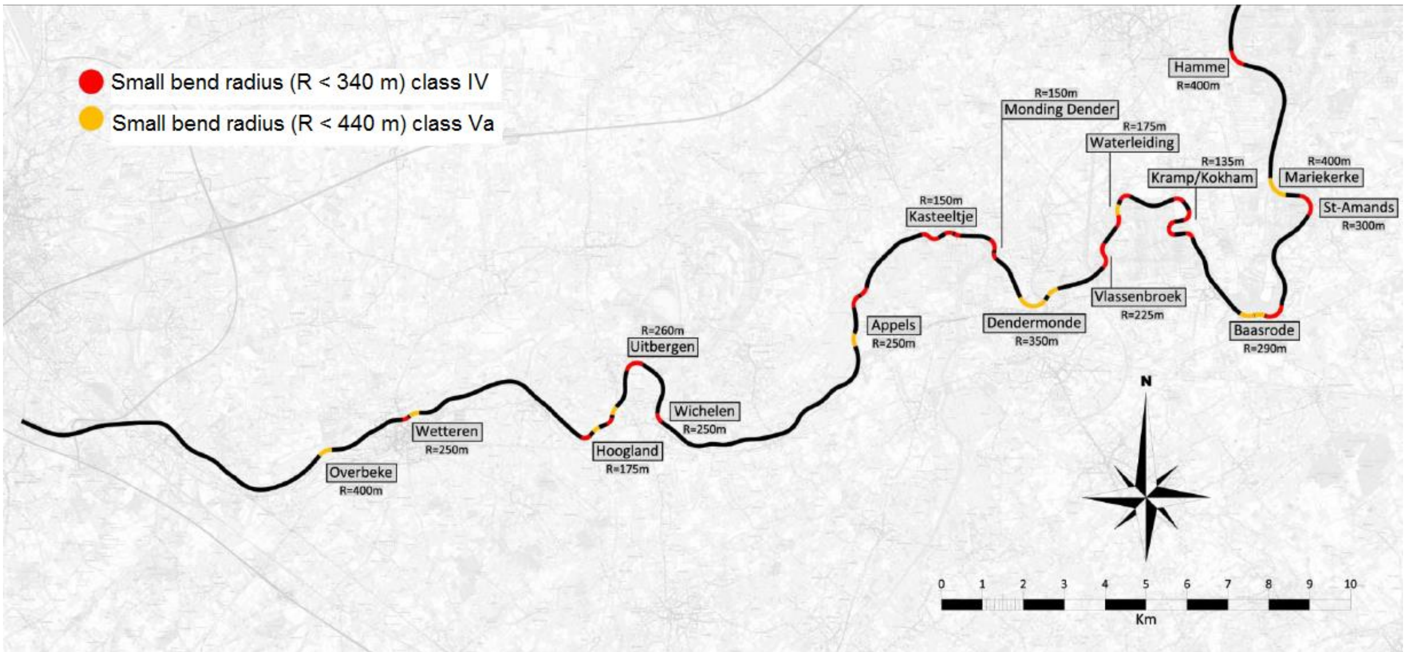

Figure 3: Evaluation of the bend radii which are too small for class IV and Va (Adams, 2011)

Based on the levels of the LW and HW values and the bottom level, the height of the water column (with 30 % under keel clearance for a narrow profile) and the acceptable drafts at LW and HW can be determined. In Figure 2 five coloured zones are detected with a maximum draft at the lowest water level and the highest water level. It can be clearly seen that the maximum accepted draft at HW decreases sailing inbound the river from Antwerp to Merelbeke from 8 m (unrealistic for inland vessels) in Hamme to 3.5 m in Merelbeke. At LW the maximum draft is only 1.5 m in Merelbeke (Ringvaart canal) and grows to 3.5 m in Hamme. A fully laden vessel with a draft of 3.5 m can therefore only sail to the locks in Merelbeke using the flood tide and the high water level.

For the comparison of the available river profile with a designed profile based on guidelines for canals, a class Va vessel was considered with a maximum draft of 3.65 m. This design ship has increased dimensions compared to the class IV vessel with a draft of 2.65 m. In (Adams, 2011) a comparison was made of the (bottom) profile using different design guidelines, but finally the narrow profile based on the Dutch guidelines was proposed. This profile gives for two-lane traffic:

- a bottom width of 2B with B the ship’s beam (19 m/22.8 m for a class IV/Va);
- a width of 3B at the keel of the laden vessel (28.5 m/34.2 m for a class IV/Va);
- a width of 3B plus a wind increment of 7 m at the keel of the unladen vessel.

An important remark is that a full design of the Upper-Seascheldt for a class Va is not envisaged as the impact on the river and its natural quality would be too large. Instead an evaluation and optimization of the river for an acceptable service quality for class Va vessels is the goal of the design process.

