CHAPTER 29

FIELD INVESTIGATIONS IN SURF ZONES

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ABSTRACT

During storm surges considerable wave energies are dissipated in surf zones; the energy transfer rates are in the order of one up to two powers of ten higher than outside the surf zone. A breaker parameter β introduced by FÜHRBÖTER (1974) with regard to a quantitative breaker classification, especially of the intermediate types between surging and spilling, was found to be convenient for practical application. The breaker parameter β is in close relation with the horizontal asymmetry parameter α of the breaking wave. With decreasing breaker parameter the asymmetry is increased and reverse.

Within the longshore currents macro-turbulences were discovered. The periodical fluctuation parameter γ was found to increase nearly lineari-ly with decreasing breaker parameter; the narrower the area is, where the main energy is dissipated the smaller becomes the mean periodical fluctuation which seems to be independent of the wave period but reaches up to 7 and more fluctuations within the wave period.

The mean longshore currents velocities reached up to 1.5 m/s above the seabottom; the coefficient of variation was scattering considerably be-tween 400 per cent at low velocities ($\overline{v}_L$= 0.1 m/s) and 20 per cent at the highest velocities ($\overline{v}_L$= 1.5 m/s). The instantaneous longshore current velocities were nearly symmetrically distributed around the mean veloci-ty, the mean amplitudes were nearly constant and reached approx 0.35 m/s whereas the periodical fluctuation decreased from 2.6 s at low mean velocities up to 1.7 s at high velocities.

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1. INTRODUCTION

Surf zones are known as areas of strong interactions where the wave energy originating from hundreds of miles is dissipated within a narrow zone. In prototype the wave energy is mainly transformed by air entrainment during wave breaking and turbulent mixing processes.

So far mostly qualitative-morphological investigations in surf zones are known. The comprehensive field measurements carried out at the west coast of the North Sea Island of Sylt were aimed at quantitative-physical data with regard to the energy dissipation rates and the bottom wave induced longshore currents which mainly affect the longshore transport of sediments in surf zones.

By chance valuable data obtained during the unusual series of 5 heavy storm surges in November and December 1973, a sequence which had not been observed since 100 years (LAUCHT,1974) could be included into the study.

2. WHY INVESTIGATIONS IN PROTOTYPE?

Before results are presented the necessity of expensive prototype investigations instead of surf investigations carried out at low expenditure in laboratories has to be discussed. In the field of wave research hydrodynamic conformities can be transferred from small scale models to prototype in most cases by means of FROUDE's and REYNOLDS's law of similarity; but this procedure is doubtful with regard to surf studies, even in theoretical approaches surf processes cannot be described completely.

Surf investigations at small scales must lead to wrong results due to the influence of surface tension because the air entrainment during breaking and thus a main dissipation factor cannot be taken into consideration (FÜHRBÖTER, 1970). According to SKLADNEV and POPOV (1969) waves should have at least heights of about 0.5 m in order to avoid scale effects. Due to the fact that such wave heights cannot yet be rebuilt in three-dimensional models surf research consequently has to be carried out in prototype at higher risks.

3. LOCATION OF THE SURF INVESTIGATIONS AND MEASURING EQUIPMENT

At the German North Sea coast the west coast of the Island of Sylt (Figure 1) is most favourable for surf investigations, because it is exposed to wave attack from southwest to northwest and waves higher than 1 m can be expected all over the year.

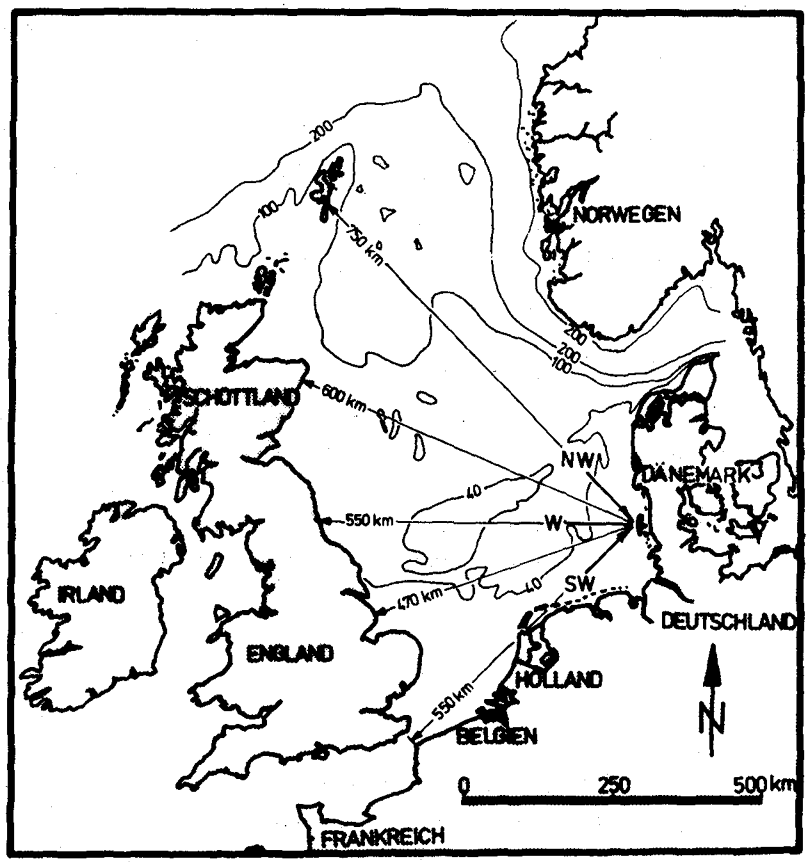

Figure 1: Exposed location of the Island of Sylt/North Sea

The offshore area of Sylt (Figure 2) is characterized by a longshore bar extending at a distance of approx. 300 m parallel to the shoreline.

