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A HOLISTIC EVALUATION OF A TYPICAL COAST NOURISHMENT ON THE DANISH WEST COAST

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Abstract

The case described in this article regards 4.7 km of beach in Ferring, situated approx. 5 km south to the mouth of the Limfjord strait on the west coast of Denmark. In 2005, this section of the beach was nourished with 721,000 m^3 of material in order to protect backshore properties, natural heritages and the recreational value of the beach. After the nourishment, the beach was monitored by levelling profiles on four dates to monitor and track the evolution of the nourished material. Furthermore, laboratory tests involving different gradations of nourishment material are shown which indicate solutions to different kinds of coastal protection strategies, estimate the time in between two nourishments and evaluate the cost of maintaining a beach with a high recreational value for the public.

1. Value of coastal zones in Denmark

Parts of the Danish West Coast are severely eroded and are at present undergoing coastal erosion. Starting in 1875 around 100 groins has been placed in order to protect the coast line (Kystdirektoratet 2005). This kind of system has not been working to well, so new ways of battling coastal recession, together with a change in the common perception of Nature, were invented and applied. This resulted in the realization of the first coast nourishment back in the early 1970'ies (Figure 1).

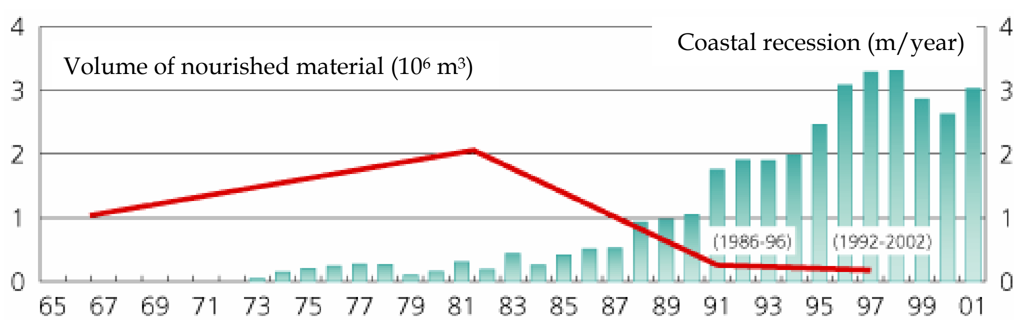

Figure 1. Effect of volume of coast nourishment (bars) applied on coastal erosion (red line) 1966-2001 (Danish Coastal Authority 2007).

The coastal landscape in Denmark is characterized by multiple areas of geologic, biologic and recreational interests both at a national and international level (e.g. RAMSAR and NATURA2000 habitats). Recognizing the value of a healthy natural environment, the aims for the future are to ensure the presence of naturally shaped beaches and at the same time to reduce the risk of erosion (Holmgren et al. 2006a).

For this reason coast nourishment is used widely along the Danish North Sea coast. This method, invented in the early 1970'ies, is preferred to solid constructions and nowadays resembles the primary method used by the Danish Coastal Authority for coastal protection. Furthermore, it serves a dual purpose as management tool (Holmgren et al. 2006a). Coast nourishment is protecting coastal lands as well as backshore properties (infrastructures, buildings etc.) and preserving natural heritages and the material used for coast nourishment is characterised by a medium grain size (d_{50}) and the gradation U (Pilarcyzck 2000). Nevertheless, more and more attention is also being paid to the recreational values of the beaches, i.e. tourism, so that an additional purpose of coast nourishment is to increase the recreational space along the shore, while protecting as well.

Danish people and tourists as well enjoy the beauty of the beaches in many ways: activities like bicycling, horse riding, car driving, fishing, sun tanning, swimming and aquatic sports are common and coexisting on the most beautiful Danish beaches. This is possible mainly because of the natural gentle slopes and wideness of the shore. Therefore, international and national tourism are giving value to the natural heritage of the coast. Nowadays families using the beaches prefer small grain sizes and gentle slopes.

