CHAPTER 85

A REFRACTION GROYNE BUILT BY SAND

by Alfred FÜHRBÖTER [1)]

ABSTRACT

The interaction between a normal groyne and waves mostly is by diffraction, i.e. the structure of the groyne, especially the width, is very small in comparison to the wave length. But when a groyne is built with lateral slopes comparable with normal beach slopes, also refraction processes occur and surf zones are created nearly parallel to the center line of the groyne. It can be shown that, for all directions of wave approach, the longshore currents always are directed shoreward. So, when such a groyne is built by sand, due to the erosion of the groyne an artificial sand spit is formed and a beach nourishment at the adjacent areas of the shore can be expected. Furthermore, sand originating from the normal littoral drift can be caught by such a structure as it happens in case of normal groynes.

In a field experiment at the shore of the city of Westerland on the island Sylt/Germany, with 680,000 m^3 of sand such an artificial sand groyne was built in 1972. One year later, this sand masses were grown up to nearly 1,050,000 m^3. After a sequence of five heavy storm surges in November and December 1973, still 770,000 m^3 could be detected before the shore in 1974. The evaluation of the experiment is continued; the aim of it is find out whether repeated beach nourishment is more economic than protective works. For this reason the knowledge of the "half decay time" of a beach nourishment is necessary.

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1. ABOUT THE CONCEPT OF SAND GROYNES (REFRACTION GROYNES).

The main effect of normal sea groynes against approaching waves is by diffraction, i.e. the groynes are acting as an obstacle against wave motion. On the side of wave attack, waves may be broken and/or reflected; sometimes even MACH-stem reflection can be observed. The structures themselves can be regarded as more or less linear elements; their widths are small in comparison to wave lengths. Even when the cross sections are built with slopes on the sides, these slopes are very steep; waves do break on these slopes but no refraction process occurs.

However refraction will play an important roll when a groyne is built in the form of a large, flat and three-dimensional body in such a manner, that the lateral slopes and the head of the groyne are as flat as the natural beach. Such a groyne only can be constructed in sand itself because of the immense masses which are necessary for building it. Such an artificial sand spit may act partially also by diffraction like a normal groyne. It is of essential importance, however, that refraction processes are produced on the slopes and influence the surf and longshore currents along the beaches of the groyne (FÜHRBÖTER et al. 1972, FÜHRBÖTER 1973).

The refraction processes, their influence on the angle of wave approach at the breaker line and on the longshore currents caused by surf are shown schematically on Fig. 1. For each direction of wave approach there is a point of divergence at the head of the groyne; the longshore currents on the sides of the groyne are always directed shoreward. At the side of wave approach (left hand on Fig. 1), a nodal point is formed where the normal longshore current along the shore meets the longshore current caused by the surf on the slope of the groyne; on the other side (right hand on Fig. 1) there is a point where the energy due to the longshore current is nearly zero. So it is easy to explain that at the head of the groyne always erosion and in the nearshore sections of the groyne always sedimentation will occur. The same effect can be expected when wave approach is perpendicular to the shore.

