Paper 136 - Design Guidelines for River Harbours and Verification of Harbour Layouts in the Portable REMBRANDT-INLAND Bridge Simulator Including Public Demonstration

VELDMAN J.J.; DUBBELMAN J., ZUIJDERWIJJK W.M.
BMT ARGOSS, Voorsterweg 28, 8316 PT MARKNESSE, The Netherlands;
Aquater, Paul Butterfieldstraat 49, 4337 PM MIDDELBURG, The Netherlands;
Witteveen+Bos, Postbus 2397, 3000 CJ ROTTERDAM, The Netherlands.

Email (1st author): hans.veldman@bmtargoss.com

ABSTRACT: The Rhine is the most important inland waterway in Western Europe. Near Lobith every year more than 130,000 vessels transport 150,000,000 tons of cargo across the Dutch/German border. To satisfy overnight rest needs for inland vessel crews, two sites near Lobith have been selected for implementing harbours with mooring facilities for a total of 70 vessels. Manoeuvring simulations have been applied to verify the newly developed design rules for the variants for the harbours. Licensed skippers, and lay people living in the area were involved in the simulations. This resulted in a valuable contribution to the design rules for the design process and also, in the local community, a better understanding of the development process for the harbours.

1 INTRODUCTION

The Rhine is the most important inland waterway in Western Europe. Every year more than 130,000 vessels transport 150,000,000 tons of cargo across the Dutch/German border near Lobith. Push-barge units and most of the largest vessels sail on a 24/7 scheme. Navigation regulations prescribe that vessels are allowed to sail for 14 to 18 hours between breaks, depending on the number of crew and its qualifications. Due to the intensive traffic on the river, anchoring along the navigation channel is no longer a safe or tranquil option for staying overnight.

Therefore, the existing harbour at Tuindorp will be upgraded to receive 20 vessels with a length of 110 m. Some 4 km upstream near Spijk a new harbour will provide some 45 berths for vessels with a length of 135 m and 4 pushed convoys with a length of 190 m.

2 STAY-OVERNIGHT HARBOURS

2.1 Government Policy

The Dutch government has decided to create special harbours along the main routes at a maximum interval of 30 km (2 hours sailing) to provide mooring facilities to satisfy overnight rest needs for the inland vessel crew. At the border on the main transport route between Rotterdam/Amsterdam and Germany a total of 70 berths has to be made available (RWS,2013a).

2.2 Project History

On several occasions (1996 and 2007) a plan was drawn up for the creation of a new harbour at Spijk with the capacity for about 70 vessels. Due to budgetary reasons and the introduction of new European environmental law (Natura2000), that asks for alternatives and to mitigate negative effects, the plan was delayed and the actual creation never came to pass.

In 2010, a strategic consideration of various sites was made that resulted in the selection of three promising (combinations of) sites.

In 2011 the Minister of Infrastructure and Environment decided to follow a new approach. In this new approach the creation of the mooring facilities became a joint effort between three administrative levels (national, provincial and municipality) that work together on different levels: from their respective boards to the project members.

In June 2014, the Minister – in close cooperation with province and municipality – selected one combination of two sites for the mooring facilities (after the appraisal of the promising sites).
The decision entails the upgrading of the existing harbour at TUINDORP for about 20 berths for 110 m long vessels (CEMT Class Va/M8) and the creation of a new harbour at SPIJK with about 50 berths for 135 m long vessels (CEMT Class Va/M9), see Figure 2.1 for locations.

Figure 2.1 Rhine near Lobith; left the existing harbour at TUINDORP; right the new harbour at SPIJK.

2.3 Present Studies

At present, both harbours are further assessed in terms of i.e. environmental impact and costs and designed in order to be implemented in a locally accepted spatial plan in 2016 and regulated in permits. An important part of this effort is a nautical study by which the project aims to select the preferred variant. This study is part of the Environmental Impact Assessment (EIA) conducted by the consultant (W+B,2014). To achieve the first objective, various layouts were generated to examine various aspects that are relevant to design a safe and swift facility.

One very important aspect is the “safe and swift” arrival to and departure from the harbour. For the appraisal of this topic various nautical studies, including nautical simulations were carried out.