Seen from a coastal protection point of view it is on the other hand wiser to use coarser materials, and place these materials as close to the dunes as possible. Such a procedure will ultimately lead to the generation of somewhat steep, unattractive and sometimes even dangerous local sandy cliffs, thus modifying the characteristics that are needed to maintain a high recreational value of the coastline.

This paper deals with the holistic problem of coastal protection seen in the light of mechanical stability of coast nourishment and cost effectiveness, and the interest of the public in a coast consisting of fine grained sand for recreational purposes.

2. Beach nourishment at Ferring

Estimating the benefits from the nourishment project requires an estimate of the current economic value attributable to the beach, as well as an estimate on how this value will change if the beach is not nourished. Such a kind of study can be done only by making assumptions.

In our case scenario, a coastal protection plan was strictly necessary and had been adopted due to the severe erosion conditions of the area: an initial nourishment of 721,000 m^3 along 4.7 km of beach was realized at a cost of approx. 2 million Euro in 2005. The nourishment is protecting a clear water basin, dunes, private properties and a high value recreational beach. Owing to the inherent characteristics of the applied material and the actual wave climate the nourishment developed into an unwanted cliff.

Figure 2 gives examples of the development of the coast nourishment at Ferring. The top photo shows a nice gentle slope beach with characteristics as wanted, while the 2 other photos show an example of the unwanted local cliffs and progressing degradation of the beach. The stick is indicating 1 m height, as much as the vertical extension of the specific slope.

The unwanted geomorphic feature in which the case study develops (Holmgren et al. 2006a), has major consequences on the leisure value of the location, considering the followings; the recreational value of coast nourishment is represented by:

1. the society's willingness to pay a visit to the beach,
2. the increased quality and quantity of beach activities,
3. the natural level of conservation.

These three points can be translated in a number of locally recognized characteristics that a good recreational beach should have in order to allow numerous beach activities:

1. wide extension
2. homogeneous sediment texture
3. fine sediment texture
4. gentle slope to the water

Figure 2. Beach development: gentle slope leading to the shore generates in a dangerous and ugly cliff.

2.1 Measurements of the profile of the beach.

The profile of the beach has been measured right after the nourishment and three other times during winter 2005 and the spring of 2006. Those where the 13/12/05, 01/02/06, 13/03/06 and 15/05/06.

The data presented in figure 3 show a considerable regression of the shore line and a reduction of the beach volume of approx. 40 m^3/m after the winter (Figure 3, top). In a condition where 32% of the initial nourishment is lost after a typical winter, its life time is expected to be only 3- 5 years. In fact, the beach becomes more and more narrow (Figure 3, middle) and after such a period, a new nourishment must be planned. The development of a cliff occurs immediately and the cliff then moves further inland with the protruding regression of the beach (Figure 3, bottom).

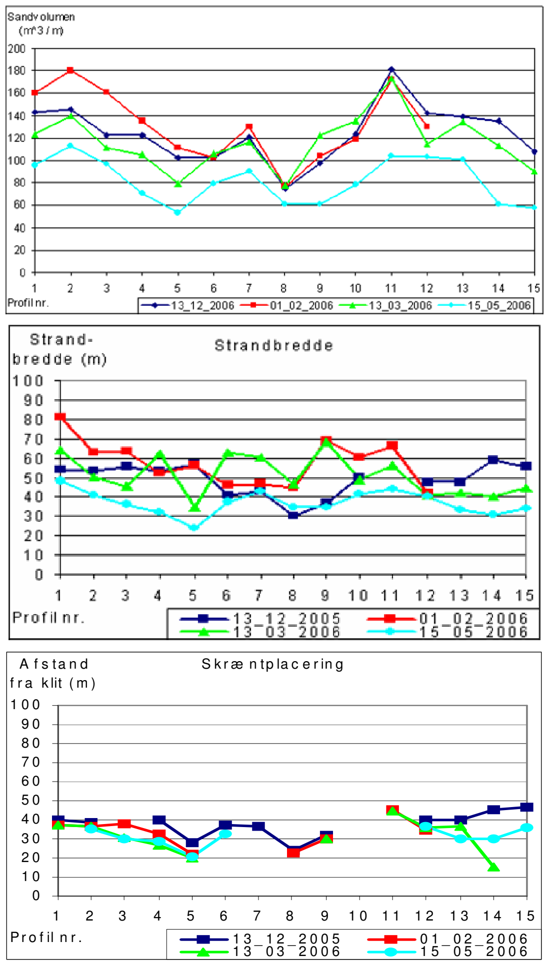

Figure 3. Behavior of the nourishment with regard to the eroded volume in m3/m (top), regression of the shore line (middle) and the movements of the cliff (bottom).