Outside the surf zone wave recordings are carried out continuously by the AMT FÜR LAND- UND WASSERWIRTSCHAFT HUSUM at the stations W_1 up to W_4 (1280 m distant from the shoreline). The wave recorders are placed on the seabottom and work an the principle of ultrasonic. Additionally two electromagnetic two-component current meters (type: COMEX) working on FARADAY's principle were installed at the stations W_1 and W_3.

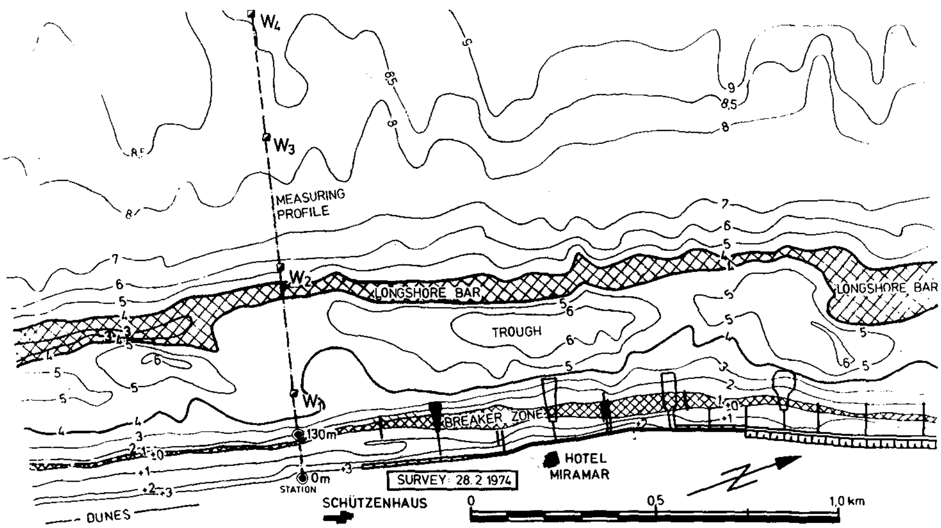

Figure 2: Offshore area of the west coast of Sylt

The data obtained from the above mentioned stations (further details see DETTE (1974 a)) were used as input for the evaluations of field measurements carried out in the surf zone. The measuring equipment there consisted out of pressure cells and two electromagnetic two-component current meters (type: COLNBROOK, Ltd.). Figure 3 shows the installation of the current meter and a pressure cell protected against seawater; fixed at a steel pipe.

Figure 3: Installation of a two-component electromagnetic current meter and a pressure cell protected against seawater

4. ENERGIES IN THE SURF ZONE

In order to illustrate the strong interactions occurring in surf zones Figure 4 shows the evaluation of the mean power delivery rate $\Delta \overline{N}$ in the offshore area of Sylt obtained from a sequence of 100 waves by application of the linear wave theory and expression in the electrical unit of power kW (see FÜHRBÖTER (1974)).

From these results it is obvious that the energy transfer rate is by one up to two powers of ten lower outside the surf zone than inside where in the breaking zone a maximum of .6 kW per m^2 and unit width was obtained during a measurement in April 1973 (Figure 4).

Regular visual observations of the waves breaking in the surf zone revealed the difficulty if not impossibility of defining the position and extension of the main breaker zone. By means of measuring sequences of waves at short distances in- and outside of the breaker zone and evaluating the characteristic wave height parameters for each station it seems possible to find the breaker zone; this is shown for one example on Figure 5.

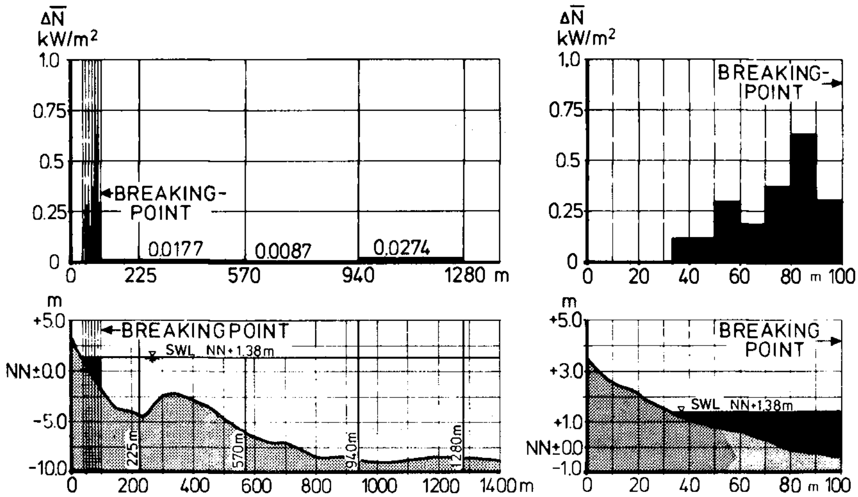

Figure 4: Energy transfer rates outside and inside the surf zone by evaluation of a sequence of 100 waves and application of linear wave theory

