CHAPTER 44

BEACH AND DUNE EROSION TESTS

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INTRODUCTION

In the Netherlands a large part of the country lying below sea level is protected by sand dunes. The erosion of sand dunes during storms at the North Sea, by which the strong wave action is attended with a high sea level, is therefore of extreme importance in the Netherlands.

It is almost impossible to do adequate measurements along the coast during storms. Accordingly the Delft Hydraulics Laboratory was requested by the Public Works Department of the Dutch government to investigate in a model a number of matters related to both the maintenance of existing dunes and the design of artificial sand dunes as sea defence works.

The investigations reported in this paper are concerned with the following problems

a) the influence of the height of sand dunes upon the amount of coastal recession during storm conditions.

b) the influence of the wave characteristics upon the amount of coastal recession.

c) the differences in coastal recession and profiles obtained with regular waves and those obtained with wind waves.

The reproduction on scale of the phenomena in the surf zone is a difficult matter. Many investigators have come to the conclusion that there are several scale effects. Till now our knowledge is not sufficient to determine the magnitude of the scale effects. Owing to this the described tests can give only qualitative information.

DESCRIPTION OF THE TESTS

A synopsis of the tests is shown in table 1. The tests have been carried out in different wave basins, which dimensions are given in table 1. In all tests the wave direction was perpendicular to the beach. The bed of the model and the dune were composed of fine sand ($d_m = 0.22 \times 10^{-3}$ m). A wave filter has been placed in front of the wave machines to reduce the effect of innatural reflection from the wave paddle.

The starting profile was the same for all the tests and was obtained by regular waves $T = 1.56$ secs and $H_o = 0.155$ m with normal water level (N.W.L.). The slope of the upper beach obtained with this wave condition was produced till 0.12 m above normal water level. From this point a sand dune was placed with a slope and a height as marked in table 1.

For the erosion tests the still water level was heightened till 0.12 m above normal water level and this water level was marked as storm surge water level (S.S.W.L.).

The test $T_1 - T_5$ give information about the influence of the dune height, $T_6 - T_{12}$ give information about the influence of the wave steepness and the period, while $T_{10} - T_{15}$ give some information about the influence of wind waves in regard to regular waves.

The basis of comparison between the wind waves and the regular waves was:

1) The period of the regular waves is equal to the central spectral period of the wind waves.
2) The root mean square wave height of the wind waves (calculated from the energy density spectrum) is equal to the root mean square wave height of the regular wave (sine wave: $H_{rms} = 0.707\ H$).

The wind velocity in the wind flume was 10.5 m/s, 16.2 m/s and 21.7 m/s, respectively for T_{13}, T_{14} and T_{15}.

test	dune height in m	slope	period in sec	H_o in m	model dimensions in m	type of waves
T1	0.10	1:1.75	1.56	0.197	16x15	regular waves
T2	0.20	1:1.75	1.56	0.197	16x15	regular waves
T3	0.30	1:1.75	1.56	0.197	16x15	regular waves
T4	0.40	1:1.75	1.56	0.200	16x15	regular waves
T5	0.80	1:1	1.56	0.207	16x15	regular waves
T6	0.40	1:1.75	1.63	0.176	100x4	regular waves
T7	0.40	1:1.75	1.63	0.195	100x4	regular waves
T8	0.40	1:1.75	1.56	0.107	16x4	regular waves
T9	0.40	1:1.75	1.56	0.154	16x4	regular waves
T10	0.40	1:1.75	1.04	0.098	16x4	regular waves
T11	0.40	1:1.75	1.16	0.134	16x4	regular waves
T12	0.40	1:1.75	1.29	0.182	16x4	regular waves
T13	0.40	1:1.75	1.00	0.134 *	100x4	wind waves
T14	0.40	1:1.75	1.11	0.190 *	100x4	wind waves
T15	0.40	1:1.75	1.29	0.210 *	100x4	wind waves

table 1

* H_{15}

MEASUREMENTS

The beach profiles were measured from the crest of the sand dune seawards through the surf zone to the 16 metres distance mark (i.e. just in front of the wave filter for the basins of 16x15 m and 16x4 m). The measurements were made by ordinary level and staff at 10 cm intervals up to the 5 metres distance mark and at 20 cm there after along each profile. The distance between the profiles was 1.5 m for the basin with a width of 15 m and 0.75 m for the flumes with a width of 4 m. The measurements were made at 0, 1/2, 1, 2, 3 1/2, 5 1/2, 8, 11, 14 1/2 and 19 hours after the commencement of the test.

