CHAPTER 62

WAVE SET-UP IN THE SURF ZONE

by Uwe A. Hansen[1)]

In designing coastal protective structures the knowledge of the static load due to the water level elevation is as important as that of the dynamic load due to the waves.

The structure,designed at sandy coasts with well formed surf zones on the beach - these areas are the basis of this examination - has to stand against both, the superposition of the static and dynamic load, which are dependent on each other. Undoubtedly a rise in the design water level (a summation of different influences - see figure 1) will cause an increase in the wave heights and the reverse will happen, when the design water level decreases.

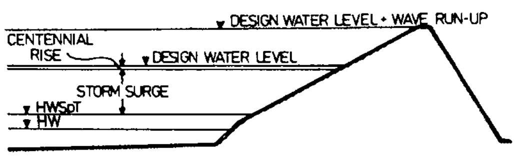

Fig. 1. - Design water level for the determination of the height of a sea dyke

The location of the wave breaking point in the surf zone will also shift with changing water levels and also the magnitude of the wave run-up and the unknown wave set-up. That shows that only the exact knowledge of all possible factors - including wave-

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set-up, influencing the height of the design water level, makes a construction safe and economical.

Up to now, the magnitude of the phenomenon wave set-up and its influence on the design water level remains practically unknown. Though formulas exist to compute the magnitude of wave induced set-up in the surf zone, which mainly were developed out of small scaled model tests, e.g. Munk(13), Savage(14), Fairchild(4), Dorrestein(3), and Longuet-Higgins and Stewart(12) and many others (see Hansen(8)), comparisons with measurements show, that the existing wave theories are not adequate to describe the difficult processes in the surf zone as a non-stationary three-phase-flow of water, air and solid particles. Comparisons of measured run-up heights at sea dykes after heavy storms with calculated values showed, that there must be an unknown factor up to now, which could be the wave set-up.

Therefore field measurements were made by the LEICHTWEISS-INSTITUT of the Technical University of Braunschweig, sponsored by the GERMAN RESEARCH FOUNDATION (Bonn), at the west coast of the island of SYLT in the North Sea (see figure 2) in winter 1975/76 to determine the wave set-up in the surf zone under prototype conditions.

The measuring profile is shown in figure 3 with the locations of the measuring points. At stations W_4,W_3 and W_1 wave measurements were made with ultrasonic wave gauges. At the stations in the surf zone wave sensors with pressure cells were installed. The incident significant wave height $H_{o,s}$ was measured at station W_4, 1280 m seaward of the toe of the dune.

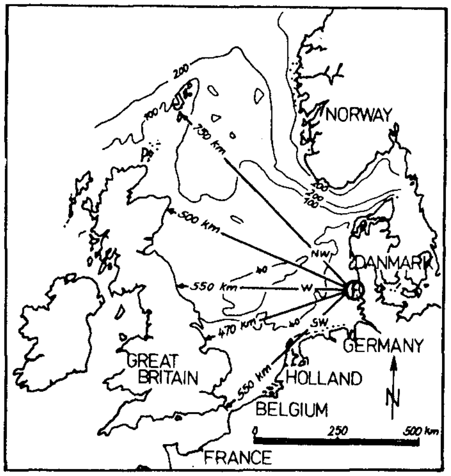

Fig. 2. - Location of the island of SYLT in the North Sea

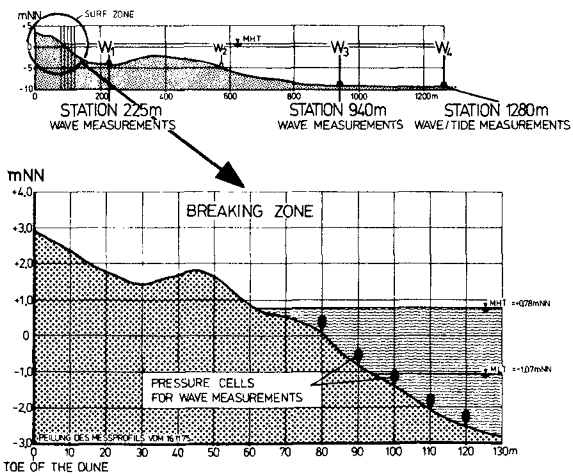

Fig. 3. - Measuring profile at the west coast of SYLT in North Sea

Though the definition of wave set-up is a simple one:

> the height difference between MEAN WATER LEVEL and STILL WATER LEVEL,

the determination of those two different water levels in field measurements under prototype storm conditions is a rather difficult task.
The water level, even under calm conditions and without any movements by waves, changes with the tide. In the area off SYLT the difference between high and low water is about two meters. To compute or measure wave set-up in the surf zone, the height of the water level, defined as SWL, must first be determined there. As this water level can not be measured directly in the surf zone because of the influence of the unknown wave set-up, the place for registration this SWL must be positioned at a far seaward location where this unknown influence of wave set-up does not exist. As former measurements had shown, that the wave climate at the most seaward measuring point W_4 (1280 m seaward of the tos of the dune) is not influenced by the shore and that shelf response effects are negligible there, this tide gauge was used to give the time variations of the SWL, the tide, by filtering out the wave components and translate it into the surf zone.

The second necessary value, the time variation of the MWL, was not defined by one of the well-known methods like "crest-to-crest"method or "zero-crossing" method. The analog wave records, obtained at the five measuring stations in the surf zone were first converted into digital values with a time span of 0.4 seconds.

The water level variations between two extremes, the maximum and the following minimum, was then defined as a wave (see figure 4).

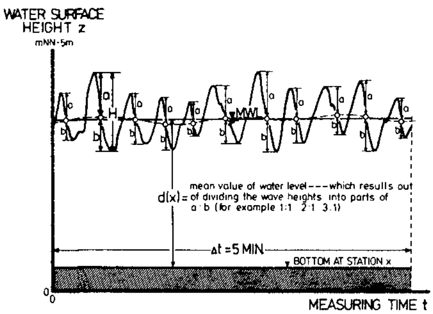

Fig. 4. - Determination of MWL out of prototype wave records by dividing height between wave crest and following trough into parts of a:b after Hansen(8)

Within a time span of 5 minutes measuring time the result was a number of 750 digital values z_i, representing the water level fluctuations, out of which the MWL was computed as the mean value of all these water level variations. This method, done by a computer, is not very difficult and gives good results as comparisons showed.

These comparisons were the following:
due to the well known behavior of the vertical asymmetry of waves in the surf zone, the part of the wave over the MWL is about 66% to 85% of the total wave height just before breaking (see Gaillard(6), Galvin and Eagleson(7) and Inman and Quinn(10),

so that only 33% to 15% of the wave height remains <u>below</u> the MWL. With these criterions the MWL was determined by dividing the heights in water level fluctuations between wave crests and wave troughs into these parts of percentage. Then the MWL was defined as the mean value of all these resulting points within a designated time span of 5 minutes (see figure 5).

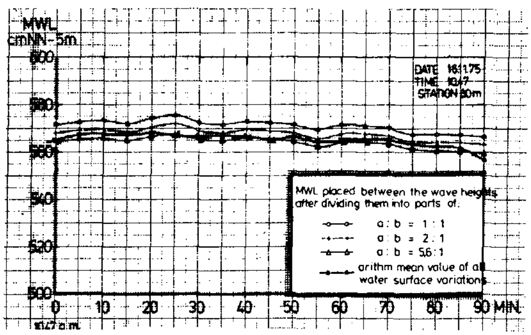

Fig. 5 - Time variation of MWL at station 80 m after dividing all wave heights by differnt parts

The comparison showed, that the results of these more time-consuming methods of dividing all wave heights into parts between 66% to 85% <u>over</u> and 33% to 15% <u>below</u> the MWL differ only a few centimeters from those calculated by taking only the mean values of <u>all</u> water surface variations measured over a certain time span of 5 minutes.