The sections where the bottom profile is too narrow, compared to the proposed profile according to the design guidelines, are shown on Figure 2 in orange with bend increment or in red (more restrictive) without bend increment. The bend increment ΔB was chosen as the increment calculated with the Graewe formula considering a laden and unladen vessel meeting each other with L the ship length and R the bend radius.

$$\Delta B = (0.5 + 0.25)\frac{L^2}{R}$$

Table 1: Description of the bends with small radii on the Upper-Seascheldt (Figure 3)

Bend location / name	Number of bends involved	Minimum bend radius [m]
Hamme	1	400
Mariekerke	1	400
St-Amands	1	300
Baasrode	3	290
Kramp/Kockham	*5*	*135*
Waterleiding	*3*	*175*
Vlassenbroek	2	225
Dendermonde	2	350
Mouth of Dender	*2*	*150*
Kasteeltje	*4*	*150*
Appels	3	250
Wichelen	*1*	*250*
Uitbergen	*1*	*260*
Hoogland	*4*	*175*
Wetteren	2	250
Overbeke	1	400

Minimum bend radii

The bend radii of the bends are summarised in Table 1 and can be compared with the minimum bend radii proposed in the Dutch guidelines for canals. This minimum bend radius is 4 or 6 times the ship length for respectively a narrow or normal profile. In Figure 3 and Table 1 the bends are described as a number of consecutive bends with a minimum radius and are coloured based on the minimum value for a class IV or Va design ship in a narrow waterway profile. For the accessibility of the bends not only the bend radius and waterway profile at the bend are important but also the presence of several (counter-rotating) bends for which the distance in between the bends is of importance for executing the bend manoeuvre.

A large number of bends do not fulfil the design guidelines for canals. The smallest value occurs at the bend Kramp/Kockham with 135 m radius which is only 1.23 or 1.59 times the ship length of a class Va or IV vessel. Following bends have radii between 150 and 400 m.

A subjective evaluation was made of the accessibility of each of the bends based on interviews with skippers familiar with the Upper-Seascheldt (Adams, 2011).

- Seven bends (in italic in Table 1) were evaluated as not suited for meetings in the bend although for four this decision depends on the experience of the skipper, the dimensions of the ship and the loading condition.
- For the other bends the bottleneck based on the bend radius is rather small (Vlassenbroek and Sint-Amands) or acceptable if good agreements between the skippers are made before meeting in the bend (communication by VHF).

Although a large difference is seen between the actual bend radius and the designed proposal based on the Dutch guidelines, other guidelines accept lower radii up to 2 times the push convoys length and 3 times the cargo vessel’s length in the Chinese guidelines.

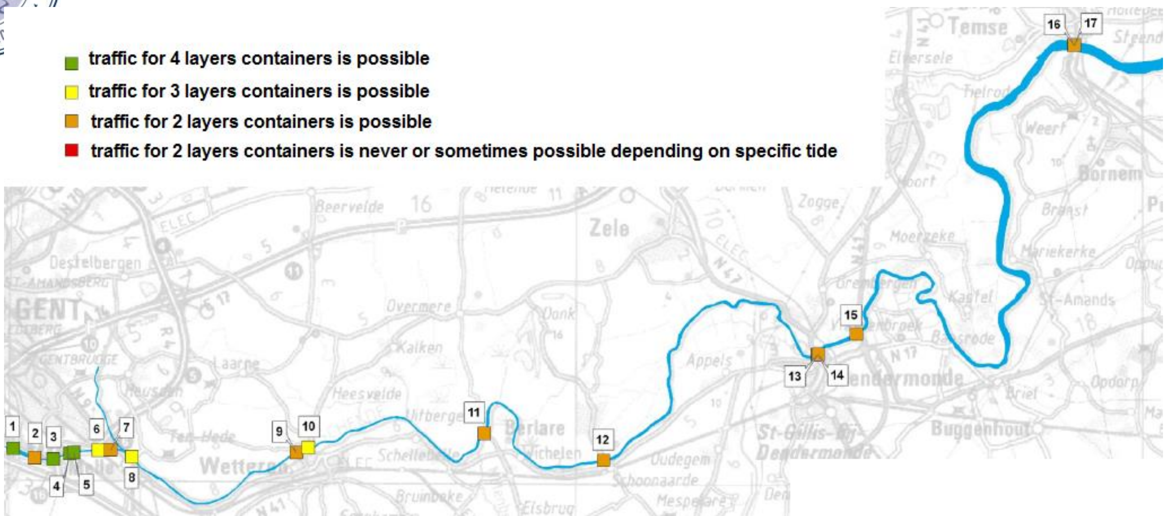

Figure 4: Evaluation of available air draft and waterway width at the bridges (Adams, 2011)