The wave heights were measured using the Laboratory's own design of temperature compensated parallel resistance wave height meter.

The regular waves were measured at 13 points spaced over a distance of one wave length in the direction of wave propagation and located on the deeper part of the beach profile (i.e. at a depth of roughly 0.5 m). With this information it was possible to distinguish the incident wave and the reflected wave from the beach. During a test large variations of the reflection coefficient were observed, which can be related with the changes in the beach profiles. The wave heights in table 1 are the wave heights of the incident wave.

The wind waves were measured at a fixed point (at a depth of roughly 0.5 m) over a period of at least 500 waves, mostly every half hour during a test. Records were made upon both Sanborn recorder and magnetic tape. The latter were used to produce a punched paper tape from which the energy density spectrum was calculated using a digital computer. An anoloque root mean square analyser was also used in the wind wave tests to obtain a rapid evaluation of the root mean square wave height, which values generally compared favourably with those calculated from the wave spectra.

RESULTS OF THE TESTS

Results of the tests $T_1 - T_5$

At the beginning of all the tests the sand eroded from the dune is deposited largely inshore of the 5 metres distance mark and rapidly builds up an inshore breakpoint bar. Visual observations on the model indicated that a definite plinging breaker occurred in this vicinity. Spilling breakers however occur at the initial breakpoint near the 7.5 metres distance mark. After a maximum building up of the inshore bar the slope of the seaward face of this bar flattens as an increasing part of the eroded sand moves seawards into the outer bar, which builds up steadily during the test and at which the initial breakpoint finally stabilises. In the latter part of the test plunging breakers occur in the initial breakpoint.

The profiles after a long time for different dune heights are basically the same except that they has been displaced in position along the horizontal axis (fig. 1 for T_1 and T_5). The represented profiles are average profiles of ten individual profiles. Especially in the surf zone 3-dimensional effects such as rip currents occur. In T_1 the inner bar is shifted away by taking an average profile. The difference in the seaward slope of the outer bar between T_1 and T_5 can be caused by a too short time of testing.

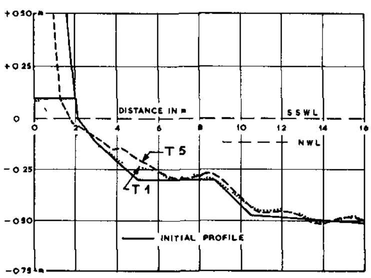

Fig. 1 Average profiles after 19 hours T_1 and T_5.

In figure 2 the recession of the dune foot for several dune heights is represented as function of time. The recession is measured as the horizontal displacement from the initial storm surge waterline. The dune foot corresponds in the tests to the limit of wave run up, so the dune foot is the limit of the wave formed profile.

The recession of the storm surge waterline shows the same tendence as the recession of the dune foot, but of course with a smaller amount of recession. Figure 2 shows a very definite influence of the dune height upon the recession of the dune.

In figure 3 the eroded volume from dune and beach is represented as a function of the time. From the two figures one can make the statement that with an increasing dune height the recession of the dune decreases, but the sand volume eroded from the dune and the upper beach increases.

Dune erosion is very rapid in the early stages of the test. Almost 50% of the erosion expressed in eroded volume occurs in the first 1/8 of the time required to reach more or less equilibrium.