2.4 Stakeholders: “The Public” and the skipper

The communities Tuindorp and Spijk have strong ties to the shipping industry as for instance many of the inhabitants of Tuindorp are skippers or retired skippers themselves, or have them as relatives. The users of the new facilities are represented by the Royal skippers’ association ‘BLN-KSV Schuttevaer’, an advocacy organization for Dutch skippers and owners of inland vessels. Involving skippers as experienced user, gains time, and provides valuable pragmatic input for the optimization of the layout of the harbours.

The project team from “Provincie Gelderland” (the regional authority) decided to involve the public and the skippers in the design process and to be open on the content of the ongoing studies.

2.5 Present Nautical Studies

The nautical studies were set up systematically to enable an efficient approach of the nautical aspects. This approach comprised the following steps:

- Review of local situation and navigation;
- Collection of design rules for river harbours;
- Review of layout of nearby river harbours;
- Development of design rules for the two harbours;
- Development of six harbour variants (2* Tuindorp + 4 * Spijk);
- Develop approach for verification of harbour variants in manoeuvring simulator;
- Compose simulator variants for the harbours Tuindorp and Spijk;
- Verification in manoeuvring simulator with licensed and active skippers; including a demonstration witnessed by the general public;
- Verify (and where necessary adapt) the design rules developed for the harbour entrances with the results of the manoeuvring simulations
- Evaluate the nautical safety and swiftness of the six variants (2* Tuindorp + 4 * Spijk);
- Composition of preferred variant for Tuindorp and for Spijk;
- Assess the nautical safety and swiftness of preferred harbour variant for Tuindorp and Spijk.

The above steps printed in *italics* are elaborated further in the present paper.

3 DEVELOPMENT OF DESIGN RULES FOR RIVER HARBOUR NEAR LOBITH

3.1 Objective of the Harbour

The objective of the harbour is to contribute to safe and swift transport over water and enable vessel crews to take the rest required by law. It aims to be available for berthing at all conditions to rest and provide possibilities to (dis-)embark the crew and their car.

Furthermore, the facility aims to provide a tranquil environment to enable resting. Hence the design is optimised to protect the berths from flow and waves caused by the traffic on the river.

3.2 Situation and Environmental Conditions

The Rhine is the most important inland waterway in West Europe used by inland vessels up to a length of 135 m (CEMT Class VI), pushed convoys (CEMT Class Vb) and push-barge units with 6 barges (total length 269.5 m).
Every day between 300 and 400 vessels pass the Dutch/German border near Lobith. The average interval between the passages of two subsequent vessels is 4 minutes in two directions.

On an average day about 60 vessels manoeuvre in between this through traffic to or from the harbour entrances. Furthermore particularly to this location many manoeuvres are being carried out, related to fuel supply stations, berths along the river and shipyards nearby.

Therefore, the speed of access is a very important design aspect for these harbours as well as the nautical safety of manoeuvers around other traffic.

The range between navigable high water in Germany (Marke II) and low water level is more than 8 m and the flow velocity in the river varies from 0.8 m/s to more than 1.9 m/s (3 to 7 km/hr).

3.3 River Harbour Design

At the beginning of the design process guidelines have been collected for the design of the harbours entrances. These guidelines taking into account nautical, hydraulic and morphological aspects and concern:

- Level of nautical bottom level;
- Crest level of the harbour groynes;
- Width and shape of the harbour entrance;
- Extension of the manoeuvring area inside;
- Orientation of the berths;
- Departing vessels’ view of through traffic.

3.3.1 Design guidelines for harbours along navigation canals (RVW or WG)

The Waterway Guidelines - WG2011 (RWS, 2011b) and the supplement for larger vessel sizes - S RVW (RWS, 2013b) present design rules for inland waterways and harbours. However, these rules were developed for canals and situations without strong currents (<0.5 m/s). The two harbours near Lobith are along a slightly curving river with high flow velocities that have to be accounted for separately.

The WG recommends an under keel clearance (UKC) in the harbour of 40% of draft of the design vessel. For CEMT Class Va vessels with a draft of 3.5 m this results in a UKC of 1.4 m (maximum nautical bottom level at 1.4 m below the minimum level of the vessels keel).