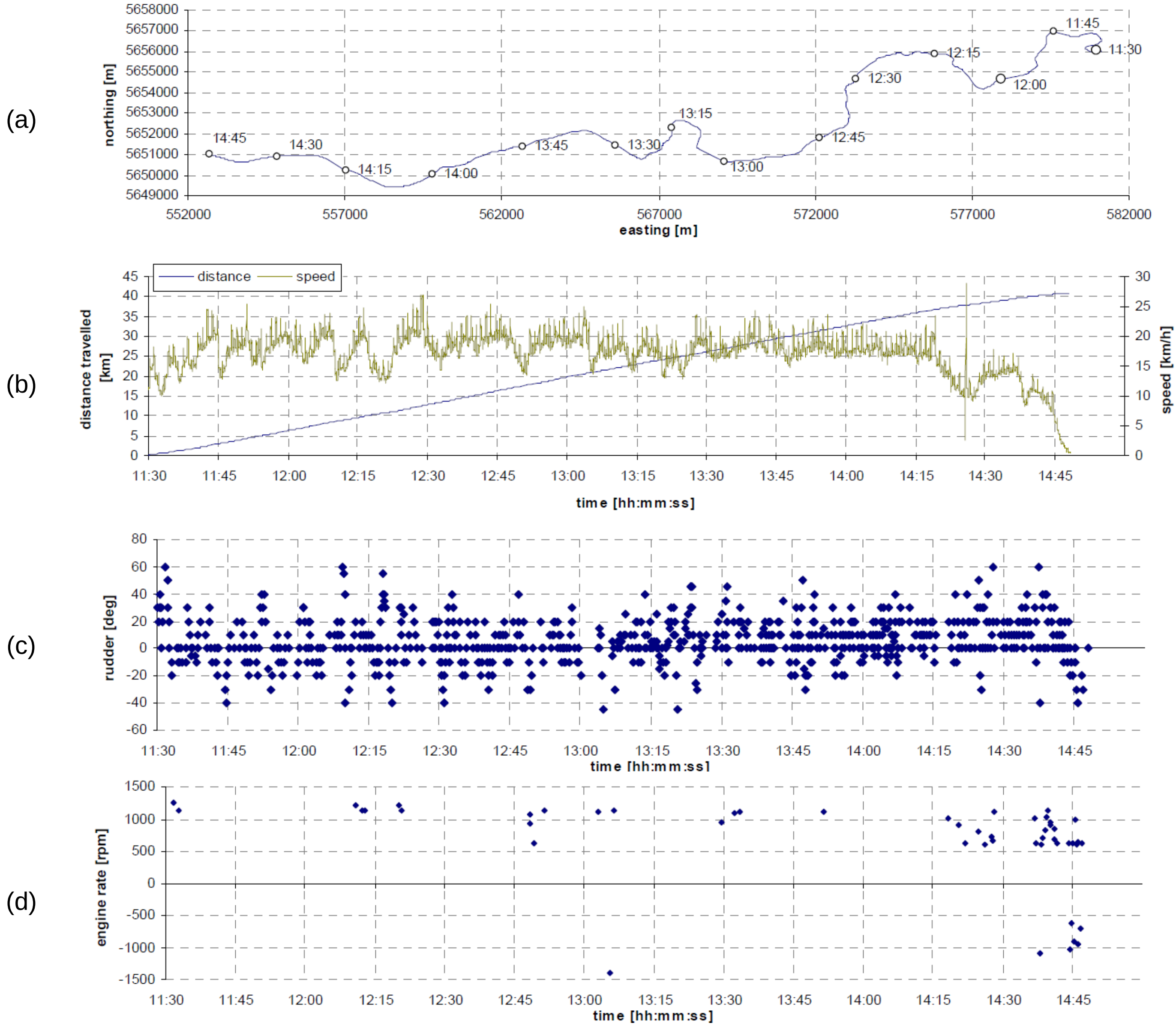

Figure 5: Full-scale measurements on a class IV vessel on the Upper-Seascheldt: (a) track in easting and northing with time indication, (b) distance travelled and speed, (c) rudder angle settings (manually logged, positive to port, negative to starboard) and (d) engine rate (manually logged) (Richter, 2010)

Bridges

In the design guidelines for bridges one or more of following parameters are considered:

- the air draft of the bridge at a chosen reference water level in relation with the necessary waterway width for two-lane or one-lane traffic (Figure 4);
- the positioning of the bridge in the waterway: preferably a bridge is placed in a straight section of the waterway. Nevertheless on the Upper-Seascheldt bridges are also available in bends so that requirements concerning the necessary view while approaching the bridge (lowering of the ship bridge for containers) cannot be met. Additionally a minimum distance is proposed between successive bridges to give the skipper the possibility to align before passing a bridge.

3 ACCESSIBILITY FOR CLASS IV VESSELS

Class IV vessels with a length of 85 m and a beam of 9.5 m are the largest ships which are regularly sailing on the Upper-Seascheldt so far. Although the concept design guidelines are not met over the entire length for this vessel's class (see for example the minimum bend radius in Figure 3) the actual accessibility of class IV vessels can give more insight in the possible combination of guidelines and practices. To be able to evaluate the possibilities and limitations of the actual river, full-scale measurements have been executed on an inbound sailing class IV vessel loaded at a draft of 2.65 m. Considering the accessibility of the river with different maximum and minimum drafts shown in Figure 2 the tidal range must be used to sail from Antwerp to Merelbeke so that the flood tide was used to pass all shallow water zones on the Upper-Seascheldt.

3.1 *Full-scale measurement*

A description of the track with time steps, the distance travelled, the speed over ground, the rudder settings and the propeller rate are shown in Figure 5. Not the entire track from Antwerp to the locks in Merelbeke is visualised but only the most shallow and confined section from the bend Kramp to the locks.

Although the ship was fully laden the speed over ground is rather high and decreases from 20 km/h to 10 à 15 km/h while taking bends depending on the bend radius and the course change. While proceeding more inbound the speed reduces to 15 à 17 km/h as the river section decreases and thus the blockage (ratio of the ship midsection to the river cross section) increases with larger resistance and thus lower speed as consequence. Approaching the locks the speed further reduces to 10 km/h and lower.

The speed through water is for flood tide and an inbound sailing ship lower than the speed over ground and can be reduced with 4 km/h and more according to the two-dimensional flow field shown in Figure 6. For rivers with important tidal variations and rugged profiles a one-dimensional description of the flow field does not fulfill the high demands of swept path simulation with large drift angles in bends. The numerical simulations of the flow field for the Upper-Seascheldt had to be improved by implementing a secondary flow component (helical flow) to incorporate a three-dimensional flow effect in bends.

