CHAPTER 127

ABOUT THE INFLUENCE OF EROSION VOLUME ON CROSS-SHORE SEDIMENT MOVEMENT AT PROTOTYPE SCALE

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ABSTRACT

In order to estimate erosion of sand beaches attacked by storm surges, experiments at prototype scale are necessary, since small scale models do not reproduce physical processes in the surf zone.
The present study describes the influence of erosion volume on cross-shore sediment movement during the development of beach profile.
The discussion includes parameters which affect the erosion volume and the accuracy of assessment.

INTRODUCTION

Breaking waves of major storms cause a three-phase flow consisting of sediment, fluid and air in a complex three-dimensional pattern. In order to avoid unknown scaling effects the sediment motion under such conditions requires experimental investigations at full scale.

A set of such experiments was carried out in the "BIG WAVE CHANNEL" (GWK) - length: 324 m, depth: 7 m, width: 5 m - in Hannover. The aspects of the study described below relate to the influence of instantaneous erosion volumes on suspended sediment content from commencement of wave action to the equilibrium of beach profile.
These studies are a continuation of the series from which the analysis of sediment transport volumes was presented at 20th ICCE in Taipei.

The sediment transport calculated from suspended sediment measurements amounted to about 30 % of that given by profile surveys, Fig. 1.
In the following the influence of erosion volume on the suspended sediment at a fixed location in the surf zone is discussed.

EXPERIMENTAL CONDITIONS

Repeated test series were carried out on a beach profile with foreshore. Fig. 2 shows the initial test profile. The dune had a 1 to 4 seaward slope from 2 m above still water level (SWL) to 1 m below SWL, followed by a 1 to 20 slope down to channel floor, i. e., it represented the conditions during a storm tide.

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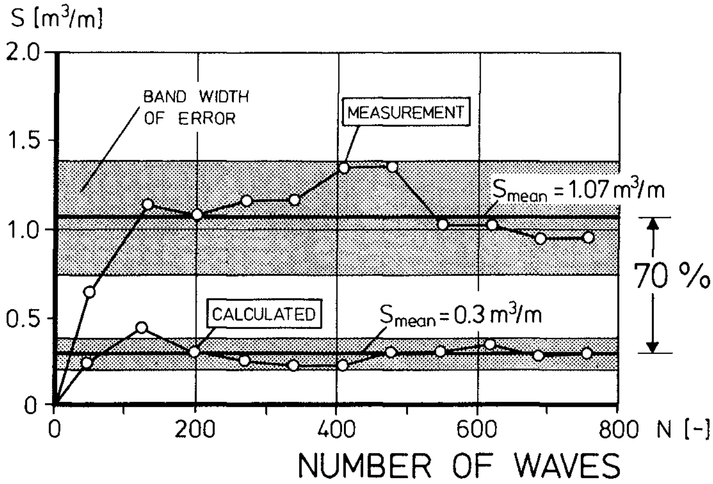

Fig. 1: Comparison of sediment transport between the calculated transport and that computed from profile changes during development phase of beach profile (Dette/Uliczka, 1986)

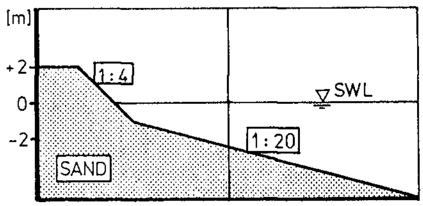

Fig. 2: Initial beach profile

The wave parameters selected were as follows:

1. Monochromatic waves: H_{rms} = 1.5 m, T = 6 s, d = 5.0 m
   H_o/L_o = 0.04, ξ_o = 0.29
2. Irregular waves (theoretical JONSWAP-spectrum):
   $H_{1/3}$ = 1.4 m, T_p = 6 s, d = 4.0 m, γ = 3.3, α = 0.0081,
   σ_a = 0.07, σ_b = 0.09

where ξ_o is the similarity parameter and γ, α, σ_a and σ_b are parameters of the JONSWAP-spectrum, H is the wave height, T period, L wave length, d water depth. Subscript $_o$ refers to deep water values.

The measuring station for initial wave height was at x = 150 m and x = 185 m, respectively.