The WG recommends a free view from the skippers position in the wheelhouse of the departing vessel on the through traffic over a 600 m in both directions. This is however for the situation without current where vessel speed is independent of sailing direction. On rivers with high flow speed (3 to 7 km/hr) the sailing speed in upstream direction (8 to 12 km/hr) is only 50% of the sailing speed in downstream direction (16 to 24 km/hr). In order to equalise the sailing time in the free view triangle to the harbour entrance, the base of this triangle has been moved 200 m in upstream direction (800 m free view in upstream direction and 400 m in downstream direction from view point from the stern of the vessel in the harbour).

The WG further recommends a maximum crest level of 2.5 m above the average water level (MW) for harbour groynes (or other objects or vegetation) inside the free view triangle. However, in view of the huge variation in water level in the river Rhine (approx. 10 m) this would result in significant flooding of the harbour groynes at high water and endanger the tranquillity at the berths. Moreover the height of MW+2.5 m is based on the characteristics of small vessels including recreation. Most of the vessels in the harbour will be much larger and have a viewpoint in the wheelhouse that is much higher than 2.5 m above the water level. Using this benefit it is possible to apply a higher crest level in part of the free view triangle as follows: near the harbour lights at the end of the harbour groynes, the crest is set at a level of MW+2.5 m as before; however from there the level slowly increases to MW+4.0 m at the upstream and downstream extremes of the free view triangle.

Figure 3.1 Free view triangle and crest level of harbour groyne

Outside the free view triangle the crest level should be even higher to ensure maximum tranquillity in the harbour, especially in periods with high river discharges. A reasonable value could be the water level that is exceeded 1/year or on average during 1 day per year.

3.3.2 Simulation study for river harbour

Results from a simulation study for a river harbour in the floodplain Beijenwaard of the Rhine at Spijk are available from an earlier stage of the project (Marin, 2002).

This simulation study concluded that the required stopping length of CEMT Class Va vessels (L=135 m) reached about 270 m (=2*L).
3.3.8 Information on river harbours

Information on the layout of river harbours has been gathered from existing harbours (and canal connections) along the Rhine. This comprised the analyses of aerial photographs from harbours along the Rhine upstream (Germany lower Rhine) and downstream of Lobith (Dutch Waal, Lek and IJssel).

- reduces the exchange of water (with sediment) between the river and the harbour (and thereby reduces sedimentation and circulation flow in the harbour); and
- pushes the flow in the river to the middle of the riverbed (thereby opposing the riverbed sedimentation near the harbour entrance).

This leads to the recommendation to extend the upstream harbour groyne with a vertical pile groyne with a vertical pole (with harbour light on top) at the end.

The width of the harbour entrance on the keel level of the vessel in general ranges from 1.0 to 1.4 * L (L=vessel length), depending on the shape of the harbour entry and the local situation. For the new harbour the minimum width of the entrances should be equal to the length of the vessel.

3.4 Effect of the harbours on the river flow

3.4.1 Criteria for riverbed and floodplain

To avoid negative impact from projects in the riverbed or floodplain of on the primary function of the river (discharge) and the navigation channel in the river, three main aspects have to be dealt with, and kept in compliance with the strict criteria presented in the hydraulic and morphological assessment framework - RBK (RWS,2014):
- Extreme water level in the river (=high-water defence);
- Sedimentation in the main channel (=water depth in the navigation channel); and
- Cross-currents in the navigation channel near the river banks (sailing safety).

The above criteria are strict and have to be traded with other goals: e.g. high groynes around the harbour increase the tranquillity at the berths, but may hamper the flow at high river discharges (and thereby increase the maximum flood level at the high-water defence).

3.4.2 2-D Flow modelling

The impact of a project on the three aspects (extreme water level, sedimentation, and cross-current) has to be determined with the WAQUA-flow model. The reference model schematisation from the Rhine branch is obtained from Rijkswaterstaat. The reference model is based on a curve-linear computational mesh with average grid sizes of approx. 40 m in flow direction and approx. 15 m perpendicular on the flow.

The reference model represents the geometry and roughness of the (existing) situation, as well as the boundary conditions for the flow (discharges and water levels at the model boundaries). This model is prescribed in the assessment framework RBK.
Referring to (RWS, 2014) as reference for the determination of the impact of the project on the river flow and sedimentation.

