Model Tests for the New Ems-Pier in Emden

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Abstract

The port of Emden is situated in the southern German Bight nearby the Dutch border in the Ems-Dollart-Estuary. The port area is more than 20,000,000 m² wide, with more than 20 km of quay walls, piers and embankments and a 40 berths for vessels up to 80,000 tdw. There are also two sea-locks, movable bridges and some gates in the sea-dike. The port of Emden is worldwide well known as the distribution-hub for cars, manufactured by the German Volkswagen Company. In the year 2006, the annual port throughput will reach one million cars. Other important goods handled in the port of Emden are forest products (one million tons), liquefied marble (one million tons), some hundred thousands tons of magnesium sole and liquefied fertilizer and more than 200,000 m³ of preassembled elements for wind energy farms, like towers, wings and generators.

In the year 1998 it was decided to built a new pier at the embankment of the river Ems to create new facilities for the turnover of vehicles, because the existing berths were no longer able to handle the increasing rate of imported and exported cars. This should be the second berth directly at the river.

The Ems fairway, its maintenance and dredging belongs to the German Waterway Authority. Due to a new berth on the banks of the river it was expected, that there would be an important influence to the behaviour of the tidal current, the water level and the siltation in the river. So the waterway authority has demanded of the Emden Port
Authority (EPA) to built a hydro morphological model of the Ems-Estuary and to make tests with different layout proposals of a new berth.

This paper will deal with:

- Port planning and construction
  - the future port development at the Ems embankment
  - the first discussion of the berth-layout,
  - the construction of the pier (open pier, sheet-pile pier or combined solution)
- Demands to port planning (approval procedure)
- Model tests in the hydro-morphological model
  - model borders
  - data input of the existing situation (bottom, tidal current and volume)
  - description of the model tests and the results
- Demands to the execution works
- Pile driving and dredging in the years 2002 to 2005
- Monitoring before, during and after the execution of the dredging works
- Comparison of the monitoring results with the forecast of the model test

The result of the monitoring was, that the basis-data of the model-tests were nearly the same, like the reality will show it after building the Ems-Pier. Model-tests, if they will be carried out by high accuracy and a good data-input are able to give a real introduction of behaviour changing in a tidal river due to any kind of river training and port building.

## 1 Introduction

The port of Emden is situated in the southern German Bight nearby the Dutch border in the Ems-Dollart-estuary (Figure 1 a-b).
The landscape is characterized by the wadden-sea and low flatlands, partially under the mean sea-level. Its name is East Frisia with several small fishery harbours and the main port of Emden. The port area is more than 20,000,000 m² wide, with more than 20 km of quay walls, piers and embankments and nearly 40 berths for vessels up to 80,000 tdw. There are also two sea-locks, movable bridges and some gates in the sea-dyke (Figure 2). The port of Emden is known worldwide as the distribution hub for cars, manufactured by the German Volkswagen Company. In the year 2006, the annual port throughput will reach one million cars.

Other important goods being handled in the port of Emden are forest products (1 million tons), liquefied marble (1 million tons), some hundred thousands tons of sole and fertilizer and more than 200,000 m³ of wind energy parts, like towers, propellers and generators (see figure 3). The Thyssen shipyard is another important customer of Emden Port.
The history of Emden Port is more than 1,000 years old. In former times the port was situated at the outer bend of the river Ems, where strong currents were able to keep free the port from sedimentation. Several very high and destructive storm surges had built in the ages between the 12th and 16th century the Dollart estuary and the Ems-River got a new bed far off the old port layout. The people had tried to bring back the Ems-River to the former port, but this so called landmark Nesserlander Höft has had only an existence of less than 100 years. In the early ages of the 19th century the port authority has decided to built a new canal between the new settled Ems-River, nearly 3 km away from the old port. This new canal was closed by a lock against the tidal conditions of the Ems (Figure 4a-e). Besides the new canal, called the new Emden Fairway, several port infra- and superstructure elements were installed, the layout of Emden port has gotten his today’s architecture.

The early 20th century needed a lot of coal and ore in the heart of Europe. The steel production was on an increasing trend. The import of ore was of high importance. By a decision of the German emperor Wilhelm Emden was made as the main port for the Ruhr District, where the most important German and European steel manufacturers has had their factories.

