CHAPTER 20

ABOUT THE ENERGY DISSIPATION OVER BARRED BEACHES

by

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Abstract:

Since wave energy dissipation in the surf zone is a stochastic process closed mathematical formulations cannot be expected. The dissipation was computed using several analytical and/or empirical approaches and compared with prototype measurements in the Big Wave Flume (GWK) in Hannover as well as with field measurements from the west coast of the Island of Sylt/North Sea. Generally good agreements were found for moderate energy dissipation conditions (spilling-breaker), whereas in the case of plunging breakers, however, the fitting is not solved satisfactory.

1. Introduction

Due to the stochastic nature of energy dissipation in the surf zone, closed mathematical solutions for the given sea state in the nearshore zone cannot be expected. It is therefore the task to idealize the problem and/or to apply empirical approaches based on laboratory- and/or in-situ measurements of waves in the area of interest.

Laboratory investigations were carried out in the Big Wave Flume (GWK) and in-situ measurements at the Island of Sylt in order to obtain data representing spilling- and plunging breaker conditions for comparison with the results from selected decay models.

2.1 Emperical Wave Height Decay Formulations

Two emperical approaches have been selected for computational tests. HORIKAWA/KUO(1966) derived from laboratory tests the following formulation for the determination of wave height decay:

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$$\frac{H_i}{d_i} = 0.5 + 0.3 \cdot \exp\left(-0.11 \cdot \frac{x_i}{m \cdot x_b}\right) \tag{1}$$

H_i = wave height at x_i in [m]
d_i = water depth [m]
x_i = distance shoreward from break-point [m]
i = arbitrary location index
x_b = distance of shoreline to break-point [m]

This approach was modified by ANDERSON/FREDSØE(1983) for plane slopes. The coefficients were adapted to spilling-breakers as they do occur along the westcoast of Jütland/-Danmark:

$$\frac{H_i}{d_i} = 0.35 + 0.65 \cdot \exp\left(-0.12 \cdot \frac{x_i}{H_b}\right) \tag{2}$$

H_b = wave height at the break-point [m]

In case of partial wave breaking over a bar TUCKER et al.(1983) found that waves restabilize themselves at:

$$\frac{H_i}{d_i} = 0.5 \tag{3}$$

2.2 Analytical Wave Height Decay Formulations

Three analytical approaches were applied for describing wave height decay of periodic waves. DALLY et al.(1984) have developed an approach based on energy conservation law:

$$\frac{H_i}{H_b} = \left[\left(\frac{h_i}{h_b}\right)^{\left(\frac{K}{m_i}-0.5\right)} \cdot (1-\alpha_i) - \alpha_i \cdot \left(\frac{h_i}{h_b}\right)^2\right]^{0.5} \tag{4}$$

$$\alpha_i = \frac{(K \cdot \Upsilon)^2}{m_i \cdot \left(2.5 - \frac{K}{m_i}\right)} \cdot \left(\frac{h_b}{H_b}\right)^2$$

h_i = water depth at still water level [m]
h_b = still water level at the breakpoint [m]
m_i = beach slope at location x_i [-]
K = waveheight decay factor [-]
Υ = waveheight stabilization factor [-]

BATTJES(1986) published an approach based on the analogy of energy dissipation of a spilling breaker to the energy dissipation in a bore:

$$\frac{H_i}{H_b} = \left[\left(1 - \frac{4}{9} \cdot k\right) \cdot \left(\frac{d_i}{d_b}\right) + \frac{4}{9} \cdot \left(\frac{d_i}{d_b}\right)^{-3.5}\right]^{-0.25} \tag{5}$$

$$k = 2 \cdot B \cdot \gamma \cdot \frac{1}{m_i \cdot T_m} \cdot \left(\frac{d_b}{g}\right)^{0.5}$$

$$\gamma = 0.7 + 5 \cdot m_i \qquad (0.01 \leq m_i \leq 0.1)$$

B = dimensionless coefficient [-]
d_b = water depth at the breakpoint [m]
T_m = mean wave period [s]

STIVE(1984) derived a formula based on the same analogy but added an energy dissipation factor A_ε for better adaptation:

$$\frac{H_i}{H_b} = \left[\left(1 - \frac{4}{3} \cdot \sigma\right) \cdot \left(\frac{d_i}{d_b}\right)^{0.25} + \sigma \cdot \frac{4}{3} \cdot \left(\frac{d_i}{d_b}\right)^{0.5} \right]^{-1} \tag{6}$$

$$\sigma = \left(\frac{1}{2 \cdot \pi} \cdot \frac{H_b}{d_b}\right)^{0.5} \cdot A_e \cdot \xi_b^{-1} \qquad \xi_b = m_b \cdot \left(\frac{H_b}{L_o}\right)^{-0.5} \leq 0.4$$

$$A_e = 2 \cdot \tanh(5 \cdot \xi_o) \qquad \xi_o = m_b \cdot \left(\frac{H_o}{L_o}\right)^{-0.5} \leq 0.5$$

H_o = deep water wave height [m]
L_o = deep water wave length [m]
m_b = bottom slope at the break-point [-]

Another five approaches have been selected to take as well wave height distribution as water level set-up/set-down into account.