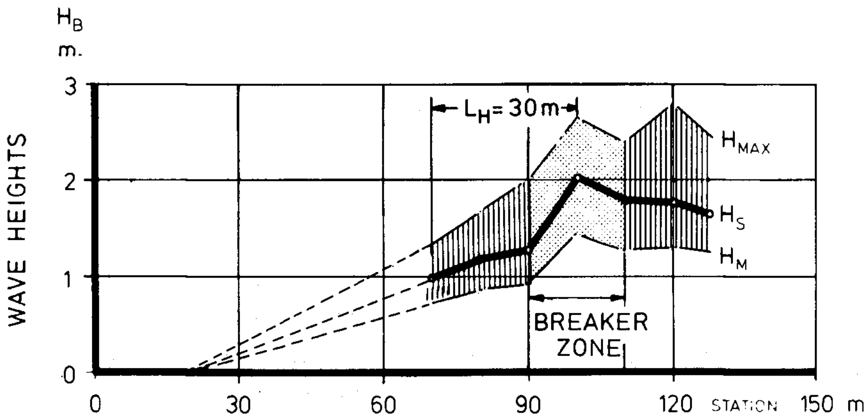

Figure 5: Characteristic wave height parameters evaluated from a sequence of 100 waves inside and outside the surf zone during the storm surge of November 6th, 1973

Instead of using the maximum wave heights the significant values are preferred because they represent approximately the mean wave energy. For the example on Figure 5 the breaker zone lies between station 90 m and 110 m.

By means of the wave measurements at short distances in the surf zone a theoretical quantitative breaker classification suggested by FÜHRBÖTER (1974) could be checked with regard to a practical application.

The breaker parameter β is defined, as follows:

$$\beta = \frac{L_H}{L_B}$$

L_H = Half-decay length = horizontal distance from the breaking point of the wave up to that point where the maximum wave height (breaker height) has been reduced to 50 per cent (in analogy to the half-decay time in nuclear physics)

L_B = Wave length in the surf zone.

Low breaker parameters mean plunging breakers ($\beta < 1$) and high ($\beta > 3$) spilling breakers. The qualitative difference between these breaker types and their intermediate types prevailing in most cases is replaced with breaker parameter β by a quantitative classification which represents from the physical point of view that width of the surf zone where 75 per cent of the approaching wave energy is dissipated.

The half-decay length L_H on Figure 5 is for the significant values L_H = 30 m, the appropriate significant wave length reached L_B = 70 m so that a breaker parameter $\beta = 0.43$ was calculated. From 19 measurements during the first storm surge between November 5th and 7th, 1973 the β parameters were evaluated (DETTE (1974 b)); they varied in between $\beta = 0.2$ and $\beta = 1.0$. These results are in agreement with visual classifications in which an intermediate breaker type ranging in the neighbourhood of plunging breakers was observed.

The breaker parameter β was found to be in close relation to the horizontal asymmetry-parameter α

$$\alpha = \frac{\Delta L}{L}$$

ΔL = Length of the leeside part of the wave

L = Total wave length

of the breaking wave. With decreasing breaker parameter the asymmetry is increased and reverse. This is of high importance with regard to the orbital velocities of the surf waves (BÜSCHING (1974)) which are decisive with regard to the on- and offshore transport of sediments.

5. CHARACTERISTICS OF THE LONGSHORE CURRENTS

5.1 GENERAL RESULTS

The orbital velocities are acting in the direction of wave propagation; they can be ragarded as alternating currents according to the movement of the waves. Contrary to this the longshore currents are generally treated as a continuous current generated by the longshore component of the wave movement and maintained as compensating current due to the balance of wave energy and friction losses. In prototype however the longshore currents are not only affected by the orbital currents they are additionally superimposed by complex two- (e.g. bottom return flows, mass transport) and three-dimensional currents (rip currents as local return flows into the open sea). Being aware of these facts nevertheless field studies on the longshore currents and relations to the wave heights in the surf zone were started. With regard to the longshore currents it was found that their structure mainly depends upon a phenomenon that steep waves in shallow water decompose in two or more waves (solitons) with different heights and periods during the process of breaking (Figure 6). GALVIN (1972) recently pointed out that this occurrence influences the mechanism of breaking waves. HOM-MA (1962) and later on KENNEDY and LOCHER (1972) indicated that the above decomposition might be of importance for the longshore transport of sediments but denied that this phenomenon would stand in any relation to the longshore currents.