The sand used for the test series had the following parameters:

- D_{50} = 330 µm, σ_g = 1.47, w = 0.0477 m/s
- D_{50} = 220 µm, σ_g = 1.48, w = 0.0284 m/s

where σ_g is the geometric standart deviation and w the mean fall velocity of sand at 18° C.
The measurements were carried out in test increments:

- with monochromatic waves the generator was stopped after about 80 waves when the initial wave form became significantly effected by reflection,
- with irregular waves after about 9 minutes, equal to two repetition intervals of the generated wave spectrum.

Before restarting the waves the profile was surveyed and the sediment concentration samples analysed. Restarting followed after the water surface had calmed.
The vertical distribution of suspended sediment concentration in the breaker zone was obtained by the suction method. The results of sediment concentration and wave height are time-averaged data for about 80 monochromatic waves (8 minutes) and about 9 minutes for irregular waves (about 90 waves).

The horizontal distance of the measuring stations for suspended sediment from the initial dune face was x = 26 m (D_{50} = 330 µm, monochromatic waves), and x = 22 m (D_{50} = 220 µm, location B, irregular waves), Fig. 3. The difference in x of 4 m has to be noted, when comparing data.

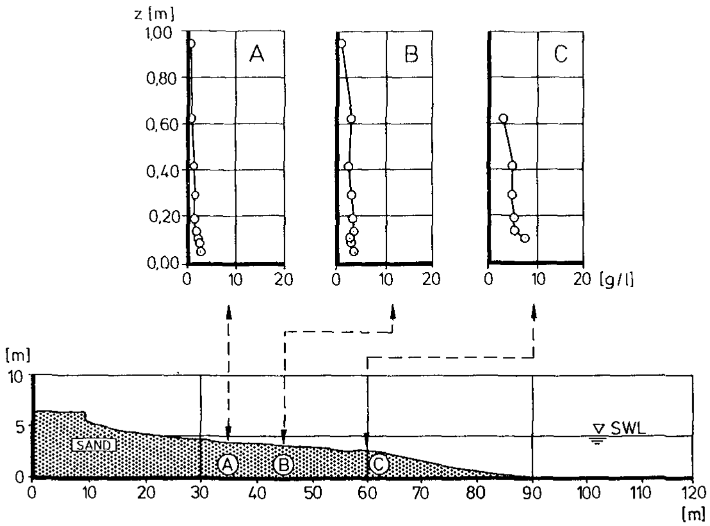

Fig. 3: Suspended sediment distribution over the equilibrium profile due to irregular waves (D_{50} = 220 µm)

At equilibrium conditions the sediment in suspension was measured at the station A, B and C, identical in Fig. 4. The measuring points for suspended sediment were vertically spaced as follows: 0.02 m, 0.02 m, 0.025 m, 0.025m, 0.05 m, 0.1 m, 0.125 m, 0.2 m, 0.325 m. On the average the lowest measuring point was 0.06 m above the bed but this varied with the movements of the bed and at times the lowest point was even burried.

Thus, the suspension was measured in the lower about 1 m thick layer.

SUSPENSION DISTRIBUTION ACROSS THE SURF ZONE AT EQUILIBRIUM CONOITIONS

The suspension distribution over the equilibrium profile due to monochromatic waves (D_{50} = 330 µm) was presented at the 20th ICCE.
The sediment concentration distributions over the equilibrium profile of D_{50} = 220 µm sand after about 2,000 irregular waves are plotted in Fig. 3.

The arithmetic mean of the 33 % highest waves, evaluated for the test increment at equilibrium conditions, yielded at the ponts A, B and C:

$$A:\ H_{1/3} = 0.9\ m, \quad B:\ H_{1/3} = 1.1\ m, \quad C:\ H_{1/3} = 1.4\ m$$

The water depths were:

$$d_A = 0.9\ m, \quad d_B = 1.3\ m, \quad d_C = 1.7\ m$$

The water temperature was about 20^{o} C. The breaker zone extended from about x = 65 m to nearly x = 30 m.

In order to give a description of wave conditions during the suspension measurements at equilibrium state a statistical expression for the breaker location was used. The waves were grouped into those with breakpoints seaward, landward and near (± 1 m) the measuring station. This information was obtained by analysis of video-tape and yielded the following values (% of waves at station):

	seaward	near	landward
A:	74 %	13 %	14 %
B:	65 %	16 %	19 %
C:	6 %	39 %	55 %

The high percentage of breaking waves near the point C is reflected in the high suspended sediment concentration, as well as in the wave height.