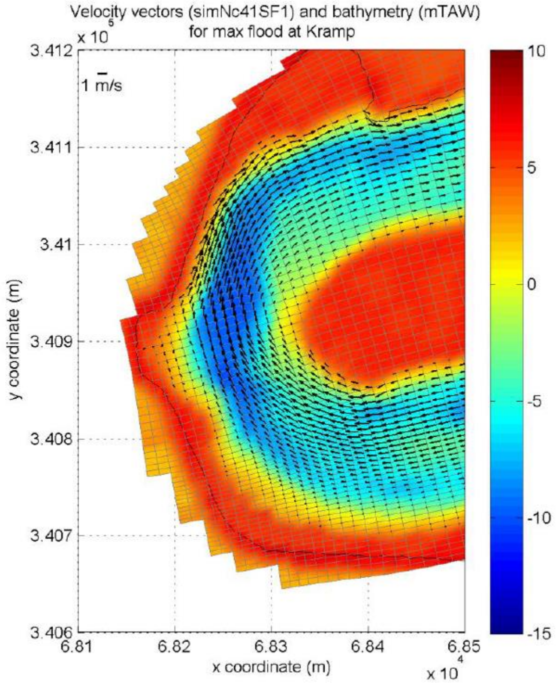

Figure 6: Numerical simulation of the two-dimensional maximum flood current at the bend Kramp: bathymetry and flow velocity (Maximova, 2011)

A comparison between the simulated track of a class IV vessel in a flow field without secondary flow and the measured swept path of the class IV during a real voyage on the Upper-Seascheldt is shown in Figure 7. In the measured track some outliers due to bad DGPS communication are seen and the simulated track ends while grounding (red: depth line at keel of the vessel, blue: waterline).

Although the river is wide at high tide (108 m or 11.4B at the keel of the class IV vessel in the smallest section of the Kramp, see also Figure 2), the successive sharp bends are taken with large drift angles (up to 45 degrees) and thus swept paths (58 m or 6.1B).

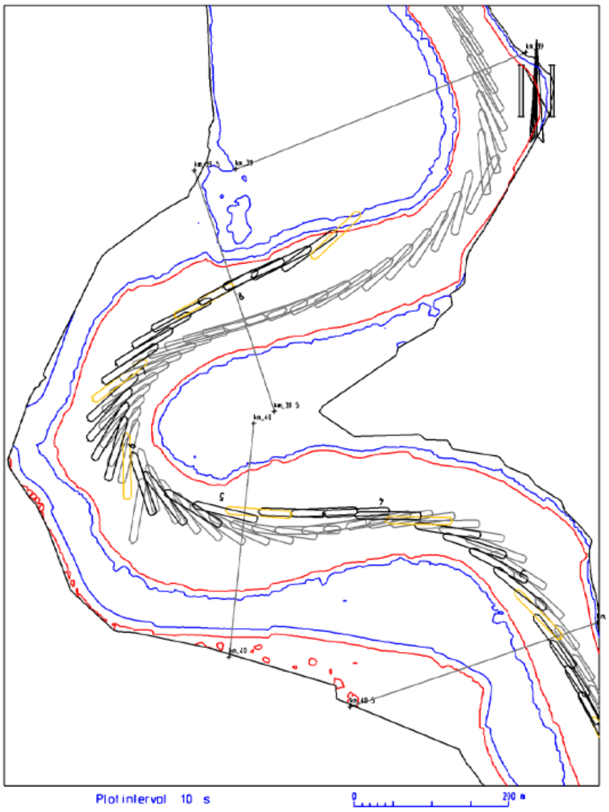

Figure 7: Comparison of simulation (black/orange) and full-scale measurement (grey) of a track at maximum flood current in the Kramp (Richter, 2010c)

The vessel's length is more qualifying than the beam and as half of the width at the keel is taken by one class IV vessel, meetings in the sharp bends are strongly discouraged.

In Figure 5 (c) and (d) the rudder angle and engine rate are presented with mostly medium rudder angles (20 degrees) and medium engine rates (1100 to 1200 rpm). Larger rudder angles are requested in sharp bends.

3.2 *Evaluation of the accessibility for class IV*

The evaluation of the Upper-Seascheldt for class IV vessels is not straightforward due to the wide variety of parameters for a river as waterway. An attempt was made to evaluate the river for a particular design so that necessary dredging volumes and a maintenance program could be determined (Fahy, 2014).

For this evaluation a reference level was determined which is the minimum water level for a section profile so that a class IV vessel with a draft of 3.0 m can pass the considered section with 20% under keel clearance (UKC, water depth of 3.6 m) and the vessel can pass all other sections of the entire river with this prescribed minimum UKC (grounding during a voyage is excluded). The UKC of 20% of the ship's draft is small compared to the 30% and 40% proposed values for a narrow and normal profile in the Dutch guidelines but has been considered taking into account the tidal range.

Based on the assumptions determined for a class IV river the Upper-Seascheldt can be evaluated theoretically at the reference level as (Fahy, 2014):

- for straight sections: a one-lane waterway in the most inbound section but mostly a two-lane waterway;
- for bends: a one-lane or two-lane waterway in bends depending on the bend radius, the width and depth.

Actually, meetings are not forbidden on predefined sections so that the skippers themselves organize meetings depending on the available water level and the speed through water and thus flow velocity. Therefore communication is very important as visibility is often poor in the bends.

Straight sections

Meetings preferably take place on the straight sections in between the bends. An example of a meeting area and the corresponding section details are shown in Figure 8 for Uitbergen. Referring to Figure 2 the bottom profile is indeed within the bathymetry in the straight section for ship drafts up to 2.5 m at low water (LW) when the evaluation is based on a two-lane narrow profile for class IV.

