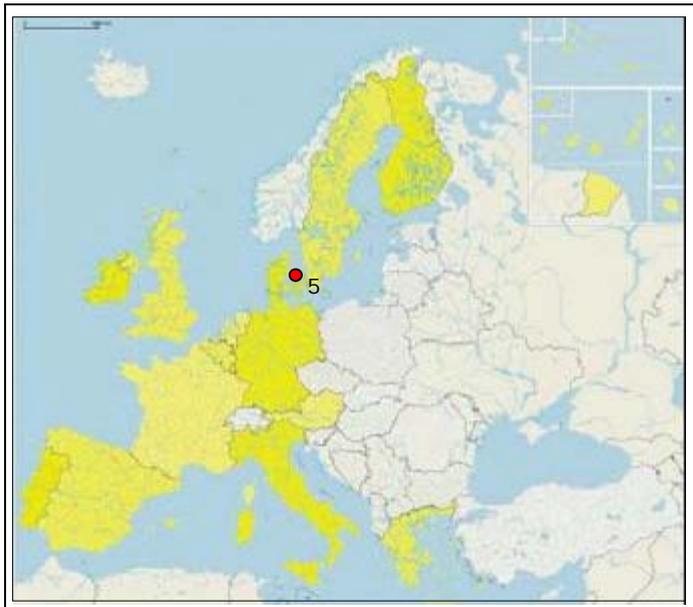

HYLLINGEBJERG – LI SELEJE (DENMARK)



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1. GENERAL DESCRIPTION OF THE AREA

1.1 Physical process level

1.1.1 Classification

The Danish coastline is 7400 km long. There are three different types of coast in Denmark:

1. Tidal coast protected by sea dykes;
2. Highly exposed North Sea coast;
3. Less exposed coasts of Baltic Sea and Kattegat.

The Kattegat and Baltic Sea Coast are moderately exposed. The case area Liseleje-Hyllingebjerg is located along 2.8 km of North Zealand (Sjælland) coastline. The coastline consists of both large cliffs and shallow beaches. According to the typology in the scoping study, the coast is characterized as:

2. Soft rock coasts.
High and low glacial sea cliffs.



Fig. 1: Location of case area.

1.1.2 Geology

During the Pleistocene glaciations, Denmark was an area of peripheral accumulation in contrast to Norway and Sweden, which mainly constituted an erosion area. The Scandinavian ice sheet did not cover the whole of Denmark during the Weichselien; its western margin stopped in northwestern and central Jutland. The surface of southwest Jutland is dominated by sediments of the Saalian glaciation while deposits of the Weichselien glaciation form the surface layers in the northern and eastern Denmark.

1.1.3 Morphology

The coast of Zealand is indented by numerous deep bays and fjords; the Ise Fjord in the north, with its branches the Roskilde Fjord on the east and the Lame Fjord on the west. At the Liseleje-Hyllingebjerg case area, in the west cliffs with a height of about 25 m are present. In front of the high cliffs, consisting of fine sediment, narrow beaches are present. Towards the east, the cliffs become lower and the beaches become wider.



Fig. 2: Coastal protection area Liseleje-Hyllingebjerg.



The natural dynamics of the coast is characterized by the west-east directed sediment transport. For instance, due to the Holocene sea level rise after the ice age, the former Bay of Arre was cut off from the sea by a spit and turned into a lake; Arre Sø. After the post-glacial sea level rise had slowed down, in the last centuries the coastline has been quite stable, because large stone reefs in front of the cliff served as natural coastal protection.

1.1.4 Physical processes

Tide

The tidal range is below 0,5 m and can be considered to be negligible at this case area.

Waves

A significant wave height with a return period of 1 year is 2,8 m with a water level of 0,75 m above DNN (mean sea level).

Storm events

Significant wave height return period 50 years; $H_s = 3,8$ m and a water level of 1,72 m above DNN (mean sea level).

Wind

The wind can cause currents and water level variations that are of importance in the Kattegat. During hard winds from the west, Kattegat is filled with water from the North Sea, while eastern storms normally cause a low water level in Kattegat.

