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Shock pressure interactions on prototype sea dykes caused by breaking waves

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ABSTRACT: This paper deals with shock pressure phenomena due to breaking waves acting on sloping faces of sea dykes. The full-scale investigations were carried out in the new research facility LARGE WAVE CHANNEL in Hannover, Germany. Maximum shock pressure estimations are given for practical slopes 1:4 and 1:6. An extension of the results to steeper and flatter slopes is proposed. For the slope 1:6 the spatial shock pressure distribution and the shock pressure transfer to the subsoil are treated additionally.

1 INTRODUCTION

In the past, dykes and revetments at coastal zones of Germany were frequently destroyed by heavy wave attack during storm surge tides. There are several reasons which are important for dyke failures:

- shock pressures due to wave breaking,
- wave run-up and overtopping,
- up- and down-rush velocities,
- dyke construction (slope, cover layer, material etc.) and
- local sea state characteristics.

This paper deals with shock pressure phenomena on sea dykes with uniformly sloping faces. Shock pressures due to plunging breakers may cause very first damage of the cover layer and the subsoil (Führböter(1966), Stephan(1981)).

First investigations on this topic were published by Bagnold (1939). Contributions by Skladnev and Popov (1969) dealt with impact forces and scale effects. Stive (1984) published results of nearly full-scale tests on wave impacts. Führböter (1986) compared results of model and full-scale tests of wave impacts on a 1:4 slope.

Wave breaking processes in coastal engineering are mostly investigated experimentally. Small-scale models are always affected by scaling problems. In the case of breaking waves there are to consider the model laws of FROUDE and REYNOLDS which govern the forces of gravity, inertia and viscosity. Due to aeration effects the surface tension must be considered applying the model law by WEBER. With regard to elasticity the model law by CAUCHY is important.

It is well-known that scale effects do exist for breaking waves in small-scale models, but until now, sufficient informations about their quantitative influences are not available.

The new Large Wave Channel in Hannover offers the opportunity to investigate coastal problems with special reference to the German coastal zones in full-scale. Being able to neglect scale effects reliable solutions for coastal protection problems can be established (Führböter (1982)).

The main dimensions of the channel are: depth 7.0 m, width 5.0 m and length 325 m. Regular and random waves are produced mechanically by a wave generator (pusher- and flap-type). The maximum wave height is 2.5 m. More details about the Large Wave Channel were published by Grüne and Führböter (1975). Design criteria and technical works were reported by Grüne and Sparboom (1982).

2 PROTOTYPE DYKES

The core profiles of the prototype dykes were constructed by sand. The compact cover layers were built by asphalt-concrete in a thickness of about 0.20 m. During the wave tests the core was drainaged to avoid dyke failure caused by positive water pressure below the impermeable cover layer.

With regard to modern dyke protection works the faces of the prototype dykes were constructed with uniform slopes 1:4 and 1:6.

The investigated dykes were supplied with measuring devices to obtain calibrated electrical signals for:
- wave impact pressures on the slope surface,
- wave run-up on the slope and
- wave impact pressures in the subsoil.

The corresponding wave heights were measured at the toe of each dyke. In Fig. 1 the prototype dykes and the measuring equipments are represented schematically. The scheme of the signal processing and data recording is given in Fig. 2.

3 SHOCK PRESSURE INVESTIGATIONS

A typical record of a shock pressure (wave impact) due to wave breaking (plunging breaker type) on the slope can be seen in Fig.3. The peak pressure which is much higher than the wave or breaker height is highly effective during a relative short time. Due to the included airvolume by the plunging breaker the shock pressure occurrence can be explained by a compression phase. The time of compression Δt_c of all evaluated impacts lies between 10 and 60 milliseconds. The amplitude as well as the time history of shock pressures are strongly dependent on:
- breaker process and aeration,
- angle of the sloping face,
- thickness of the backrush-water and
- wave characteristics (regular and random).

3.1 Probability theory

In the analysis of jet impacts (Führböter (1966) and (1969)) the maximum pressure p_{max} is described by

$$p_{max} = \delta \rho v c \sqrt[3]{\frac{c}{v}} \qquad (1)$$

$$\text{with } \delta = \left(\frac{E_a}{E_w} \cdot \frac{R}{D}\right)^{2/3}$$

E_a, E_w = elasticity of air and water
R = hydraulic radius of impact area
D = representative thickness of included air content
δ = dimensionless impact number
ρ = density of water
v = impact velocity vertical to the wall
c = sound velocity in water.