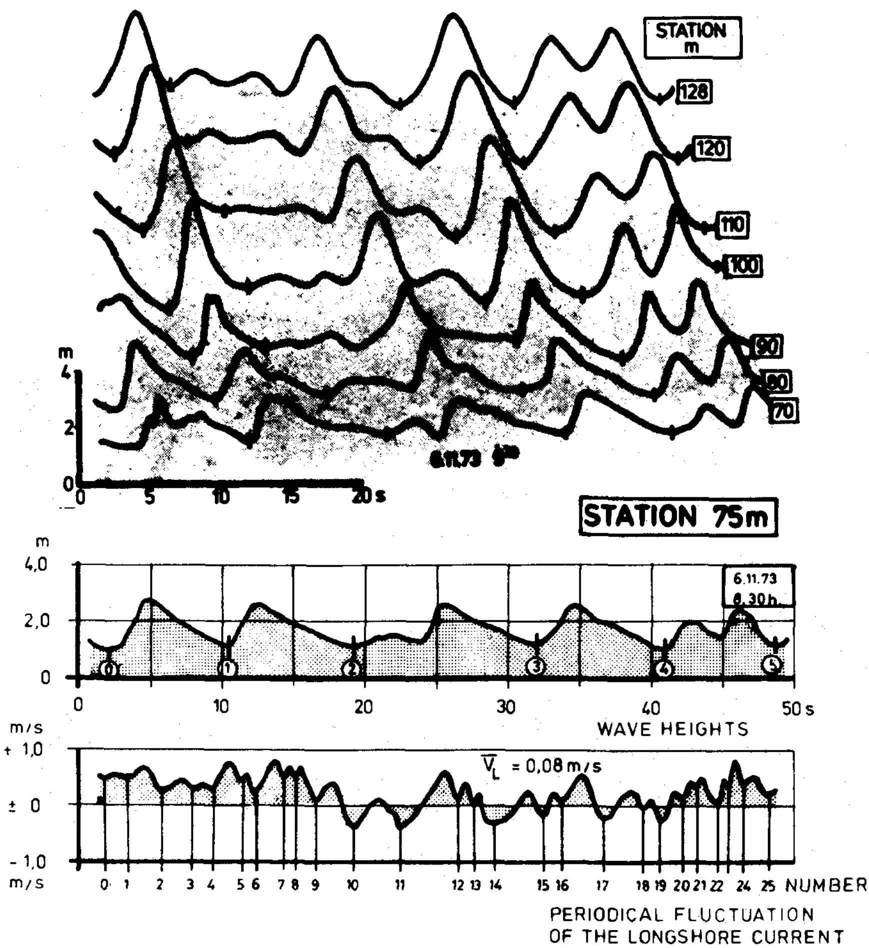

Figure 6: Decomposition of steep waves (solitons) within the surf zone and relationships to the structure of longshore currents

By means of a high time-limit release (approx. 0.1 sec) of the used electromagnetic two-component current meters it was possible in comparison to earlier field measurements with floating buoys, dye, balloons etc. which only allowed to obtain mean velocities, to discover macro-turbulent processes within the longshore currents. It could be proved that the longshore currents cannot be regarded any longer as steady or quasi-steady flows, they showed fluctuations in the range of $\pm$ 100 per cent and occurred with periods up to 9-fold of the wave periods. It was not unusual that a mean longshore current velocity of $\bar{v}_L$ = 1.0 m/s fluctuated within fractions of time from $\pm$ 0 m/s up to 2 m/s as it can be seen e.g. on Figure 7.

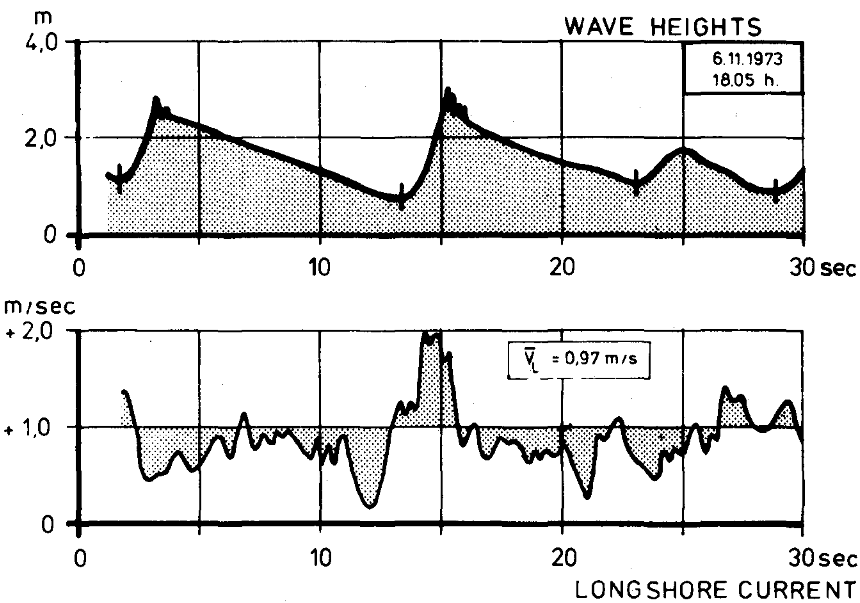

Figure 7: Fluctuations of the longshore current velocity

Based on this fact the high transport capacities of such currents can be explained, besides the orbital and surf turbulences within the longshore current, additionally accelerations and retardations were observed so that comparisons with steady flows having the same mean velocity seem to be impossible. By definition of a periodical fluctuation parameter γ

$$\gamma = \frac{T_B}{T_V}$$

T_B = Mean wave period in the surf zone

T_V = Mean periodical fluctuation of the longshore current

finally a nearly linear relationship was discovered (Figure 8); the periodical fluctuation parameter increasses with decreasing breaker parameter β (see Chapter 4). This means that the smaller becomes the area where the main energy is dissipated (75 per cent) the smaller also becomes the periodical fluctuation of the longshore current.