1.1.5 Erosion

Until the 60s of the 20th century, many of the present large stones were removed by stone fishing to get building material. Hence, the natural protection of the coast was destroyed and the erosion at the cliffs increased. Nowadays the average erosion rate amounts to maximum 1 m per year.

Before the project started, several local coastal protection measures disturbed the sediment balance along the coastline. Hence, certain parts of the cliff remained without protection and were thus being more eroded than others. This situation should be overcome by creating a common project.



Fig. 3: Situation before coastal protection; old measures and narrow beaches are clearly seen.

The erosion is structural; it is caused by a net sediment transport gradient in combination with human interference. Due to human interference, namely removing the large stones and local coastal protection measures, the sediment balance has been disturbed and the coast is no longer stable and structural erosion of the coast has started. The estimated average net sediment transport is 10,000 to 30,000 m³/year eastwards. The transport was estimated with the help of a coastline analysis. Acute erosion due to heavy storm events also occurs.

1.2 Socio-economic aspects

1.2.1 Population rate

The area at Liseleje is not densely populated; a lot of the houses are summerhouses, which are not occupied throughout the entire year. Along the case area, about 80 landowners are situated directly at the cliff tops and are threatened by the erosion.

1.2.2 Major functions of the coastal zone

- **Tourism and recreation:** The north coast of Zealand is also known as the Vacation Coast, because it is a popular holiday area for the better-situated people from Copenhagen. Hence, many summer cottages are situated along the coastline mostly on top of the cliffs.

1.2.3 Land use

The case area is built up with (small) summer cottages along the entire coastal stretch. The soft cliffs are usually vegetated.



1.2.4 Assessment of capital at risk

The case area is not very densely populated, but the recreational value of the area is considered to be very high. About 80 landowners along the coastal stretch (summer cottages on the cliffs) are involved in the project.



2. PROBLEM DESCRIPTION

2.1 Eroding sites

The project area is 2.8 km long and located on the northwest coast of Zeeland. To the west the boundary is the municipality limit and to the east it is a major breakwater with a tombolo, "Liselejemolen". The breakwater was originally built to give shelter for small fishing boats but has also created a beach to the west. Significant lee-side erosion has occurred in a military area to the east of the breakwater but is not considered a problem.

An aerial photo of the coast in 1993 in Figure 10 (Chapter 4) shows that the beach is narrow or non-existing except just to the west of "Liselejemolen".

2.2 Impacts

The erosion threatens the existing summer cottages and the beaches that are intensely used for recreational purposes.

3. SOLUTIONS/MEASURES

3.1 Policy options

The policy option for the coastal protection scheme is “Hold the line”. The beaches should be recovered and the summer cottages on the cliffs have to be protected.

3.2 Strategy

The Master Plan stated in 1989 that the area Hyllingbjerg – Liseleje was in need of coastal protection. The purpose of the project is to protect the summer cottages at the top of the cliff and to do this in an environmental friendly and visually acceptable way. In 1995 the Hyllingbjerg-Liseleje Coast Association conducted a private survey among the 80 involved landowners (summer cottages) to see whether they were interested in coastal protection - 63% were positive and 15% were negative. The Coast Association then asked the county of Frederiksborg to initiate the process stated in the 1st paragraph of the Coast Protection Act.

In 1996 the county decided to go on with the process and started pre-project investigations. At the same time a follow up group was formed to ensure the involvement of the stakeholders. It consists of the County, the Municipality and the Coast Association and functions as a tool for the integration of local interests. The public is informed about the project on the internet, e.g. by putting the minutes of the group meetings into the internet and by showcases. DCA is involved at the sideline as technical advisor for the county.