In the late 70th of the last century the port of Emden has had an annual ports turnover of more than 16 mill. tons, but the increasing growth of the international bulk carrier fleet had given to Emden Port the signal, to deepen the Ems-River or to loose its importance as an ore-hub port to Rotterdam and Antwerp. But only deepening the Ems-River hasn’t had any economical value against the benefit to take on the very cheap load of ore. The so called Dollart-Dock Project was created.
The Ems-River should be bypassed through the Dollart estuary to minimize dredging cost and a huge new port area should be able for the settlement of several industrial factories. But the project-costs increased while the interest of companies to settle in Emden where decreasing. In 1989 the Dollart-Dock-Project was finally cancelled. That was the beginning of a process to restructure the port of Emden from an ore and coal port to a modern multi purpose industrial harbour.

At this time in the early 90th the Ems-River has had a depth of 8,50 m at low tide. To developing the port for those vessels, being able to reach it under the given circumstances was the huge task to the port planning division.

2 The International Car Producers Need the Hub Port Emden

In the early 1960th the German Government has decided together with the Volkswagen Company to built assembling facilities in the neighbourhood of a harbour, to increase German export of Volkswagen-Cars especially into the USA. Emden was the winner in this comparision. Always in the early 70th Emden Port has had an export rate for cars of more than 500.000 pieces/p.a.

The up and down of car business has brought in the late 90th the decision of the Volkswagen trust (incl. AUDI, SEAT and Skoda) to develop the port of Emden as the Volkswagen hub port worldwide. The import and export of Volkswagen cars should be done via the quay walls of Emden Port. But therefore the existing port facilities would not be able to handle the forecasted number of 1,0 mill. cars/p.a. and more. Via the former fully developed system in the port not more than 250.000 cars/a to western Europe via Terminal I (2 berths) in the Inner Port and another 500.000 cars/p.a. via the three berths at the Outer port to overseas can be handled (Figure 6).

Therefore in the year 1998 it was decided to built a new pier at the embankment of the river Ems to create new facilities for the turnover of vehicles. This should be the second berth directly at the river. But the Ems fairway, its maintenance and dredging belongs to the German waterway authority (WSD). Due to a new berth at the banks of the river it was suspected, that there would be an important influence to the behaviour of the tidal current, the water level and the siltation in the river. So the waterway authority demanded of the Emden Port Authority (EPA) to built a morpho-dynamical model of the Ems and to make model-tests with different solutions of a new berth.
3 Planning of the New Ems-Pier

3-1 Port Planning

There was the demand to take-on car-carrier up to a length of 220 m, a beam of 32 m and a draught of 8,50 m at a new berth. This vessels are able to transport up to 8,000 car-units (a car unit equals 6,34 m²). The pier-level should be 2.50 m over the mean high water level (MHW). Because there is the possibility to arrive at Emden Port over high tide with a draught of nearly 11 m the nautical depth of the new berth was fixed on 14,50 m under MHW and so the retaining height of the pier would be 17,00 m.

The length of the pier deck was asked to be 250 m, but on both ends a 50 m long berthing walkway including several bollards and quick release hooks should being situated. At the seaside end of the new berth should be some infrastructure like a movable bridge and some dolphins to allow smaller car carrier to take over cars and Ro-Ro trailer via any kind of stern ramp.

3-2 Future Port Development on the Ems – River Embankment

With a view in the future it was found a place for the new berth in a distance from 500 m western the existing Ems-Quay. So it will be possible to enlarge the Ems-Quay by 250 m and to enlarge the new Ems-Pier also by 250 m, but in eastern direction. The total length of the Ems-River embankment quays than could be 1,200 m with 5 berths for ocean-going vessels up to 220 m length (figure 7).
3-3 The construction of the Ems-Pier

To built a quay wall with a retaining height of 17,00 m (plus 2 m safety distance against scour and dredging tolerance) needs either a very strong and heavy steel sheet pile solution or an open pile construction with a high pier deck. A combination of both is possible. Finding the right solution is a matter of economy at one side but also a question of hydrology and morphology. Model tests would be necessary to give an answer to the second question.

At first was found out, that the pure steel sheet pile construction doesn’t give a practical adequate construction, because waves would be reflected and the water would swamp over the pier deck. An open construction would avoid this and so two different pier layouts were detailed:

- Pier platform with a concrete deck, 30 m wide, with 7 rows of piles and a small steel sheet pile wall in the landside 7th row. An open non armoured embankment was under the pier platform. (Figure 8 a).