Based on linear wave theory wave height is calculated:

$$\frac{H_i}{H_o} = \left[\frac{1 + \dfrac{\frac{4\pi d_o}{L_o}}{\sinh\left(\frac{4\pi d_o}{L_o}\right)}}{\dfrac{\sinh\left(\frac{4\pi d_i}{L_i}\right) + \frac{4\pi d_i}{L_i}}{\sinh\left(\frac{4\pi d_i}{L_i}\right)}} \cdot \frac{\frac{2\pi}{L_i}}{\frac{2\pi}{L_o}} \right]^{0.5} \tag{7}$$

set-up/set-down offshore the break-point:

$$\eta_i = -\frac{1}{8} \cdot H_o^2 \cdot \frac{2\pi}{L_o} \cdot \frac{\coth^2\left(\frac{4\pi d_i}{L_i}\right)}{\sinh\left(\frac{4\pi d_i}{L_i}\right) + \frac{4\pi d_i}{L_i}} \tag{8}$$

set-up/set-down inside the breaker-zone:

$$\eta_i = \frac{3 \cdot \gamma_b^2}{3 + 3 \cdot \gamma_b^2} \cdot (h_b - h_i) + \eta_b \tag{9}$$

$$\gamma_b = \frac{H_b}{d_b} = 0.78$$

η_i = deviation from still water level (set-up/set-down) [m]
η_b = set-up/set-down at the breakpoint [m]

L_i = wave length [m]

Wave height decay formulations of DALLY et. al. (1984) are mentioned above. The set-up/set-down is calculated by:

$$\eta_i = \eta_{i-1} - \frac{3}{16} \cdot \frac{1}{d_i} \cdot (H_i^2 - H_{i-1}^2) \tag{10}$$

At barred coastlines waves restabilizes at:

$$\frac{H}{d} = \alpha \tag{11}$$

α = 0.35 - moderate beachslopes
α = 0.48 - steep beach slopes

IZUMIYA/HORIKAWA (1978) calculated wave height and wave set-up/set-down from energy dissipation rate due to wave breaking and bottom friction. There expressions are:

$$H_i = \left(\frac{8 \cdot E_i}{\rho \cdot g}\right)^{0.5} \tag{12}$$

$$E_i = E_{i-1} \cdot \frac{C_{gi-1}}{C_{gi}} - \frac{x_i - x_{i-1}}{C_{gi}} \cdot \left[\alpha_1 \cdot \left(\frac{2k_i d_i}{\sinh(2k_i d_i)}\right)^{1.5} + \alpha_2 \cdot \left[\left[\frac{E_i}{\rho \cdot g \cdot d_i} \cdot \left(\frac{1}{2} + \frac{k_i d_i}{\sinh(2k_i d_i)}\right) - \alpha_3\right]^{0.5} \cdot \left(\frac{2k_i d_i}{\sinh(2k_i d_i)}\right)^{0.5}\right]\right] \cdot \frac{E_i^{1.5}}{\rho^{0.5} \cdot d_i^{1.5}}$$

$$k_i = \frac{4 \cdot \pi^2}{T_m^2 \cdot g \cdot \tanh(k_i \cdot d_i)}$$

$$C_{gi} = \frac{1}{2} \cdot \left[\frac{g}{\frac{2\pi d_i}{L_i}} \cdot \tanh\left(\frac{2\pi d_i}{L_i}\right)\right] \cdot \left[\frac{1 + \frac{2\pi d_i}{L_i}}{\sinh\left(\frac{2\pi d_i}{L_i}\right)}\right]$$

E_i = wave energy [kWs/m²]
C_{gi} = group velocity [m/s]
k_i = wave number 2π/L [-]
α_1 = bottom roughness coefficient = 0.01 - 0.03
α_2 = wave breaking coefficient = 10
α_3 = wave breaking coefficient = $0.9 \cdot 10^{-2}$

The water level deviation is calculated based on radiation stress theory:

$$\eta_i = \eta_{i-1} - \frac{S_{xxi} - S_{xxi-1}}{\rho \cdot g \cdot d_i} \tag{13}$$

$$S_{xxi} = \left(\frac{1}{2} + \frac{2k_i d_i}{\sinh(2k_i d_i)}\right) \cdot E_i$$

S_{xxi} = radiation stress [kWs/m²]