In this equation the air content term expressed by D (see Bagnold (1939)) is strongly stochastic and has an important influence on the impact as well as the hydraulic radius R of the impact area and the relation E_a/E_w. The following transformation of equation (1) yields:

$$p_{max} = \underbrace{\left(\frac{E_a}{E_w} \cdot \frac{R}{D}\right)^{2/3}}_{\text{stochastic}} \cdot \underbrace{\rho v c \sqrt[3]{\frac{c}{v}}}_{\text{deterministic}} \qquad (2)$$

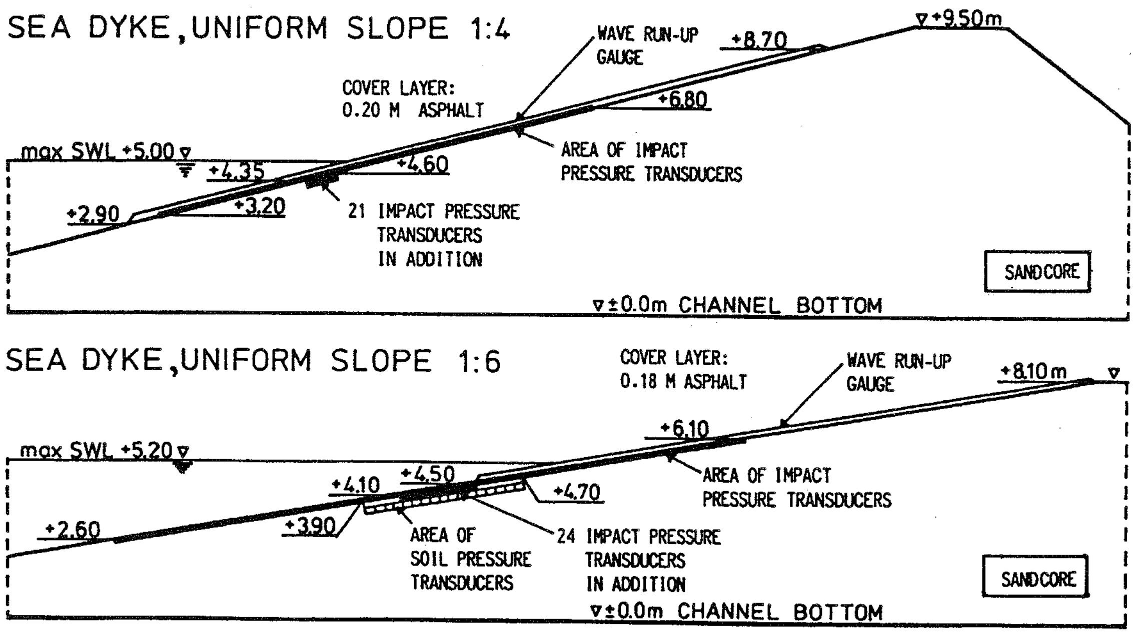

Fig. 1 Investigated prototype sea dykes in the Large Wave Channel

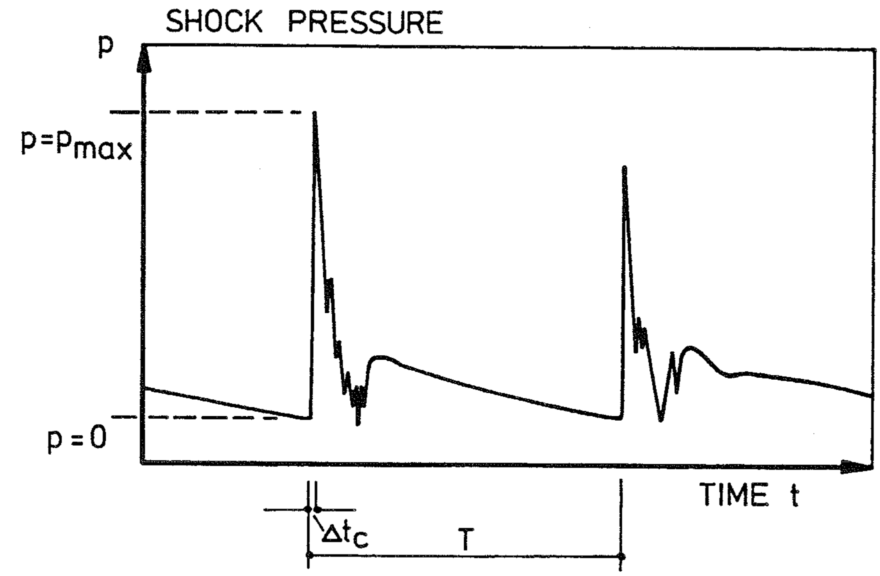

Fig. 3 Typical shock pressure caused by breaking waves (plunging type)