Table 1 gives the sediment concentration data associated with irregular waves.

CALCULATION OF WAVE ENERGY

In order to compare the beach development due to monochromatic and irregular waves, wave energy was calculated for each test series before the waves reached the beach profile using the socalled linear, AIRY or first order STOKE's wave theory.

DUNE WITH FORESHORE			
IRREGULAR WAVES	$H_{1/3}$ = 1.4 m		T_p = 6 s
Height above bottom	Sediment Concentration		
	$\bar{c}$	$\bar{c}$	$\bar{c}$
m	g/l	g/l	g/l
0.05	2.8	3.7	-
0.09	2.5	2.8	-
0.11	2.2	2.7	7.6
0.14	2.0	3.6	6.2
0.19	1.8	3.2	5.3
0.29	1.7	3.1	4.8
0.42	1.4	2.5	5.1
0.62	0.9	2.4	3.1
0.94	0.8	1.8	-
Location	A	B	C

Table 1: Sediment concentration data for irregular waves (D_{50} = 220 µm)

The average wave energy per unit surface area is

$$\bar{E} = \frac{1}{8} \cdot \rho \cdot g \cdot \frac{1}{N} \sum_{i=1}^{N} H_i^2 \qquad (1)$$

The erosion and suspended sediment data for profile development are plotted against accumulated wave energy instead of time or number of waves, i. e., against $\bar{E}$ N, where N is the number of waves. For irregular waves is N = $\Delta t/T$, i. e., the duration of the test increment divided by peak wave period.
The energy flux, $\bar{E}$ c_g, and the shape of the erosion volume and suspended sediment volume curves will be discussed in the section dealing with estimates of accuracy.

CALCULATION OF SUSPENDED SEDIMENT VOLUME

The suspended sediment mass during the development phase of beach profile was calculated from the expression

$$SV = \int_0^z \bar{c} \cdot b \cdot dz \qquad (2)$$

where b is the length of profile unit and z = 1.0 m, approx. Fig. 4 shows the suspended sediment mass in this lower about 1 m thick layer for the two grain sizes plotted against wave energy input per unit surface area seaward of breakers. Each point on the graph represents time-averaged sediment concentration volume for test increment at the energy input since commencement of test.

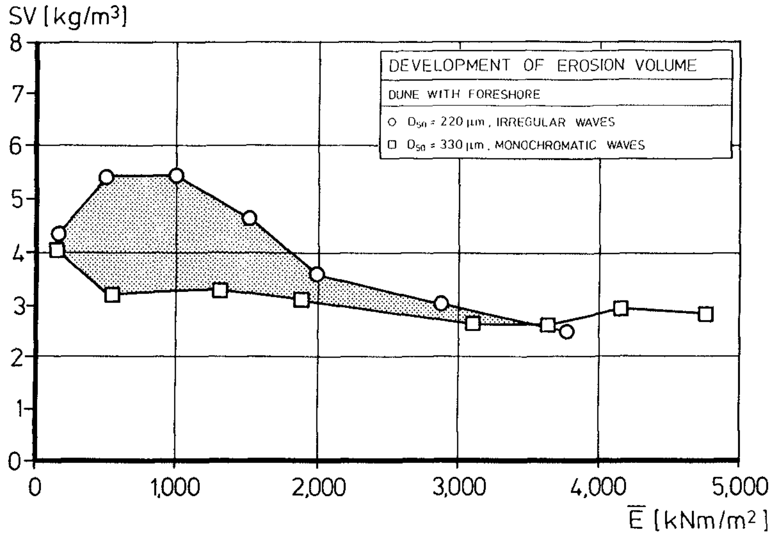

Fig. 4: Suspended sediment volume versus wave energy of monochromatic and irregular waves

The measured data on the suspended sediment volume yielded the following information:

- At the beginning of both test series the volumes coincided, but at about 1,000 kNm/m² the difference was about 40 %.
- When the equilibrium conditions of the profiles were approached suspended sediment volumes converged to about 2.5 kg/m³.
- The suspended sediment volume with monochromatic waves reached its maximum value in the first test increment whereas with irregular waves the suspension due to erosion reached its maximum after about five increments, Fig. 4.