The break-point is defined as a critical relative wave-height due to a critical energy:

$$(\frac{H}{d})_{crit} = 0.17 \cdot \frac{L_o}{d} \cdot \left[1 - \exp\left[-1.5 \cdot \frac{\pi d}{L_o} \cdot (1 + 15 \cdot m)^{1.33}\right]\right] \tag{14}$$

BATTJES/JANSSEN (1978) calculated the energy dissipation rate for RALEIGH distributed waves:

$$H_{rms\,i} = (\frac{8 \cdot E_i}{\rho \cdot g})^{0.5} \tag{15}$$

$$E_i = E_{i-1} \cdot \frac{c_{gi-1}}{c_{gi}} - \frac{\alpha}{8} \cdot \frac{1}{T_m} \cdot \frac{0.88^2}{c_{gi}} \cdot \left[\frac{Q_{bi}}{k_i^2} \cdot \tanh^2(k_i \cdot d_i) + \frac{Q_{bi-1}}{k_{i-1}^2} \cdot \tanh^2(k_{i-1} \cdot d_{i-1})\right] \cdot (x_i - x_{i-1})$$

$$\frac{1 - Q_{bi}}{\ln(Q_{bi})} = \frac{H_{rms\,i}^2}{H_{bi}^2}$$

$H_{rms\,i}$ = root-mean-square-wave-height [m]
$Q_{b\,i}$ = probability of broken- or breaking waves [-]
α = 1.0

The wave set-up is calculated due to radiation stress theory mentioned above.

The approach of GERRITSEN (1980) is similar to BATTJES/-JANSSEN(1978) (eqn.15) but assumes the waves as WEILBULL distributed:

$$\frac{1 - Q_{bi}}{((1+0.71) \cdot (Q_{bi}-1)^2)^2 \cdot \ln(Q_{bi})} = \frac{H_{rms\,i}^2}{H_b^2}$$

The energy dissipation formula was modified for the WEILBULL distribution as follows:

$$E_i = E_{i-1} \cdot \frac{c_{gi-1}}{c_{gi}} - \left[\frac{2}{3} \cdot \alpha_1 \cdot \frac{\rho}{\pi} \cdot (\frac{\pi \cdot H_{rms\,i}}{T_m \cdot \sinh(k_i d_i)})^3 + Q_{bi} \cdot \frac{\alpha_2}{5.66} \cdot \rho \cdot g \cdot \frac{2\pi}{T_m} \cdot H_{rms\,i}^2\right] \cdot (x_i - x_{i-1}) \cdot c_{gi}$$

α_1 = bottom friction coefficient = 0.1 - 0.5
α_2 = wave breaking coefficient = 0.1 - 0.36

The energy dissipation thus can be calculated in correspondence with the decay of wave height for different nearshore profiles and wave conditions.

3. Applications of Wave Height Decay on a natural Profile in Full Scale Experiments

In the Big Wave Flume (GWK) full scale experiments over natural beach profiles with sand (D_{50} = 220 μm) have been carried out under a wide range of wave-, beach- and profile conditions.

3.1 Wave Height Decay of individual Waves

The wave height decay from the breakpoint up to the uprush zone was recorded by means of video registrations of breaking wave trains trough a grid at one of the tank walls and analysed for nearly 100 successive waves. The waves have been characterized by the breaker parameter β (FÜHRBÖTER(1976))(see Fig. 2).

Fig. 1 shows the measured and computed wave height decay in the surf zone for a spilling breaker (above) and a plunging breaker (below).
The comparison of computed values with measured data is illustrated in Fig. 2. in terms of the difference in wave height ΔH and the standard deviation $\sigma(\Delta H)$. For DALLY et al. (1984) and BATTJES(1986) the parameters K, Γ, and B have been adapted to the individual wave heights in order to minimize the differences ΔH. Table 1 shows the results of the parameters as functions of H_b/d_b and breaker parameter β.

3.2 Energy Dissipation of irregular Wave Trains in Full-Scale Experiments

Dissipation of wave energy profile changes are caused until a morphologic equilibrium is reached. For investigations during such profile transformation processes the wave heights were measured by resistance wave gauges at 10 locations at intervals of 10 m along the beach profile for regular waves as well as irregular waves.

The results of statistical analysis are presented in Fig. 3. for each wave gauge as follows:

- deviation from SWL η (set-up/set-down)
- dimensionless probability density function $p(H/H_m)$
- statistical wave height parameters H_m, $H_{1/3}$, H_{max}

The results of spectral analysis are shown in Fig. 4 for each wave wire:

- spectral density function presented as block diagram
- spectral parameters H_s, $T_{m0,2}$, and band width parameter ν

The computed wave heights and set-up, respectively, of the models described in section 2. are plotted together with wave height parameter Hm and deviations for the initial wave parameters of the reference wave gauge and the actual profile from SWL as obtained from measured data (see Fig. 5).