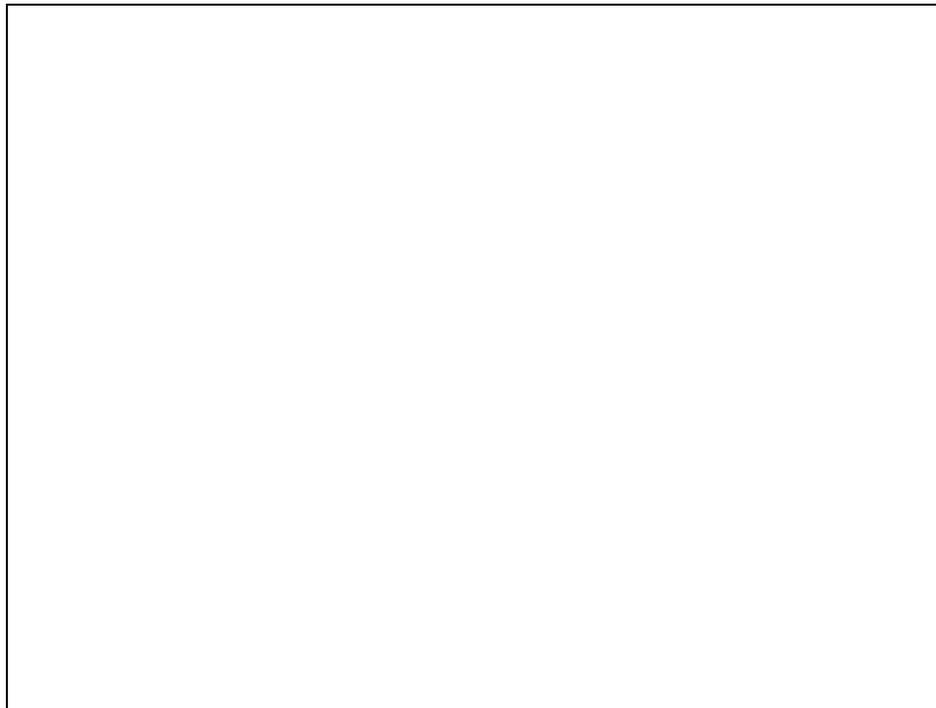


Fig 4: Situation after the new breakwaters were built, beach nourishment not completed yet.

An external consulting engineer was hired and in 1997 two alternative proposals (I and II) were presented to the landowners at the 1st public hearing. Based on this hearing the county decided to go on with proposal II. The consulting engineer worked out a final project description and in late 1997 the 2nd hearing was held.

The following requirements were established for the project:

1. Protect summer cottages against slope erosion;
2. Prepare an overall plan for the coastal protection;
3. Establish as much beach as possible especially close to where the public access points are made;
4. The coast protection must be nearly maintenance free, i.e. maintenance after major storms or every 10 to 20 years for structures and every 5 to 10 years for beach nourishment.
5. Uninterrupted passage along the coast during normal weather conditions.

At this 2nd hearing the final project was presented. Likewise the distribution of the costs among the county, municipality and the landowners was presented. The Coast Protection Act empowers the county to decide upon how the costs are divided among the parties. The total costs are divided as follows: county 1/3, municipality 1/3 and landowners 1/3. The landowners have to pay according to how much land they own along the coastline.

Not all the landowners accepted this division of costs and therefore a complaint was filed to the Minister of Transport. The Minister handled all complaints with regard to the Coast Protection Act. Finally the complaints were handled and an agreement was reached. In 1998 the county invited tenders and in February 1999 the works started. In June 1999 the work was finished.

3.3 Technical measures

3.3.1 Historic measures

Throughout the years, individual landowners and local coastal protection groups have built a variety of slope protection structures consisting of concrete piles/elements, timber piles, sheet piles, rubber tyres, branches and twigs, and rocks. Furthermore, a number of wooden groyne and non-integrated small detached rock breakwaters, located in shallow water, were built along the coast. In the beginning of the project, a registration was made of the great variety of more or less functioning structures at each of the 80 parcels along the coast. Inadequately designed structures and a lack of maintenance have led to a deterioration of the slope protection structures and some of the detached breakwaters.

3.3.2 Type

The coastal protection should be based on technically sound solutions, e.g. rock slope protection to reduce wave reflection and thus beach retreat. The solutions should also be aesthetic, e.g. by making the slope protection more uniform and remove all deteriorated and disfiguring structures.