3.2 Results of shock pressure experiments

Maximum shock pressures were evaluated from each individual breaking wave. As already shown by Führböter (1986) the maximum shock pressure values follow a Log-Normal distribution. In Fig. 4 and 5 the results for i = 50, 90, 99, 99.9 % are plotted as dimensionless relative impact pressures. Each line represents the results of a test serie with nearly 200 waves. For this wave number sufficient estimates were reached up to a level of 99.9 % probability. In Fig. 6 and 7 there are compared the results obtained by test cycles with regularly generated waves with those obtained by field measurements at the EIDERDAM storm surge barrier. In Fig. 7 results from a narrow banded wave spectrum in the channel are completed. All impacts of this test are plotted in relation to the breaker number (Fig. 8). Looking towards a practical approach of sea dyke design (see equation (5)) the distribution of the worst case is estimated with a tendency to the safe side.

Based upon the worst case distributions for both slopes 1:4 (Fig.6) and 1:6 (Fig.7) it seems to be possible to establish a formula which contains the influence of the slope angle:

$$p_{max} = p_i = \text{const.}\ \frac{1}{n}\rho g H \qquad (6)$$

with i = 50, 90, 99, 99.9 %

and n = front slope 1:n .

The empirical equation (6) may be justified by the important damping influence of the backrush-water on the impact amplitude. The thickness of the backrush-water increases with flatter slope and the impact pressure decreases proportionally. The application of this formula to slopes in general is shown in Fig. 9. With respect to the real experiments with 1:4 and 1:6 slopes it should be considered that only for the range 1:3 to 1:8 a high reliability can be achieved. For the range 1:0 to 1:3 the values are extrapolated and should therefore be considered very cautiously. Based upon jet impact investigations, Führböter (1966) also determined relative impact pressures for the vertical wall. Expected values for breaker heights of 1.0 m are added in Fig. 9. Future full-scale investigations on very steep slopes up to the vertical wall could be useful to proof the proposed empirical formula.

In order to get informations about the spatial distribution of shock pressure occurrence the measured pressures ($p_{i\,max}$) of each transducer at the slope were determined for each test cycle. Fig.10 represents results of two test cycles. The level of the highest maximum shock pressure, evaluated relatively to the wave height is drawn in Fig.11 versus the relative shock pressure. The mean occurrence point for the slope 1:6 can be characterized by 0.5 H below SWL. The same value was found by Stive (1984) for steeper slopes 1:3 and 1:4.