Fig. 7 Planned berth development along the Ems-River

Fig. 8 a) Pier platform, 30 m wide

b) platform with 2 sheet piles and embankment
Pier platform like above, but with two rows of sheet piles and an embankment under the pier (This alternative was investigated in the model, but has later been cancelled (Figure 8 b).

Finally a pier platform with a concrete deck, 15 m wide, with 3 rows of piles was realized. Heavy steel sheet pile wall in the middle row. Open space without embankment waterside of the sheet pile wall. (Figure 8 c).

By means of this two quay section solutions the model tests had been started.

4 Model Tests in the Morpho-dynamical Model

4-1 General

In Germany and in the European Union the planning of a new harbour or only a quay wall in an existing harbour requires a very intensive approval procedure. To shorten this procedure the EPA had instructed the waterway authority in advance about the planning of the Ems-Pier. The demand of model tests was the result (see below). Because the hydraulic laboratories of the waterway authority should be their adviser, it needed a scientific institute to make this model tests.

The Institute for Hydraulics of the Technical University of Darmstadt has well known in practise and experience of morpho-dynamical computer models and it also has the knowledge about the tidal conditions in the Ems Dollart Estuary. Prof. Zanke from Darmstadt was asked to give an expertise about the changing of the river behaviour in the neighbourhood due to the planned Ems-Pier.
4-2 The Task to the Experts

The layout showed that new quay-line of the Ems-pier will be nearly 100 m seaside away today’s high water-line. This would reduce the cross section of the Ems-River of about 300 m² at one side and it will widen the cross section of about 200 m² on the other side, while the river would be deepened.

Three main questions were discussed:

- What is the changing of the current situation due to Ems-pier in the near Ems-River?
- Which extension would have this changing’s?
- What is the influence of the Ems-pier to the sediment-behaviour in the Ems-Fairway?

A satisfactory answer to this questions could be given by the following means:

- The morphological changing’s need a morpho-dynamical model with a separate calculation of the sediment load near the river-bed and suspension load in the water body.
- The sediment load must be partitioned in several fractions
- The subsoil below the river-bed needs some different layers

This procedure was recommended by the scientists and discussed and approved by the port authority and the waterway authority.

4-3 Data Model and Model Borders

Prof Zanke of Darmstadt University has recommended using an explicit FEM-system for the calculation of currents in the Ems-River and the Dollart-estuary. To avoid 2-delta-x-waves, the so called bubble-function should be used for a harmonic solution.

For the following morpho-dynamical survey was used the well-known model system TIMOR3. This model is able to simulate as well the sediment as the suspension transport. TIMOR3 is based on a two dimensional FEM model for currents. Because there is the possibility to built several layers of soil the sediment transport can be given back in the three-dimensional space. The system can verify as well soft clay as sand or gravel. Non erosional structures like groins or jetties can be considered.

For modelling the Ems-Dollart-estuary a collective of data, taken by the German waterways authority due to surveying the fairway water depth was used. It was decided to set widening of the estuary to the open sea as seaside border and the entrance of the Ems-River into the Dollart-bay as inland border (Figure 9 a-b).
4-4 Data Input of Today’s Situation (River Bed, Tidal Current and Flow, Tidal Volume)

The digital topographical model was constructed out of 19,000 knots and 36,000 triangles. The planned Ems-Pier with its new geometry and the new riverbed level was brought into this model after verifying model data with the data measured in the nature (Figure 10 a-b).

In a second step it was necessary to verify also the morphological situation. Because there was not enough information about the sediment composition all over the estuary, a synthetic sediment composition was calculated. The climate of the currents will mix this composition and a characteristic sediment distribution will be found.

Fig. 9 a) Morphological situation in the borders Ems-Dollart estuary  b) FEM grid with model

Fig. 10 a) Morphology nearby the Ems-Pier;  b) Plannend morphology with Ems-Pier
4-5 Description of the model tests and the results

At first the existing current situation without the Ems-Pier was tested. Where the Pier should be built a maximum current of 0,8 m/sec for the ebb-tide and also for the flood-tide was found out. Now it was possible to render the two geometries of the Ems-Pier into the model. Because the Ems-Pier should be built as an open system with several piles it needs to give each pile a separate resistance for the calculation. This was very difficult and therefore another friction at the river bed was brought into the model as a substitute.