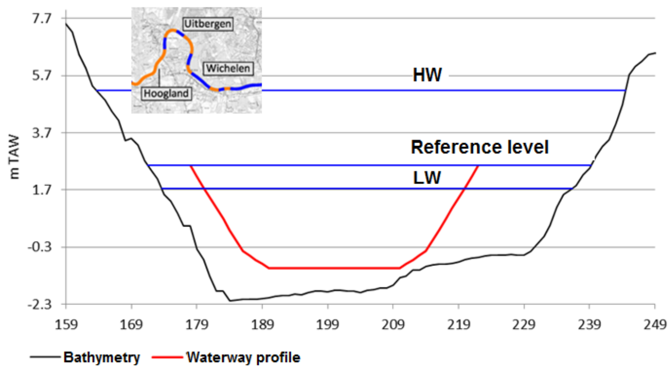

Figure 8: Actual bathymetry (black) and designed profile (red, two-lane narrow profile for class IV) for the straight section in Uitbergen (Fahy, 2014)

Considering Figure 2 globally, in each stretch of the river with different maximum allowable drafts at LW and HW, straight sections are found where ships can meet. Consequently if the total fleet passing per year, which was 10,000 vessels in 2007 and which did not grow due to the crisis, gives still some possibilities in handling the ease of meetings, a challenging river as the Upper-Seascheldt can be maintained as accessible waterway for a class for which the guidelines based on canals are not fulfilled.

Bends

For the evaluation of the bends on the Upper-Seascheldt a comparison could be made with other rivers. PIANC Working Group 141 has tried to evaluate the fairway width to ship's beam ratio of existing rivers to a parameter involving the ship length, beam and bend radius (abscis in Figure 9). In Figure 9 a comparison is made for a one-lane traffic situation in the bend Kramp for a class IV vessel (measured swept path without safety distances to the banks). The full description of Figure 9 can be found in the draft report of PIANC WG 141. The purple dot for the class IV vessel in the bend Kramp on Figure 9 lies within the registered values for other rivers. This evaluation based on practices shows that even though the individual criteria for the bend radius and width according to the guidelines for canals are not met, both at the same time, an existing river bend is accessible for a class IV vessel in one lane.

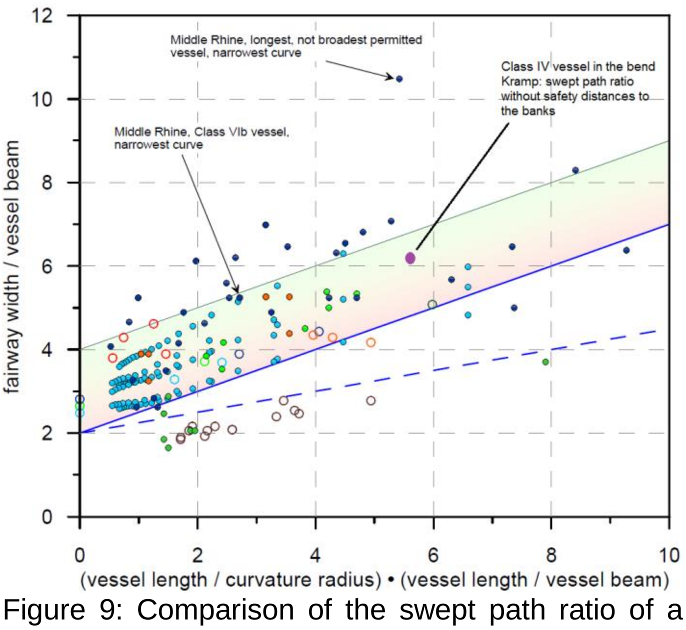

Figure 9: Comparison of the swept path ratio of a class IV vessel in the Kramp with fairway width to ship's beam ratios of other rivers and waterway bend evaluations

Figure 9 shows a large variety of relations between the fairway width and the bend radius for rivers worldwide but the tendency is clear that with increasing abscissa (or thus decreasing bend radius for example) the fairway width must be increased.

Overall evaluation

PIANC working group 141 proposes a qualitative evaluation method to judge the ease of sailing on a waterway. The quotation of a river varies between A, B and C:

- A: waterway without restrictions and characterized by easily sailing;
- B: waterway with moderate to strong restrictions and not characterized by easily sailing;
- C: waterway with strong restrictions and characterized by dangerous sailing.

The ease of sailing is evaluated based on 11 criteria belonging to:

- Waterway related criteria with specific geometrical and operational parameters such as water depth, width, vessel equipment, traffic situation and human factor
- Vessel speed related criteria such as the maximum achievable vessel speed and the speed range between the critical speed and the minimum speed to ensure steerability
- Traffic density related criteria such as the hindrance of recreational boating and the traffic density.

For the Upper-Seascheldt the river is finally evaluated as belonging to class B for class IV vessels. Although the many sharp bends could transform the river into a score C waterway, thanks to the lower traffic density and the higher speed that can be maintained in a waterway with a variable tidal water depth, the ease of sailing with a class IV vessel gives still some possibilities for upgrading the waterway.

4 ACCESSIBILITY FOR CLASS VA VESSELS

The ship dimensions for the upgrade of the Upper-Seascheldt are these of a class Va vessel with a length of 110 m, a beam of 11.45 m and a draft of 3.65 m (which is higher than the 2.8 m mentioned in the TEN-T network class Va description). This draft is the maximum draft of a class Va vessel while the maximum design draft could be restricted to 3.5 m which is also the design draft for the Seine-Scheldt connection.