It should be noted, that the accuracy of the sediment concentration measurements in the breaker zone was about $\pm$ 30 % related to the average (see Dette/Uliczka 1986).

Table 2 gives the data of suspended sediment volume due to monochromatic and irregular waves for the two grain sizes.

EROSION VOLUME AND SUSPENDED SEDIMENT VOLUME

The erosion volume was obtained by profile surveys after each test increment. The accuracy of profile measurements ($\pm$ 0.01 m) in terms of erosion volumes is about $\pm$ 1 %. The maximum erosion volume was about 15 m³ for monochromatic waves (D_{50} = 330 µm) and about 22 m³ per metre width for irregular waves (D_{50} = 220 µm).

DUNE WITH FORESHORE					
MONOCHROMATIC WAVES			IRREGULAR WAVES		
D_{50}= 330 μm			D_{50}= 220 μm		
Test Increment -	$\bar{E}$ kNm/m^2	SV kg/m	Test Increment -	$\bar{E}$ kNm/m^2	SV kg/m
1	137	4.1	1	170	4.4
3	547	3.2	3	509	5.4
7	1313	3.3	6	1019	5.5
10	1888	3.1	9	1528	4.6
15	3119	2.6	12	1994	3.6
17	3640	2.6	18	2886	3.0
19	4159	2.9	24	3781	2.5
21	4754	2.8			

Table 2: Data on suspended sediment volumes during development of beach profile under monochromatic and irregular waves (Test increments and energy input were continually summed, whereas the suspension data were time-average for each test increment)

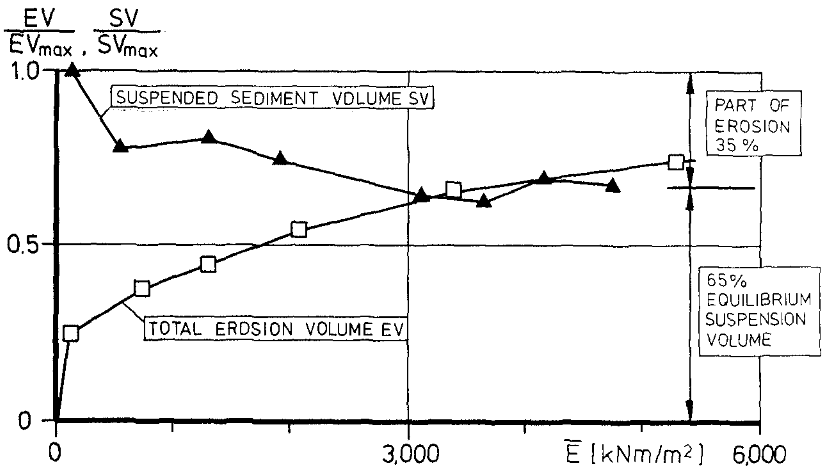

Fig. 5: Erosion volume and sediment in suspension volume as a function of wave energy input under monochromatic waves (D_{50} = 330 μm)

Erosion volume and suspended sediment volume were normalized with their maximum values. Fig. 5 and Fig. 6 show the erosion volume and suspended sediment volume as a function of wave energy under monochromatic waves (D_{50} = 330 μm) and irregular waves (D_{50} = 220 μm), respectively. The data on erosion volume are presented in Table 3.

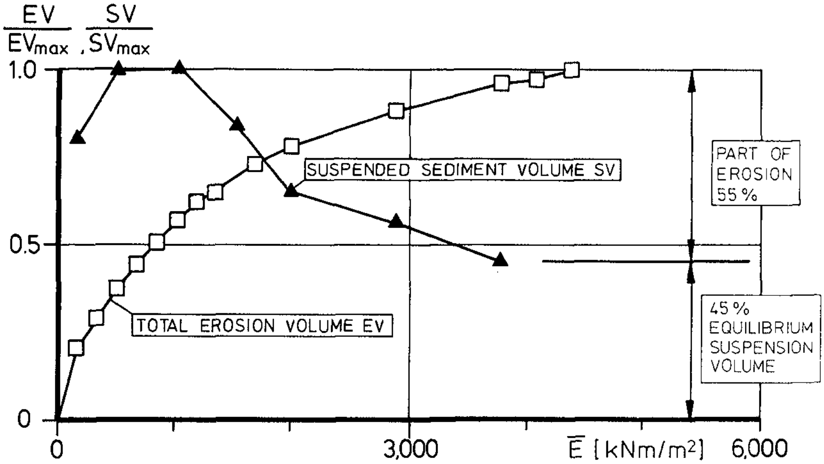

Fig. 6: Erosion volume and sediment in suspension volume as a function of wave energy input under irregular waves (D_{50} = 220 μm)