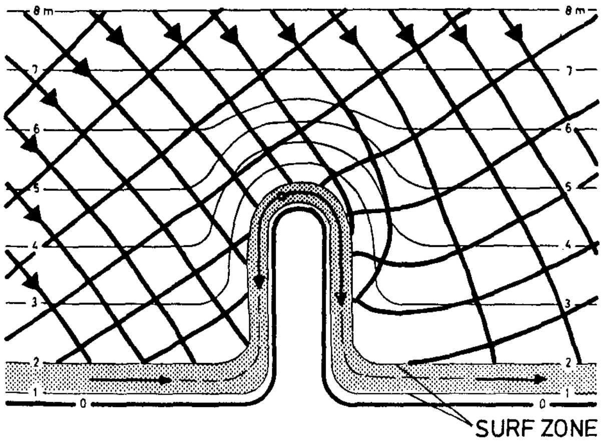


Fig. 1: Refraction processes and longshore currents upon a sand groyne

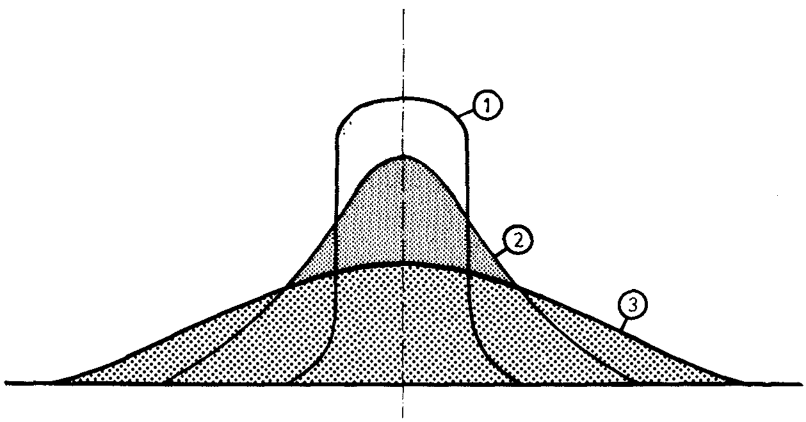


Fig. 2: Deformation of a sand groyne into an artificial sand spit by wave attack from all directions

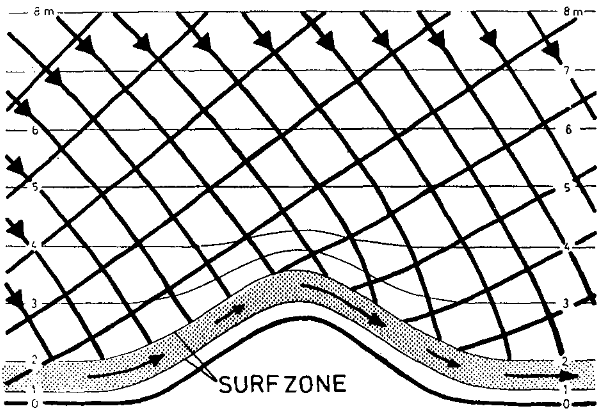
The groyne as to be seen on Fig. 2 will be deformed continuously under the assumption that waves are approaching from all directions. By the process of erosion at the head, sediment transport upon the slopes at both sides is caused and sedimentation occurs in the corners between groyne and shore so that gradually the groyne changes into the contour of a flat sand spit. During the phase of deformation, a reduction in length of the groyne will be compensated by increasing width at the shorelines besides it (Fig. 2). This process is very complex in the detail due to the interactions between waves, longshore currents and beach profiles.

After deformation into a sand spit, the system of longshore currents will have another pattern, too, as to be seen on Fig. 3 for the case of a small angle of wave approach. There are no more points of divergence at the head of the groyne. But Fig. 3 also shows two zones with remarkable reduction of the longshore component in comparison to that on Fig. 1.

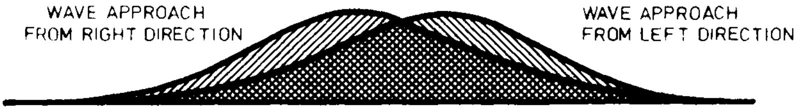
According to the predominant wave direction of the season the groyne or spit will change the form according to the scheme on Fig. 4. Similar to a tidal dune, a certain amount of sand will move from one slope to the other but without leaving the system.

The model presented here is simplified and qualitative but it demonstrates that an effect on shore stabilisation can be expected from such a structure. Moreover it is possible that sand from the natural longshore transport can be caught in the sedimentation zones of the groyne here acting like a normal groyne. With regard to the flat form of the sand body, it can be expected that no lee erosion will occur.

It should be noticed that the concept of a depot nourishment in form of a sand groyne as described here is only applicable for coasts with wave action occurring from nearly all directions. For predominat wave attack from one direction only, this concept has to be modified.



<u>Fig. 3</u>: Refraction processes and longshore currents upon an artificial sand spit



<u>Fig. 4</u>: Changing of the form of the spit due according to the prevailing wave direction

2. FIRST APPLICATION OF THE SAND GROYNE CONCEPT BEFORE WESTERLAND/SYLT.

The island of Sylt before the west coast of Schleswig-Holstein/Germany suffers from strong wave erosion by the North Sea. In the average, in the last century an annual erosion of nearly 1 m was started; a comprehensive study of this problem is given by LAMPRECHT (1955).