4.1 *Real time simulation*

The evaluation of the Upper-Seascheldt for a class Va design ship based on the design guidelines is described in chapter 2.2. To evaluate the possibilities and limitations of sailing with a class Va vessel on this existing river, an additional detailed analysis was executed based on real time simulations on the inland simulator Lara of FHR (Figure 10). Different alternatives with adaptations to the river were proposed to increase the safety and ease of the manoeuvres of a single ship or meeting ships. The simulation runs were restricted to the most difficult situations with lowest water level (and negligible current) or maximum ebb or flood current. In this way the number of simulation runs could be kept to a number of for example 129 for the reference case or scenario 0 which was the actual Upper-Seascheldt. The ship draft was also varied between ballast, 2.85 m and 3.65 m.

Figure 10: Example of a meeting during a real time simulation on two simulators of FHR: inland simulator Lara (presented) and simulator SIM225

4.2 *Evaluation of the accessibility for class Va*

The different scenarios of the real time simulation study have been evaluated and compared based on:

- the feedback of the skippers;
- the under keel clearances;
- the use of engine, rudder and bow thruster;
- the variation of the ship's speed.

In the reference case it was clear that in a majority of the runs the under keel clearances were not enough compared to the proposed 20% of the ship's draft. Especially in the most inbound sections where the Upper-Seascheldt is more narrow structural or operational measures should be taken to improve the accessibility. The use of engine, rudder and bow thruster was increased with a clear indication that the manoeuvres are becoming more difficult for the class Va. The difficulty of the manoeuvres can be handled by decreasing the ship's speed although the overall passage of the river in one tidal cycle must be guaranteed.

For the evaluation of the accessibility for class Va vessels, some examples will be given for straight sections, bends and bridges. These examples illustrate that design guidelines can only give some background if a river is involved and a detailed study on a microscopic point of view is necessary to interpret the guidelines.

Straight sections

In Figure 11 a simulation run is shown of a meeting between two class Va vessels in the inbound straight section following the bend of Uitbergen. The red line indicates the depth line at the keel of the vessel and the blue line the water line. The actual width of the bend at the keel is restricted and the radius is small (260 m) so that taking into account the drift of the vessel in the bend no meetings can take place in the bend. Only the straight sections in the vicinity of the bend of Uitbergen can be considered as possible meeting sections.

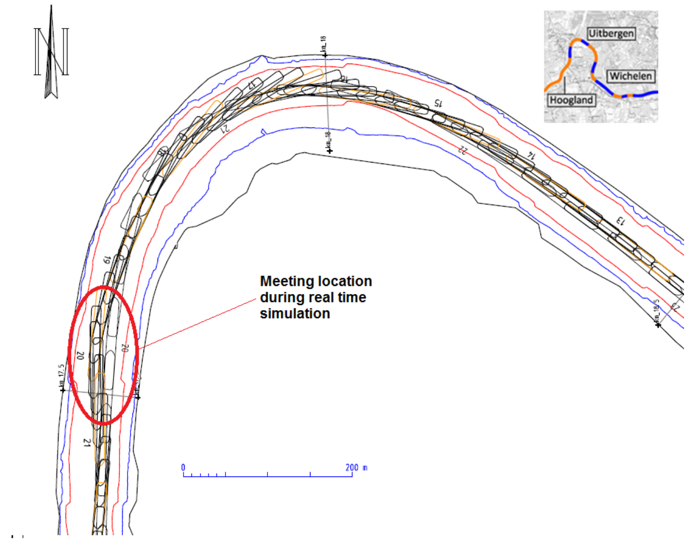

Figure 11: Simulation run 162 with a meeting of class Va vessels (inbound, draft 2.85 m) at the bend of Uitbergen at maximum ebb current (Richter, 2010b)

Bends

As meetings should be avoided in bends and many bends have radii which are much smaller than the proposed radii of the guidelines, simulation runs have been executed with a single Va vessel with different drafts in varying tidal conditions. In Figure 12 and Figure 13 the swepth paths are given of an inbound sailing Va vessel at the bend Kramp at maximum flood current and different drafts. The red depth line in the keel of the vessel varies between Figure 12 and Figure 13 with a more narrow width in the keel plane for the vessel at 3.65 m draft. Based on these figures it is clear that the swept path generally increases with increasing draft and that although the width in the keel is large enough for a two-lane waterway according to the guidelines, no meetings should take place in the bends themselves. Meetings should be organised outside these consecutive bends and even for a single vessel the bend width should be increased if Va vessels with a draft of 3.65 m should be accepted in the bend Kramp.

