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Building elements made of geosynthetics and sand resist the North Sea surf

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ABSTRACT: After the storm tides at the beginning of 1990 the distance between the house "Kliffende", the guest house of the Deutsche Bank near Kampen/Sylt (Germany), and the edge of the cliff had been reduced to five metres only. A pilot project was carried out to protect the house: a second defence line was set up consisting of a sand renourishment combinated with an integrated embankment encapsulated in geosynthetics. This paper presents a closer look at the special design and the construction of the work.

1 INTRODUCTION

At the beginning of 1990 a series of storm tides had caused severe morphological modifications to the west coast of Sylt. After this event, the historical house "Kliffende", located near Kampen at the west beach of Sylt, was only 5.40 m away from the edge of the cliff. There was a big danger that the west gable of the house "Kliffende" would fall down into the sea during one of the next storm tides and that the house would thus suffer irreparable damage.

On behalf of the Deutsche Bank, the proprietor of the house Kliffende, supported by the Husum Department of Agriculture and Water Resources, the Consulting Engineers Stefan Knabe + Peter Knabe developed in spring and summer 1990 a measure to protect this building. The project was then carried out in autumn 1990 in the form of a geotextile construction.

2 AIM OF THE PROJECT

The extreme beach losses after storm tides in this section of the coast are caused by the special geological circumstances in the underwater area and the beach section of Kliffende. In addition to the sand renourishments carried out since years a 165 m wide geotextile reinforced artificial dune was built as a second line of defence. Furtheron, the State of Schleswig-Holstein continued to provide sand renourishments to protect the sandy coast of Sylt. The function of the artificial dune is to prevent a further successful attack on the cliff and to serve as a second line of defence in front of the house Kliffende if the sand depot from the renourishment is used up again by hydrodynamic loads.

3 EXAMINATIONS ON PROTECTION MEASURES

As further storm tides had to be expected in the winter of 1990/91, it was necessary to work out, on the short term, a constructional solution for the protection of the house Kliffende which would be approved. Different possibilities to protect the building had been examined and discussed with the contractor and the approving authorities.

Different constructions had been developed by the Consulting Engineers Knabe and different cross sections comprising rigid, partially flexible and flexible building materials were examined [Knabe 1990].

Since the house Kliffende is located directly at the west beach of Sylt within a nature reserve of zone I, the authorities already indicated to the client at the time of the initial plannings that solid (massive) construction methods, for instance a stone revetment or a barrier (protective wall) made of concrete shaped bricks would not be permitted due to the location in the nature reserve. For this reason rigid constructions were regarded critically.

On this basis the Consulting Engineers mentioned above developed a new system consisting of geotextile "sand cushions".

4 REMARKS ON THE STABILITY DESIGN OF THE CONSTRUCTION

The measure described above with the application of geotextile sand cushions for the protection of the house Kliffende is a pilot project. There are no comparable constructions which are exposed to similar hydraulic loads. For this reason also the mathematical basis for the design of the construction

is nothing usual. Thus, the client engaged the *Bundesanstalt für Wasserbau* in Karlsruhe to make stability calculations. The constructional requirements which resulted from the calculations were then transformed by the Consulting Engineers Knabe.

Approach for the calculations

It was taken as a basis that rising waves with water overpressure loadings acting from the outside would hardly influence the stability and deformability of the construction. Outgoing waves with pore-water pressures acting from the inside - which should be rapidly released towards the front of the construction - should be decisive for the stability and the possible deformations of the construction. Therefore, sand permeability, permeability of the woven fabric and drain performance of the nonwovens had to be matched with each other.

Due to their tensile strength the planned geotextile sand cushions prevent the encapsulated sand from being washed away by the action of the waves and the outgoing tide. A condition is that the geotextiles are integrated deep enough in the subsoil where waves have no influence. In this way sufficient frictional forces can be mobilized which develop tensile stresses in the geotextile areas where the sand is usually liquefied by the action of the waves to flow away.

The effect of liquefaction under wave action has been examined with the help of approaches developed at the *Bundesanstalt für Wasserbau* in Karlsruhe and *Delft-Geotechnics*, The Netherlands [BAW 1990].

On the basis of extensive calculations the dimensions of the construction could be optimized and defined, and a statement could be made on a sufficient stability.

5 THE SYSTEM "GEOTEXTILE SAND CUSHION"

The geotextiles provided as a cushion wall for the embankment stabilization take over the function to hold and to anchor the sand cushions, as covering of the same, in the specified installation position. Fig. 1 shows a cross section of the measure.

Storm tide water levels with heights of approx. + 4.5 m NSL in connection with wave heights of H_S = 2.5 m and wave periods of T_S = 5.5 s exert special forces on the outer zones of the complete geotextile construction at this exposed location.

In addition, it had to be assumed that after erosion of the sand renourishments the materials would partly lie at the surface and not in the soil as in case of classical geosynthetic applications.

This happened lateron, and the construction withstood storm tides.