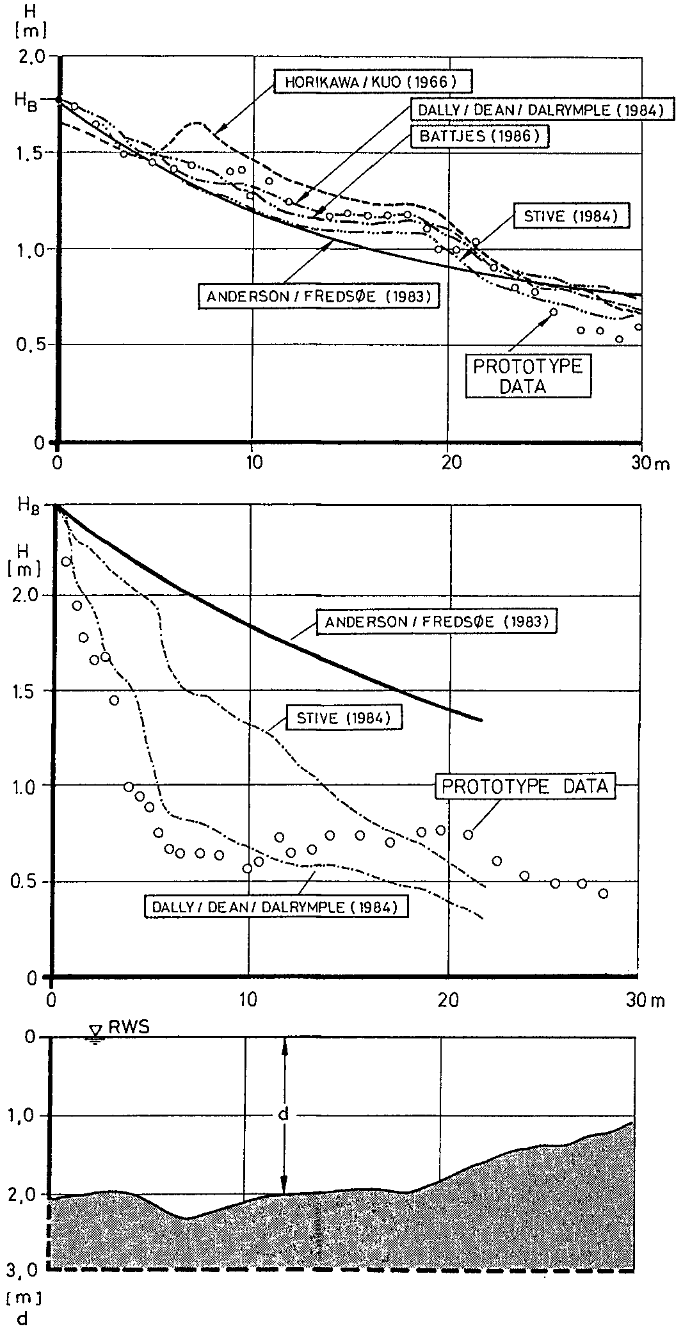

Fig. 1: Comparison between measured data (GWK) and wave-height calculations by empirical and analytical wave decay models for a spilling breaker (above) and an extreme plunging breaker (below) at a natural profile.

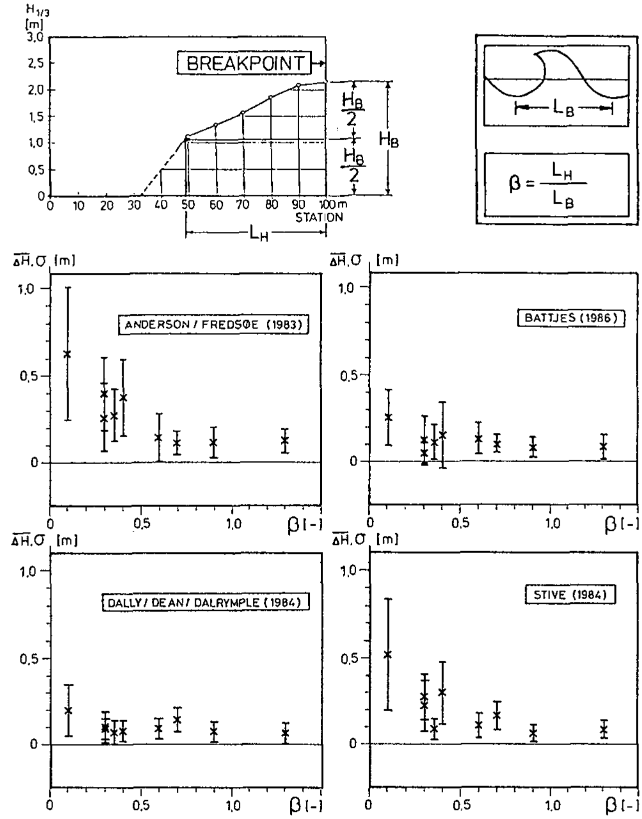

Fig. 2: Mean differences between measured and computed wave heights ΔH and standard deviations $\sigma(\Delta H)$ as function of the breaker parameter β.