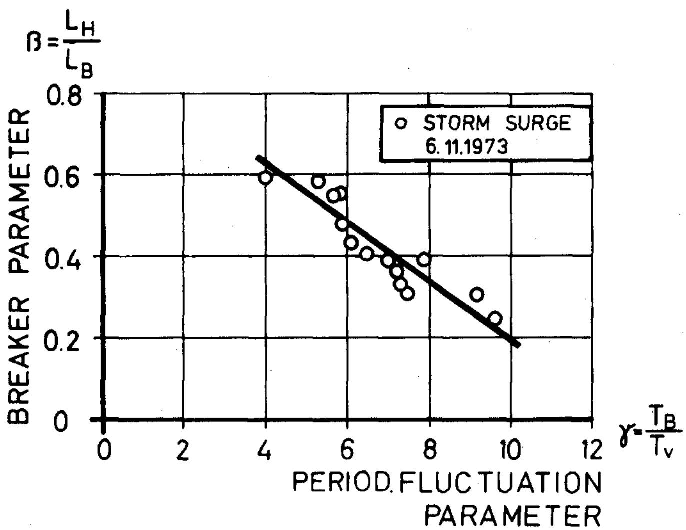

Figure 8: Relationships between the breaker parameter β and the periodical fluctuation parameter γ of the longshore currents

5.2 DETAILS OF THE LONGSHORE CURRENT ANALYSIS

5.2.1 METHOD OF DATA EVALUATION

With regard to an evaluation of the longshore currents occurring in the surf zone of Sylt more than 150 analogous registrations of 15 minutes duration each were collected, most of them during the unusual sequence of 5 heavy storm surges in November and December 1973. Intervals of 10 minutes duration were deemed to be sufficient in order to receive representative data for each measurement. The analogous registrations were digitized at intervals of one fifth of a second so that a total of 3000 instantaneous velocities was available for the analysis of longshore current characteristics by means of electronical data processing (ICL 1906 S of the Technical University of Braunschweig).

5.2.2 MEAN LONGSHORE CURRENTS, THEIR STANDARD DEVIATIONS AND COEFFICIENTS OF VARIATION

By the measurements of the longshore currents it could be confirmed that the highest longshore current velocities have to be expected during two different weather conditions:

1. Heavy storm surges with the waves approaching at small breaking wave angles ($\Theta_B < 25^o$) and high breakers of more than 3 m (Figure 10).

2. Winds blowing nearly parallel to the shoreline causing great breaking wave angles ($\Theta_B > 25^o$) and low breakers with heights less than usually 1 m (Figure 11).

In both cases mean bottom longshore current velocities up to 1.5 m/s were evaluated. Figure 9 shows for example the time history of the heaviest storm surge in the sequence of storm surges which occurred at the 19th and 20th of November 1973 when wave heights up to 7.2 m were recorded at station W_4 (1280 m distant of the shoreline) and wave heights up to 3.3 m in the surf zone. The drawing gives an idea of relationships between tide, wind velocity and direction as the causing factors and the longshore currents and wave heights as the generated parameters.

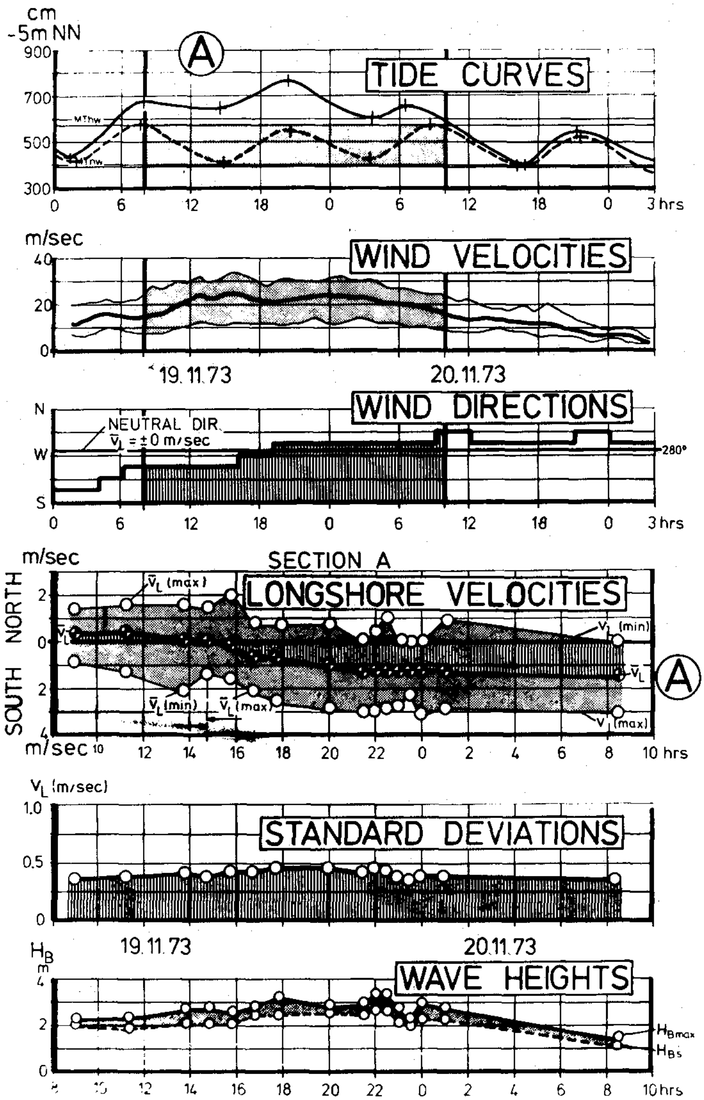

Figure 9: Time history of a heavy storm surge

With the shifting of the wind directions the mean longshore flow direction changed nearly at the same time; besides it is remarkable that instantaneous velocities in opposite flow direction at mean values of more than 1.0 m/s occurred.