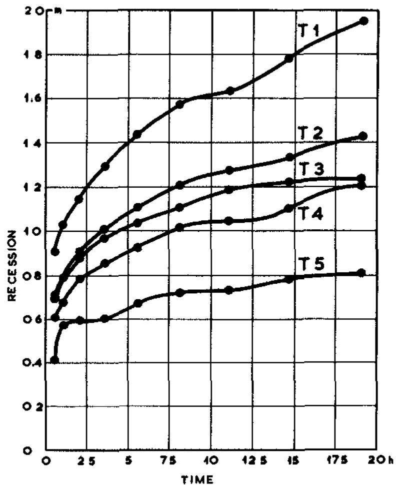

Fig. 2 Dune foot recession $T_1 - T_5$.

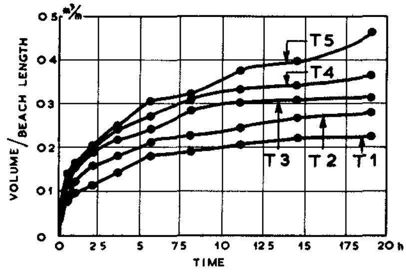

Fig. 3 Total volume eroded from beach and dune $T_1 - T_5$.

The recession of the dune foot is much more rapid. After 1/40 of the time required to reach more or less equilibrium almost 50% of the obtained maximum dune foot recession is reached.

For the given wave conditions, storm surge water level and sediment the profiles seem to be independent of the dune shape. The obtained profiles after 19 hours can be practically considered as equilibrium profiles. Their general shape can be represented by a parabola similar to that given by the empirical formula of Larras (reference 1). However bars occur in the profiles in the model and therefore this formula is not adequate for calculation purposes mentioned here after.

Maximum dune recession can be determined by moving the initial and the final (equilibrium) profile relative to one another until the eroded and deposited volumes are equal. This means that the dune recession is influenced by the initial profile.

Of course the above mentioned method is only valid if the eroded material from the dune and the upper beach is deposited in the cross section perpendicular to the coast, which we can expect with waves perpendicular to the coast and with no resulting currents along the coast.

Results of tests $T_6 - T_{12}$

In figure 4 the dune foot recession has been plotted as a function of time for $T_6 - T_{12}$. From this figure it is apparent that the recession of the dune foot at a given time is greater when the wave height is greater while the period is the same or almost the same.

For waves with wave heights of the same order but different periods the recession of the dune foot is smaller for the waves with the smaller period.

So we can conclude that the recession is not alone a function of the wave steepness, but also a function of the wave length. This is in agreement with the investigations of Saville (reference 2) and Iwagaki and Noda (reference 3) for initial profiles with one straight slope.

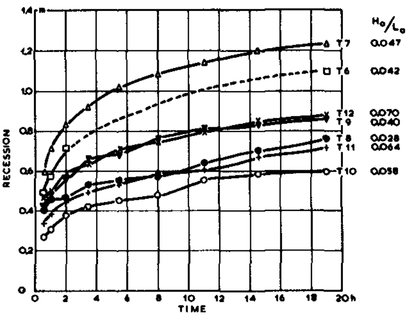

Fig. 4 Dune foot recession $T_6 - T_{12}$.

The number of tests is too small to determine a functional relationship between dune foot recession, wave steepness, wave length and time for a given sediment, water level, shape of sand dune and initial profile.

Results of tests $T_{10} - T_{15}$

There is no consistent difference in the recession of the storm surge waterline for wind waves as compared with regular waves. The recession of the dune foot however is consistently greater for wind waves than for comparable regular waves (fig. 5, 6 and 7).

The beach slope near the storm surge waterline is not much different for wind waves, but the dune foot is laying higher than for regular waves (fig. 8).

This can have several causes:

1° The greater wave run up height due to
  a) a certain percentage of the wind waves is higher than the wave height of the regular waves.
  b) the direct action of the wind as the uprush moves up the beach.
  c) the smoother profiles which are obtained with the wind waves.

2° The wind is moist from spray blown off the wave crest, which fact probably results in a dune face having a higher moisture content than with regular waves. The extra weight of this increased water content of the sand will increase the rate of collapse of the dune face due to instability.

