CHAPTER 139

BEACH NOURISHMENT AND DUNE PROTECTION

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ABSTRACT

The environmentally favoured method of beach maintenance by nourishment with sand raises the question of minimization of the average annual sand requirement. In the following sand loss estimation models are compared to field data. A concept for protection of the dry beach and dune areas against erosion during stormtides is discussed as a means of reducing the required sand volumes for the beach maintenance.

INTRODUCTION

Sand beaches play a rapidly increasing part for general holiday and weekend activities. Consequently, the "stability" of beaches receives more and more attention. A stable sand beach assumes under a constant wave action an equilibrium form on which the hydrodynamic forces are in equilibrium with the resistance forces of sand grains to movement. The shore normal net movement of sand ceases on such a profile and the amount of sand mobilized by the wave action has a minimum. Large disturbances can be caused to the dynamic equilibrium conditions (average due to usual wave conditions) by the erosion due to heavy storms and storm tides. The sand carried by the storm waves from the high beach into the usual surf zone is after the storm "surplus" to the requirements and has to be redistributed, i.e. in the amount of loss increases.

BEACH NOURISHMENT

Beach nourishment is regarded today as the environmentally acceptable method of beach protection. The need for nourishment may arise from a number of causes. For example, an island may lose its beach by littoral transport that is carried beyond the ends of the island and is not returned to the beach; i.a. an open sand system. Likewise a reduction of sediment supply to a coast, by whatever cause, will lead to local erosion that may have to be counteracted by nourishment.

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Nourishment itself also disturbs the dynamic equilibrium of the underwater profile and leads to increased losses. The extent of the disturbance depends on the grain size of sand used in nourishment relative to the native beach sand and on the coastwise extent of the beach fill.

Dette et al. (1994) introduced the assumption that for a two-dimensional beach fill, Fig. 1, the erosion rate under constant energy flux is proportional to the volume. Hence, the eroded volume is

$$V(t) = k_2 e^{-kt} = V_o e^{-kt} \tag{1}$$

for $V(t) = V_m$ at $t = 0$. A renourishment is required when $V(t) = V$ and the required volume is

$$V_n = V_m \left(2^{T_r/T_h} - 1\right) \tag{2}$$

where V_n is the volume of nourishment per m, V_m the minimum volume under an equilibrium profile (Fig. 2), T_r the renourishment interval and T_h is the half-life of the beach fill when $V(t = T_h) = V_0 / 2$.

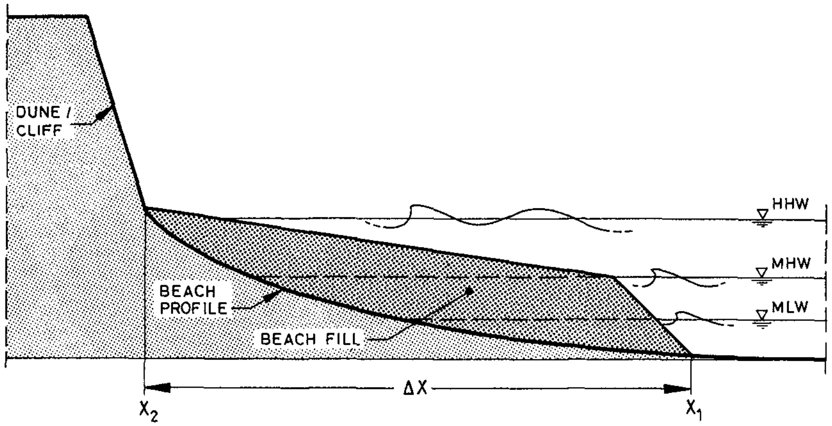

Fig. 1 Cross-section of beach nourishment (schematic).

According to eqn (2) the required renourishment volume, V_n, at a constant V_m is a function of T_r and T_h only. Consequently, the same condition can be maintained with a shorter repetition interval, T_r, and smaller volume of beach fill, V_n, or with larger volumes at longer intervals.

