INNOVATIVE QUAY STRUCTURES AND DEVELOPMENT OF THE PORT OF EEMSHAVEN, THE NETHERLANDS

by

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Abstract

The Eemshaven, located in the north eastern part of the Netherlands, is developing rapidly since 2004 introducing new port infrastructure for various clients such as AG Ems (Borkum ferry line), Wijnne & Barends stevedoors, Bio Value, Essent/Vopak/Gasunie (LNG plant) and the Energy Park comprising amongst others new power plants for Nuon and RWE.

Figure 1: Admiralty chart Eemshaven

Western part of the Eemshaven (Westlob)

Witteveen+Bos has been involved in these maritime developments from the beginning as consultants to Groningen Seaports (GSP), AG Ems and currently BAM Infraconsult. For the extension of the quays at Juliana harbour phases 3 + 4 and the realisation of the Beatrix harbour quays phases 1+2 Witteveen+Bos was commissioned in 2004 by GSP to design an innovative quay structure, using prefabricated concrete coping beam elements. Both projects are located at the Westlob (western part of the port) reclaimed area.

In 2007 Witteveen+Bos was commissioned by AG Ems to design the Ro-Ro terminal located in the to-be-dredged Beatrix harbour as well.

In the period 2006 - 2008 Witteveen+Bos assisted Groningen Seaports with the preparation for the design of the new Beatrix harbour within the Westlob of the Eemshaven. The scope

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comprised design, contract documents, tender procedure and project management during construction.

From December 2008 up to date Witteveen+Bos is involved in the preparation of the design for the extension of the Beatrix harbour phases 2 till 4, deepening and widening the entrance channel and deepening of the existing Juliana harbour.

**Eastern part of the Eemshaven (Eastlob)**

Since the end of 2008 Witteveen+Bos is preparing the tender design and the detailed design in co-operation with BAM Infraconsult, on behalf of BAM Civiel for the 25 m retaining quay structures at the Energy Park project, located at the Wilhelmina harbour, Eastlob (eastern part of the port) reclaimed area. Construction will start in 2010.

**Focus of paper**

The paper will focus on the design aspects and some construction aspects of the innovative quay structures at the Westlob of the port of Eemshaven.

After dealing with the innovative design aspects of the above structures the paper will further deal with the design aspects of the quays at the Wilhelmina harbour located in the Eastlob of the Eemshaven. Also the design of the Ro-Ro terminal in the Westlob will be highlighted.

![Figure 2: Bird’s eye view presenting future Port of Eemshaven with at the back (Westlob) Juliana harbour phase 3 and Beatrix harbour phase 1 and 2 realised. In front the Wilhelmina harbour finished (Eastlob). Artist impression © GSP.](image)
1. **INTRODUCTION**

The Eemshaven, located in the north eastern part of the Netherlands, is developing rapidly since 2004 introducing new port infrastructure for various clients such as AG Ems (Borkum ferry line), Wijnne & Barends stevedoors, Bio Value, Essent/Vopak/Gasunie (LNG plant) and the Energy park comprising amongst others new power plants for Nuon and RWE.

Witteveen+Bos has been involved in these maritime developments from the beginning as consultants to Groningen Seaports (GSP), AG Ems and currently BAM Infraconsult.

2. **WESTLOB: QUAY WALLS JULIANA HARBOUR AND BEATRIX HARBOUR**

In 2004 a secondary dike protected the land reclamation of the Westlob at the location of the quay walls phases 3+4 to be build at the Juliana harbour. A sludge deposit area was present directly behind the dike. In the Juliana harbour, quay walls phases 1+2 were already realised in the past. The new quay walls were to be built directly adjacent to those quays.

The Short Sea Beatrix harbour quay structures were located in a green field area where the harbour basin was dredged after the quay structures were realised. The secondary dike at the Doekegat entrance channel was partly dredged in order to realise the entrance of the new basin (Beatrix harbour).

![Figure 3: Bird’s eye picture of project locations of the quays at Juliana harbour (left) and Beatrix harbour (right) in 2004.](image)
Figure 4: Quay wall Juliana harbour phase 3 finished as well as quay wall Beatrix harbour phase 1. Beatrix harbour under construction as well as the Ro-Ro terminal for AG Ems. Photograph by GSP.