Especially at the site of the city and well known recreation place of the island, Westerland, already at the beginning of this century a protection work in form of a seawall became necessary in order to prevent further dune erosion. The further development of these defense structures is described on Fig. 5; no comment is necessary here, it is the normal process at all places where a coastline under erosion is fixed. Even supported by a system of heavy groynes,the erosion could not be stopped; the groyne effect is less because of the fact that the average of wave approach is nearly perpendicular to the shoreline here.

Fig. 6 shall may give an impression of the strength of wave attack against the seawall (storm flood in 1954). By the reflection of wave energy at the nearly vertical defense works the natural erosion process is superimposed by human made erosion additionally.

At the top of Fig. 7, the morphological development of the area before the shore is illustrated. The longshore bar (Fig. 7) is a typical feature along the west coast of Sylt.

About 1970, it became necessary to design a further toe protection of the seawall due to the danger of underscour; this measure would have been the third toe protection (see Fig. 5). Because of the increasing costs of construction and maintenance of the works and because of the fact that erosion could not be delayed but was even accelerated due to the vertical face of the structure, alternative solutions were discussed and an artificial beach nourishment was taken into consideration.

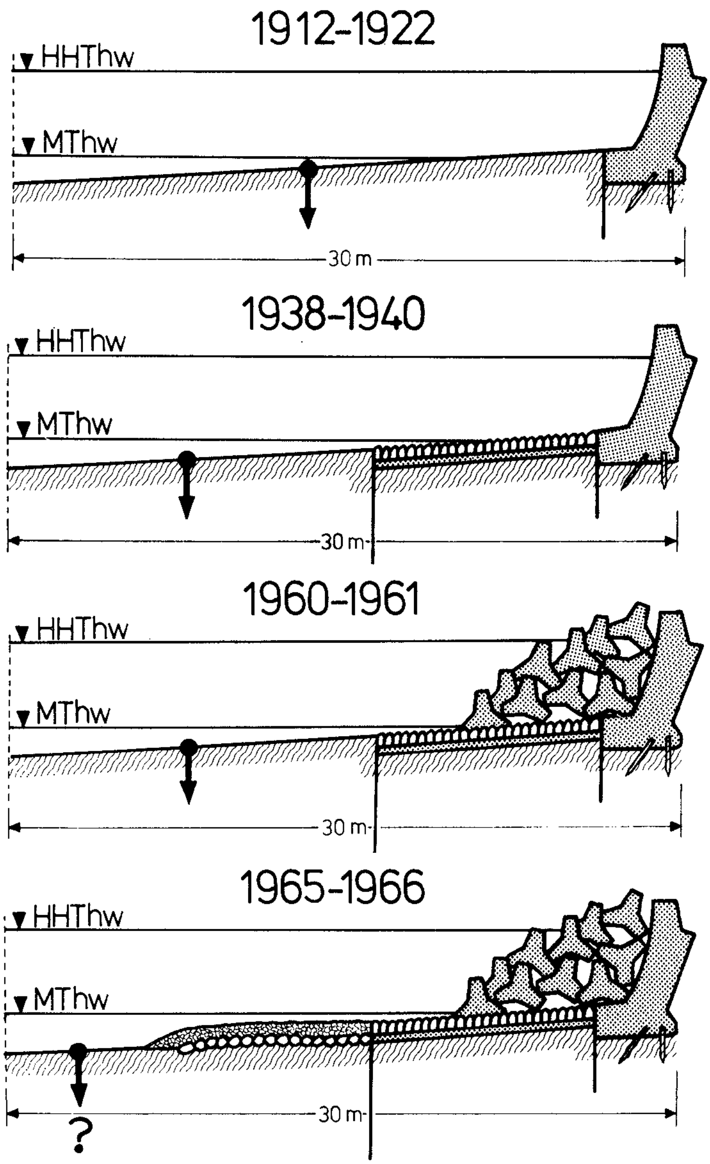


Fig. 5: Developement of the coastal defense works before Westerland/Sylt

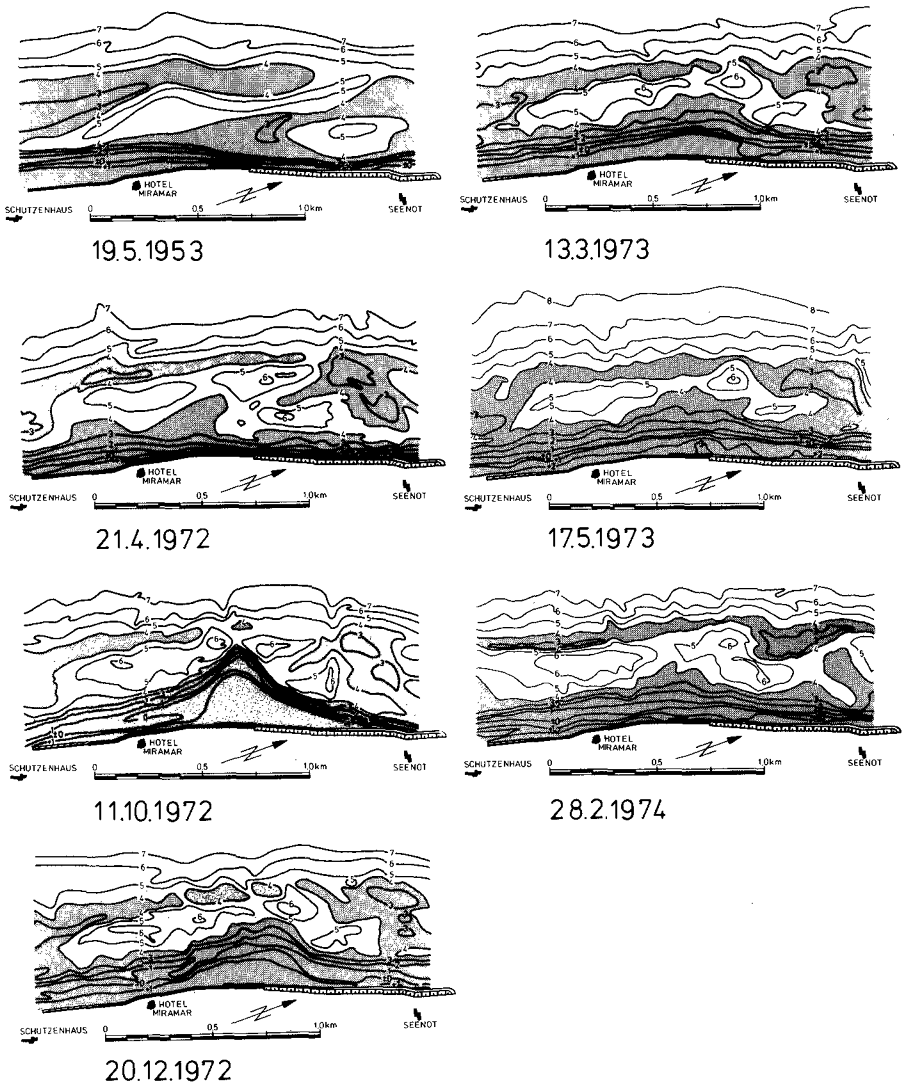


Fig. 7: Development of coastal morphology before Westerland/Sylt since 1953 (after surveys of the AMT FÜR LAND- UND WASSERWIRTSCHAFT HUSUM)

Fig. 6: Wave attack at the seawall of Westerland/Sylt during a storm surge in 1954 (after LAMPRECHT 1955)

Although being aware that such a measure would have to be repeated after several years this solution seemed to be more economical than further reinforcements of the existing structures and their toe protections. An exact calculation for economy, however, only can be carried out with the knowledge of the time when the nourishment has to be repeated.

In a first plan, a field experiment was considered with a normal beach nourishment along the shoreline where toes of the defense works had to be protected. By this "linear" fill-up an artificial beach slope due to the sedimentation process of hydraulic transport would have been created which is not in response to the wave-beach-profile. During change of the profile, with longshore currents additionally perhaps, an important loss of sand masses cannot be avoided.