Due to the exposed location at a regional headland, the protection of the coast was designed to consist of three elements:

- Detached breakwaters
- Beach nourishment
- Slope protection

The breakwaters and beach nourishment will reduce the wave impact on the slopes and thus reduce the requirements to the slope protection. Further, these two elements will be necessary to fulfil the requirements outlined for the project.

3.3.3 Technical details

Detached breakwaters

The detached breakwaters could be constructed as singular long coastal breakwaters with large gaps, segmented breakwaters consisting of long coastal breakwaters or segmented breakwaters consisting of short coastal breakwaters. It was preferred to minimise the number of breakwaters due to the aesthetic appearance.

The locations of the new-detached breakwaters were based on the experience with "Liselejemolen" and so that tombolos should develop behind them. Six new breakwaters with lengths of 40 to 60 m were included in the final plan, together with two small existing detached breakwaters just to the west of "Liselejemolen". The two old and small detached breakwaters were deteriorated in 2000, and had to be strengthened to retain the beach in this area.

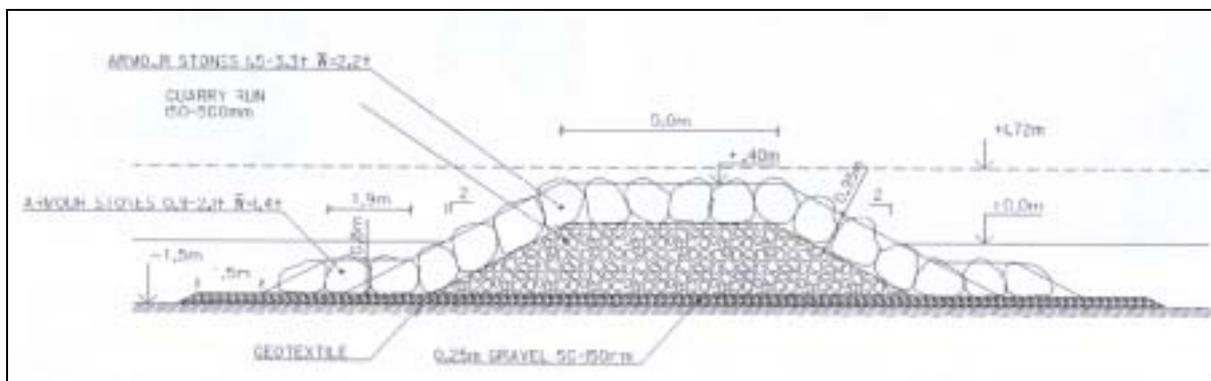


Fig. 5: Typical cross section of a breakwater.

In the eastern end the protection consists of a segmented breakwater consisting of long coastal breakwaters whereas in the western end the distance between the breakwaters are increased and they become singular long coastal breakwaters. The detached breakwaters are located in water depths ranging from 0.5 to 2.0 m and are designed with low crest elevations (+0.5 to +1.4m above mean sea level) to minimise the visual impact. A typical cross section of the detached breakwaters, having a wide crest to be stable against heavy overtopping, is shown in Figure 5.

In Figure 6, the locations of the new breakwaters are shown, the dimensions are shown in Table 1.

Table 1: Dimensions of new breakwaters.

Breakwater no.	Breakwater length [m]	Crest height [m+msl]	Depth [m]	Distance from coast [m]
1	40	+0,5 m	1,2	40
2	60	+1,0 m	1,5	60
3	60	+1,4 m	1,5	60
4	60	+1,4 m	1,5	60
5	60	+1,4 m	1,5	60
6	40	+1,0 m	1,0	40

