APPLICATION OF SHORE PROTECTION SCHEMES IN HORNBÆK

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ABSTRACT

Hornbæk Harbour was built more than a hundred years ago on a sandy coast with predominant eastward longshore sediment transport. After construction of the harbour the littoral transport was disrupted leading to a large accretion of sand upstream of the harbour whereas lee-side erosion occurred downstream of the harbour. Soon problems were experienced due to sedimentation in the harbour entrance and in the beginning of the century a breakwater was constructed for blocking the sand transport. This breakwater was later extended and finally a lee-side breakwater was constructed.

Hornbæk harbour represents a classical case of the problems encountered when constructing a harbour on a coast with littoral drift. Only in recent years focus has been put on environmental issues and the present project shows a good example of remedial measures by involving a number of shore protection schemes.

The applied shore protection schemes consist of beach nourishment, beach de-watering and maintenance of shingle beaches along with extension and repair of existing slope protection. On completion of the project a monitoring programme has been started in order to track the development of the coastline in response to the beach nourishment scheme.

1. HORNBÆK HARBOUR - HISTORICAL ASPECTS

Hornbæk is situated in Denmark in the northern part of Zealand as seen in Figure 1. The harbour is largely sheltered from waves from all directions except from the northwest.

Hornbæk harbour represents the classical case of harbour construction on a uniform coast with pronounced longshore sediment transport. Before construction of any transverse structures the coastline was near-stable even though there is a significant eastward longshore transport of sediment.

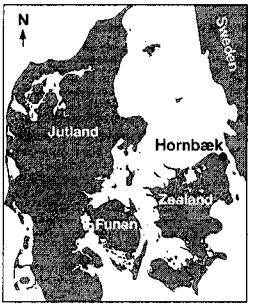

Figure 1 - Denmark.

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Subsequent construction of the harbour has had the effect of blocking this longshore transport resulting in accretion upstream of the harbour (west) and lee-side erosion downstream of the harbour (east).

The harbour originated as a shore-connected single breakwater creating a sheltered area for mooring fishing vessels.

As shown in Figure 2 the breakwater west of the original basin has been extended gradually from 1878 to 1924 in response to continuous upstream accretion and sedimentation in the protected area east of the breakwater.

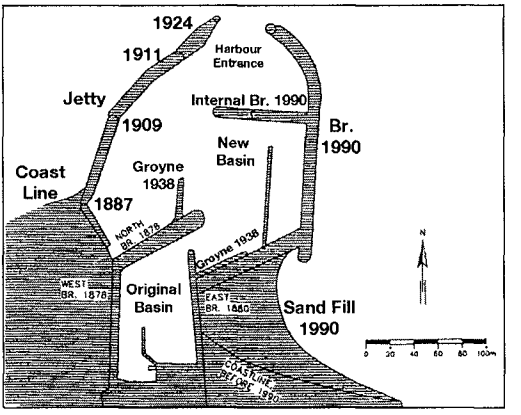

Figure 2 - Development of Hornbæk Harbour 1878-1990.

Due to the continuous sedimentation and increased cost of dredging, a new secondary breakwater was constructed in 1990. Sand dredged from the harbour basin was placed as sand fill east of the harbour forming a small beach area. The construction of the eastem breakwater reduced the sedimentation in the fore harbour from several thousand cubic metres to a few thousand cubic metres a year. In recent years the western breakwater has been renovated, which also involved a more smooth plan shape mirroring the eastern breakwater and this has even further reduced sedimentation of the fore harbour. There is, however, still a requirement for annual maintenance dredging of the access channel.

The continuous extension of the breakwater has had a dramatic effect on the town of Hornbæk. Due to the pronounced accumulation of sand upstream of the harbour the main activities of the town has moved from fishing operations towards recreation and tourism. The beach west of the harbour is today one of the most popular beaches on Zealand and through the fifties and sixties the town hosted a reputed health resort which emerged into a beach hotel and has in later years become a hospital.

2. COASTAL PROCESSES

The construction of the harbour has significantly influenced the morphology in the area. The coastline west of the harbour has accreted continuously necessitating the extension of the western breakwater. The retreat of the coastline east of the harbour has occurred more slowly due to self-armouring of the seabed with gravel and stones originating from erosion in moraine tills. This implies that the erosion in the considered area is mainly caused by storms in conjunction with high water.