INDIVIDUAL BREAKING WAVES BIG WAVE FLUME HANNOVER					
Breaker-type	Wave-Parameter		Energy-Dissipation-Parameter DALLY et. al.		BATTJES
	β [-]	H_b/d_b [-]	K [-]	Γ [-]	B [-]
extreme plunging	0.1-0.2	1.4-1.8	0.5 -1.0	0.5	5.0-20.
plunging	0.2-0.7	0.7-1.4	0.2 -0.3	0.35-0.5	1.0-10.
spilling	0.7-1.4	0.7-1.1	0.2	0.35-0.5	1.0- 2.
	H_o/gT^2 [-]	H_b/d_b [-]	K [-]	Γ [-]	B [-]
	0.0025	1.2-1.8	0.35-1.0	0.5	5.0-20.0
	0.0035	0.8-1.1	0.15-0.35	0.3 -0.5	1.0-10.0
	0.0070	0.7-1.1	0.15-0.35	0.25-0.35	1.0-10.0
	0.0110	0.7-0.9	0.2 -0.25	0.35	1.0

Table 1: Variations of parameters K and Γ for DALLY et. al. and B for BATTJES' models to minimize the differences between measured data and computed values.

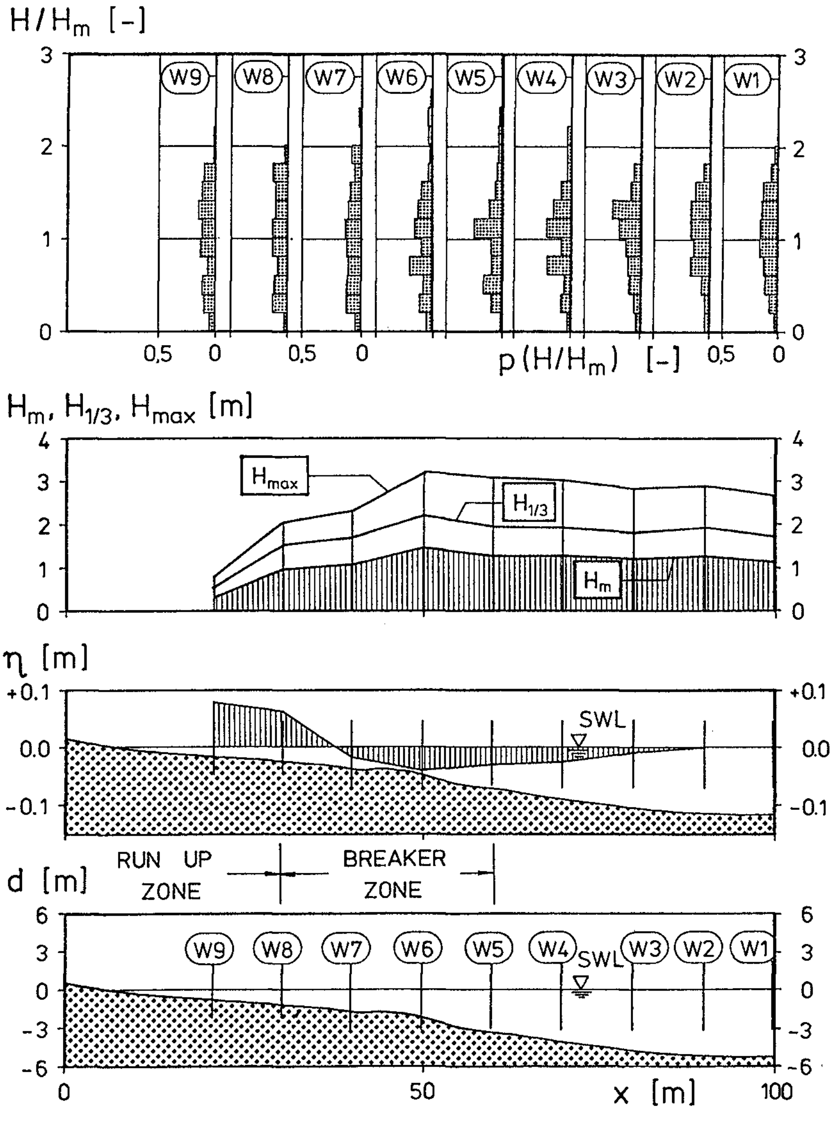

Fig. 3: The results of statistical analysis for a spectrum of Hs = 1.5 m and Tp = 6.0 s