Additionally to the short lifespan of the protection and the fast decrease of the recreational value of the beach, the development of an unwanted cliff and slope is compromising even more the recreational value of the area. This phenomenon is of course related to the grain size utilized for the nourishment that is bigger than the original one in order to decrease the applied volume. The question arises how much more it would cost to protect the beach with a nourishment utilizing finer sand?

In the year of the nourishment (2005) the profile of the beach has been scanned and compared to the profile of the beach of 2004 and 2003 (Figure 4). It is obvious that the eroded volumes deposit just a few meters in the water, creating a very close to shore bank and probably moving the 1,300 m bank to 1,430 m. In this way the bathymetry of the littoral has been changed by the coastal nourishment

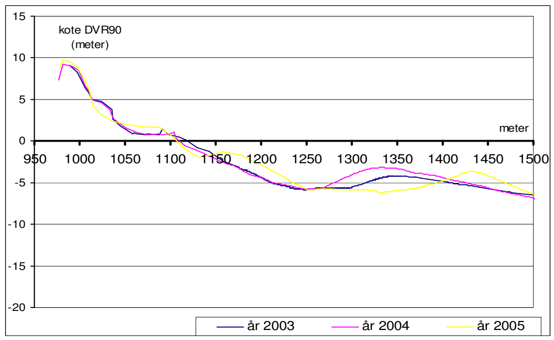

Figure 4. Scanned profiles of the beach at Ferring site (Holmgren et al. 2006b).

3. Laboratory tests

3.1 Setup

The tests have been realized in an 18 m long and 1 m deep flume equipped with wave generator (Figure 5). At and end of it the desired profile of the beach was reproduced using layers of different sands in order to Laboratory tests have been made in order to investigate the life time of nourishments exhibiting different gradation at Ferring. This was made by changing the medium grain size distribution (d_{50}) of the sand and the profiles volumes (i.e. initial beach slope). For different wave conditions corresponding to small waves, medium and storm waves, and the damage of the protection was been measured and monitored.

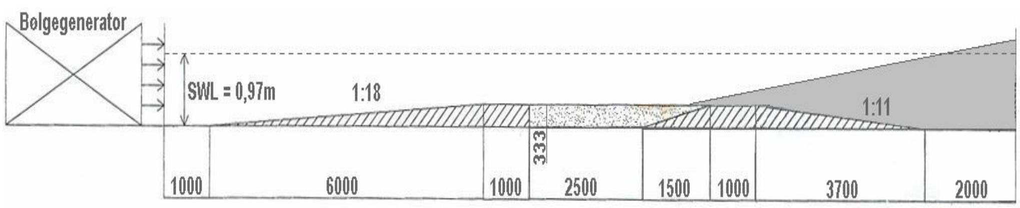

Figure 5. Flume equipped with wave generator (left) and beach settings (right) for the experiments (Holmgren et al. 2006a).

3.2 Tests

The tests have been run with small, medium and storm waves, corresponding to normal conditions, average storm and big storm conditions (Table 1). The purpose of the tests was to reproduce the behaviour of the protection and to test different gradations to improve the performance of the nourishment (Table 2).

Table 1. Characteristics of the generated waves.

Waves	Hs	Tp	Hs (model)	Tp (mode)
Small	1m	6 s	0,03 m	1,10 s
Medium	3 m	8 s	0,10 m	1,46 s
Storm	6 m	11 s	0,20 m	2,01 s

Table 2. Characteristics of the applied gradations.