![Figure 3.3 Reference situation Spijk, bottom and flow lines at extreme water level (1/1250 year)](image)

Starting from the reference situation the geometry and bottom roughness for the respective variants for the harbour have been incorporated in the WAQUA flow model (W+B, 2015) following the procedures in the assessment framework RBK.

### 3.5 Selected design rules for harbours near Lobith

Based on the forgoing, guidelines have been presented for the design of the harbours near Lobith. These guidelines concern the basic dimensions for the entrance of and the manoeuvring area in the harbour:

- Water depth inside the harbour entrance and inside the harbour;
- Width of the harbour entrance; and
- Shaping of the harbour entrance (e.g. vertical pole with harbour light that provide clearly visible and sharp marked harbour entrance).

And for the stopping and manoeuvring area inside:

- Minimum stopping length in the harbour;
- Manoeuvring area in the harbour;
- Orientation of the berths inside the harbour; and
- View angle on the river for departing vessels.

These design guidelines have been applied for the preliminary design of the entrances of the harbours, the stopping and manoeuvring area, and for the orientation of the berths inside the harbour.

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### 4 DESIGN OF HARBOURS TUINDORP AND SPIJK

#### 4.1 Upgrading of the harbour at Tuindorp

##### 4.1.1 Upgraded of existing port:

The existing harbour at Tuindorp (see Figure 4.1) has originally been developed for 85 m long vessels (CEMT Class IV/M6).

![Figure 4.1 Tuindorp: existing layout](image)

The harbour needs to be upgraded for vessels with a length of 110 m long (CEMT class Va/M8). In addition the bottom and water level in river Rhine decreased significant over the last century, which reduced the water depth in the harbour.

The following measures have been developed to upgrade the harbour (see also Figure 4.2):

1. Increase the length of the design vessel from 85 to 110 m (CEMT class IV/M6 to Va/M8);
2. Lower the bottom in the harbour (to compensate lower water levels and riverbed erosion);
3. New longer mooring jetties (about 20 berths for vessel with length of 110 m);
4. Adaptation of the groyne at the harbour entrance (extending with pile groyne with pole with harbour light at the end);
5. Widening of harbour entrance (widen the narrow part); and
6. Mitigation of harbour siltation and sedimentation (short groyne in beacon line).

##### 4.1.2 Two variants:

The above elements were elaborated in two harbour variants:

- reduced (only dredging, new jetties and adaption of groyne: items 1-4)
- extended (including widening entrance and groyne to mitigate sedimentation: items 1-6)
4.2 New harbour at Spijk

4.2.1 New harbour in Beijenwaard flood plain of the river:

The new harbour at Spijk is planned in the Beijenwaard, a floodplain area between the high water defence dyke and the main channel of the river Rhine. Figure 4.3 shows the Beijenwaard between the sand industry and the village Spijk.

In this area a harbour with about 50 berths will be created. The new harbour in the floodplain at Spijk is designed in compliance with:

1. Design vessel: CEMT Class Va/M9 (vessels with length of 135 m);
2. Accessible for CEMT Class Vb/C3l (push barge units with length of 190 m);
3. Design of harbour entrance that allows safe and swift entry and departure; and
4. Mitigation of harbour siltation.

4.2.2 Four variants:

As the available floodplain is slightly larger than the minimum required for the berths, this allows for some freedom for the exact location of the mooring facilities, the layout of the harbour and the smooth implementation in the landscape. This results in four variants for the position of the harbour:

- West: in western part of the Beijenwaard, as far as possible from the village Spijk;
- East: in eastern part of the Beijenwaard, far from mineral industries in the west;
- South: in southern part of the Beijenwaard, far from the existing high water defence;
- Bril (=pair of glasses): far from the small residential spot north of the harbour.

Figure 4.4 shows one of the harbour layouts (South variant) for the new harbour Spijk.

In the new harbour (all variants) concern a significant lowering of the level of the floodplain inside the harbour and the impelmentation of new high groyns around to protect the berths inside the harbour from flow and waves.

The effect of the harbour variants on the extreme water level has been determined with the WAQUA-flow model. Figure 4.5 presents the increase (yellow-red) and decrease (green-blue) of the waterlevel.