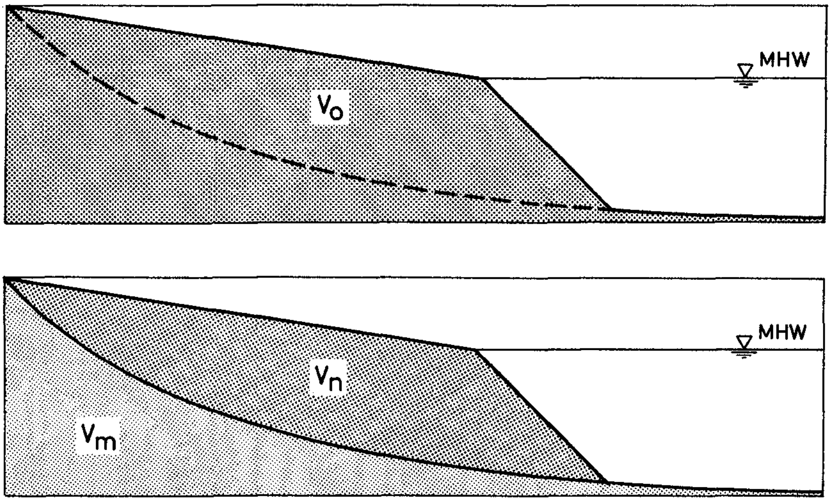

Fig. 2 Definition of volumes V_0, V_m at t = 0 after placement of the beach fill (schematic)

The average required rate of sand supply is $Q_n = V_n / T_r$ or

$$Q_n = \frac{V_m}{T_r}\left(2^{T_r/T_h} - 1\right) \tag{3}$$

The rate increases exponentially with T_r. Conversely, Q_n goes to minimum if T_r goes to zero, i.e. a continuous nourishment. Whether a continuous nourishment (according to demand) is practicable is another matter that is not further discussed here, except to say that hydraulic conveyance as sand by - passing has been used for a long time.

Expressing the rate of required nourishment as a ratio of Q_n (T_r) to Q_{min} as

$$\alpha = \frac{2^{T_r/T_h} - 1}{\left(T_r/T_h\right)\ln 2} \tag{4}$$

shows that both the required beach fill volume (eqn (2)) and the average sand supply rate increase exponentially with repetition interval, Table 1.

T_r / T_h	V_n / V_m	α
0	0	1
1/2	0,41	1,20
1	1	1,44
3	7	3,37
5	31	8,94

Table 1 Dimensionless beach fill volumes V_n / V_m and average dimensionless annual sand requirement as a function of the ratio of nourishment interval to the half life of the fill, T_r / T_h.

The result also indicates that for a given V_m, which is a function of the wave climate and grain size of the beach material, the minimum required sand supply rate occurs at $T_r = 0$, i.e. continuous supply.

The deduction is that the optimum supply rate $Q > Q_{min}$, is a compromise between practical requirements and aspects that affect the half-life.

Dean (1983) showed on the basis of the Pelnard-Considère (1956) equation that the length of the beach fill, l, affects the loss rate as

$$\left(t_p\right)_2 = \left(t_p\right)_1 \frac{l_2^2}{l_1^2} \frac{H_{b1}^{5/2}}{H_{b2}^{5/2}} \tag{5}$$

where t_p is time required for a percentage p of the fill volume to be lost, H_b is the breaker height and subscripts 1 and 2 refer to particular fills.

FIELD DATA

Data are available from six beach nourishment sites on the island of Sylt in the North Sea (by the courtesy of ALW Husum). The coast is a high energy coast with a mean annual shore normal energy flux of ca. 30 000 kWh per m beach. The data from Westerland are plotted in Fig. 3. The volumes were recorded as those above the 4 m datum below mean sea level.