Sand	d50	U
Fine	0,14 mm	2,72
Medium	0,48 mm	1,32
Coarse	0,66 mm	1,64
Mixed	0,48 mm	4,97

3.3 Measurements

Measurements have been done at the beginning and at the end of each test (Figure 6). A laser profiler mounted on rails on the flume enabled the estimation of the damage to the protection (Figure 7 left). The laser profiler can plot the results of the profile measurements in real time and constitutes a user friendly interface with the EPro software. In a second time it is possible to calculate the damage in terms of lost volumes to the protection (Figure 7 right). Waves have being measured by wave gauges and generated by AwaSys 5.

Figure 6. Profile of the beach before (left) and after (right) the test, (Holmgren et al. 2006a).

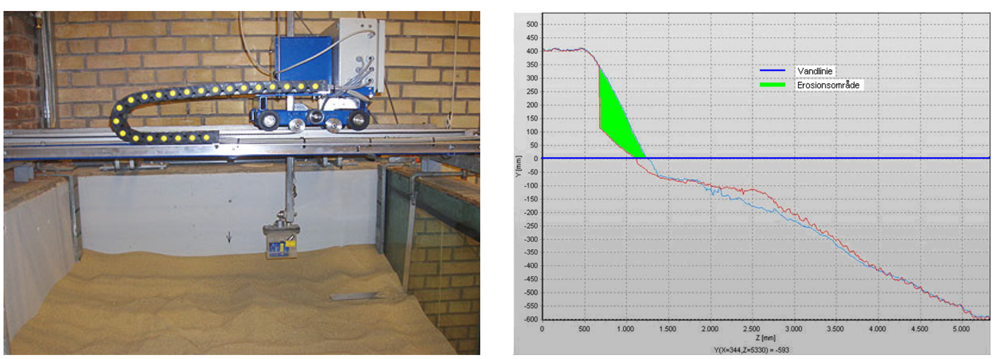

Figure 7. The laser profile and a measurement of the eroded area (section). (Holmgren et al. 2006a).

4. Results

General results have been found concordant to established knowledge: a large grain size leads to less erosion but to the development of larger cliffs; a nourishments which gets laid out in a more fan like manner (resulting in the creation of gentle shore angle) leads to the development of smaller cliffs. The results with mixed sand showed an increased erosion of 12%, while a small decrease of the cliff occurs (12%).

In figure 8 the erosion of the nourishment on the beach (left) and on the sandbanks (right) is reported. On the top, the eroded volumes under small, medium and storm wave regimes for the mixed sand nourishment (d_{50} = 0.48 mm and d_{50} = 1.32 mm in equal parts) appear to increase constantly on the beach. As it is obvious, the higher erosion occurs for storm waves. On the lower graphics, the height of the erosion is plotted against time. It seems as if the erosion of the sandbank reaches the equilibrium before the erosion on the beach.