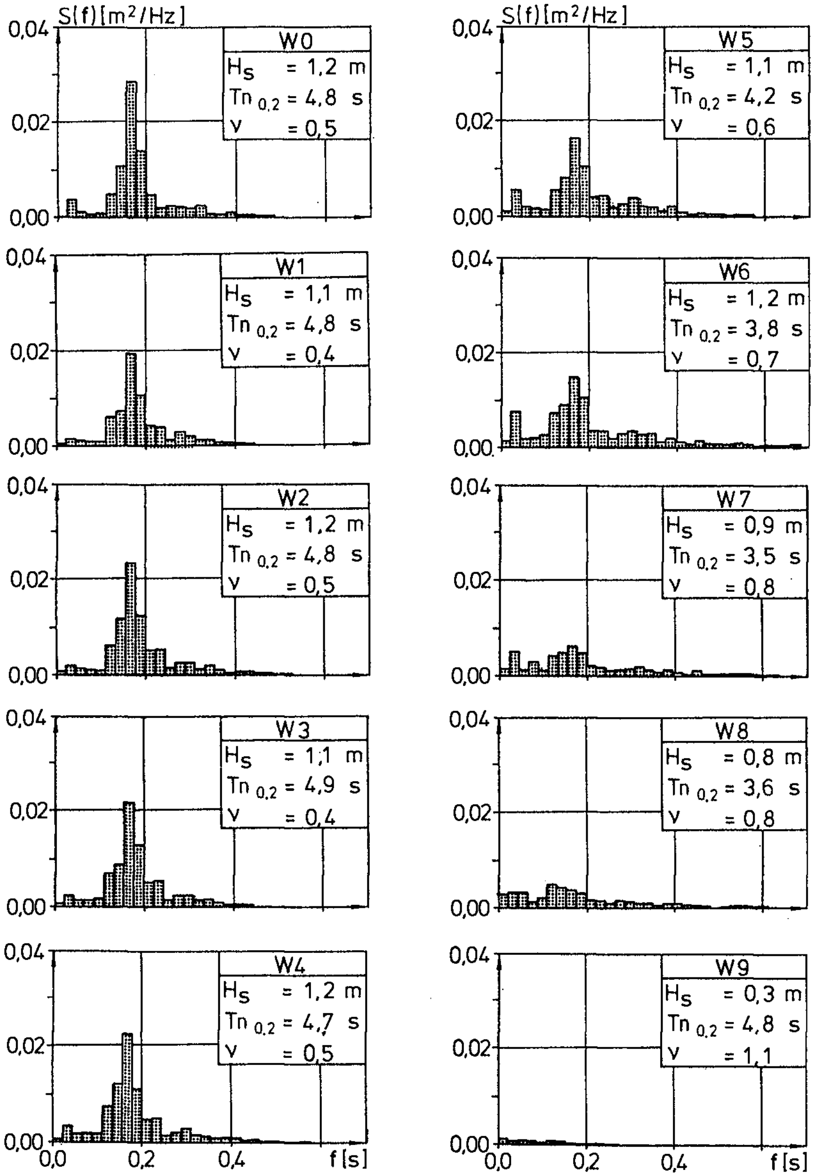

Fig. 4: The results of spectral analysis for a wave spectrum of H_s = 1.5 m, T_p = 6.0 s, where n_0 and n_2 denotes the spectral moments