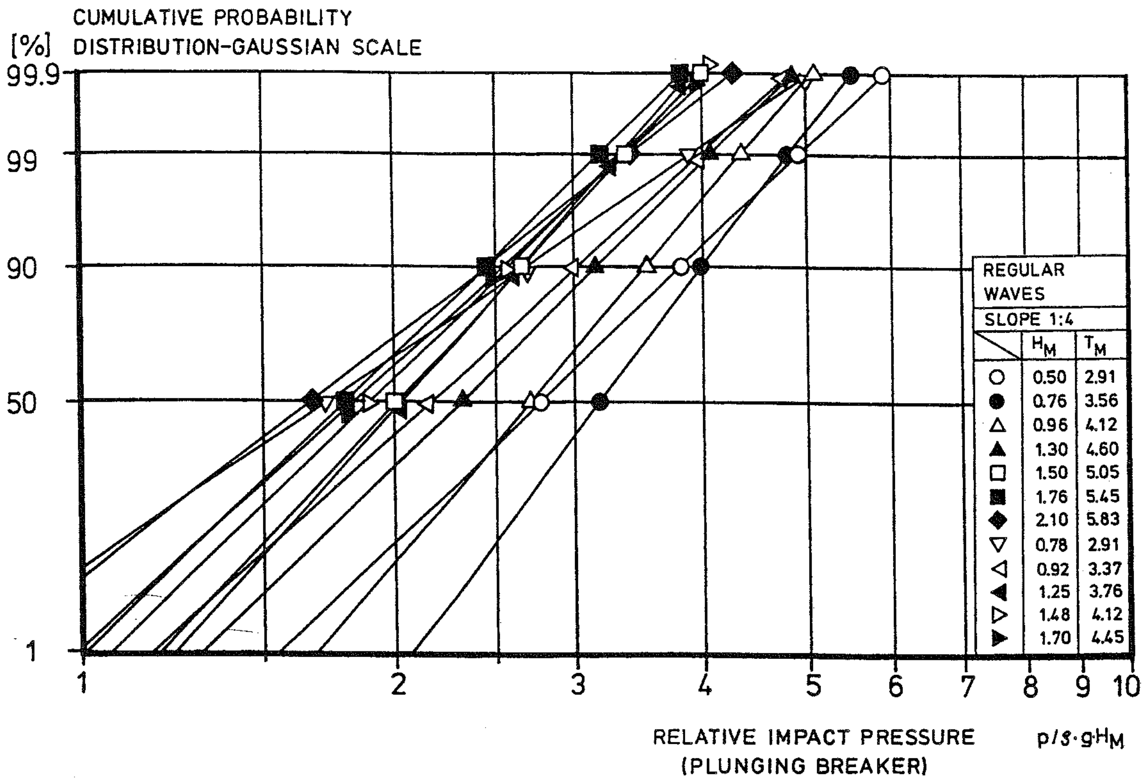

Fig. 4 Shock pressure results, slope 1:4

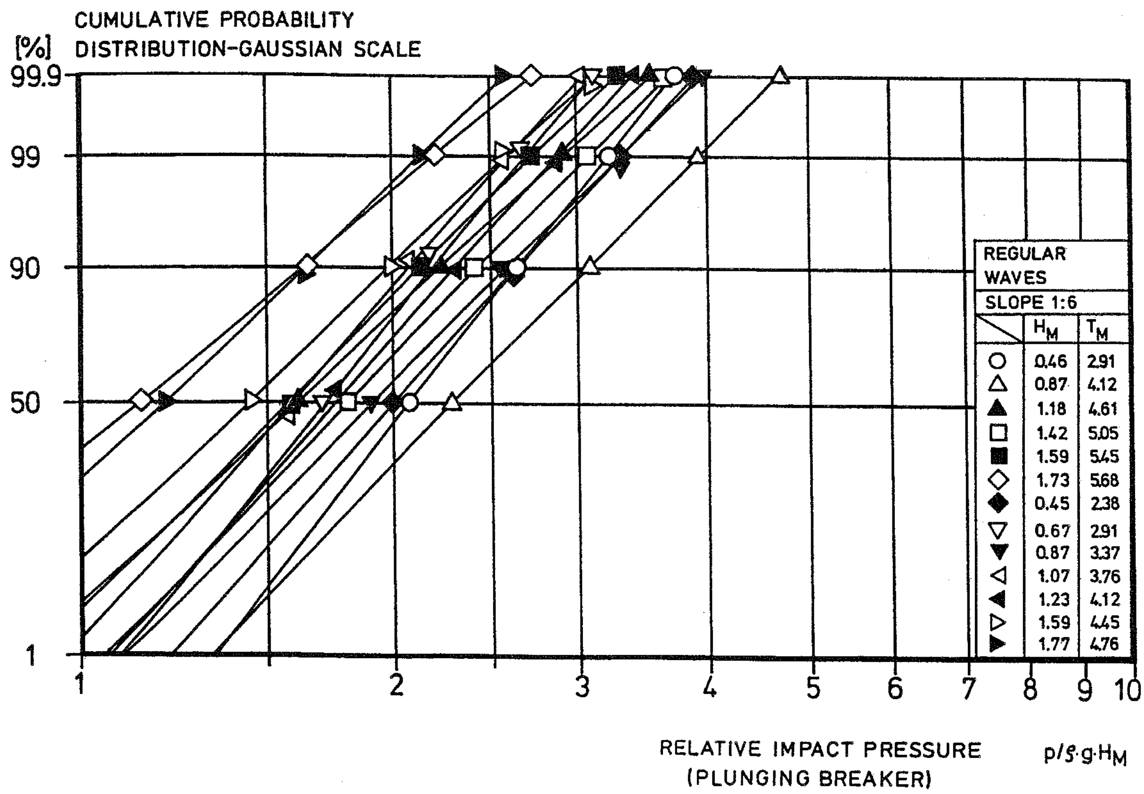

Fig. 5 Shock pressure results, slope 1:6

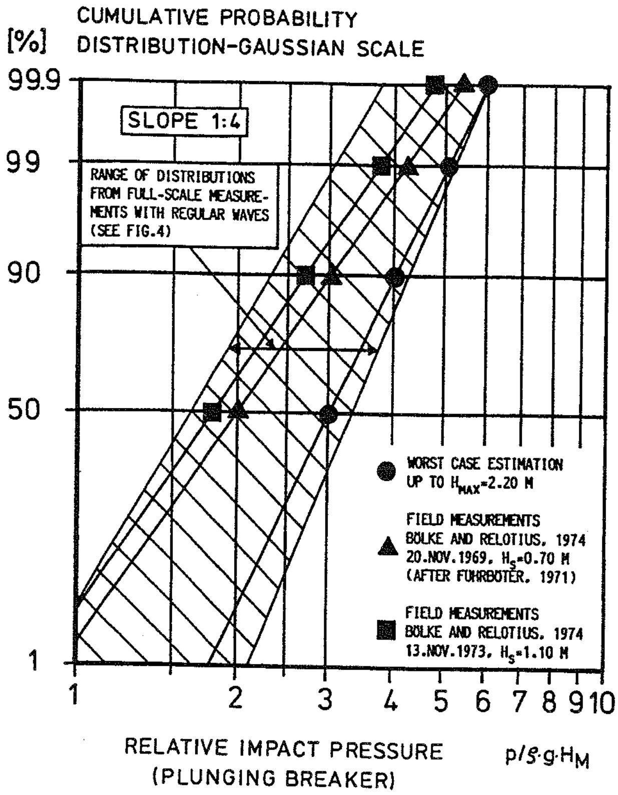