DUNE WITH FORESHORE					
MONOCHROMATIC WAVES D_{50}= 330 μm			IRREGULAR WAVES D_{50}= 220 μm		
Test Increment –	$\bar{E}$ kNm/m^2	EV m^3/m	Test Increment –	$\bar{E}$ kNm/m^2	EV m^3/m
1	137	3.8	1	170	4.4
4	739	5.7	3	509	8.1
7	1313	6.8	5	849	11.0
11	2080	8.2	6	1019	12.3
16	3379	9.9	10	1697	15.7
23	5273	11.2	12	1994	16.8
27	6437	11.9	18	2886	19.0
29	7020	12.3	25	3930	20.7
39	9889	15.1	28	4378	21.6

Table 3: Data on erosion volume during the development of beach profile under monochromatic (D_{50} = 330 μm) and irregular waves (D_{50} = 220 μm) (Test increments, energy input and erosion volume were continuously summed)

A smaller total erosion volume was generally associated with a smaller suspended sediment volume in the surf zone. This is a well known observation but some additional features immerge from the graphical presentation above:

- The erosion of the profile with sand D_{50} = 220 µm started more intensively than that of coarser sand at the same wave energy input
- After 3,000 kNm/m² about 90 % of the equilibrium erosion volume was reached for the finer sand, whereas for the coarser sand only 60 % erosion had occurred
- After 4,000 kNm/m² both suspended sand concentration profiles reached equilibrium conditions
- The effect on transport rate, described above, shows that the maximum suspension volume was reached with finer sand when about 40 % of erosion volume had been accomplished
- In terms of the equilibrium state, it is seen that 35 % and 55 %, respectively, of the maximum suspended sediment volume is transient sediment of the erosion process
- During the erosion process the suspended sediment volume at the measuring station reaches about twice the value at the equilibrium.

The 1.4 times higher suspended sediment volume of coarser sand (65 %/ 45 % = 1.4) seems to be due to the higher energy density of monochromatic waves. Under irregular waves the sediment can settle out during periods of small waves of the wave spectrum.
In order to find a direct relationship between suspended sediment volume and erosion volume the incremental data were analysed. The results are summarized in Table 4 and plotted in Fig. 7.

DUNE WITH FORESHORE			
MONOCHROMATIC WAVES D_{50}= 330 µm		IRREGULAR WAVES D_{50}= 220 µm	
EV m^3/m	SV kg/m	EV m^3/m	SV kg/m
3.8	4.1	(4.4)	(4.4)
1.4	3.2	1.8	5.4
1.6	3.3	1.3	5.4
0.7	3.1	0.5	3.6
0.6	2.6	0.4	3.0
0.7	2.9	0.3	2.5
0.7	2.8		

Table 4: Incremental data on erosion volume and suspended sediment volume under monochromatic and irregular waves

The volume in suspension and eroded for each point were determined for the same time.
There appears to be a linear relationship between erosion volume and the volume in suspension.