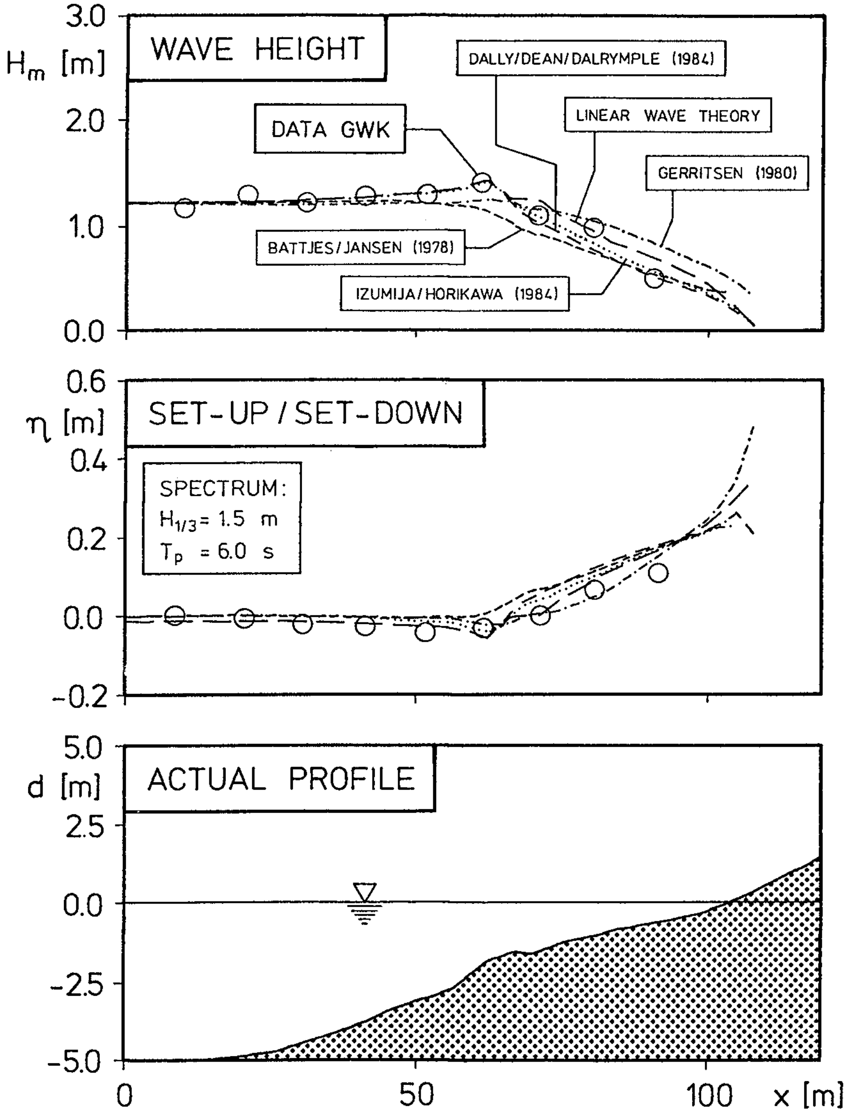

Fig. 5: Comparison of computed and measured values for a spectrum of H_s = 1.5 m, T_P = 6.0 s across the profile.

The above results, Fig 4, show, that (I) the energy density spectrum shows dissipation of wave energy in the breaker zone in direction of wave approach, Δn_0 = 95 %, (II) the peak of the energy spectrum is reduced and, (II) the transformation of incident wave energy to lower and higher frequency contributions i.e. higher frequency oscillations and in the surf zone disintegration of waves and turbulence.

The statistical analysis of wave heights and comparison with selected wave height decay models show fairly good agreement between computed values and measured data, even for the more simple models predicting only regular waves (Fig.3 and Fig 5).

The comparison of measured and computed water level deviations shows slight underprediction of set-down and significant overprediction of set-up in the surf zone for the examples (Fig. 3 and Fig. 5).

3.3 Energy Dissipation of Waves in Field Investigations

Measurements of wave height have been recently started in a profile perpendicular to the shoreline at the west-coast of the island of Sylt (North Sea) near the village of Rantum with a typical nearshore bar- and trough topography
Using as initial values the measured data from a wave rider buoy offshore (10 m-depth) wave heights and set-up/set-down were computed by the models described in section 2.4 and compared with wave height measurements inside the surf zone.

Fig. 6 shows time series of measured and computed data for a storm event in february 1988 with offshore wave heights up to Hs = 4.0 m.

3.4 Application to a 2-Dimensional Nearshore Topography

A wave refraction model based on the wave ray method was adapted to the study site by implementation of a breaker criterium (WEGGEL(1972), a wave height decay model (ANDERSON/FREDSØE (1983)) and a criterion of wave height stabilization (TUCKER et al. (1983).

The topography of the investigation area was taken into account up to the MSL-10.0 m depth contour line. Fig. 7 shows as an example areas of wave height exceedance in the nearshore topography, the breakpoints (•) and points of restabilization (o) for incident wave parameters of H = 6.0 m , T = 10.0 s and the direction of wave approach perpendicular to the shore.