Figure 5: Quay Beatrix harbour phase 1 under construction Photograph by K. Boertjens.
2.1 Innovative design of quays at Juliana harbour and Beatrix harbour

In the invitation for proposals in 2004 the Client (Groningen Seaports, GSP) explicitly requested that the design of the quay structures (coping beam) should be innovative. The reasons for the innovative design were: limited construction time, criteria from European funds, to limit the groundwater extraction during construction, maintenance costs and safety during construction and cost reduction.

For this, 4 alternatives were developed which can be characterised as follows:

1. U-shaped precast beam (sections of 3 m high, 2.5 m wide and 6 m long), placed on top of the combi wall piles, combined with a prefab wall of 2 m height beneath the U shaped beam, in front of the combi wall. Connection of wooden fenders to concrete.

2. Single precast plate in front of the combi wall, 4.5 m high. Connection of wooden fenders to concrete.

3. U-shaped precast beam (sections of 3 m high, 2.5 m wide and 6 m long), placed on top of combi wall. Connection of wooden fenders to combi wall piles.

4. Traditional cast in place coping beam.

An impression of the alternatives for the capping beam are presented below.

*Figure 6: Alternative coping beam configurations*
Alternative 3 was not attractive because of the vulnerable connection of the wooden fenders directly to the steel tubular piles of the combi wall. Alternative 4 was not chosen because it was not innovative and due to bad experiences in the past (bulk quays 1 and 2 Juliana harbour). Alternatives 1 and 2 scored virtually equal. Alternative 2 is more vulnerable to water level fluctuations during construction. A temporary building pit is required. Alternative 1 can in theory be built without such building pit and was determined as most innovative (at a later design stage the Client requested for a retaining structure). The following criteria were analysed: Robustness, Costs Innovation, Construction time, Complexity and Risks.

2.2 Proposed building sequence of chosen alternative

Below the proposed building sequence is presented below in figure 2.5.
Both quays (phase 3 Juliana harbour and phase 1 Beatrix harbour) were finalised in 2007. The Beatrix harbour basin was dredged in 2008. The contractor for the quay at Juliana harbour phase 3 chose alternative 2 instead (including building pit) of the tender design of alternative 1. The contractor for the quay at the Beatrix harbour applied tender design alternative 1.

Although it was requested to minimize the groundwater extraction at the project locations, it was inevitable to extract temporarily ground water. The design comprised a temporary dike in front of the quay wall (Juliana harbour). At Short Sea port an open building pit with ground slopes, combined with a groundwater extraction was designed. Groundwater flow modelling with FEM package Microfem was applied to prove that the groundwater extractions would be within the limits of the existing permits of the Client.

**Figure 8: Results of groundwater extraction modelling with Microfem.**

### 2.3 Other innovative aspects of the design of quays at Juliana harbour and Beatrix harbour

The quays were designed without expansion joints which required special attention during the design. Because of the stiff prefabricated structures and the joints in between the structures every 6.23 m, special attention was required for the reinforcement of the coping beam to introduce a well divided crack pattern in the in situ concrete. A large flexible joint connects one quay phase to the other quay phase.

Another innovative aspect was the application of a new interlock K101 on the tubular piles of the combi wall at Juliana harbour phase 3, which was originally developed by Witteveen+Bos (amongst others) to absorb high ice loads in arctic offshore environment in the Caspian Sea, Kazakhstan and to guide sheet piles well.

**Figure 9: New developed interlock K101**

### 2.4 Summary Terms of References

#### 2.4.1 Quays Juliana harbour phases 3 + 4

The new quay wall will have a total length of 700 metres. The extension of the quay will be realised in two phases, phase 3 (completed 2007) and 4, each comprising 350 meters of length. The contract depth is NAP –15 m (construction depth NAP –16.8 m). The terminal area has a surface level at NAP +4.5 m resulting in a retaining height of approximately 20 meters. The quay will be able to receive sea-going vessels of capacity 6,000 DWT to maximum 60,000 DWT and inland vessels to class CEMT-class Vb.
The design is carried out in accordance with Dutch guideline CUR 166 Sheetpile structures [3]. A verification was made with the Handbook quay walls [2] and the German guideline EAU 1990 (drainage aspects) [1].

CPT’s were carried out in line with the new berthing line and at the location of the grout anchor every 25 running m’. The following soil layers are encountered:

- surface until a level of NAP -5 to -6 m: silty very fine sand (with intermediate mud layers), loose to medium dense;
- NAP –6 m until NAP -13.5 m: medium dense silty sand;
- NAP -13.5 m until NAP –18.5 m/-23.5 m a medium stiff clay layer with locally an intermediate peat layer is encountered (glacial “pot” clay, with high sand content);
- medium dense sand until the investigated depth of NAP –30 m.