The development of lee-side erosion east of the harbour and accretion west of the harbour is seen in Figure 3. From 1880 to 1997 the lee-side erosion has been of the order-of-magnitude of 50 m whereas the advance of the coastline to the west has been in the order of 100 m.

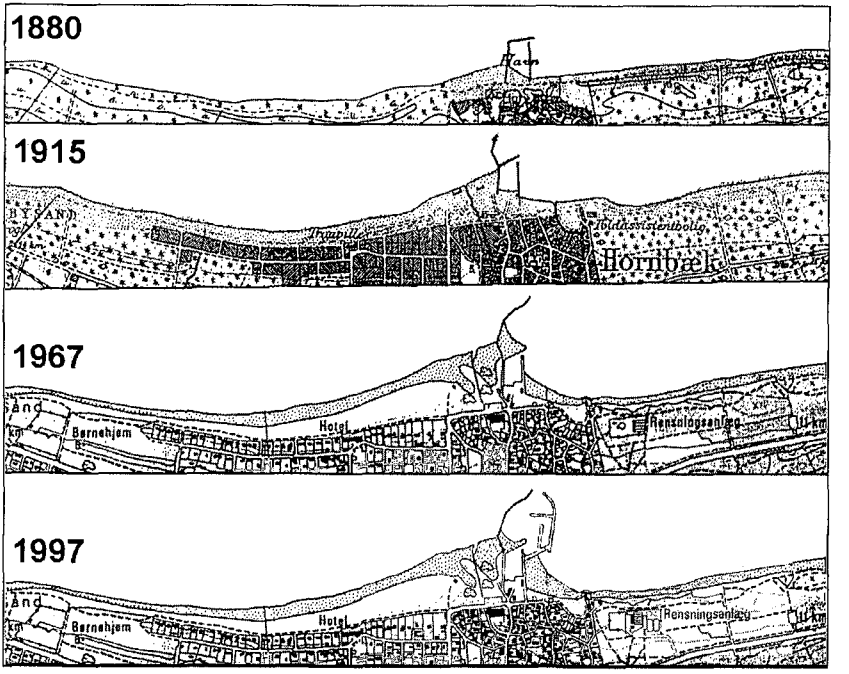

Figure 3 - Development of the coastline adjacent to Hornbæk Harbour, 1880-1997.

Throughout the years approximately 7,000 m^3 of sand has been mined from the accretion area each year in order to minimise sedimentation problems in the harbour entrance. The sand was used by local contractors and has thus been missing in the sediment budget east of the harbour.

Before the construction of the eastern breakwater the yearly maintenance dredging was approximately 15,000 m^3, most of which was dumped in deep waters. After construction of the eastern breakwater, approximately 4,000 m^3 of sand has been dredged yearly in the harbour entrance and in the access channel and deposited in the shallow water area east of the harbour.

The coastal areas adjacent to Hornbæk Harbour are dominated by waves coming from the northwest originating from the large fetch areas in Kattegat. Waves coming from west and from the direction range north to east are limited due to sheltering effects from Zealand and Sweden (Figure 1).

Based on a study of the wave climate and storm surges a numerical study of the littoral drift budget was carried out using the LITPACK modelling system. Findings from this study was used for assessing the amount of sand needed for beach nourishment east of the harbour. Figure 4 shows a detail of the sediment budget for the harbour area in 1995. The cumulated transports show a net accumulation of sediment in the region just east of the harbour of around 2,000 m^3/yr.

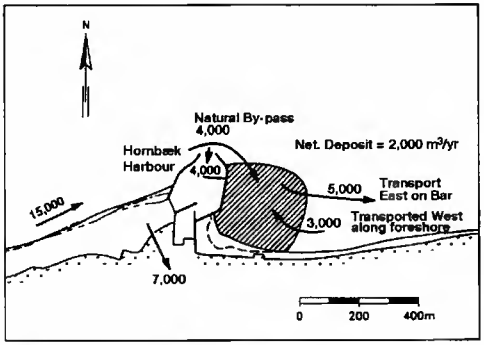

Figure 4 - Sediment at Hornbæk Harbour, before nourishment and artificial bypassing.