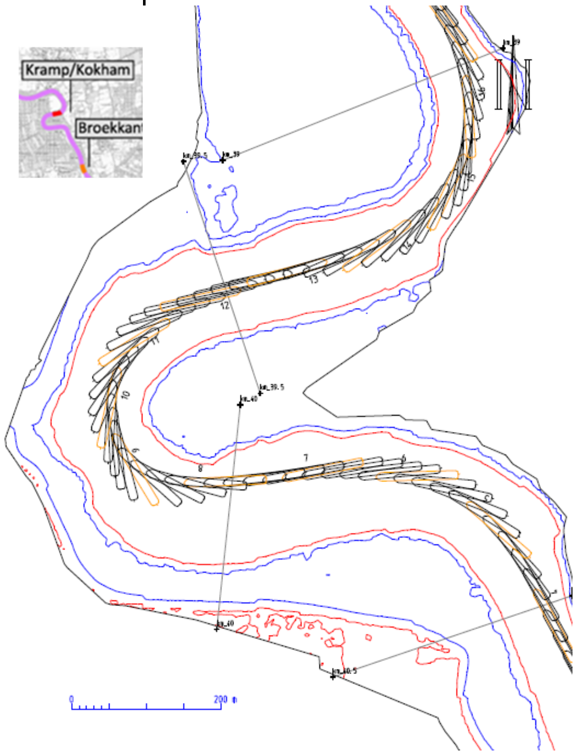

Figure 12: Simulation run 117 with a one-lane voyage of a class Va vessel (inbound, draft 2.85 m) at the bend of Kramp at maximum flood current (Richter, 2010b)

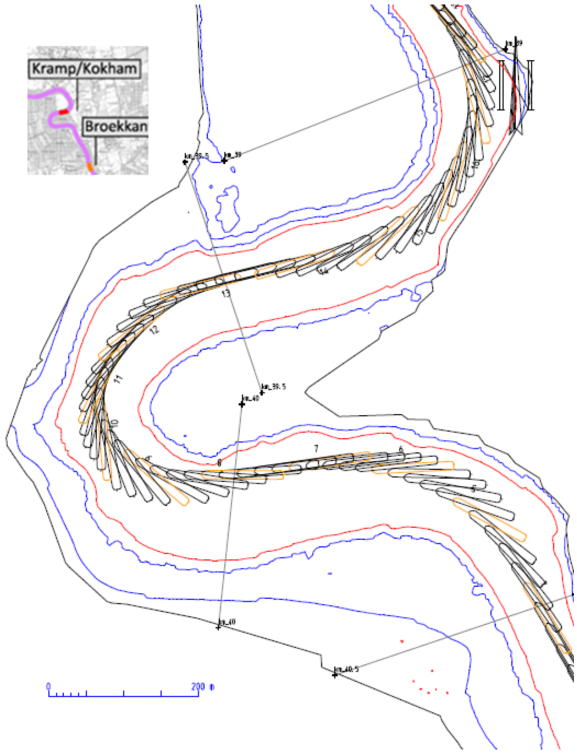

Figure 13: Simulation run 118 with a one-lane voyage of a class Va vessel (inbound, draft 3.65 m) at the bend of Kramp at maximum flood current (Richter, 2010b)

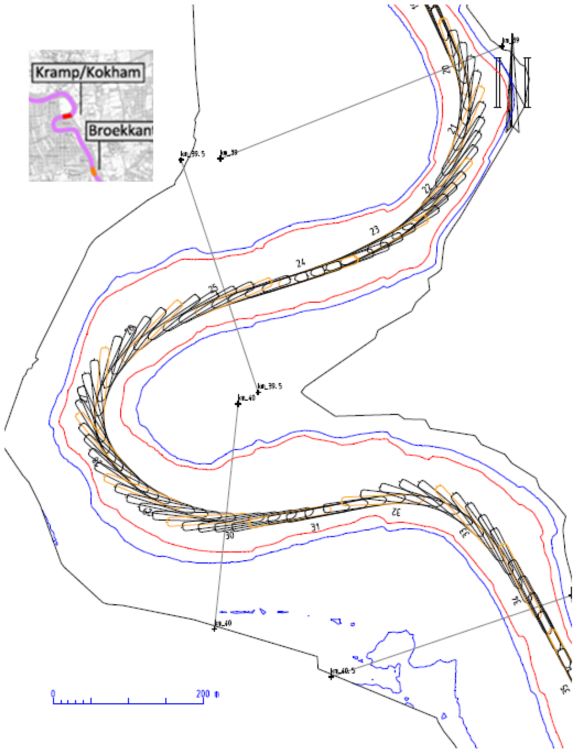

Figure 14: Simulation run 116 with a one-lane voyage of a class Va vessel (outbound, draft 3.65 m) at the bend of Kramp at maximum ebb current (Richter, 2010b)

In Figure 14 the sailing direction has been changed with an outbound voyage with maximum ebb current. In Figure 12 to Figure 14 the speed through water, which is of importance for the ship behaviour, is smaller than the speed over ground but the difference in magnitude of the ebb and flood current results also in a different swept path.

All these environmental parameters (water level, tidal current), ship related parameters (dimensions, draft) and operational parameters (ship's speed, ship's controls) have to be taken into account in the evaluation of a river for a design or upgrade.

Bridges

In Figure 15 a swept path is shown of a class Va vessel passing a bridge in between two bends. Under the bridge a narrow path, more or less determined by the ship's beam, is seen although the swept path in the following bend (Dendermonde, radius of 350 m) does not accept a meeting with another vessel in the bend. This is due to the small radius but also the passage of the bridge influences the swept path in the bend.