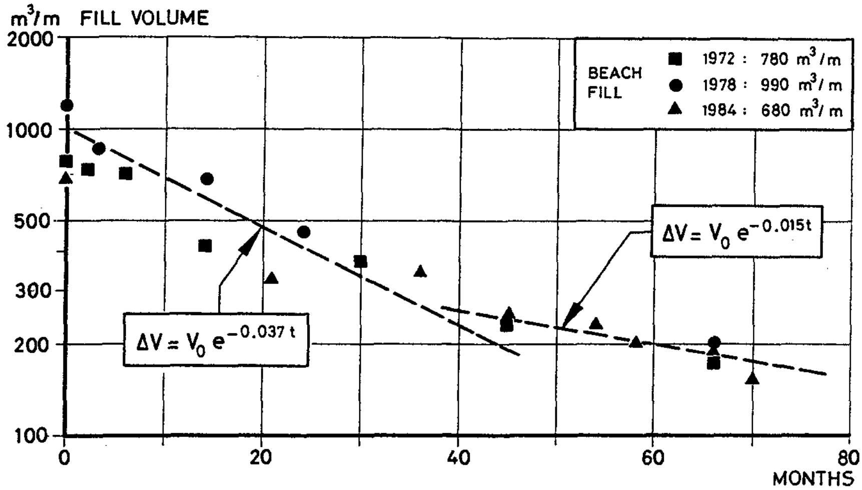

Fig. 3 Decay of repeated beach fill volumes in front of coastal structures at Westerland; Sylt/North Sea

The data show that the initial rate of decrease of the beach fill volume tends to support the exponential loss concept according to eqn (1). However, after about 2.5 to 3 years the slope changes appreciably and the data approach another exponential loss rate. Similar behaviour is illustrated by the data from the other five sites along the southern half of the coastline, Fig. 4. Although the scatter of data points for the reduced loss rate is substantial, the trend is unmistakable.

The relationships like eqn (5) are difficult to verify because although the fill profiles are known as a function of time the amounts of material brought into the study area by littoral transport are essentially unknown. At Westerland the three fills had different lengths. The 1972 fill was in the form of a peninsula into the surf zone with l ~ 350 m, extending about 250 m seaward at mean sea level. In 1978 an about 1 km long beach fill of 80 m width and in 1984 one of 1.5 km were placed. Assuming that the wave height remained the same eqn (5) indicates that the time to lose the same percentage of sand from the 1984 fill volume should be approximately 18 times that of 1972. Even for the similar fills of 1 km about 1.5 km lengths the ratio should be 2.25, yet Fig. 3 indicates that the volume was halved in approximately in the same length of time.

An additional feature of the field data is that the seaward slope of the beach fill has a strong effect on the loss of material during storms from the normally dry beach as illustrated by Fig. 5 for two successive winters with comparable storm tide histories.

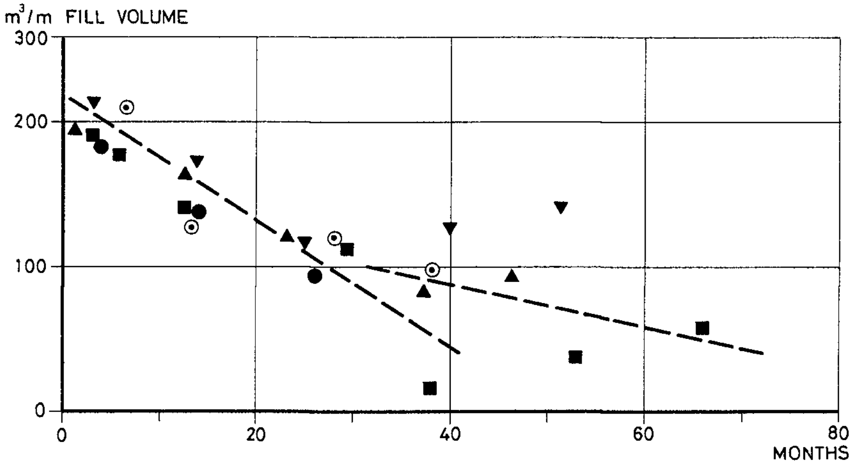

Fig. 4 Decay of beach fill volumes at 5 sites in front of dunes at the west coast of Sylt/North Sea