The current velocity nearby the new pier would be 0,4 to 0,6 m/sec lower than today. But this changing was found out only at the maximum, compared with the existing situation. To give a practical result, the difference of the absolute currents at each point with or without Ems-Pier was calculated as shown in Figure 11.

Building an Ems-Pier will have an influence to the current:

- The new pier demands widening the river for the vessels and therefore the resistance of the current will be lower
- But the resistance of the piles below the pier will bring locally more resistance against the current
- Both effects will influence each other

The effects differ only at some points in the whole planning area, mainly directly nearby the pier. There was no essential difference between the two proposals.

With this knowledge it was possible to give a one-year forecast for sedimentation. May be deepening activities in front off the pier will result in a sedimentation between 50 and 75 cm each year. Figure 12 gives an idea of the behaviour at the river bed.

![Fig. 11 a) Changing of currents at ebb-tide; b) Changing of currents at flood-tide](Image)

(blue colour = increasing, red colour = decreasing)
5 The Formal Approval Procedure for the Ems-Pier

The results of the numerical tests were rendered into the Ems-Pier design and the above shown section (fig.8c) was chosen for the approval procedure. Some additional tests were made by the hydraulic laboratory. But the result didn’t differ from what was found of the originally model - tests.

5-1 Demands of the Waterway Authority to the Dredging Execution Works

5-1-1 Monitoring Program

It was calculated that the cross-section of the river-bed due to the new Ems-Pier will be lessen it by 250 m² at one side and will be widened by less than 400 m² on the other side. To widen it means about 300,000 m³ sand, silt and clay needs totally to be dredged. It was foreseen to do this work by a section cutter dredger (see fig.13)

Due to the clay in the upper layers and a maximum flood and ebb current with more than 1,5 m/sec the waterways authority was concerned, that too much particles would be driven off into the Ems fairway for sedimentation there. Therefore they have demanded for a monitoring program during the execution of the dredging works. The port authority has excepted this demand and has given an order to the Hydraulic Institute of the University of Applied Science Bremen, Professor Horst Nasner.
5-1-2 Requirements to the dredging works

To minimise the effect, that fine dredged material will go into suspension due to cutter heads activities and will sunk than as sediment in the fairway it was forbidden to use hopper dredgers with an overflow-system. Only the directly way from a section cutter dredger into the floating transport tube and than into the nearby disposal area was accepted.

5-2 Ems-Pier and dredging works as an impact to the environment

Due to the Ems-Pier an area of 250 ha waddenzee banks and low river bed will be impacted by dredging works (deepen the river) or by the pier construction (high up the river bed). A lot of different species will be disturbed, expelled or killed. Therefore it needs to find a substitute. But the impact was not all over the construction and dredging works. Only at low tide the banks are used especially by the birds and not all times it will be worked. So a very difficult calculation came to the result, that the time impact component would reduce the area of disturbance down to 15 ha. Because it was not possible to create a new river bed, a nearby located today intensive used farm land was chosen to develop it as wetland with ponds and marshy zones. To substitute 15 ha river bed, it needs a factor of 1,8 to found the total area of the substitute.
6 Execution of the Ems-Pier

6-1 Sheet Pile Wall Installation, Pile Driving and Concrete Deck

Step one in execution was to drive into the sea-bottom the steel sheet-pile of 350 m. Behind the wall nearly 100,000 m³ soft clay was dredged and pumped into a nearby disposal area. The anchor-piles were driven down and the space between dyke and sheet-pile wall was reclaimed with sand. The second and the third row of piles could be driven down. The concrete deck was built and the foreseen reclaiming level was filled up with sand. The surface of the new pier was covered with an asphalt layer. See in figure 14 some introduction from pile driving and concrete works.

6-2 Dredging Works

6-2-1 Soil Replacement and Reclamation Works

Very soft clay layers need to be substituted by sand behind the sheet pile wall to reduce the settlement but also to increase the resistance into the subsoil against internal friction. Therefore some 100,000 m³ was excavated by a section cutter dredger. Than the sand was filled in by pumping from a hopper dredger. The sand was found 15 km away in the Ems-River mouth. See figure 15 for excavation and reclaiming works.