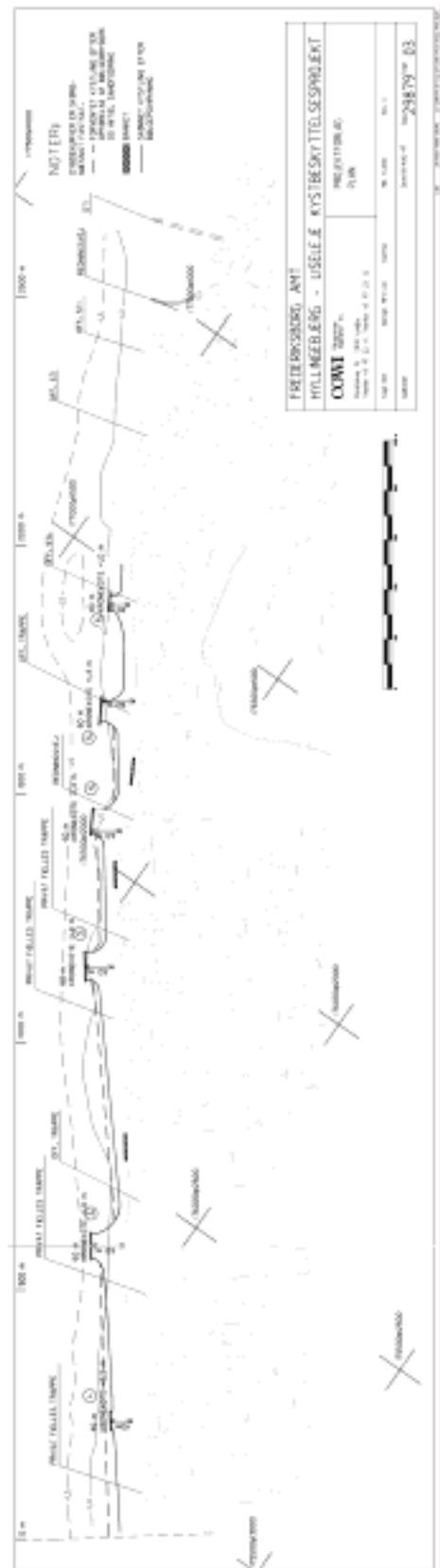


Fig. 6: The historic measures (A) and the new coastal protection plan (B) at Hyllingebjerg-Liseleje coast.

Beach nourishment

An initial nourishment with about 80,000 m³ of sand was included in the plan to fill up the beach to the new expected equilibrium profiles and to avoid significant erosion of the coastline between the breakwaters when sand is trapped behind the breakwater in formation of the tombolo's.

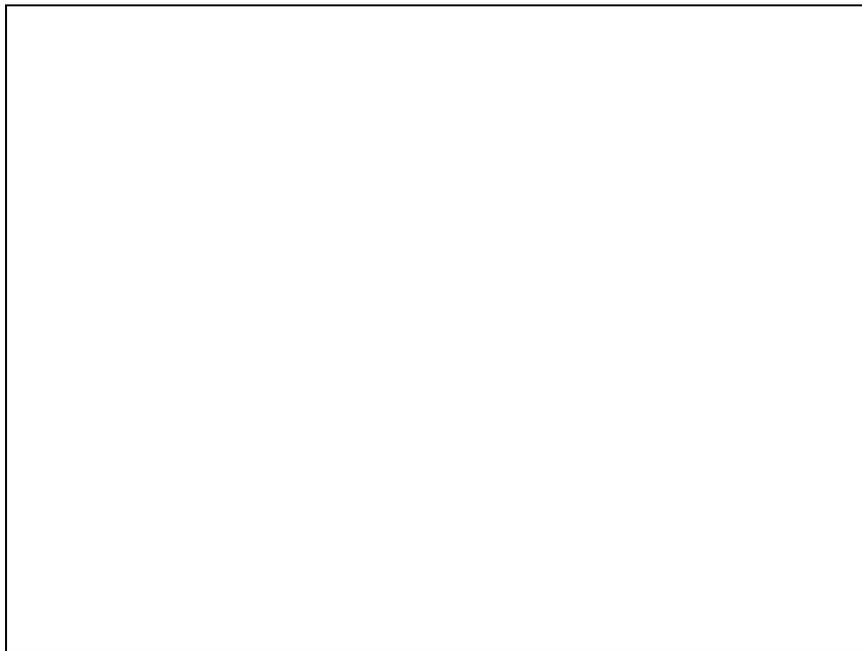


Fig. 7: The construction of the beach through artificial beach nourishment.