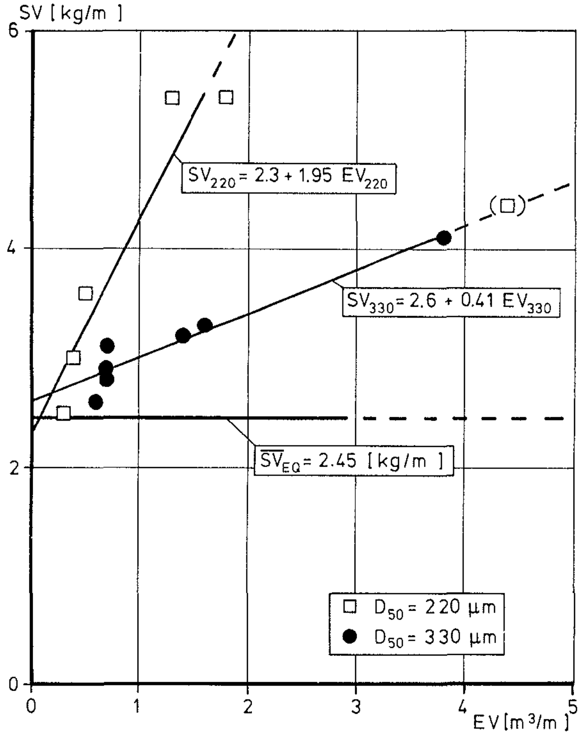

Fig. 7: Relationship between instantaneous suspended sediment volume and erosion volume for 330 µm-sand and monochromatic waves as well as 220 µm-sand and irregular waves

The suspended sediment volume at equilibrium state is about the same as presented in Fig. 4, i. e., about 2.5 kg/m after 4,000 kNm/m² energy input.

The slope of the Linear Regression Functions in Fig. 7 demonstrates the influence of grain size on suspended sediment concentration and erosion volume.

BEACH PARAMETER AND EROSION VOLUME

At first water level and wave conditions influence the erosion volume and the sediment movement as bed load and suspended sediment.

Below is a discussion of aspects of erosion as observed in full scale at the GWK.

A comparison of the growth of the erosion volumes, starting with different initial profiles, is shown in Fig. 8. The profiles were a 1 : 4 slope from channel floor to the top of dune (+ 2 m SWL) and that shown in Fig. 2, referred to as dune without and with foreshore.

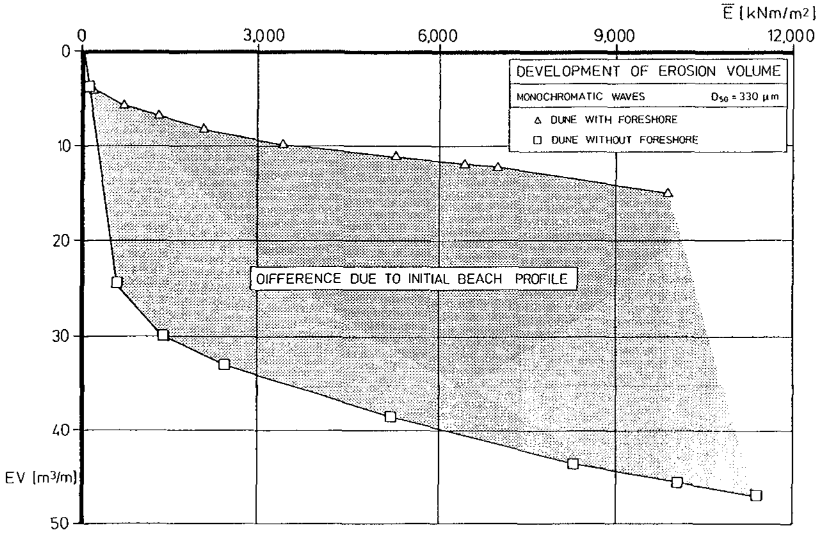

Fig. 8: Growth of erosion volume versus wave energy input for two different initial beach profiles

The erosion volume on the profile without foreshore is seen to be about three times that on the profile with foreshore. The 1 : 4 slope from channel bottom to the top of the dune lead to wave energy transformation directly in front of the dune face and therefore to large erosion volume as well as to extremely high suspended sediment concentration.

The influence of grain size on the erosion volume of a profile with dune and foreshore was determined by using two sediment sizes. A reduction of the mean diameter by about 30 % resulted in an increase of erosion volume by 100 % at energy input of 4,500 kNm/m², as shown in Fig. 9.

The comparison relates to the time, when the profile of the finer sand reached equilibrium. At the time only 70 % of the equilibrium volume of the coarser sand had been eroded.
Taking the total erosion volumes of both equilibrium profiles, after an energy input of 10,000 kNm/m², the difference was about 30 %. The energy input up to the equilibrium stage for the coarser sand was about twice that for the 220 µm-sand.

The foreshore slopes at both equilibrium profiles in the surf zone (330 µm and 220 µm sand) stabilised to about 1 : 20, whereas the slopes reported from nature for beaches with sand 220 µm are generally flatter.