Figure 4.2 Tuindorp: new design (extended layout).

Figure 4.3 Spijk: existing floodplain

Figure 4.4 Spijk: new harbour (Variant South).

Figure 4.5 Spijk: effect on water level at design level (Variant South).
The water level increase was mitigated by optimising the crest levels of the harbour groynes using the WAQUA-flow model. This results in a compromise between the tranquillity for the vessels in the harbour and the increase of the water level.

The morphological effect of the four variants was determined with the WAQUA-tool WAQmorf. This tool uses the change the flow velocity to calculate the yearly average effect on the bedlevel. Figure 4.6 presents an example of the effect on the bed level.

![Figure 4.6 Spijk: effect on morphology (Variant West).](image)

The effect of the harbour on the riverbed is affected by the:
- Crest level of the the harbour groynes;
- Position of the harbour groyne w.r.t. the beacon line (river side or land side); and
- Shape and exact position of the head of the harbour groynes w.r.t. the beacon line.

4.2.3 Variant composed of design modules:

Each variant has been developed according to the design guidelines and applying design modules. Main nautical modules are:
1. The width of the harbour entrance;
2. Shape of the harbour entrance (length of pile groyne, pole with harbour light); and
3. The distance between the harbour entrance and the berths.

The available stopping distance and manoeuvring area between the harbour entrance and the berths is decisive for the safety. In the “South variant” this distance to the berths is the smallest of all four variants. Therefore, the South variant was selected as the so-called simulation variant to be verified with manoeuvring simulations. The exact location of the harbour entrance in longitudinal direction of the river (along the beacon line) is more or less indifferent for the nautical safety.

5 MANOEUVRING SIMULATIONS

5.1 Portable Inland Bridge Simulator REMBRANDT

The nautical safety and swiftness, including the speed of access for the proposed harbour layouts were tested using BMT’s portable manoeuvring simulator REMBRANDT-INLAND. The manoeuvring simulator REMBRANDT is used by pilots, skippers, ship operators, naval architects and harbour authorities.

The REMBRANDT system has a wide range of high-fidelity ship models which can interact with varied environmental conditions (current, wind and waves), geometry (shallow water and bank effects) and also with other vessels and tugs to produce realistic vessel behaviour. Mathematical ship models are based on specific ships and are modelled individually by naval architects, based on many years’ experience in the manoeuvring performance of surface vessels. REMBRANDT is principally designed for the following applications:
- Manoeuvre rehearsal;
- Ship performance and operational assessments;
- Assessment of harbour arrangements (berths, channels, etc.);
- Assessment of tug requirements; and
- Ship-handling training (and education).

Various types of control consoles or touchscreen controls have been designed to replicate a ship’s controls layout. For the simulation of the inland vessels the portable inland bridge has been used. This bridge complies with a generally applied layout in the wheelhouse of inland vessels. The portable bridge has a U-shaped console, see Figure 5.1. The console is fitted with seven screens and equipped with four industry standard calibrated control levers from Kwant Controls.

![Figure 5.1 REMBRANDT’s inland bridge](image)
5.2 Set-up of Simulation Programme

A wide range of conditions has been made available for the simulations:
- 2 harbours (Tuindorp and Spijk, both with minor layout variations);
- 3 vessel sizes (110 m, 135 m and a coupled unit of 190 m);
- 2 loading conditions (bulk cargo and high stacks of container cargo);
- 4 sailing trajectories (upstream, downstream, arriving, departing);
- 3 river discharge/water levels combinations; and
- 4 wind conditions.

5.2.1 Model vessels in manoeuvring simulations

The vessel dimensions are the maximum for the vessels berthing in each of the harbours. For Tuindorp the maximum length is 110 m and for Spijk 135 m. In addition the harbour of Spijk is called by coupled units with a length up to 190 m in a special manoeuvre: entering the harbour stern-first.