Therefore here the concept of a depot nourishment in form of such a sand groyne was planned as a field experiment with the scale 1 to 1 (FÜHRBÖTER et al. 1972, KRAMER 1972). For observation of the full scale experiment, a comprehensive measuring and survey program was carried out by the AMT FÜR LAND- UND WASSERWIRTSCHAFT HUSUM together with university institutes, amongst it the LEICHTWEISS-INSTITUT FÜR WASSERBAU of the Technical University of Braunschweig with a wave and current measuring program (FÜHRBÖTER et al. 1972, BÜSCHING and FÜHRBÖTER 1974, DETTE and FÜHRBÖTER 1974).

After surveys and investigations on the shore before the beach nourishment, in summer 1972 an additional mass of nearly 700,000 m^3 was deposited before the center of the defense works from Westerland. Only one feeder pipeline was used for it being lengthened perpendicularily to the shore across the surf zone.

The grain size of the sand deposited at the beach was nearly similar to that of the natural beach sand; from the nearly 1,000,000 m^3 excavated in the wadden sea behind the island, about 300,000 m^3 with grain diameter less than .2 mm were lost; this is in good agreement with other beach nourishments on the german coast of the North Sea where about 30 % were estimated as spoil loss during beach fill process (KRAMER 1972).

Because of heavy wave action even during summer season, the sand groyne was formed into an artifical sand spit already during construction. The survey from 11.10.1972 shows the form of the spit with the additional mass of 700,000 m^3 of sand (Fig. 7).

Fig. 7 shows the further development of this sand spit; Fig. 8 shows the wave climate of the 3 winters after the nourishment (measured about 1,300 m ashore at a water depth of about 8 m below MSL). Additionally, on Fig. 9 the change of the distribution of the additional sand masses in m^3/100 m shoreline for a length of 1.7 km around the center line of the sand groyne and for the whole length of 8 km is given.