Fig. 6 Shock pressure distribution for the worst case, slope 1:4

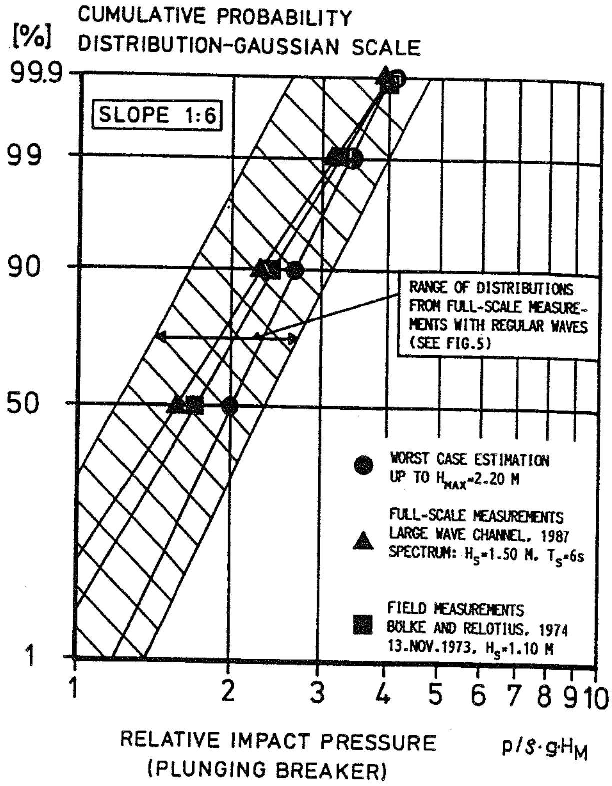

Fig. 7 Shock pressure distribution for the worst case, slope 1:6