Sediment trapped in the harbour mouth (4,000 m^3/yr) is dumped near-shore along the beach east of the harbour resulting in a total transport of 6,000 m^3/yr further east along the coast.

The sediment is clearly deposited in the formation of a large shoal (Figure 5) which is expected to connect with the beach area further east of the harbour closing off a shallow water area. At this point in time there will probably be a decision about whether to fill in the shallow water area creating a wide beach or about relocating the sediment in the shoal to the coastline proper.

Figure 5 - Aerial view of Hornbæk Harbour.

3. SURVEYS AND DETAILED DESIGN

Consulting services covered the following main topics:

- Assessment and modelling of the coastal processes
- Preparation of alternative schemes for shore protection
- Surveys
- Detailed design and preparation of tender documents
- Construction supervision
- Monitoring of the beach development

A series of surveys was made including bathymetric and topographic measurements and borings at sea for determining the soil conditions. A detailed design was produced for the selected protection schemes and was followed by preparation of tender documents divided into beach nourishment and slope protection, respectively. The design detailed:

- Beach Nourishment, 7-14.000 m^3/yr for five years in succession.
- Maintenance of shingle beaches
- Repair of existing slope protection
- Extension of the slope protection at the most exposed location (100 m berm and an additional 10 m protection of the slope)

Upon receipt of the tenders for the beach nourishment, it was decided to have the sand by-passed by dredging and pumping instead of using trucks as the pumping solution was preferable from an environmental point of view.

4. SHORE PROTECTION SCHEMES

The present project is part of a larger plan for the area financed by the County of Frederiksborg (lead partner) together with the Municipality of Helsingør and the State Forest District of Kronborg. Other parts include the following:

- About 1.5 km west of the harbour another project including the beach face dewatering concept has been completed. The purpose is to stabilise and widen the beach in this area which is considered one of the best bathing resorts in the northern part of Zealand.
- The outer breakwaters of the harbour have been modified within the last 10 years with the purpose: to increase the capacity of the harbour, to minimise the sedimentation and to increase the natural bypass of sand.

The final project focused on rehabilitation of a 2.5 km stretch of coastline east of the harbour where protection was needed against further erosion. The project included general repair of existing slope protection and extension of the slope protection in the form of a berm at the most exposed location. Furthermore the shingle beaches were replenished in order to slow down erosion and finally, beach nourishment was carried out along 300 m of the coastline just east of the harbour. The beach nourishment was

carried out through bypassing of sand from the accretion area west of the harbour, which has also reduced sedimentation in the harbour entrance. Figure 6 shows the repair works and extension of the existing slope protection. A 100 m long berm is placed along the toe of the slope protection. In front of the berm a 1 m thick layer of shingle is placed acting as a kind of nourishment.

Figure 6 - Placing of geotextile and armour.

Figure 7 shows the berm shortly after completion. The waves have washed some of the shingle ashore which conceals the larger part of the berm structure and allows for safe passage along the beach.

Figure 7 - Berm Structure on completion

Beach nourishment was carried out east of the harbour in order to improve the quality of the beach in this partly self-armoured area. A total of about 12,000 m^3 of sand was bypassed by dredging in the accretion area west of the harbour and pumping in a pipeline to the nourishment zone east of the harbour. This was performed in April 1997 and April 1998. It is planned to repeat the beach nourishment each year for the next three years and probably more years after. Figure 8 shows the nourishment zone just after nourishment has taken place. The size of the nourishment area is approximately 300 m by 40 m.

Figure 8 - Aerial View of Beach Nourishment upon Completion of Works

Figure 9 shows the estimated sediment budget for the harbour area while nourishment is taking place (compare with Figure 4). For the given example 12,000 m^3/yr of sediment is mined west of the harbour and used as nourishment east of the harbour. The western breakwater has been rounded and sedimentation in the access channel has decreased to 2,000 m^3/yr. The corresponding maintenance dredging of 2000 m^3/yr is dumped nearshore east of the harbour.