Figure 10 gives an idea of the mean longshore velocities when the wind was blowing nearly parallel to the shoreline from south (section A) and north (section C); besides measurements are shown when the wind was blowing from land to sea (section B) and small waves were diffracted around the island of Sylt.

For all measurements carried out at Sylt the maximum and minimum longshore current velocities within the 10-minute registrations are plotted against the appropriate mean velocities in classes of 0.1 m/s (Figure 11). The regression lines indicate that there seems to exist a nearly linear relationship between the extreme (maximum and minimum) and the mean velocities.

With regard to the temporal variability the standard deviations were investigated; Figure 12 shows by the linear regression that the standard deviations increase slightly from 0.33 m/s up to 0.42 m/s over the range of mean velocities from $\overline{v}_L$= 0 m/s up to 1.5 m/s.

By means of evaluating the statistical coefficient of variation it is illustrated more clearly that the longshore current velocities are scattering in a high range between 400 per cent at small velocities ($\overline{v}_L$= 0.1 m/s) and 20 per cent at the highest velocities ($\overline{v}_L$= 1.5 m/s).

5.2.3 HISTOGRAMS OF THE DISTRIBUTION OF THE LONGSHORE CURRENT VELOCITIES, PERIODICAL FLUCTUATIONS AND AMPLITUDES

Figure 14 shows histograms of the distributions of the longshore current velocities, periodical fluctuations and amplitudes during the storm surge of 19th/20th November 1973. The mean values are inserted, as well as the wave periods and the periodical fluctuation parameter γ.

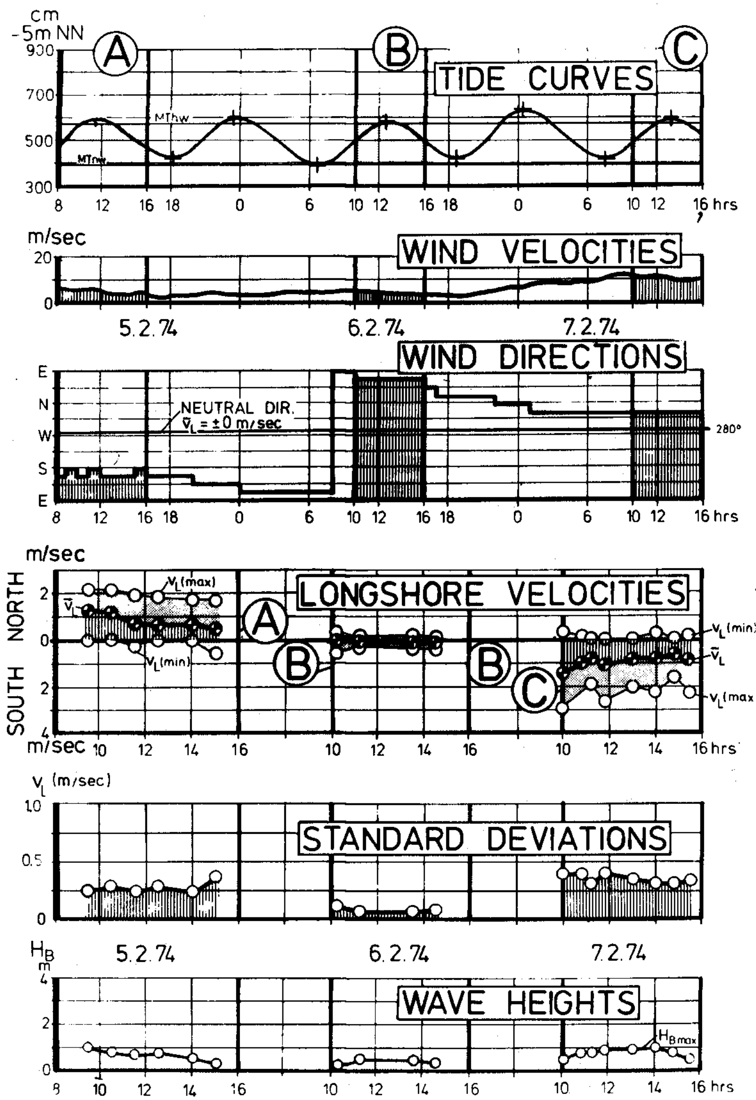

Figure 10: High longshore current velocities caused by winds blowing parallel to the shoreline