DISCUSSION OF ACCURACY

The question of accuracy of the calculations and the data plots has been mentioned earlier.
If the erosion volume was plotted against the calculated energy input, both the data due to monochromatic and irregular waves should lead to

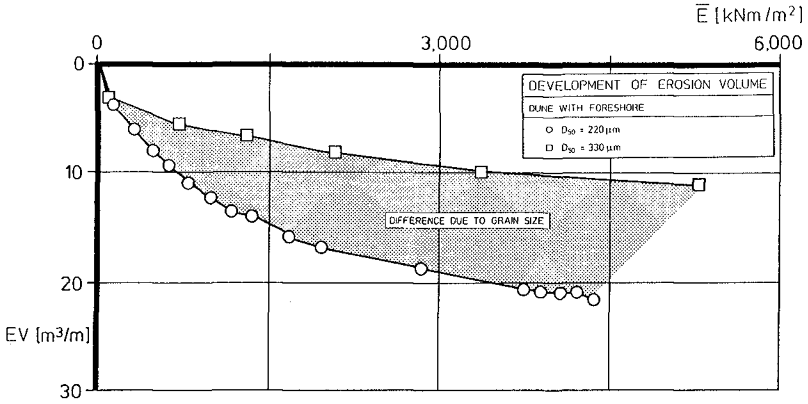

Fig. 9: Comparison of erosion volumes with different grain sizes

an identical function for equal initial profiles and the same grain size. Additional to the computation of average wave energy per unit surface area, energy flux was calculated at the measuring station in the wave channel, before breaking:

$$\bar{P} = \bar{E}\, n\, C \qquad (3)$$

with

$$n = \frac{1}{2}\left[1 + \frac{4\pi d/L}{\sinh(4\pi d/L)}\right] \qquad (4)$$

where d is the water depth, L the calculated mean wave length in the given depth of water, n is the relationship of wave group to wave phase velocity, and C is the mean wave propagation velocity in the given depth of water.

Fig. 10 shows the growth of the erosion volume of the profile with dune without foreshore under monochromatic and irregular waves using grain size D_{50} = 330 μm versus wave energy, and Fig. 11 the growth of erosion volume from the same tests versus energy flux.

Plotted at the same scale, Fig. 10 and 11, the differences in terms of energy flux are a maximum with 5 % at monochromatic waves, whereas at irregular waves the curves coincide. This shows that the erosion volume and suspended sediment volume could be compared both on the basis of energy input or energy flux. Nevertheless, the discrepancy of erosion volumes due to monochromatic and irregular waves is at maximum more than 50 %.
The wave conditions (monochromatic or irregular waves) have a major influence on the process of beach erosion.
The breaker form, breaker zone, rate of wave energy attenuation, velocity field etc. have a dominent influence on the sediment transport in the surf zone. As mentioned above, the higher energy density of monochro-

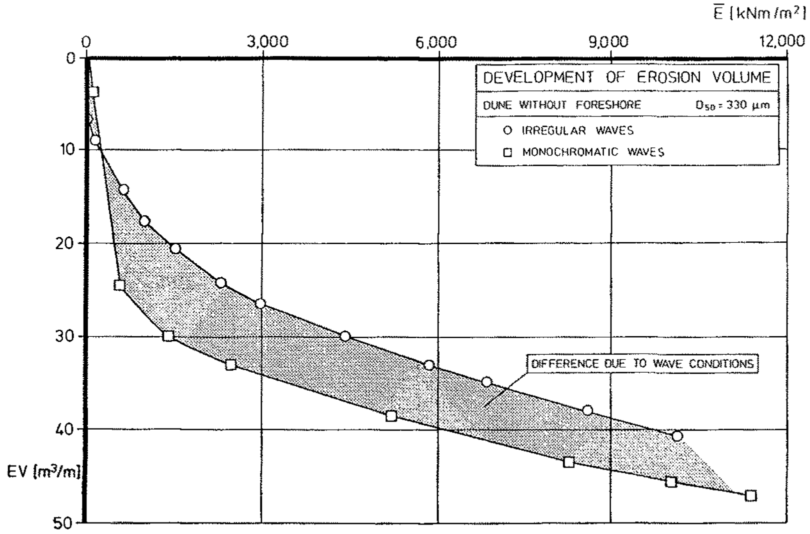

Fig. 10: Growth of erosion volume on the profile with dune without foreshore under monochromatic and irregular waves versus wave energy