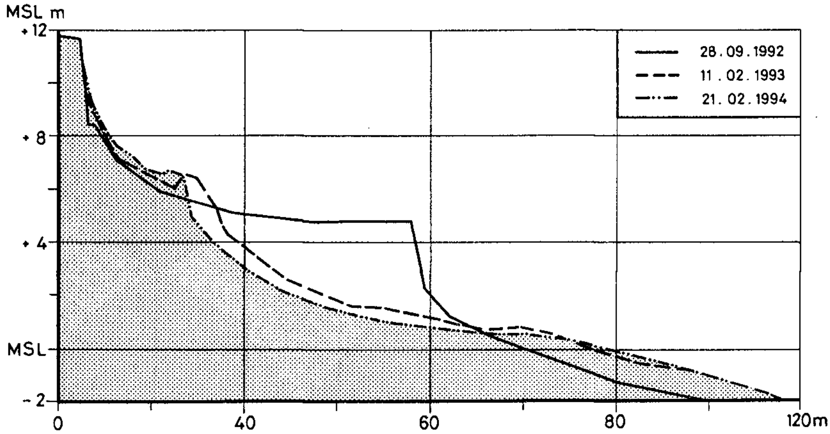

Fig. 5 Erosion of dry beach by storm tides on the west coast of Sylt

Peak water levels above MSL were 2.86 m and 3.25 m in 1993 and 1994, respectively with residence times above 2.0 m of ca. 50 and 80 hours respectively. The flat slopes with reduced losses are well described by the Dean-type relationship

$$h = A\, x^{n} \tag{6}$$

Apparently, when the waves are able freely run up and down the slope the losses are minimized.

DUNE PROTECTION

Substantial quantities of sand can be eroded by storm tides from the usually dry beach zone. Steep storm waves at raised water level transport large quantities of sand shore normal to the usual surf zone. Locally these quantities can reach 200 m^3/m. For example, the 1990 storms eroded 1.8 x 10^6 m^3 of sand from the west coast of Sylt, averaging ca. 60 m^3/m for the coastline. In many instances only a fraction of this sand is brought back to the beach face by subsequent wave action. The restoration of the dry beach and dune by wind-borne sand transport too is a slow process. Especially in open sand systems most of the "surplus" sand in the every day surf zone can be lost in littoral transport after the storm, i.e. carried beyond the ends of the island and lost from the locak sand system. On an out of equilibrium underwater profile the amount of sand mobilized by the daily wave action is higher and hence also the amounts transported currents.

Consequently, for an efficient management of beach nourishment volumes and for the protection of dry beach/dune the uncontrolled transfer of large volumes of sand into the surf zone during severe storms should be avoided. Raudkivi (1989) proposed a method of reduction of the sand loss with the aid of geotextile membrane, Fig. 6.

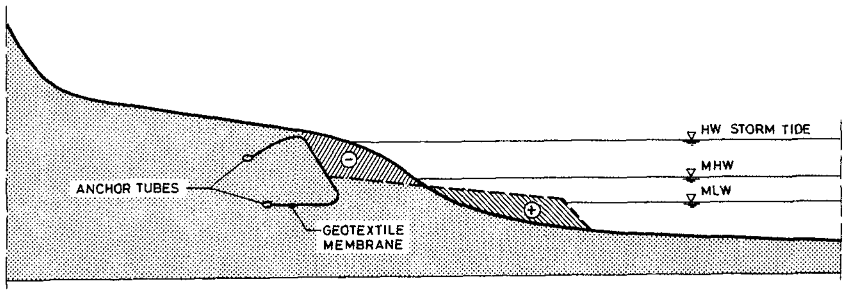

Fig. 6 Damage limitation of the dry beach and dune by a storm tide with the aid of a geotextile membrane (schematic)

The sand seaward of the membrane may be eroded during a storm or a sequence of storms but that behind it is protected. The membrane usually is called in action only a few days in a year and is thus not comparable to a seawall. If the membrane is uncovered the sand cover has to be restored from the lower beach. The location of the membrane is a matter of optimization. Too near to the water's edge the frequency of maintenance increases, too far the amount of sand lost increases.