In the calculations in operational conditions a dredging depth minus 0.3 meter for tolerances is applied. Average tide varies between NAP +1.18 m and NAP –1.38 m. LLWS is NAP –1.82 m and Lowest Low water is NAP –3.30 m.

**Loads**

The following surface loads options were implemented in the design:

- load option 1 reach stacker - 83 kN/m² directly behind coping beam, 4 m wide. Behind this 20 kPa (traffic class 60);
- load option 2 mobile crane - 167 kN/m² at 4 m from the font of the coping beam, width 1.8 m. Before and behind the crane 20 kPa (traffic class 60);
- load option 3 uniformly distributed load of 60 kN/m²;
- load option 4 extreme low water level (average 1/100 per year = NAP -3.30 m. Uniformly distributed load 20 kPa (traffic class 60).

Load option 4 (extreme low water level) was handled as a calamity or extraordinary loading case. Calculations for this option were made with representative values and the calculated steel stresses were verified with the yield stress applying an overall safety factor. This loading case dominates the anchor design. Double 1000 kN bollards are applied c.t.c. 20 m.

A drainage filter is applied directly behind the quay with outlets through the quay wall every 20 m in order to reduce the water level differences acting on the quay. The lower the drainage level, the less water level differences have to be applied in the calculations. The drainage system is applied at NAP -1,8 m.
The required technical life time of the structure is 50 years. The corrosion rates are derived from [3]. Both tubular piles and intermediate sheet piles will be coated until 1 m below berthing pocket dredge level. The life time of coating is assumed to be 10 years. The maximum corrosion rate is 0.2 mm/year and 8 mm additional wall thickness is here required. The maximum bending moments will occur in the underwater zone. Coating is more cost effective in this zone than additional wall thickness.

2.4.2 Quays Beatrix harbour phases 1 + 2

Most of the Terms of Reference for the Beatrix harbour are the same as for the Juliana harbour so only differences are presented in this section.

The new quay is realised at the south side of the Beatrix harbour and has a length of 675 meters. The new quay wall was realised in two phases, phases 1 and 2, comprising 375 (completed 2007) m and 300 m of length respectively (completed 2009). The contract depth is NAP –10.3 m (construction depth –11.4 m). The terminal area will have a surface level of NAP +4.5 m resulting in a retaining height of approximately 15 meters. The quay will be able to receive short sea vessels of maximum capacity of 10,000 DWT and inland vessels to class CEMT-classVb.

The soil profile at Short Sea port is more or less the same as at Juliana harbour although the soil layers are different in thickness and vary in depth and some liquefiable silty sand pockets are encountered, having it’s impact on the dredging activities. In the calculations in operational conditions a dredging depth minus 0.3 meter for tolerances is applied. Double 600 kN bollards will be applied c.t.c. 22.4 m.

2.5 Design features quay structures

2.5.1 Juliana harbour

The design calculations were made with a spring (multi linear) based sheet pile structure software package MSheet (version 6.1.2.8) developed by Delft GeoSystems. Check analyses were made with finite element program PLAXIS for deformation analysis, anchor analyses and insight in arching of the soil.

Several optimisations have resulted in the following configuration:

- combi wall with steel tubular piles Ø1.620 × 18 to 27 mm, X70, pile tip level tubular piles NAP -31 m;
- three intermediate sheet piles Larssen L24;
- grout anchors centre to centre 1.272 m, varying angles every anchor 23° en 25° (related to horizontal), \(l_{\text{groutbody}}\) 12.5/13.5 m, pre-stress 950 kN. Leeuw anchor type 1400 (of equal) with an auger diameter of Ø 350 mm.
- varying wall thickness: 18 mm till 27 mm.
Below the final design of the quay structure at Juliana harbour is presented.

![Figure 11: Final design quay wall Juliana harbour](image)

**2.5.2 Beatrix harbour**

In principle the same optimisation process as used for the Juliana harbour was applied, leading to:

- combi wall with tubular piles 1220 mm with varying wall thickness 22 mm and 18 mm (16 mm below dredging level); Steel quality X70. Pile tip level at NAP –24 m.
- anchorage angle chosen in such a way that the horizontal required space is less than 30 m behind the quay;
- level of drainage changed from NAP –1.2 m to NAP –1.8 m;
- 3 intermediate sheet piles;
- anchors at c.t.c 1,112 m, type Leeuwancho 1000 or equal with an auger diameter of 350 mm varying under an alternating angle of 31° en 34° with the horizontal.