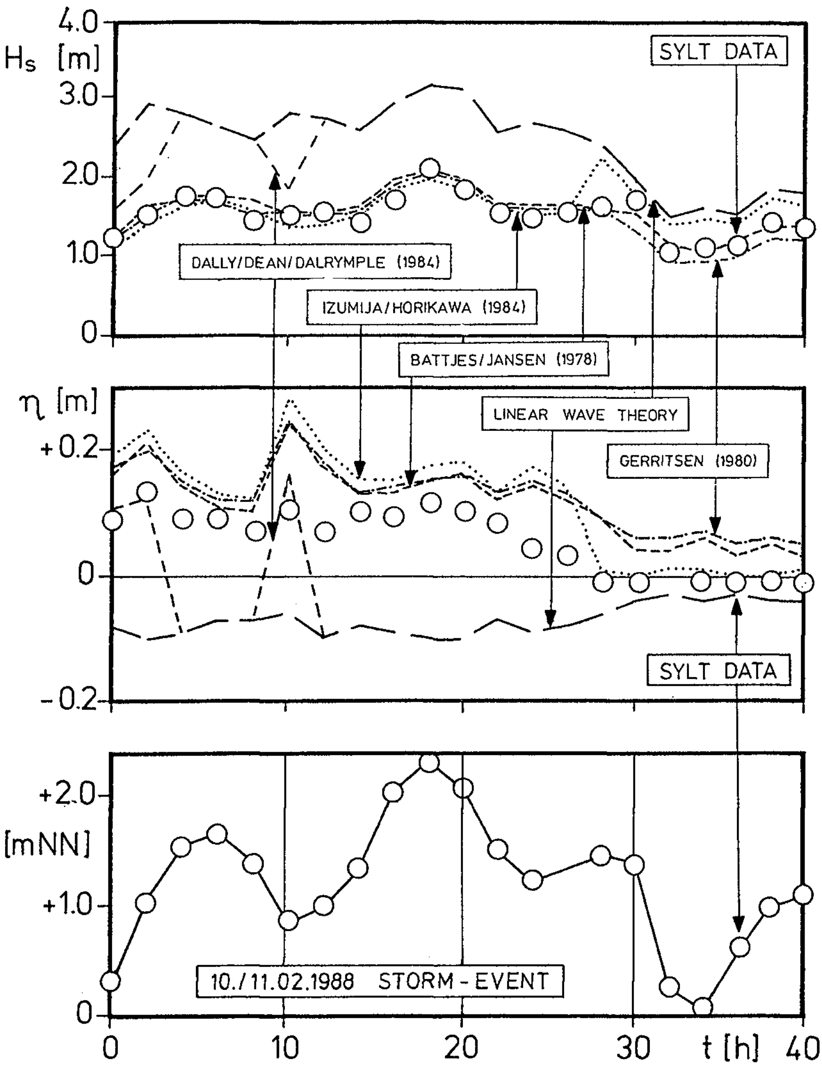

Fig. 6: Comparison of computed values and measured data for a storm event at the west coast of the Island of Sylt/North Sea

The contour lines of equal wave height indicates the effect of morphological elements as the bar (breaker zone) and the gap in the bar (wave energy intake into the trough region).

First comparisons of measured wave heights and computed wave heights show generally fairly good agreement but in some cases significant differences arise due to the inadequacy of of the energy dissipation formulation. Therefore it is the task to combine one of the more sophisticated models mentioned in section 2. with the refraction model in order to obtain better agreement between computed and measured wave parameters.

4. Discussion

Measurements in the Big Wave Flume (GWK) and at the west coast of the Island of Sylt have been carried out with respect to energy dissipation due to breaking waves. The wave height decay of individual waves and of irregular wave trains were analysed and compared with empirical and analytical models which partly take the effects of wave height distribution into account to predict the wave height variation and wave set-up/set-down over a profile.

For individual waves good agreements were found for moderate energy dissipation conditions (spilling breakers). The energy dissipation of plunging breakers, however, is not satisfactory described.

The application to a nearshore site with rough and varying topography is still under investigation. The models tested with full scale experiment data were found to predict wave height decay quite well for the 1-dimensional case.

For the rough varying bar and trough profile at the west coast of Sylt significant differences were found due to the different treatments of regular waves ,irregular waves and the breakpoint formulation.

The models will be tested in combination with a refraction model to obtain a suitable description of wave energy dissipation in a 2-dimensional topography.

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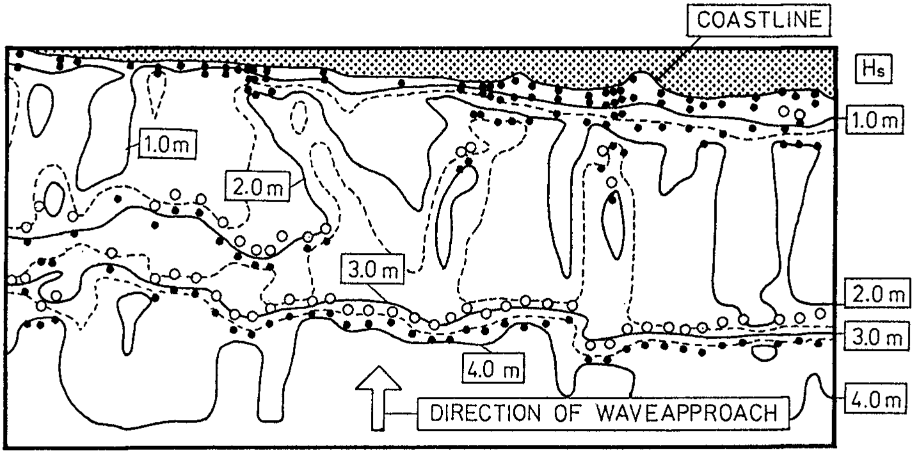

Fig. 7: Contour lines of wave height exceedance, break-points (•) and points of wave restabilization (o) for wave parameters H = 6.0 m, T = 10.0 s, Θ = 270 degrees

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