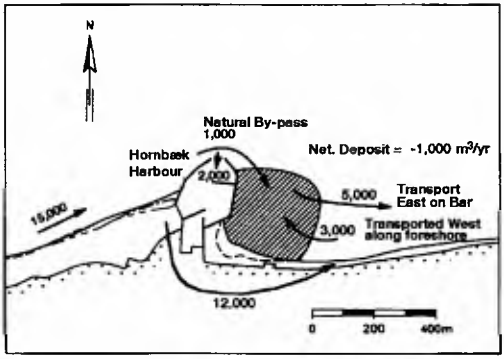

Figure 9 Sediment budget including artificial nourishment

The littoral transport west of the harbour remains the same, resulting in a natural bypass of 1,000 m^3/yr to the shoal. The shoal is also receiving 3,000 m^3/yr from the east coast and looses 5,000 m^3/yr towards east, resulting in an annual loss of sand from the shoal of 1,000 m^3/yr. The shore east of the harbour now receives 2,000 m^3/yr from the shoal and 14,000 by artificial nourishment resulting in a supply to the downdrift shore of 16,000 m^3/yr.

In total the beach nourishment scheme has the effect of maintaining the stable beach west of the harbour, reducing sedimentation in the access channel, improved beach quality east of the harbour (compared to sedimentation on the shoal) and increased littoral transport further east along the coast for the benefit of the downdrift shore.

5. MONITORING

The beach east of the harbour was surveyed prior to initiation of the beach nourishment and again after finalization. Monitoring will take place twice a year throughout the next four years in order to assess erosion and changes in beach profiles. Thereby the quantity of future requirements for beach nourishment will be assessed.

At this point in time measurements of the location of the shoreline and bathymetric surveys of the nourishment zone have been conducted in March 1997, November 1997 and March 1998. The bathymetric surveys of the nourishment zone show relocation of submerged shoals and other sand formations as well as the presence of dunes on the shore. Apart from this the preliminary monitoring results show the coastline being practically stable during the last year. This is mainly because the surveys of March 1997 and March 1998 were conducted just prior to nourishing. The survey from October 1997 shows no evidence of the nourished sand, which indicates that the majority of the material has been transported eastward along the beach as planned. This is in agreement with the philosophy of the nourishment project, which is a gradual rehabilitation of the beach east of the harbour by nourishing locally along a 300 m long section in close vicinity of the harbour. Surveys conducted in coming years are expected to reveal trends in the interaction between the native and the nourished material as well as the effectiveness of the nourishment programme.

6. CONCLUSIONS

Accretion has been taking place west of Hornbæk Harbour over decades, however, the accretion area has stabilised many years ago. The extension of the western breakwater has caused a large offset of the littoral transport in comparison with the original coastline. Historically, most of the normally bypassed sand was trapped in lee of the single western breakwater from where is was dredged and dumped in deep waters, which means that it was lost for the downdrift coastline.

Since 1990 where the eastern breakwater was constructed, sedimentation and maintenance dredging has decreased from 15,000 m^3 to 2,000 m^3 per year. The remaining bypassed sand has accumulated in the shallow area east of the harbour but separated from the coastline. The conclusion with respect to the impact of the harbour on the downdrift coast is that the harbour has caused lee-side erosion in the entire period of its existence.

The selected shore protection scheme for 2.5 km of coastline east of the harbour consisted of beach nourishment with 12,000 m^3 of sand mined west of the harbour and 2,000 m^3 dredged in the harbour entrance, maintenance work on shingle beaches along with extension and strengthening of exposed parts of the slope protection.

The new wide and sandy beach east of the harbour attracted many guests during the first summer but as expected a significant part of the sand was transported eastwards during the winter season. Additional beach nourishment will be carried out the next four years during spring time. Twice a year the development of the new beach will be monitored. The monitoring results will form the basis for assessing the amount of sand to be pumped from the accretion area to the new beach in the coming years.

This project is carried out respecting the natural processes of the sand transport along the coast and thus represents an example of the Consultant's planning with nature instead of against it, so-called shore protection in lieu of coastal protection.

7. ACKNOWLEDGEMENTS

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