In general, an uncontrolled erosion of the high beach leads to an erosion escarpment. In the sand behind the escarpment (or dune) the wave impacts maintain a water table in the sand that is a little higher than the local mean water level at the escarpment. At each wave trough a step is created in the water level, Fig. 7, and the sand starts to drain. The outflow of water concentrates at the level of water in front of the escarpment and carries sand with it. This leads to an undercutting of the sand face which tends to slide down in layers. The loose sand is rapidly dispersed by waves and the process repeats itself.

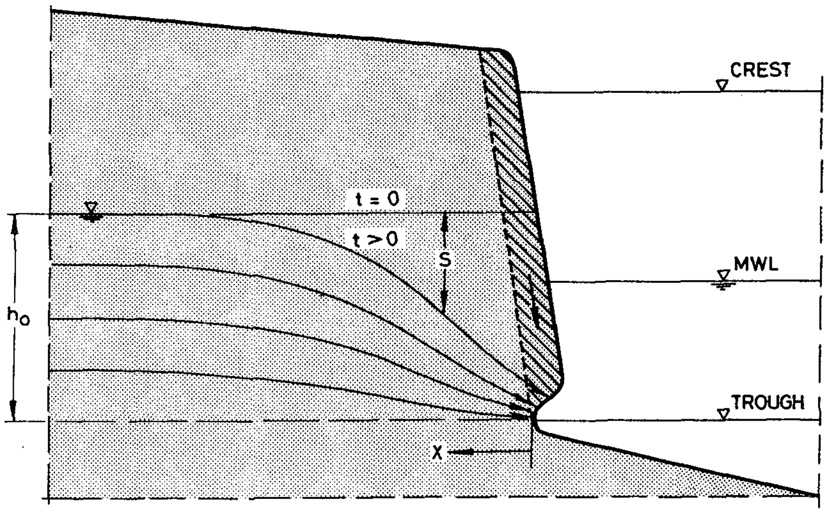

Fig. 7 Drainage and undercutting of a sand face due to wave action (schematic)

The problem of drainage through a "vertical" face was treated by Nguyen and Raudkivi (1983). Fig. 8 shows the propagation of the phreatic surface back from the sand face. The drawdown, s, at a distance x/h_0 is expressed in terms of a dimensionless time τ as

$$s = h_0 \, [1 - G \, (x/h_0, \tau)]$$

$$\tau = \left(\frac{K}{S_v \, h_0} \right) t \tag{7}$$

where K is the permeability of sand (m/s), S_v is the volume of water retained in the pore space (S_v < n the porosity) and t is time.

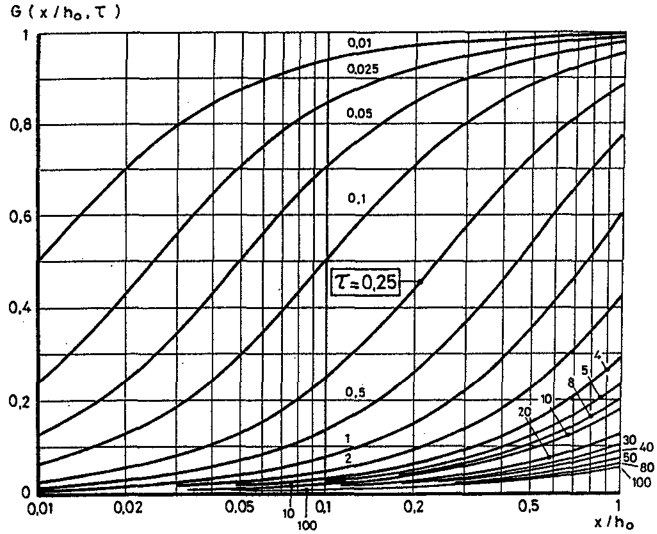

Fig. 8 Movement of the phreatic surface by drainage through a vertical face (Nguyen and Raudkivi, 1983)

The order of magnitude of the term ($k/S_v h_0$) is ca 10^{-4}. Hence, already at τ = 0.01 the position of the phreatic surface corresponds to that at ca 2 minutes. Consequently, the water surface translation are confined to the immediate vicinity of the sand face, within a fraction of h_0, i.e. ca 10 to 20 %.