Table 1. Technical data of the composite material Terrafix® 601S-G340 (80/80).

	woven component	nonwoven component
raw material	PP	PES
mass per unit area	340 g/m²	620 g/m²
layer thickness	-	6.6 mm
max. tensile strength		
longitudinal	80 kN/m	≥ 12 kN/m
transverse	80 kN/m	≥ 18 kN/m
$O_{90,w}$	0.33 mm	0.15 mm

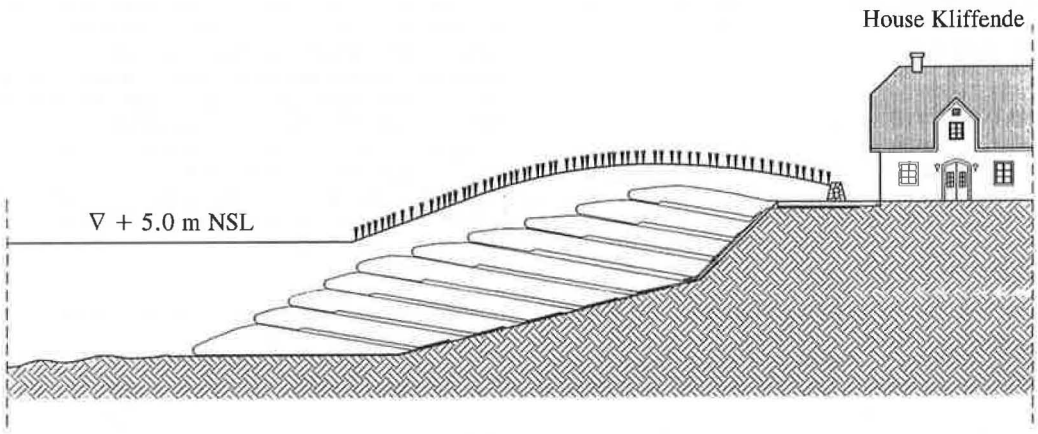

Fig. 1. Cross section

Fig. 2. Installation of the sand cushions. Construction of the fronts with concrete shuttering elements.

Fig. 3. "Cushion wall" covered with sand and planted.

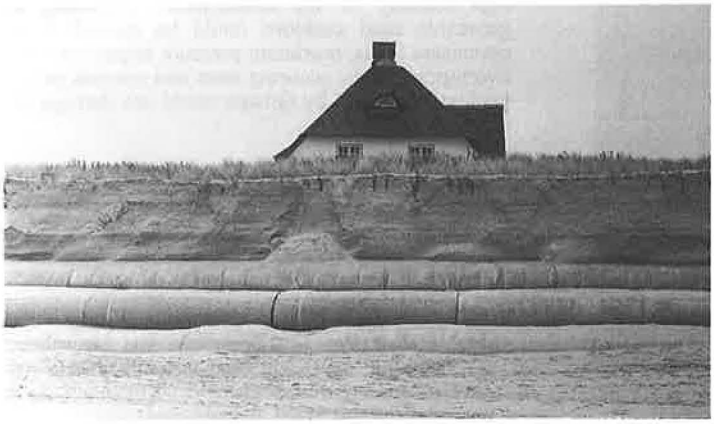

Fig. 4. Exposed sand cushions after storm tide and erosion of the sand depots.

These boundary conditions resulted in the following requirements for the geosynthetic components:

- high tensile strengths with elongations as low as possible,
- good filtering properties,
- UV resistance,
- abrasion resistance.

Due to these requirements a needle-punched composite material - specially designed and produced by Naue Fasertechnik - consisting of a polypropylene slit film woven and a polyester nonwoven was selected. The technical data of the composite material Terrafix® 601S-G340 (80/80) can be taken from Table 1.

6 INSTALLATION

Protected by a 5 m high sand renourishment, a trench was excavated at the foot of the cliff and geotextiles were installed. The geotextiles especially manufactured for this application were overlapped by 1.5 m, filled with sand provided by the depot, compacted and then folded back. On account of the particularly high loading the seaward faces of the "sand cushions" were reinforced with a highly flexible and non-abrasive nonwoven. This nonwoven also protects the polypropylene woven against UV radiation. Although the coverings consist of a number of geotexile strips of the same width, the length of the individual rolls was different depending on the installation height, so that the sand cushions were arranged layer by layer in the form of stairs.

Each roll marked with a serial number was placed according to a detailed installation plan of the Consulting Engineers Knabe. In a distance of 30 m in front of the edge of the cliff the first cushion is installed 1.0 m below the mean sea level. Fig. 2 shows the beginning of the construction measure.

Fig. 5. Detail of the front construction after having been exposed by a storm tide.

7 FINAL REMARKS

Since the construction could yet be finished in December 1990 and no severe storm tides occurred in that season, biological accompanying measures could be carried out in the summer months of the two subsequent years. Sand trap fences consisting of bushes and marram grass were put up on the embankment above the geotextile sand cushions. In this way an approx. 2.0 m thick sand cover was obtained within two years on the geotextile cushions and could be stabilized over the entire area with marram grass. The bushes resembled a natural dune which now serves as a second line of defence - after the sand renourishments - against hydrodynamic attacks of the North Sea on the house Kliffende. The structure proved worthwhile several times during winter storms in 1993 and 1994. The geotextile construction was exposed during these storm tides, but not damaged.

The achieved total height of the construction is 8 m with inclinations of (V:H=) 1:2 in the lower and (V:H=) 1:4 in the upper cross section area.

The seaward faces of the sand cushions were precisely formed with the aid of concrete shuttering elements. The excavated material from the sand renourishment was redeposited on the geotextile strips and carefully compacted. The free end of the geotextile strips was folded back and the concrete shuttering removed. In the meantime, the sand cushions laid on top of each other form a stabilized beach section.

Transverse bulkheads were provided by installing fabric/nonwoven sheets in order to counteract possible scouring of sand from the sides in case of a partial damage to the construction. Fig. 3 shows the final construction.

As the interest in this solution developed for the special protection in coastal areas increased, large-scale model tests were carried out on this structure in October 1991 at "Großer Wellenkanal" of the *Universities of Hannover and Braunschweig*. The high stability of the construction consisting of geotextile sand cushions could be proved. Even permanent loads, maximum pressure impact stresses, overtopping tests, scouring tests and stresses on the geotextiles caused by flotsam could not damage the construction.

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