6-2-2 Dredging in Front of the Pier and Deepen the Ems-River

The main dredging works have started in springtime 2004. Between June and the end of July nearly 140,000 m³ mainly pure soft clay and another 140,000 m³ clay with a little bit sand was dredged by a cutter section dredger. The material was
brought by hydraulic transport into a disposal area 3 km nearby. See figure 16a and 17 for dredging works.

Some difficulties was given by an old groin, which was used in the past as a pier for reclaiming the so called Larrelter Polder, a former wadden area and today part of the harbour and the city of Emden. See in Figure 2b the Larrelter Polder and in the back the Wybelsumer Polder (former waddenzee areas reclaimed between 1920 and 1960). To excavate this part it needs a strong grab dredger, because old wooden piles, masonry and stones was found (figure 16b).

Fig. 15 a) Geotextile big bags; b) Placement of geotextile sandbags

Fig. 16a) cutter section dredger b): Result of grab dredging

Fig. 17 Nearly finished Ems-Pier with cutter section dredger
7 Monitoring during the Dredging Works

7-1 The Demand for Monitoring of the Dredging Works

As introduced in chapter 5 it needs a monitoring during the phases of dredging. The colleagues of the University of applied science in Bremen their monitoring program already in April 2004. To get a correct comparison between today’s situation, that means after building the pier but before dredging, they have made some measurements to find out the velocity of the currents and especially the gradient of suspension at the different situations during one tide.

Fig. 18 Selected sections for surveying program

Fig. 19 current velocity at different section in the survey area
In the next step were compared the now founded results with former results of tidal components. This were mainly:

- Currents and their directions (see figure 18 and 19)
- Tidal volume and normal river volume
- Salinity and suspension
- Level of the river bed

This program was matched and approved by the German Waterway Authority.

**7-2 Result of the monitoring program**

The main question was to find out, if there will be no critical changing between the normal suspension freight in the river and the suspension freight during the execution of dredging works. No higher suspension was the result, but it was also found out, that the suspension in the river was lower like normal because the volume of the river Ems from upstream was very low at that time (see figure 20).

- No critical suspension due to the dredging works in the Ems-River!

The second question was to find out, if the velocity of the tidal current will change dramatically to the former situation and especially sedimentation will increase in the fairway of the Ems. Also this measurements has confirmed the results of the model tests done by the Institute of Hydraulics of the University of Darmstadt.

- Widen the Ems-River and diminish it by a quay construction, so that the difference goes to cero don’t change the medial situation in the neighbourhood of the Ems-Pier.
  - The new situation gives only a change, where dredging execution was done
  - The current velocities in the Ems-River fairway hasn’t changed only by cero
  - No increasing of maintenance dredging costs in the fairway will be reported

**7-3 Today’s Situation**

Today, two years after realizing the Ems-Pier can be reported:

- Several new port activities had started in import and export of vehicles
- Only a few month after opening the new Ems-Pier it needs to deepen the berth to the design depth of SKN -9.50 m. (executed was a depth of -8.50 m)
- The second step of Ems-Pier planning, realizing a ro-ro-berth is in execution

And the most important result is, that there now additional dredging work is necessary to keep clean the deeper berth at the Ems-Pier.
Fig. 20 River bed before and after dredging (a, b); difference in m at each point (c)
8 Conclusion

The increasing number of vehicles, turn over in Emden-Port via several berths has asked in 1999 to build a new pier at the banks of the Ems-River. A new pier with a total length of 350 m with the possibility to lengthen it to 550 m was planned. A very sophisticated planning procedure follows this demand. It was allowed to build the pier, but several data needs to be approved.

The most important demand was to forecast the sedimentation and erosion rate in the Ems-River estuary. At one side the University of Darmstadt (Institute for Hydraulics) and at the other side the University of Applied Science in Bremen was asked for model tests and for monitoring. The forecast given by TIMOR3 means a forecast of confidence, because each one in the planning process has had enough information for his questions and his detailed situation.

Each one has given its best, but it needs to accept a lot of several marginal conditions. In this special case we have found out that to build the Ems-Pier will be less expansive than to loose some hundred thousands cars to ports of Bremerhaven or Zeebrugge. In each case it needs to calculate profit and costs and the most profitable harbour will be the winner for the next year.

But the success of a ports in turnover or ports throughput is very often the result of a world wide connection of a few shipping companies. The port authorities must follow the development of the vessels and the demands of the shipping companies, if they will withstand the very hard competition against the other ports.

9 References


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