The reason, that this method - the arithmetic mean value of all water surface variations over a certain time span - is equally suitable to yield the MWL for these irregular waves in the surf zone is due to the great horizontal asymmetry of these waves. Just before breaking the waves have a form with very short leeward and long windward slopes (see figure 6). As a result, balance of the areas in a wave form above and below the MWL - which is equal to the arithmetic mean value of all water surface variations - can only be reached, when the waves steepen in the surf zone.

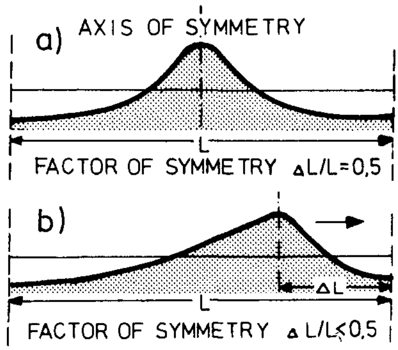

Fig. 6. - Asymmetries: (a) vertical and (b) horizontal of waves in the surf zone after Führböter(5)

Now some results of the field measurements at the west coast of the island of SYLT in the North Sea: The measurement program included 27 separate measurements of about occasionally 60 minutes registration time at different sea and wind conditions. Those who are interested in detail should refer to the report by the writer(8).

Figure 7 shows the spatial variations of wave set-up at a certain time span for run nr. 15 with an incident significant wave height of 1.58m and a

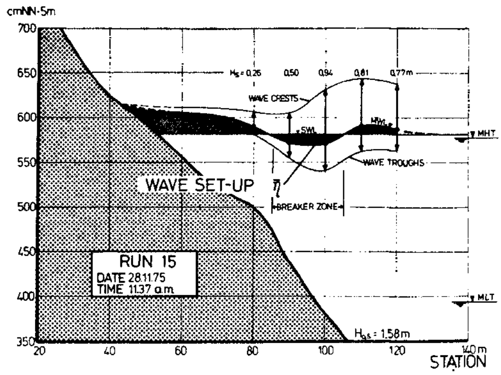

Fig. 7 - Spatial variation of wave set-up in measuring profile at the west coast of SYLT during falling tide

measuring time of about 60 minutes. The envelopes of the wave crests and troughs, measured at the stations in the surf zone are also given in this figure to clearly reveal their relationships with respect to the MWL.

Based on the 27 sets of measurements the maximum wave set-up $\bar{\eta}_{max}$ on the beach at the so called set-up line is estimated to be

$$\bar{\eta}_{max} \cong 0.3\ H_{o,s}$$

as seen in figure 8, where $H_{o,s}$ is the significant wave height measured at station W_4, 1280 m seaward of the toe of the dune (see fig. 3). The relationship shows good agreement with theoretical results of Collins(2), but less so with those of Dorrestein(3) and Saville(15).

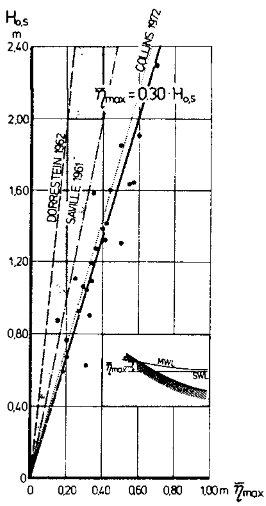

Fig. 8. - Maximum wave set-up in dependence on significant incident wave height after Hansen(8)

In relation to the significant wave height at the breaking point in the surf zone $H_{B,s}$, the maximum wave set-up can be expressed as

$$\bar{\eta}_{max} \cong 0.5\ H_{B,s}$$

as seen in figure 9, in which also the theoretical results of Hwang and Divoky(9), Battjes(1) and Jonsson and Jacobsen(11) are given.

Beside these maximum values of the wave set-up, measured at the set-up line on the beach, the values at the breaking point in the breaking zone are of great interest too. The measurements and computations showed in the area of the sandy beach off SYLT, that the wave set-up there not only depends on the height of the incident offshore wave, but also on the width and location of the breaking zone, which varies with the tidal cycle.