Winter Season
1971/1972

Winter Season
1972/1973

Winter Season
1973/1974

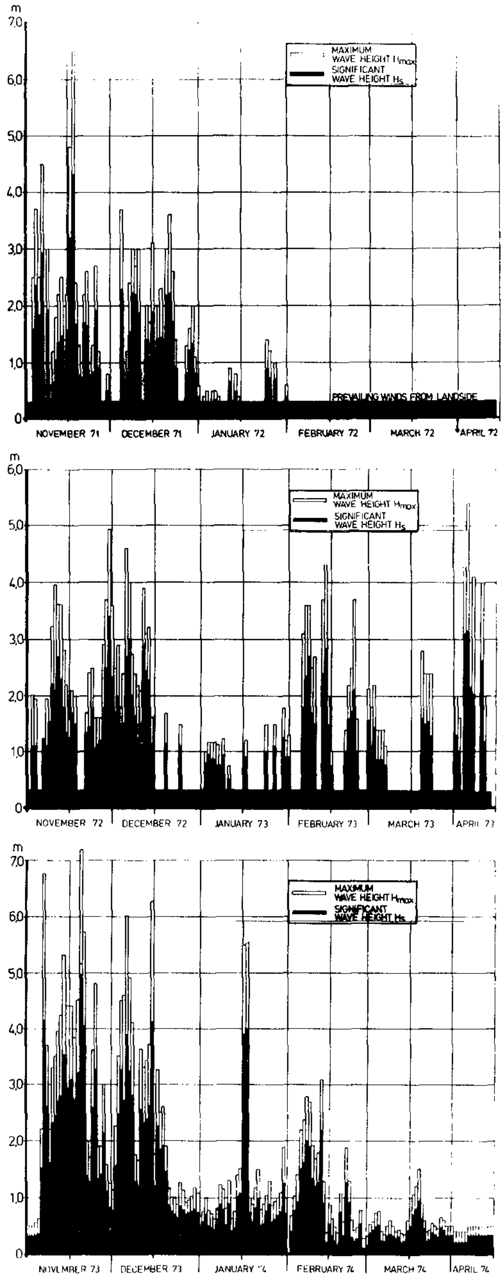


Fig.8: Wave climate before Westerland/Sylt from 1971 to 1974

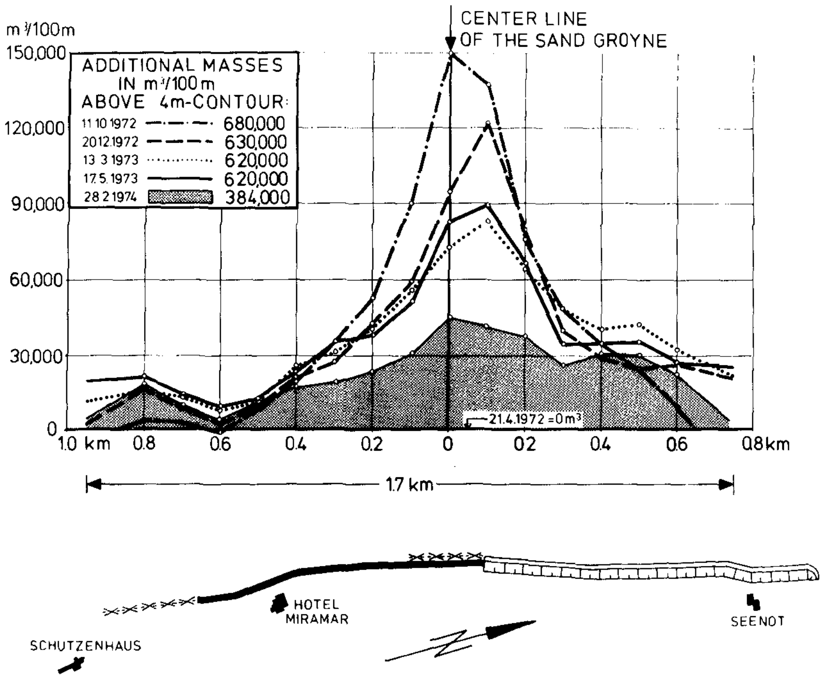


Fig. 9: Distribution of the additional sand masses near the center line of the sand groyne (length 1.7 km)

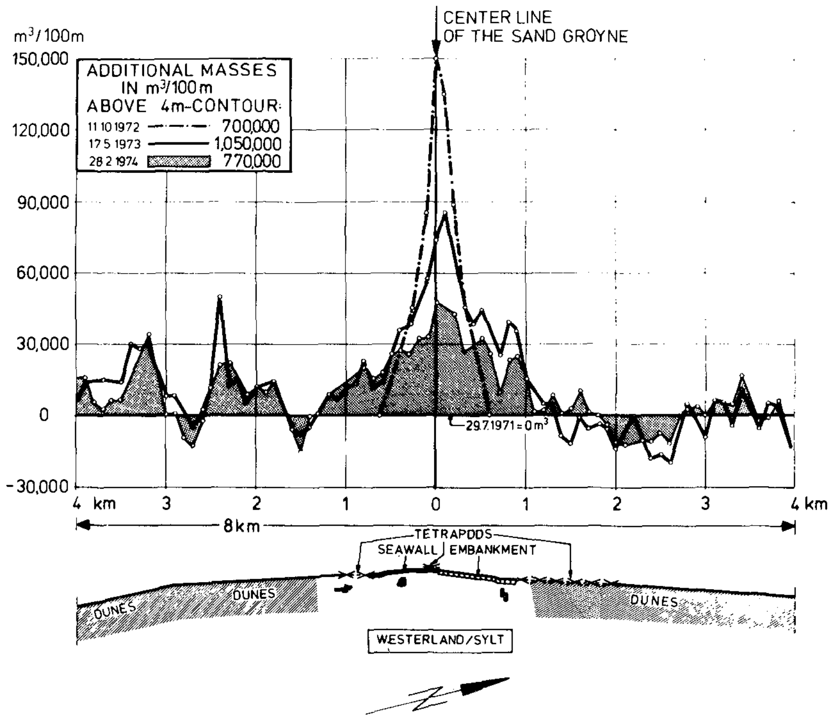


Fig. 10: Distribution of the additional sand masses near the center line of the sand groyne (length 8.0 km)

The results from Fig. 7, 9 and 10 can be summarized as followes:

a. Even during the relative weak storm season of winter 1972/1973 the changes of the shape of the artificial sand spit were more significant than in the following winter with stronger storm action.

b. The change of the form of the sand groyne as predicted in the scheme on Fig. 2 was verified by the field experiment.

c. After construction, only a length of about 1 km was protected by the sand depot at both sides of the center line of the groyne. However after one winter season already the waves and their longshore currents had distributed the sand over the whole length of the protection works.