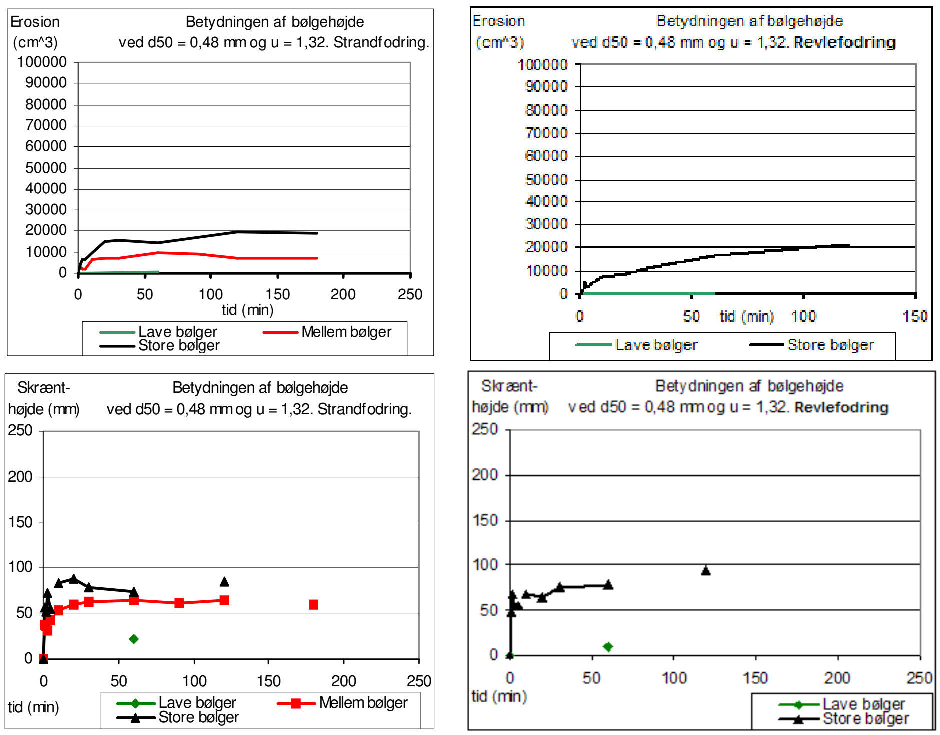

Figure 8. Laboratory results of erosion in volumes (top) and height (down) for the beach (left) and for the sandbanks (right) for a mix sand.

By comparing the results of the laboratory experiments with field measurements realized during the period between December 2005 and May 2006, a rough quantification of scale effects is made possible. In particular it is noticed that the height of the cliff that occurs in reality in average amounts to 2/3 of the one emerging under laboratory experiment conditions.

The information on scale effects has been used for calculating a more reliable cost of performing a nourishment that minimizes the risk of occurrence of the cliff and exhibits a gentle slope to the waterline. This kind of nourishment implies that big volumes of sand distributed both on the beach and stretching down into the water (Hallermeier 1978; Birkmeier 1985; Dean 1991) have to be utilized.

In figure 9 the cost per meter per year of different nourishments is plotted; the upper curve represents the cost of nourishment works derived from laboratory measurements of eroded volumes of sand, while the lower one is the estimation that takes into account a correction for scale effects on experimental measured eroded volumes.

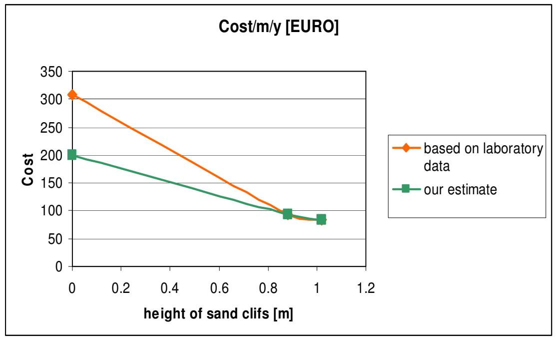

Figure 9. Cost per meter per year for a more efficient nourishment taking into account scale effects.

It appears that in order to avoid the formation of the cliff, the investment on the nourishment work should be twice the actual investment that actually allows the formation of the cliff up to 1 m height. This cost is estimated to be around 200 Euro par meter par year.

5. Conclusions

After field measurements and investigations through laboratory tests regarding a case of coastal nourishment affecting 4.7 km of beach at Ferring on the west coast of Denmark, the following conclusions can be made:

- The life span of the nourishment is approx. 5 years.
- The nourishment is as such that after a winter an unwanted sand cliff is generated.
- The cliff develops in size and time and reaches up to approx. 1 m in height during the lifetime of the nourishment.
- With progressing erosion the cliff moves further inland.
- The cliff compromises the recreational value of the beach while the nourishment still protects the properties further inland.
- The use of more spread out nourishment (using larger sand volumes also on the sandbanks, with a gentler slope) generates smaller cliffs.
- Nourishments with mixed sands generate 12% higher erosion (volume) but some smaller cliffs then in the case with uniform sands corresponding to the bigger d50.
- The cost of realizing a nourishment that will minimize the formation of the cliff and save the recreational value of the beach is prohibitive.
- No significant improvement is possible for the nourishment of the case.

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