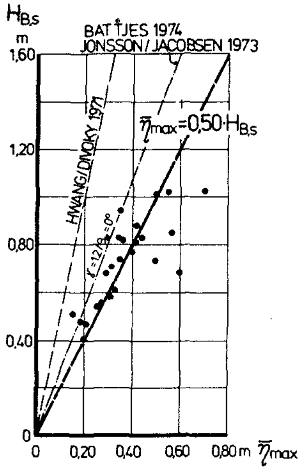

Fig. 9. - Maximum wave set-up in dependence on wave height at breaking point after Hansen(8)

As shown in figure 10, in wide breaker zones mainly intermediate forms of spilling and plunging breakers predominate, whereas in narrow breaker zones plunging breakers occur.

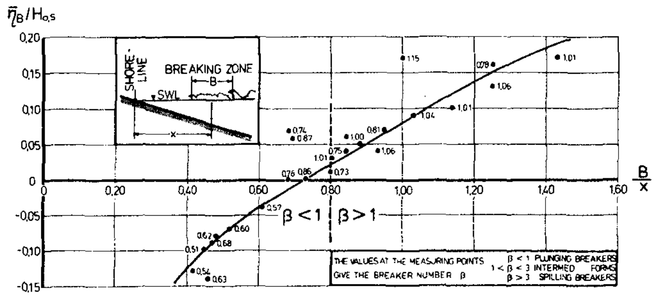

Fig. 10 - Wave set-up at breaking point versus significant wave height in dependence on width of breaking zone versus location of breaking zone after Hansen(8)

With the variation of the width of the breaking zone and the breaker forms (classification after Führböter(5)), the values of wave set-up at the breaking point vary too: values greater than 1 - a rise in water level (MWL above SWL)- were measured in wide breaker zones, values less than 1 in narrow ones (MWL under SWL).

From these interesting results the following conclusions were drawn (see figure 11 - a schematical drawing):

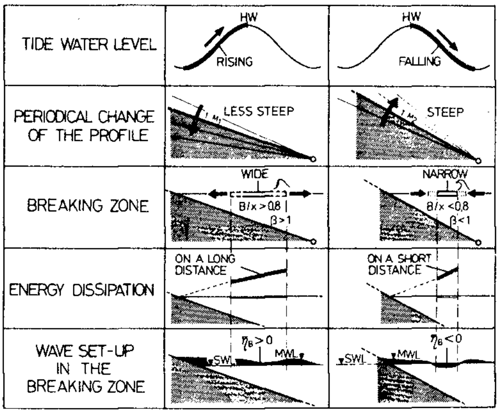

Fig. 11 - Wave set-up in breaking zone in relation to tide, measuring profile, and energy dissipation

As the underwater slope of the sandy beach varies with the tidal cycle, the wave set-up at the breaking point varies too. The reason for this variation of $\bar{\eta}_B$ is that the slope of the underwater profile in the surf zone changes more or less periodically with the tide, as profile measurements at this sandy coast of SYLT had shown. With falling water levels the slope becomes steeper. With rising water levels it becomes more gentle, so that the position and width of the breaker zone changes.

In wide breaker zones, where plunging and spilling breakers predominate, the rate of energy dissipation is less, so that a greater part of wave energy is preserved to create wave set-up and the MWL in the breaking zone remains above the SWL. On the other hand, the increased energy dissipation in narrow breaker zones, where plunging breakers predominate causes a wave set-down at the breaking point, that means the MWL lies below the SWL (see figure 11).

As a conclusion it can be said, that the field investigations at the sandy coast of the island of SYLT have shown, that the maximum wave set-up on the beach (at the set-up line) can reach values up to 30% of the incident significant wave height and up to 50% of the significant breaker height. For engineering purposes the maximum values are more important, as they directly influence the height of the design water level for coastal protective structures. The results of this study can be used for other areas, when boundary conditions like sandy beach, similar slopes and well formed surf zone are given.

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