The engine power in the vessels is the 90% exceedance values (i.e. 90% of the vessels have more engine power than used for the model vessel). Marin(2010) and BMT’s inland vessel data base that with data of hundreds of inland vessels both confirmed the 90% exceedance values applied in the model vessels. This 90% vessel was selected for the simulations to ensure that not only the modern and average vessels can safely use the harbour, but also the older vessels with less than average engine power. Table 5.1 presents the main characteristics of the model vessels:

<table>
<thead>
<tr>
<th>Vessel Code</th>
<th>M8L/C*</th>
<th>M9L/C*</th>
<th>C3L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel class</td>
<td>CEMT/RWS</td>
<td>Va/M8</td>
<td>Va/M9</td>
</tr>
<tr>
<td>Dimensions</td>
<td>Length [m]</td>
<td>110</td>
<td>135</td>
</tr>
<tr>
<td>Beam [m]</td>
<td>11.4</td>
<td>11.4</td>
<td>11.4</td>
</tr>
<tr>
<td>Draft [m]</td>
<td>3.5*</td>
<td>3.5*</td>
<td>4.0</td>
</tr>
<tr>
<td>Capacity [Ton]</td>
<td>3050*</td>
<td>3750*</td>
<td>6250</td>
</tr>
<tr>
<td>Capacity [TEU]</td>
<td>208</td>
<td>272</td>
<td></td>
</tr>
<tr>
<td>Main engine [Hp]</td>
<td>1500</td>
<td>1900</td>
<td>2 x 1521</td>
</tr>
<tr>
<td>Bow thruster [Hp]</td>
<td>470</td>
<td>972</td>
<td>3 x 543</td>
</tr>
</tbody>
</table>

*either fully Loaded (=draft 3.5m) or with 4 layers of empty Containers (=draft 2.0 m, air-draft 8.8 m).

Table 5.1 Dimensions and power of model vessels.

5.2.2 River discharge, water levels and flow velocity navigation channel

At Lobith the river discharge and thus the water level and flow velocities can vary significantly. Three levels have been selected for the simulations (see also Table 5.2):
- low water situation where vessels can just sail with their maximum draft of 3.5 m,
- medium level where the crest of the flow guiding works (groynes) is just not flooded, and
- high level at which the upstream navigation according to German regulations is partly stopped.

<table>
<thead>
<tr>
<th>Code</th>
<th>L</th>
<th>M</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>OLR +0.7 m</td>
<td>crest of groyne</td>
<td>Marke I</td>
</tr>
<tr>
<td>Exceedance</td>
<td>85%</td>
<td>15%</td>
<td>1.5%</td>
</tr>
<tr>
<td>Tuindorp RKm 863.5</td>
<td>level in m above NAP</td>
<td>8.01</td>
<td>11.01</td>
</tr>
<tr>
<td>Lobith RKm 862.12</td>
<td>8.09</td>
<td>11.15</td>
<td>13.7</td>
</tr>
<tr>
<td>Spijk RKm 859.5</td>
<td>8.33</td>
<td>11.46</td>
<td>14.0</td>
</tr>
<tr>
<td>Velocity in riverbed</td>
<td>m/s</td>
<td>0.8</td>
<td>1.3</td>
</tr>
<tr>
<td>discharge</td>
<td>m³/s</td>
<td>1363</td>
<td>3485</td>
</tr>
</tbody>
</table>

Table 5.2 Flow velocity and water level in simulations

The flow pattern was applied from the 2-D flow model WAQUA. In order to get sufficient detail of the flow in and around the harbour entrances, the WAQUA computational mesh was refined from approximately 40*18 m² to approximately 13*6 m². This mesh size enables a detailed modelling and positioning of the harbour groynes in WAQUA.

5.2.3 Wind conditions

Vessels loaded with high stocks of containers are vulnerable to wind. Therefore, a number of critical wind conditions has been modelled (see Table 4.3Table 4.3). These wind conditions have been selected based on data from three measuring stations in the area run by the Dutch National Meteorological Institute (KNMI). The highest selected wind speed exceeds 3 to 5% of total time. For three (main) wind directions (sector of 45 degree) wind speeds have been selected that exceeds 2% of total time.