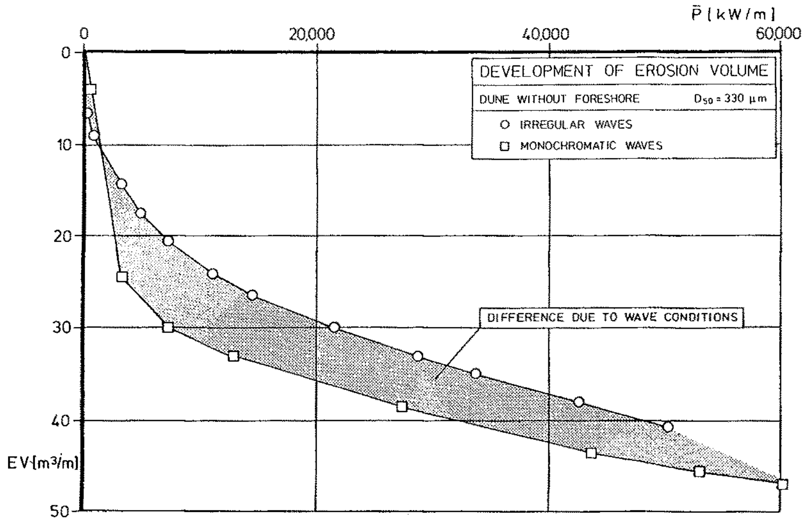

Fig. 11: Growth of erosion volume on the profile with dune without foreshore under monochromatic and irregular waves versus energy flux

matic waves at breaking leads to higher sediment transport, but under irregular waves the sediment can settle out during periods of smaller waves between groups of higher waves. The grouping as well as irregular waves leads to differences in turbulence intensity in the surf zone and hence to differences in the magnitude of the offshore sediment transport.

The computation of $\bar{E}$ and $\bar{P}$ by the extrem values of wave, trough and crest with zero down crossing method, does not describe these values correctly since the wave form is not accounted for. The method leads to an overestimating of the wave energy of irregular waves. The calculation of wave energy and energy flux from actual wave records or with higher order wave theories would improve the description.

CONCLUSIONS

Full scale test series, carried out in the BIG WAVE CHANNEL in Hannover, yielded information on the influence of erosion volume on cross-shore sediment movement in the surf zone and on the growth of erosion volumes for various initial conditions.

For comparison purpose the growth of erosion volume and suspended sediment volume were presented against the averaged wave energy input per unit surface area.

The suspended sediment volume (measured in the bottom 1 m thick layer) was related to the growth of erosion volume and was found to reach a constant value at the equilibrium conditions independent of grain size.

Initial beach profile and grain size used have a strong influence on the erosion process of a dune.

The accuracy of the results would be improved by inclusion of the detailed description of the wave form and the vortex intensity.

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LIST OF SYMBOLS

b	m	width per unit beach profile
c	kg/m^3	time-averaged sediment concentration
C	m/s	wave propagation velocity
d	m	water depth
D	µm	grain size
D_{50}	µm	mean grain size
$\overline{E}$	kNm/m^2	total wave energy per unit surface area
EV	m^3/m	erosion volume per unit width of beach profile
g	m/s^2	gravitational acceleration
H_{rms}	m	root mean square wave height
H_o	m	deep water wave height
$H_{1/3}$	m	arithmetic mean value of 33% highest waves
L	m	wave length
L_o	m	deep water wave height
n	-	ratio of wave group and phase velocity
N	-	number of waves
$\overline{P}$	kW/m	energy flux
S	m^3/m	total sediment transport
SV	kg/m	suspended sediment volume
T	s	wave period
T_p	s	peak period
w	m/s	fall velocity of D_{50}
x	m	horizontal coordinate
z	m	vertical coordinate
α	-	Phillips-parameter for JONSWAP-spectrum
γ	-	shape parameter for JONSWAP-spectrum
ξ_o	-	similarity index
ρ	kg/m^3	water density
σ_a	-	shape parameter for JONSWAP-spectrum
σ_b	-	shape parameter for JONSWAP-spectrum
σ_g	-	geometric standart deviation for grain size