Slope protection

The existing deteriorated or disfiguring slope protection was either replaced by rubble mound slope protection or a rubble mound slope was placed in front to obtain an aesthetic appearance and a proper functioning of the structures. Several types of slope protection were applied, shown in Figure 9. An example of the many structures before the implementation is shown in Figure 8 together with a photo after completion of the project.

Type 1 is a new slope protection, type 2a and 2b are applied in front of existing timber piles, type 3 is applied in front of existing concrete protection and type 4 includes a berm breakwater and is meant for severely attacked areas.



Fig. 8: Before the coastal protection plan was conducted (A) and after (B).

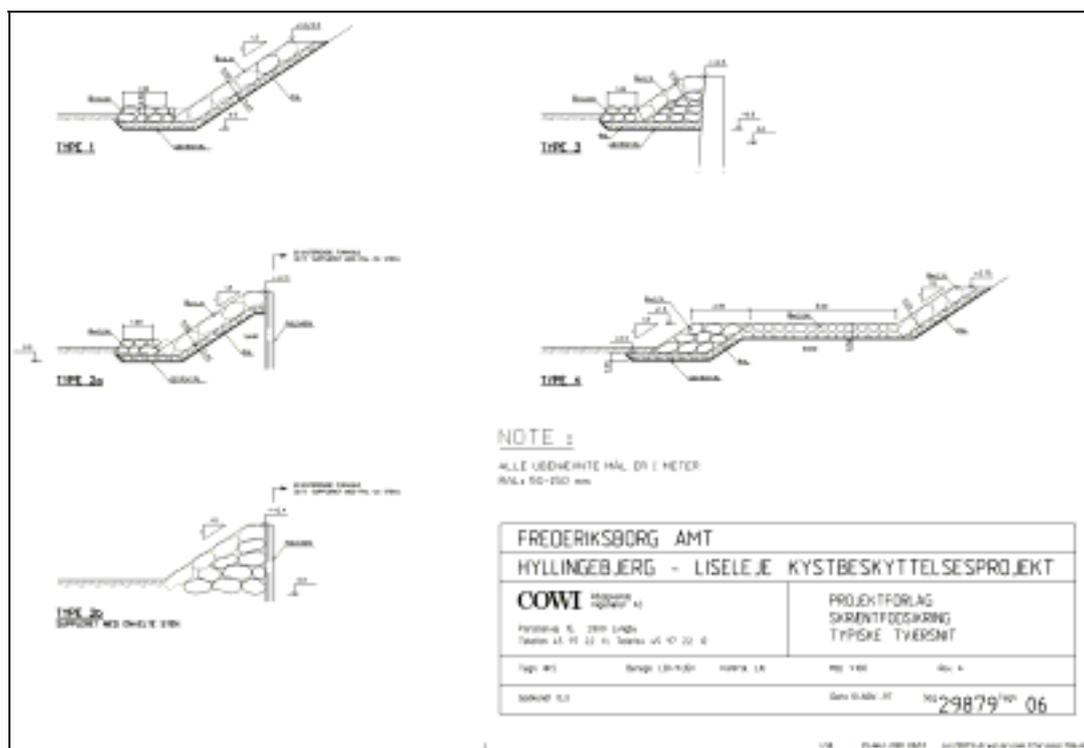


Fig. 9: Different types of slope protection applied at Hyllingebjerg-Liseleje coast.

Total project

The total project started early 1999 and was completed in time for the summer season. The maintenance of the coastal protection system is in the hands of a coastal guild consisting of members from the three stakeholders (county, municipality and stakeholders).

Granite stones for the breakwaters and slope protection were shipped in from Sweden and supplemented by stones obtained from a local gravel pit. Material from removed structures was also used in the construction of the new breakwaters and slope protection. The sand for the beach nourishment was pumped ashore through a fixed steel pipe.

3.3.4 Costs

The costs of the coastal protection plan at Hyllingebjerg- Liseleje coast are specified in Table 2. The costs of the detached breakwaters and the beach nourishment were equally shared between the three main stakeholders, whereas the individual landowners paid for the slope protection.

Table 2: Costs of coastal protection plan Hyllingebjerg-Liseleje coast.