<table>
<thead>
<tr>
<th>Code</th>
<th>Wind</th>
<th>000</th>
<th>090</th>
<th>225</th>
<th>315</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>All</td>
<td>Var.</td>
<td>E</td>
<td>SW</td>
<td>NW</td>
</tr>
<tr>
<td>Direction of origin of wind</td>
<td>°N</td>
<td>0 to 360</td>
<td>68 to 112</td>
<td>203 to 247</td>
<td>293 to 337</td>
</tr>
<tr>
<td>Wind speed</td>
<td>m/s</td>
<td>9.5</td>
<td>0.0</td>
<td>6.0</td>
<td>9.5</td>
</tr>
<tr>
<td>Exceedance</td>
<td>time</td>
<td>5%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
</tr>
</tbody>
</table>

Table 5.3 Wind velocity and direction in simulations
5.2.4 Selection of conditions for manoeuvring simulations

The nautical safety of the harbour lay-outs has been tested thoroughly both to ensure safety and swiftness during the entry and the departure manoeuvres. This included arrival on and departure from the jetties and the presence of a number of vessels moored in the harbour. Special attention has been paid to a number of critical design modules and their effect on the manoeuvre: the width of the harbour entrance, the manoeuvring area in the harbour, the swiftness of reaching the jetty, the swept-path of the vessel in the navigation channel, etc. A relative large number of simulations has been dedicated to the more difficult manoeuvres: direct entering of the harbour when sailing downstream, sailing ahead when departing the harbour and going upstream, etc.

5.3 Manoeuvring simulations

5.3.1 Simulation workshop

In five days more than 80 manoeuvring simulations were carried out. The simulation program was intended to cover the whole range of conditions, with the focus on the difficult ones. As such some 46 simulation were carried out with 110 m vessels for Tuindorp and 35 simulations for Spijk (20 with 135 m vessels and 14 with the 190 m long coupled units). Furthermore 40 simulations were carried out for the difficult harbour entry manoeuvre from sailing downstream, where only 7 were carried out for the easy manoeuvre leaving the harbour and sailing downstream.

Three active and licensed inland skippers where employed to sail the model vessels. Each simulation took about 30 minutes for instruction, sailing and debriefing. The findings of the skippers regarding the safety and the swiftness of the manoeuvre were recorded in the “sailing report”.

At the end of each day the tentative program was adjusted to account for the lessons learned.

Safety is a major concern for the local people, particularly since some of the berths will be assigned to vessels with dangerous cargo (ADN-goods). Therefore, the harbour lay-outs had to be tested thoroughly both to ensure safety during entry and during departure. This included consideration of the vessels berthed at jetties inside the harbour that may be at risk because of those manoeuvres. The result of the simulations was an assessment of the lay-outs and a proposal for alternative layouts to guarantee safety.

Since BMT’s Inland bridge was designed to be portable, the project team welcomed the idea of involving a local skipper and to execute (part of) the simulations in the town hall in Lobith (see Figure 5.2).

5.3.2 Findings from the skippers

In total three active and licenced skippers sailed the vessels in the simulator and expressed their findings about the manoeuvre and their experience on the safety and swiftness of the manoeuvre. The skippers introduced in their practical experience, which at several points resulted in new views and in an adaptation of the criteria for judging the safety and the swiftness of the manoeuvres.

The sailing experience of the skippers differed from skipper to skipper and varied from small vessels (85-110 m length) to very large vessels \((L^*B=135 \times 17 \text{ m})\) and push barge units \((L^*B=190*11.4 \text{ m})\). These variations in practical insights contributed to the adaptation of the safety margin between vessel and embankment and to the conclusion that sailing in forward direction is not automatically the swifter and safer way for a vessel to enter or depart the port.

These findings, judgements, ratings of safety and swiftness by the skippers are entered in the “sailing reports” for each manoeuvre.
5.3.3 Sailing reports with graphs

The results of each of the simulations have been presented in a brief report of 4 pages:
1. description of manoeuvre, findings of the skipper, score on safety and swiftness, and possible bottle necks in the manoeuvre;
2. Track plot on ECDIS map with position of vessel at 30 s interval;
3. Graph: directions (heading and rudder) and velocities (forward, drift and rate of turn);
4. Use of engine and bow thruster (Power, RPM, and direction of thruster)

5.3.4 Analyses of sailing reports

The initial judgment by the skippers is very valuable, but also slightly subjective, and slightly coloured by their professional experience. In addition the numerical results in the “sailing reports” have been re-analysed in a systematic way to get more objective results. This re-analysis comprises a systematic comparison of the simulations on a large number of aspects, focussing on safety of the manoeuvre and the level of distortion of the ongoing traffic on the river.