In the area near the center line (length 1.7 km), sand losses from 680,000 m^3 in October 1972 to 385,000 m^3 in February 1974 occurred. With regard to the length of 8 km, however, the masses increased to 1,050,000 m^3 in May 1973; this is surely due to the deposition of additional sand from the natural longshore current due to the sand spit acting like a single groyne. During winter season 1973/1974 with very heavy wave action (Fig. 8) and 5 extreme storm surges, the masses decreased to 770,000 m^3; this is still 90,000 m^3 more than the 680,000 m^3 after construction in October 1972 (Fig. 9 and 10).

3. BEACH NOURISHMENT AND HALF DECAY TIME

It is a rule of experience for artificial beach nourishments, especially losses of material per unit of time(monthly or annually) are predominant just after the beach fill than later on (KRAMER 1958, LUCK 1968). This is due to the necessary accomodation of the artificial spoil beach slope to the wave equilibrium profile.

It seems that in this case the law of half decay time from nuclear physics can be used

$$V = V_o \cdot 2^{-\frac{t}{t_H}}$$

V = Volume of additional sand masses at the time t

V_o = Volume of beach fill after the nourishment (t = 0)

t = time

t_H = half decay time

On Fig. 11, the reduction of a beach fill (V_o = 98,000 m^3) at the Baltic Sea (Sierksdorf) during one winter season is illustrated in linear and logarithmic scale. The straight line in the logarithmic presentation shows a quite good agreement with the expontial law. Further surveys were not available for this case study.

With a digital program also used for Fig. 9 the sand losses in the area near the centerline of the sand groyne (length 1.7 km, Fig. 9) were computed for the additional masses above different levels from MSL - 4 m till MSL + 1 m; with 680,000 m^3 = 100 % on 11.10.1972 the decrease of the beach till near the centerline is to be seen on Fig.12 with a linear time scale.

According to the occurrence of waves, for the use of the concept of half decay time a distorted scale of time should be used. Instead of time the sums of wave energy is plotted against the sand losses (Fig. 12); the total wave energy in kWh/per m shoreline was calculated by application of linear wave theory from the continuous wave records (Fig. 8) and taking the significant heights.