The membrane serves to restrain the sand grain during the drainage periods and to prevent the undercutting. The main requirement, apart from required tensile strength, weathering and abrasion properties, is that it must enable free flow of water, i.e. it must be more permeable than the sand. This is achieved by using an "opening size" in the membrane of about d_{65} of the sand.

During the wave impacts the wave forces are taken by the sandgrains and the membrane is stressed only by the through flow of water. The pressure waves attenuate in the sand very rapidly due to the air in the voids and in the water, c.f. studies by Nago and Maeno (1987). Consequently, any liquefaction of sand is confined to the immediate vicinity of the sand face.

A system of membranes as shown in Fig. 9 was tested in the Large Wave Flume in Hannover (Führböter, et al. 1991). Fig. 10 shows the initial profile and that after 15 hrs subject to monochromatic waves of 6 - 9 secs with wave heights most of the time 1.0 m and up to 1.3 m. The deformations of the installed membrane were generally less than 10 cm.

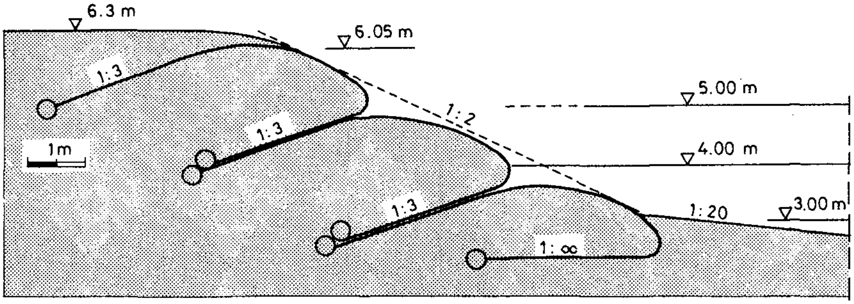

Fig. 9 Cross-section of the three-layered membrane tested in the Large Wave Flume in Hannover

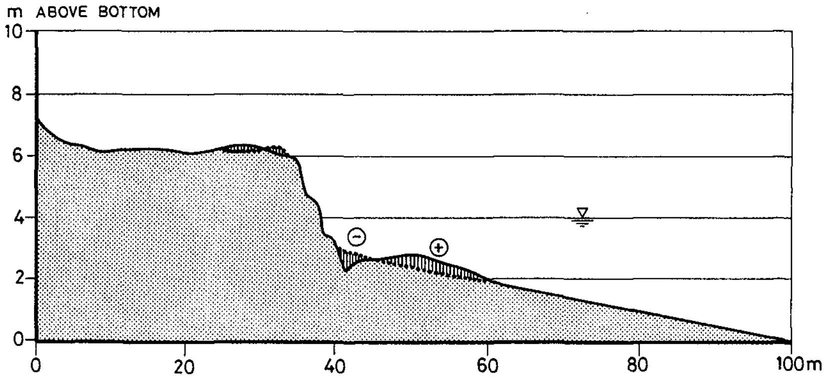

Fig. 10 Membrane after 15 hours of wave attack with waves up to 1.3 m height in the Large Wave Flume

The membrane limits the management of beach nourishment volumes to those required to maintain the surf zone under normal sea conditions, i.e. to the supply of sand to replace that lost from the system by the daily littoral transport. The membrane preserves all the sand in the high beach and dune.

About 2 km of such a membrane (two layers) were installed as hurricane protection 1992/93 in Fiji and 300 m in the three layers in a dune in front of a building at the dune's edge on Sylt 1991 (Fig. 11). Both have performed according to expectations.

Fig. 11 Uncovered geotextile membrane in front of a dune after called in action during a storm surge (phote: Raudkivi, 1994)

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