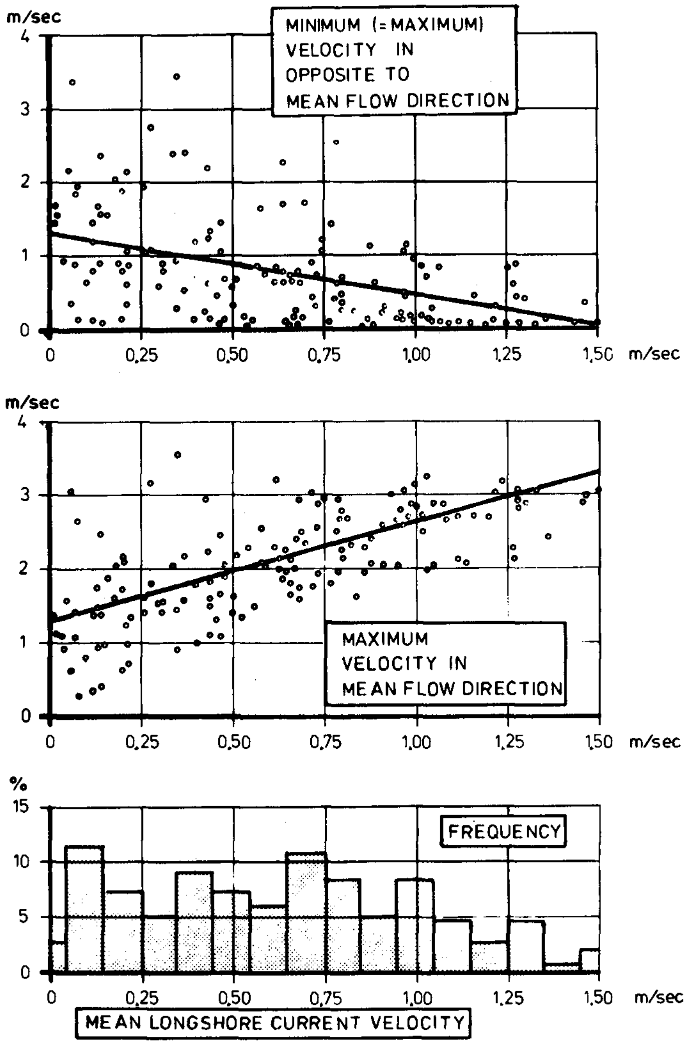

Figure 11: Maximum and minimum longshore current velocities in relation to the mean velocities and frequency

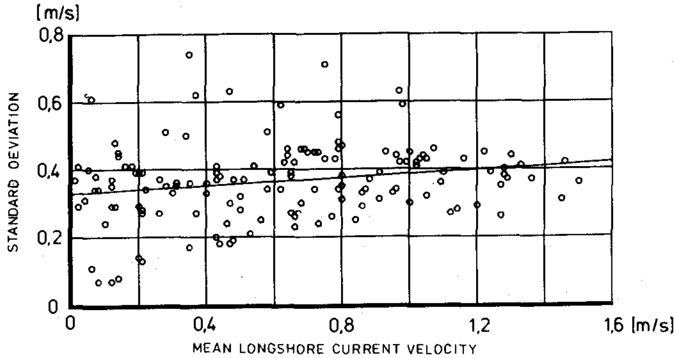

Figure 12: Temporal variability of the longshore current velocities illustrated by their standard deviations