Activity	Costs [€]
Initiative	65,000
Construction new breakwaters	520,000
Beach nourishment 80,000 m ³ between the breakwaters	465,000
Construction berm protection in between the breakwaters	55,000
Diverse (research, project management, unforeseen)	245,000
Total price (without slope protection)	1,350,000
Slope protection	350,000
Total price (with slope protection)	1,700,000

4. EFFECTS AND LESSONS LEARNT

4.1 Effects related to erosion

The coast protection has now been in function for a few years and is working well even though that it has been exposed to two severe storms where one was the worst in the 20th century. A monitoring programme has not been implemented and instead visual observations and aerial photos are used to assess the performance of the coastal protection work. Figure 10 shows aerial photos of the condition in 1993 before the project was started, in 1999 directly after completion of the project and in 2000, after some severe storms.

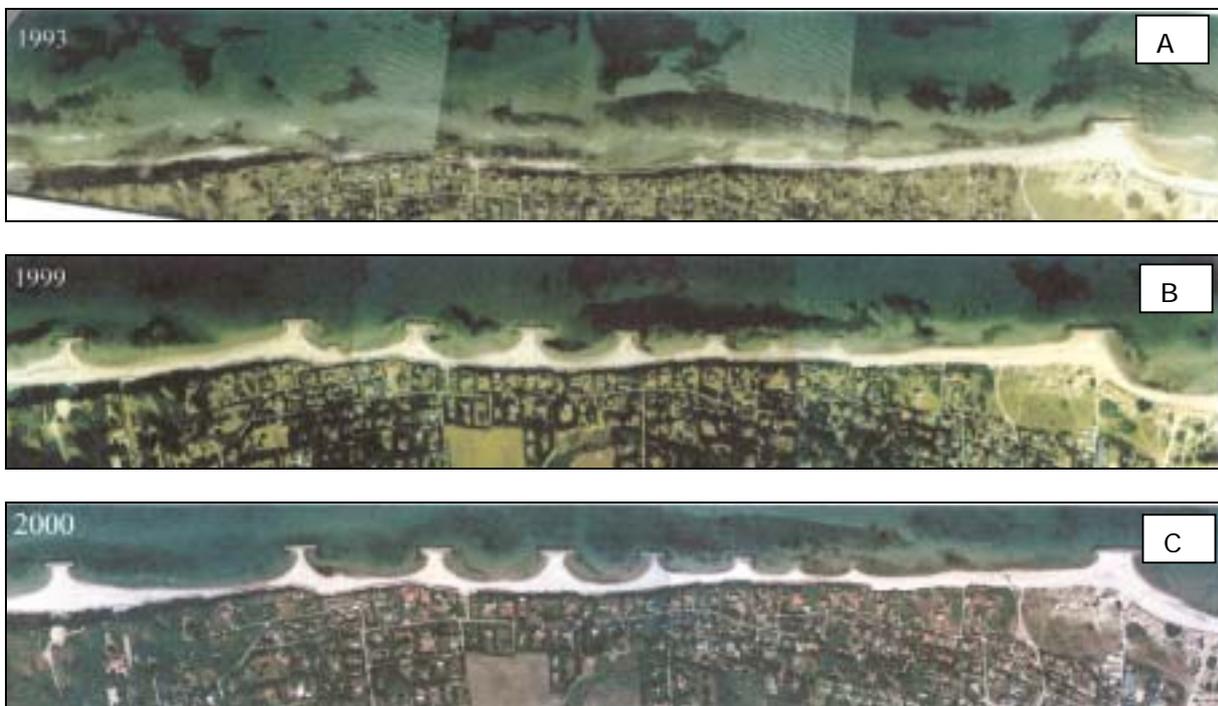


Fig. 10: Aerial photos of the case area in 1993 (A), 1999 (B) and 2000 (C).

In June 2001, large amounts of sand have accumulated behind the new detached breakwaters and are forming large tombolo's, which increase the recreational value of the beach considerably. The large tombolo's result in limited sand in a few of the bays between the detached breakwaters and a few landowners are critical now that they have not got an improvement locally. However, overall the system of breakwaters, nourishment and slope protection works well and is considered to be a success.