By the above mentioned causes extra sand is placed within the reach of the waves and probably the bottom return current may assist in the removal of this sand in the seaward direction.

Looking to the figures 5, 6 and 7 it appears that the effect of the wind velocity (and model effects) are more important than those of wave irregularity. In order to separate the influence of the irregularity and the wind velocity it would be valuable to have a third serie of tests with waves generated by a programmed wave paddle.

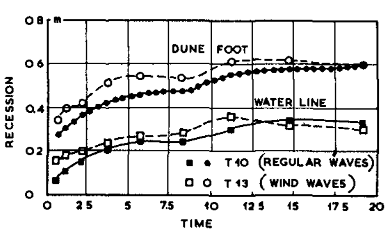

Fig. 5 Dune foot and waterline (S.S.W.L.) recession T_{10} and T_{13}.

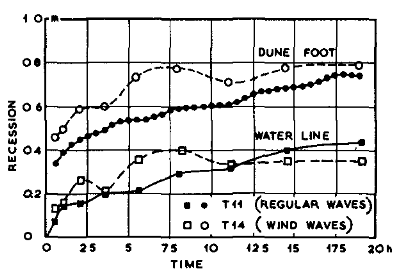

Fig. 6 Dune foot and waterline (S.S.W.L.) recession T_{11} and T_{14}.

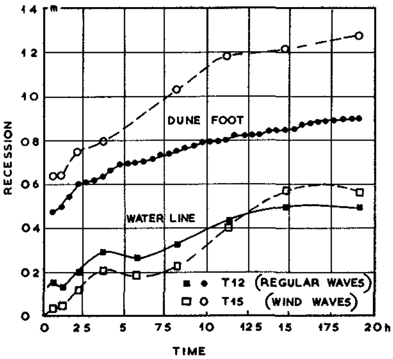

Fig. 7 Dune foot and waterline (S.S.W.L.) recession T_{12} and T_{15}.

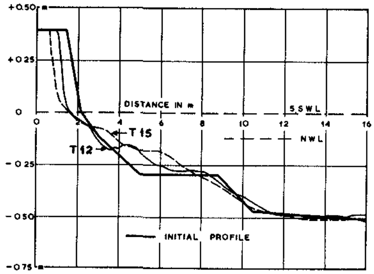

Fig. 8 Average profiles after 19 hours T_{12} and T_{15}.

CONCLUSIONS

1)The recession of a sand dune at a given time when measured by either the change in position of the storm surge waterline or the dune foot position increases as the height of the sand dune decreases. The eroded volume from the dune and the upper beach decreases as the height of the dune decreases.
2)For given wave conditions, storm surge water level and sediment the equilibrium profiles seem to be independent of the dune shape.
3)The dune erosion at a given time is a function of the wave steepness and also of the wave length for a given sediment, storm surge water level, shape of sand dune and initial profile.
4)The dune foot recession at a given time is greater for wind waves than for regular waves with the same energy (or H_{rms}) and a period equal to the central spectral period of the wind waves.
5)With wind waves the bars in the final profiles are not so prominent as with regular waves.
6)Dune erosion is very rapid in the early stages of the tests.
7)For circumstances where the eroded material is deposited in a cross section perpendicular to the coast maximum dune erosion can be determined by moving the initial profile and the equilibrium profile relative to one another until the eroded and deposited volumes are equal. This requires knowledge of:

a) the initial profile
b) wave conditions
c) storm surge water level
d) equilibtium profile for b and c
e) wave run up
f) slope of the eroded dune face

REFERENCES

1. Larras, J. - Les profils d'équilibre des fonds de sable sous la mer. Ann. des Ponts et Chaussées, vol 129, no. 4, 1959, pp. 391 - 404.

2. Saville, T. - Scale effects in two dimensional beach studies. Procs. 7th I.A.H.R. Congress Lisbon, vol 1, paper A_3, 1957.

3. Iwagaki and Noda - Laboratory study of scale effects in two dimensional beach processes. Procs. 8th Coastal Engineering Conference, Mexico City, Nov. 1962, pp. 194 - 210.