For entering the harbour and berthing:
- Number of navigation lanes occupied in the river (out of 6 navigation lanes of 25 m in the 150 m wide navigation channel);
- Time in navigation channel in the river with reduced speed;
- Minimum distance to harbour groynes (expressed in number of ship beams B);
- Vessel speed in harbour entrance
- Stopping length in the harbour (expressed in number of ship lengths L);
- Swiftness of berthing in the harbour (min);

For de-berthing and joining ongoing traffic:
- Swiftness of de-berthing up to harbour entrance;
- Vessel speed in harbour entrance
- Time in navigation channel in the river with reduced speed;
- Number of navigation lanes occupied in the river;

And finally the use of main engine, rudder and bow thruster during the manoeuvre: and frequency at maximum (or only part of available capacity).

The above information has been collected and presented in tables for all simulations and for each harbour separately. These tables with objectified information form a valuable supplement on the more subjective observations of the skippers who sailed the simulations.

5.4 Preliminary findings

The result of the analysis of the simulations was an assessment of the investigated variants of both harbours. The findings give direction to slightly adapt the design rules for the harbours near Lobith for nautically safe and swift design on:

- The width of the harbour entrance: a width of the harbour entrance equal to the length of the vessel (L) was shown to allow safe and swift manoeuvres;
- Distance between harbour entrance and berths: 2L appeared to be more than necessary, for almost all situations a distance of 1.5L is safe and well suitable for a swift entry manoeuvre;
- The width in the narrowest part of the harbour entrance (entry through harbour dyke at Tuindorp): widening of this narrow part significantly increases the safety and swiftness of the harbour entry manoeuvre;
- The possibility of a short groyne downstream of the harbour entrance (to minimise sedimentation at Tuindorp): no objection in view of nautical safety and swiftness (as long as the entrance width remains one vessel length L);
- The extension of the vertical pile groyne (between the sloping rubble mound groyne and the vertical pole) provides space for coupled units to entering the harbour at Spijk stern forward: a vertical pile groyne extension with a length up to \( \frac{1}{3}L \) (one third of the length of the coupled unit) creates the required manoeuvring area in the harbour that increases the safety and swiftness of this stern forward entry manoeuvre.

The above information has been collected and presented in tables for all simulations and for each harbour separately. These tables with objectified information form a valuable supplement on the more subjective observations of the skippers who sailed the simulations.
6 CONCLUSIONS

The findings of the study indicate that real-time manoeuvring simulations provide significant information for the determination of the basic dimensions for a river harbour entrance that are required to enable safe and swift arrival and departure manoeuvres.

The simulations have been applied as part of the studies for the new harbours. The simulations could be applied very efficient as they were an integrated part of the effect studies to provide and assess the harbour designs:

- Providing nautical input in the harbour design process, especially by providing (draft) harbour design rules for the preparation of harbour variants.
- Bringing the nautical and hydraulic aspects of harbour design together and trade out and optimise the effects jointly. General guidelines might not sufficiently cover the local situation for an optimal design;
- Selecting one nautically (most) critical variant for the simulations;
- Verification of the (draft) harbour design rules to enable the assessment of the nautical safety and swiftness of the finally preferred variants for the harbours.

In this process the pro-active participation of the skippers is highly valued. They contributed with their practical experience in the technical findings and brought these findings to a higher level, both in a practical and in a technical sense.

The portable inland-bridge simulator enables to demonstrate the study to the public. The visitors to the demonstration took an active part in the simulations and got a good idea of the type of studies that are performed to ensure that the harbour designs are safe for navigation.

The main findings from the simulation study include the width and shape of the harbour entrance, the required manoeuvring area inside the harbour, and the orientation of the berths.

ACKNOWLEDGEMENT

The preliminary findings of the studies presented in this paper are implemented in preparation of a provincial special plan and the decision (MIRT3) by which the minister of Infrastructure and Environment selects a “preferred variant” for mooring facilities for a total of 70 vessels.

The authors like to thank the project team from the Provincie Gelderland, Rijkswaterstaat and the Municipality of Rijnwaarden for their valuable contribution and for enabling this paper.

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