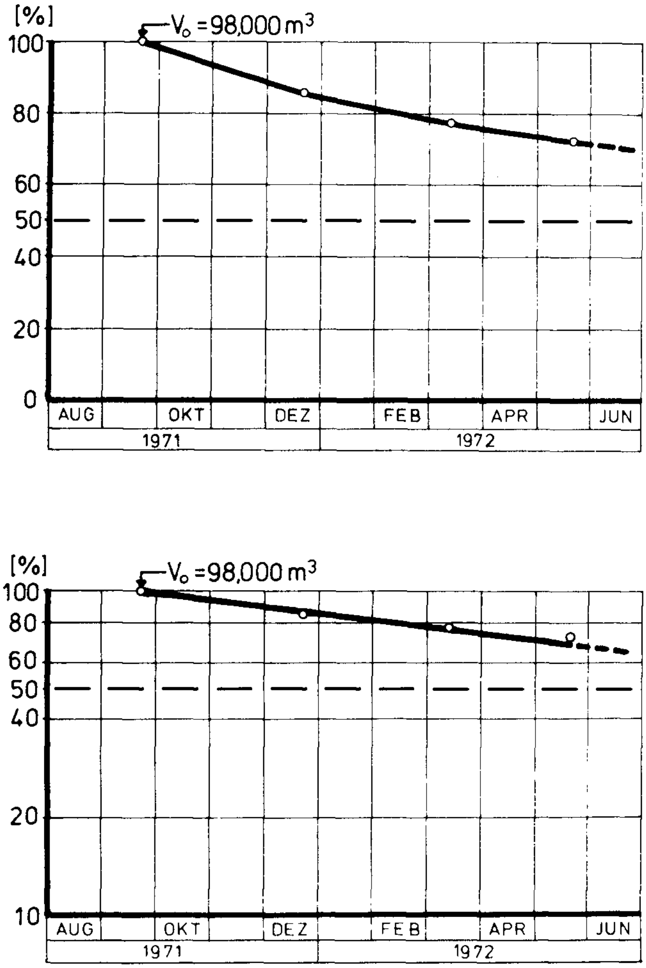


Fig. 11: Sand losses of a beach nourishment during one winter season

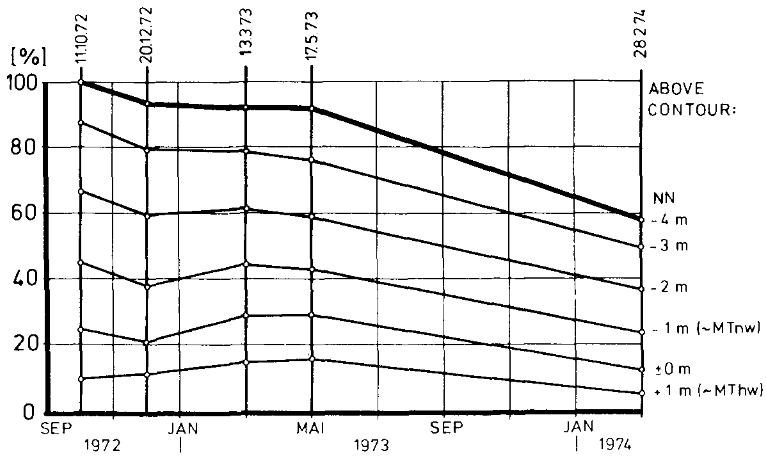


Fig. 12: Sand losses in the area near the center line (length 1.7 km, see Fig. 9)in dependence of time

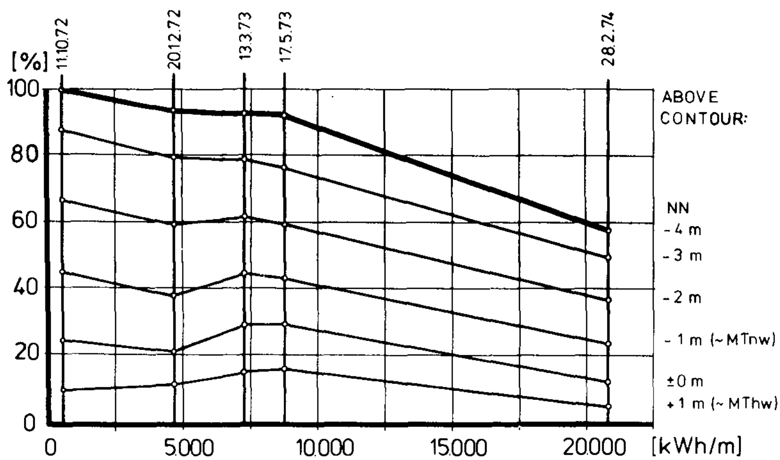


Fig. 13: Sand losses in the area near the center line (length 1.7 km, see Fig. 9) in dependence of the sum of wave energy

In both cases the plotting of Fig. 12 and Fig. 13 do not give such a clear picture like Fig. 11. This is mainly due to the fact that the length of 1.7 km is not representative for the whole length improved by the nourishment. For 8 km of shoreline (Fig.10) the result of the surveys is as already mentioned before:

11.10.1972	680,000 m^3
17. 5.1973	1,050,000 m^3
28. 2.1974	770,000 m^3

Because the surveys are expensive in costs, time, personal and evaluation and strongly dependent upon weather conditions, only a restricted number of them could be carried out. Seasonal changes or the effect of single storm surges therefore cannot be selected here. So the reduction of masses on Fig. 12 and Fig. 13 cannot be regarded as real losses because the lateral shorelines have their benefit from them (Fig. 10).

4. CONCLUSIONS

The time and number of surveys (nearly 3 years) do not allow up to today an exact extrapolation of the half decay time for the artificial sand spit. The morphological development, however, shows that a sort of stabilisation of it can be stated which also remainde during the very strong storm and wave action of the winter 1973/1974 (Fig. 7, 9 and 10). Further surveys and investigation will help to allow a judgement about the feasibility of the concept. The results seem so far to be of high interest for further planning and design in future.

4. REFERENCES

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