Plaxis calculations were made to optimise the design. Below the final design of the quay structure at Beatrix harbour is presented.
Figure 12: Final design quay wall Beatrix harbour

Figure 13: Front view of Beatrix harbour quay, basin partly dredged (5 metres)
3. WESTLOB: RO-RO Terminal AG Ems

Figure 14: Ro-Ro terminal finished in 2008

Witteveen+Bos was commissioned by AG Ems Nederland B.V. to draw up the preliminary design, the final design and the tender documents for a new Ro-Ro terminal for the Borkum ferry line. Subsequently Witteveen+Bos also assisted during the tender evaluation and provided construction supervision and contract management services. The Ro-Ro terminal is capable to accommodate ferries and catamarans with a maximum length of 80 m. The quay is located at the north side of the Beatrix harbour which was still to be dredged during construction. The retaining height of the quay wall is approximately 13 m and the tidal range is circa 3 m.

Because only short time was available for the design and realisation in relation with the planned start date of the dredging activities of the Beatrix harbour basin, the Client decided to make use of a Employers supply of steel sheet piles, combi wall and mooring piles which was arranged by Witteveen+Bos. The construction started in 2007 and was completed in 2008. Witteveen+Bos designed the Ro-Ro terminal in 2006-2007.

The terminal was opened by Queen Beatrix in march 2008.
4. EASTLOB: QUAY WALLS AT ENERGY PARK, WILHELMINA HARBOUR

The Wilhelmina harbour which is situated in the Eastlob of the Eemshaven will be extended for the logistics of the power plants of NUON and RWE. For this extension the construction of new quay walls as well as partial furnishing of the quay area is required. Groningen Seaports recently published the scope for this project. Witteveen+Bos together with BAM Infraconsult prepared the winning tender design of this D&C&M-contract on behalf of BAM Civiel. The final and detailed design are currently under preparation.

![Figure 15: Developments at the Wilhelmina harbour. Artist impression © GSP.](image)

The final situation of the Wilhelmina harbour will consist of three quay walls with dedicated terminal areas, as shown in figure 15. The total required quay wall length of 1250 m is divided into three parts:

- Northern quay wall (NUON) with a length of 525 m;
- Eastern quay wall (RWE) with a length of 275 m;
- Southern quay wall (RWE) with a length of 450 m;

Some particularities and difficulties of the design conditions of the quay walls are:

- Quay terminal area at NAP +5.5 m and maximum excavation level up to NAP -19.25 m, resulting in a maximum retaining height of 24.75 m;
- Tidal range of approximately 3.0 m;
- The quay walls are situated in the zone of influence of the primary sea defence. As the design was carried out according to CUR166 (Handbook Sheet Piling) the highest safety class of CUR166 (class III) has been selected. Furthermore an increase of the material factors has been applied because of the length effect of the quay walls (total length is 1250 m), resulting in a total applied safety level of $\beta = 4.62$.
- The available length for installation of anchors is limited to 40 m behind the quay wall.
- The southern quay wall is interrupted by a large cooling water inlet, to be built by third parties.

During preparation of the tender design several alternatives were considered. It was found that the economically most attractive solution was a relieving platform on an inclined combined wall together with MV-piles (tension piles) and Vibro-piles (bearing piles). In Figure 16 typical cross-section of the quay wall is presented.

Figure 16: Typical cross-section quay wall Wilhelmina harbour

Some particularities of the design of the quay walls are:
• The application of cathodic protection resulted in a minimal corrosion allowance on the steel tubular piles as well as on the intermediate sheet piling.

• The intermediate piles consist of two different types of sheet piles (AU25-PU28-AU25) in order to obtain a regular joint distance in relation to the required number and positioning of the bollards, fenders and other quay elements.

• Calculations were executed via an iteration procedure with use of geotechnical (Msheet, Mfoundation, Plaxis) combined with structural software (ESA-PT) as well as several spreadsheets.
5. REFERENCES

[3] Stichting CUR Publicatie 166 (2005), Damwandconstructies, Gouda