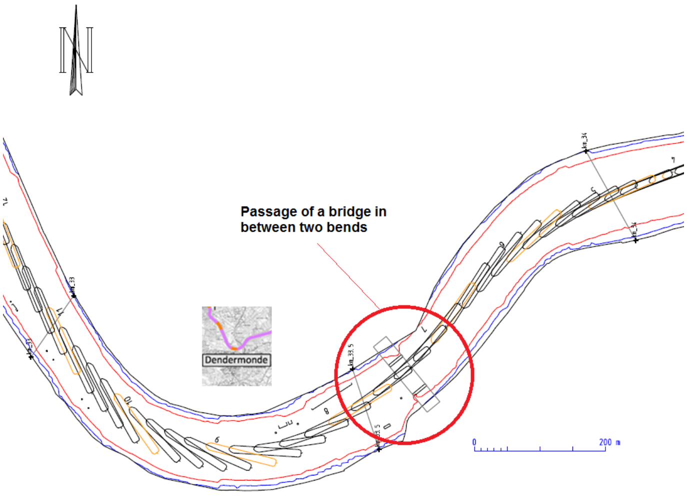

Figure 15: Simulation run 083 with a one-lane voyage of a class Va vessel (inbound, draft 2.85 m) at the bend of Dendermonde at maximum flood current (Richter, 2010b)

Overall evaluation

In the design process a comparable evaluation of the ease of sailing was made for the design case of the Upper-Seascheldt accessible for class Va vessels. Although the ease of sailing must be reduced, even in the design process, for a class Va compared to a class IV, an ease level B should be maintained. Therefore measures are necessary so that the river is widened or sharp bends are deleted. Nevertheless these measures should not destroy the environmental and ecological balance of the river. In this context five scenarios in total have been examined with real time simulations. The ease of sailing was improved one scenario to another and all scenarios were compared to the reference case which was the simulated case for a class Va on the actual Upper-Seascheldt, described in this paper.

No final decision has so far been made about the implementation of the study results to adaptations of the river. A first step was the definition of a dredging plan which guarantees the accessibility of the Upper-Seascheldt for the actual class IV vessels. Further on only occasionally vessels larger than class IV are allowed to sail to Merelbeke nowadays.

5 CONCLUSION

Design guidelines for inland waterways are in the first place meant for the design of new canals. Based on the chosen design ship and the environmental and operational conditions, the guidelines are implemented and a new design is approved. For most dammed rivers and rivers with a tidal variation an adaptation of this river to the guidelines for canals is not possible at all. The Upper-Seascheldt is an example of such a river with a tidal range of more than 5 m in Antwerp and 2.5 m at the lock complex in Merelbeke. The resulting important currents, influencing the manoeuvres on the river, require a comparative evaluation method based on a detailed analysis using real time simulation techniques. The feedback of the skippers in the design process is indeed important and a comparison with their experience and the objective characteristics of other rivers gives valuable background.

The evaluation of the design guidelines for class IV and Va vessels for the Upper-Seascheldt is summarised in chapter 2 and further discussed in chapter 3 based on the actual accessibility of class IV vessels to the river illustrated with full-scale measurements. The Upper-Seascheldt is a very challenging inland river if the swept path of a class IV vessel is compared to the fairway width of other rivers. This river should therefore not be taken as a practice example as the ease of sailing is for the existing situation rather belonging to level B with moderate to strong restrictions.

The upgrade of the river for class Va was shown based on simulation runs in chapter 4. Although only simulations from the reference case are shown, it is clear that measures (structural and/or operational) are necessary to accept this class on the river. A detailed design based on real time simulations is an interesting tool to overcome the shortcomings of the concept design technique.

Although no class Va vessels are sailing on the Upper-Seascheldt inbound of Baasrode for the moment, the studies have led to a dredging plan for an accessible river for class IV and valuable background information for future adaptations for class Va.

REFERENCES

ADAMS, R. 2011, Bevordering Binnenvaart-Zeeschelde. Studie bevaarbaarheid van de Boven-Zeeschelde en Zuidelijk vak Ringvaart voor klasse Va-schepen: Deelcontract 1, post 2: Bestaande toestand – inventarisatie, *I/RA/11363/10.093/RAD*, IMDC, Antwerpen, België

FAHY, J., ADAMS, R. 2014, Duurzaam Beheerplan Boven-Zeeschelde, Duurzame bathymetrie, *I/RA/11448/14.240/JFA/*, IMDC, Antwerpen, België

PIANC WG 141, SOHNGEN B. 2015, Preliminary report of PIANC Working Group 141, Design guidelines for inland waterways

MAXIMA, T., VANLEDE, J., ELOOT, K. 2011, Effects of Secondary Flow, *Calculation memo 840_02.* Waterbouwkundig Laboratorium: Antwerpen, België

RICHTER, J.; ELOOT, K.; DELEFORTRIE, G.; MOSTAERT, F. 2010, Bevaarbaarheid van de

Boven-Zeeschelde en Zuidelijk vak Ringvaart voor klasse Va-schepen: Meetvaart en scenario 0 - uitvoering en analyse. *Versie 2_0. WL Rapporten, 840_02.* Waterbouwkundig Laboratorium: Antwerpen, België

RICHTER, J.; ELOOT, K.; DELEFORTRIE, G.; MOSTAERT, F. 2010, Bevaarbaarheid van de Boven-Zeeschelde en Zuidelijk vak Ringvaart voor klasse Va-schepen - Vaarbaanplots - knelpunten. *Versie 2_0. WL Rapporten, 840_02.* Waterbouwkundig Laboratorium: Antwerpen, België

RICHTER, J.; ELOOT, K.; DELEFORTRIE, G.; MOSTAERT, F. 2010, Bevaarbaarheid van de Boven-Zeeschelde en Zuidelijk vak Ringvaart voor klasse Va-schepen: Validatievaarten: uitvoering en analyse. *Versie 2_0. WL Rapporten, 840_02.* Waterbouwkundig Laboratorium: Antwerpen, België