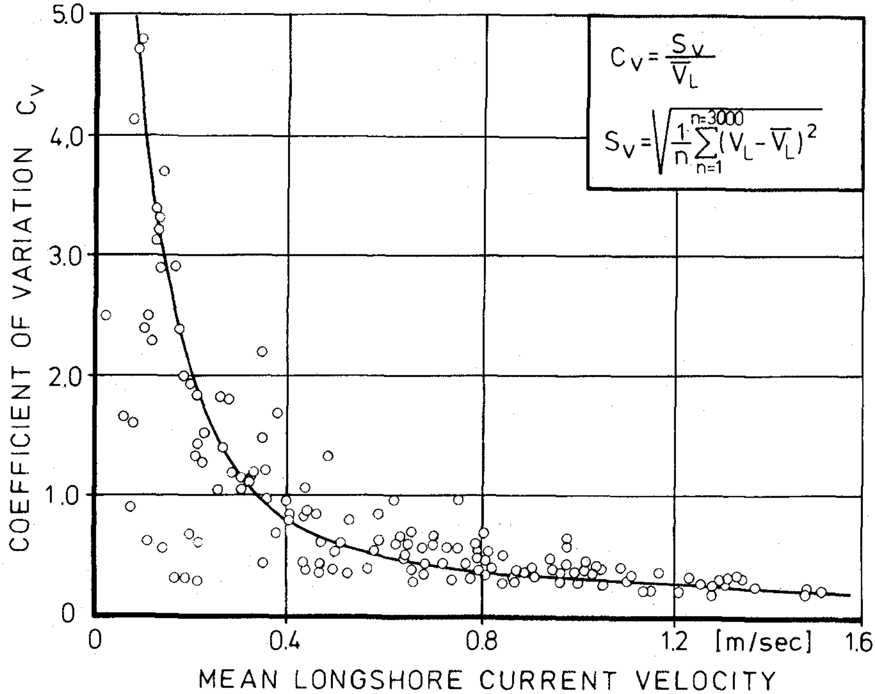

Figure 13: Coefficient of variation of the longshore current velocities

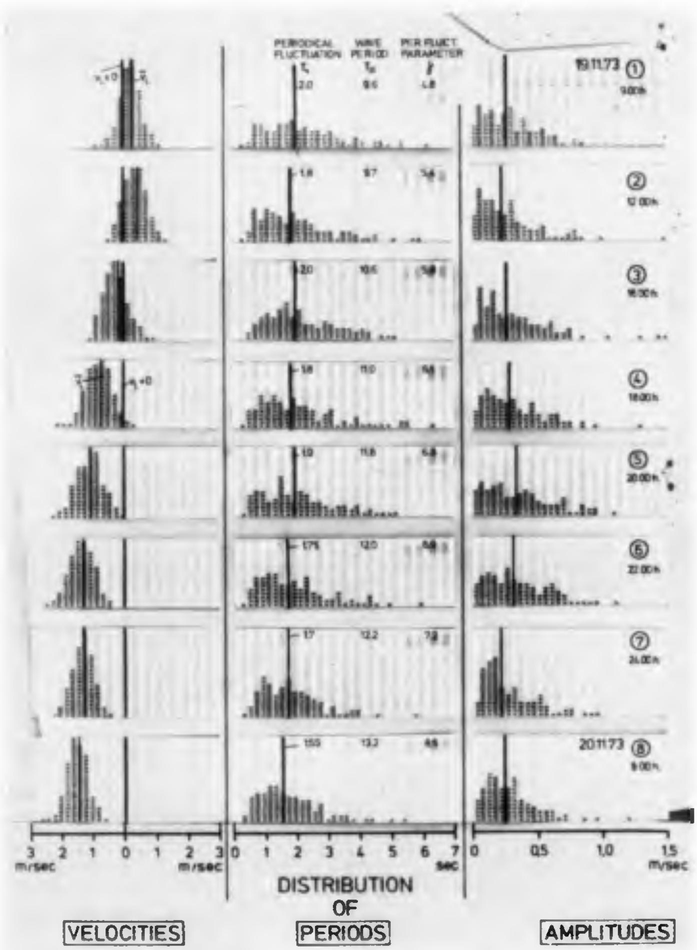

Figure 14: Histograms of the distributions of the longshore currents, periodical fluctuations and amplitudes during storm surge of 19th/20th November 1973

5.2.4 MEAN LONGSHORE CURRENT AMPLITUDES AND PERIODICAL FLUCTUATIONS

Analogous to the considerations of the maximum and minimum longshore current velocities in relation to the mean velocities the mean amplitudes and periodical fluctuations of all measurements were plotted against the mean velocities (Figure 15 and 16). The regression line shows that the amplitudes are nearly constant and reach 0,35 m/s.

whereas the periodical fluctuations decrease from T_v = 2.6 s at small mean velocities $\overline{v}_L$= ± 0 m/s) up to T_v= 1.7 s at the highest mean velocities ($\overline{v}_L$= 1.5 m/s).

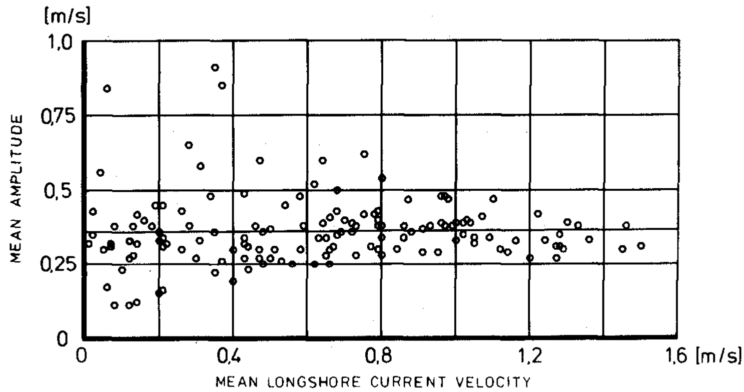

Figure 15: Mean amplitudes of the longshore currents in relation to the mean velocities

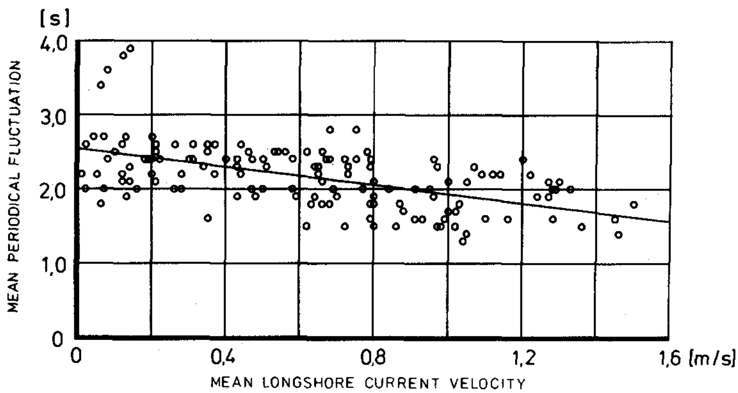

Figure 16: Mean periodical fluctuations of the longshore currents in relation to the mean velocities

6. CONCLUSIONS

With the above given results of surf measurements in prototype even during severe storm surges which are part of a thesis completed in 1974 (DETTE, 1974 b) a contribution is presented with regard to a quantitative knowledge.Though the data are scattering inevitably due to the complex nature of waves it is possible to find relationship between the governing parameters in the surf zone.

7. ACKNOWLEDGEMENTS

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