At present some small alterations works are in progress – it is often necessary to change details when the construction shows its real behaviour to the climate. Most of the landowners have agreed with the coastal protection measures and will be unified in a local board according to the Coastal Protection Act. This local board will be responsible for the maintenance of the revetments, while the county will be responsible for the maintenance of the breakwaters and for sand nourishment. Beach nourishment will be necessary about every 5 years.

4.2 Effects related to socio-economic aspects

The coastal protection plan has re-established the beach for recreational purposes. The summer cottages on the cliffs are no longer threatened by storms because of the wider beaches in front of the cliffs and the better slope protections that were constructed.

4.3 Effects in neighbouring regions

Nothing is known about the effects of the coastal protection scheme in the downdrift area of Liseleje. Because the present big breakwater "Liselejemolen" already interrupted the longshore transport, the construction of the new breakwaters is not expected to have great impact downstream.

4.4 Relation with ICZM

During the coastal protection project Liseleje - Hyllingebjerg it became clear that it is important that the public is always informed fully about the process and always has easy access to the information - you can't overinform in anyway. The web site made by the County of Frederiksborg (<http://www.fa.dk/natur/projekter/>) is a very good example, and people who live there are very satisfied with it. The county has put a lot of work in it, but they feel that it has paid off.

Other functions, besides coastal protection, were very much taken into account in the design of the coastal protection scheme at Liseleje. The main goal was to achieve an effective coastal protection in an environmentally friendly and visually acceptable way.



Fig. 11: New breakwaters with the formation of tombolos behind it.

Another interesting aspect is to view the way of financing coastal defence projects. The coast of Frederiksborg County has been classified in three categories regarding the need for coastal protection: category 1 contains coastal stretches that have a need for action and that



are of public interest (e.g. areas with recreational or transport functions); here the costs can be divided between land owners and public authorities. Other coastal areas with a need of protection fall within the second category, where landowners have to take over all the costs of coastal defence measures. The third category contains all other coastlines with no need for coastal defence measures.

It sounded very interesting that the costs for coastal protection are divided between the county, municipality and landowners. An advantage might be that landowners take a higher responsibility and do not build houses very close to the water. On the other hand there might be the risk that the costs for coastal protection could be too high for some landowners so they would not be willing to join a common project. Or maybe also they can be excluded to own land close to sea, due to these costs. It might be a problem for example for farmers who own a lot of land.

4.5 Conclusions

Effectiveness

The system of breakwaters, nourishment and slope protections is functioning well and is considered to be a success. In general, the beach surface in front of the cliffs has increased and the cliffs are being protected more effectively.

Possible undesirable effects

The formation of tombolos has locally caused a shortage of sand in between the breakwaters. This causes a retreat of the coastline locally.

In this case project the landowners are organized in a private organization to represent their interests. If there is no local organization like this, there is a risk that the money is spread to many small projects. That means that the problem can, in the worst case, be moved to another location or that the areas where the problems are worst are not dealt with. This might be the case if some owners are not willing to join any coastal defence works. So it is very important to get everyone into the boat, which was nearly successful in the presented project at Hyllingebjerg-Liseleje coast.



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Figures:

Figure 1: <http://www.icm.noaa.gov/country/denmark.html>
Figure 2: www.expedia.com
Figure 3: Coastal protection at Liseleje, Denmark
Figure 4: <http://www.fa.dk/natur/projekter/>
Figure 5: Beach nourishment in Inner Danish Waters
Figure 6: <http://www.fa.dk/natur/projekter/>
Figure 7: <http://www.fa.dk/natur/projekter/>
Figure 8: Beach nourishment in Inner Danish Waters
Figure 9: <http://www.fa.dk/natur/projekter/>
Figure 10: Beach nourishment in Inner Danish Waters
Figure 11: <http://www.liselejekyst.dk>

Tables:

Table 1: <http://www.fa.dk/natur/projekter/>
Table 2: <http://www.fa.dk/natur/projekter/>