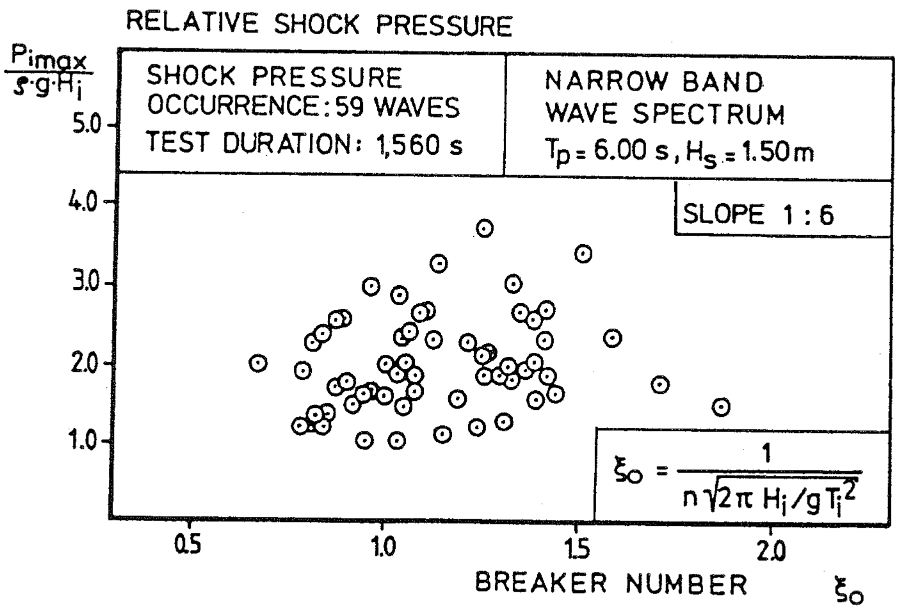

Fig. 8 Random wave impact vs. breaker number, slope 1:6

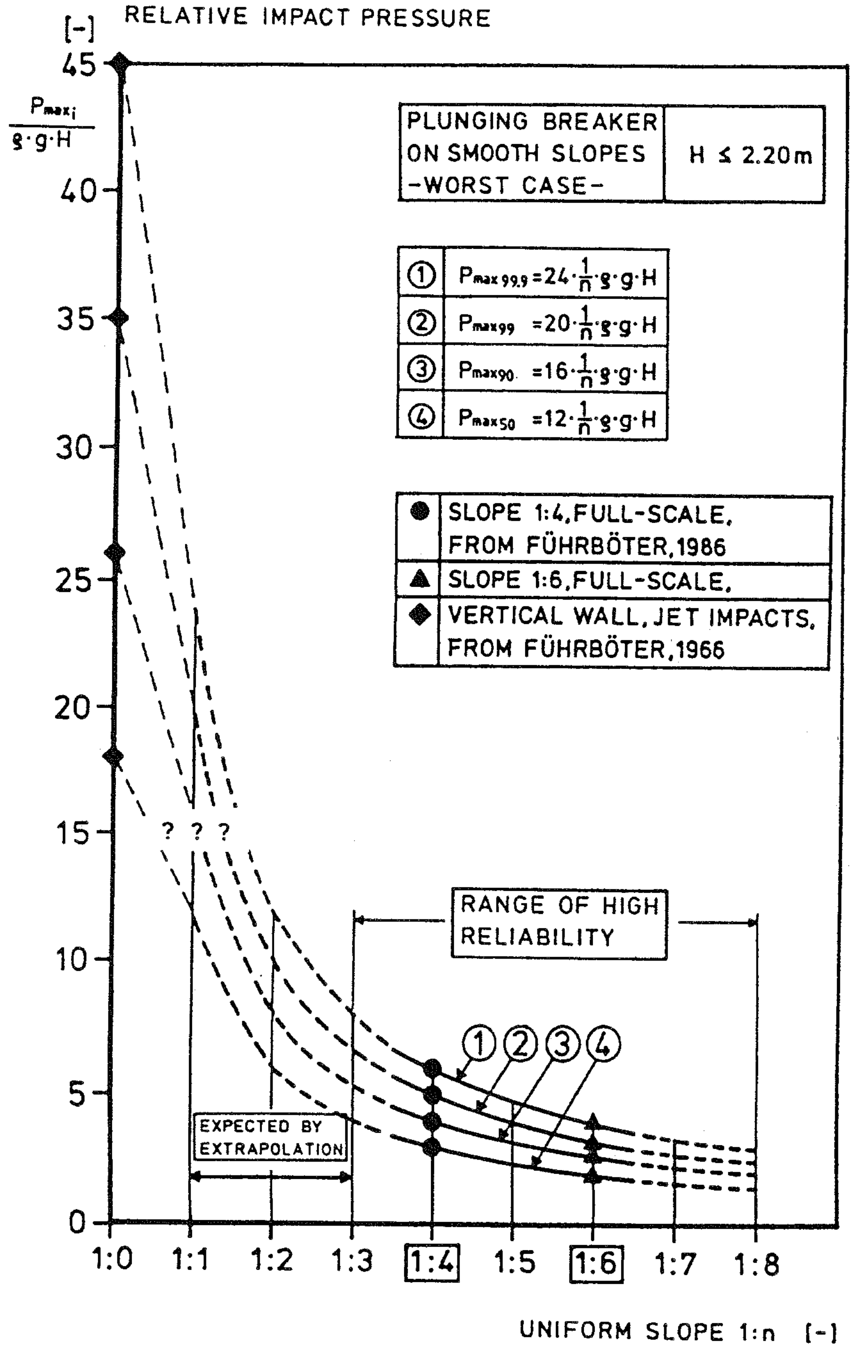

Fig. 9 Generalized proposal for breaker-induced shock pressures on smooth slopes

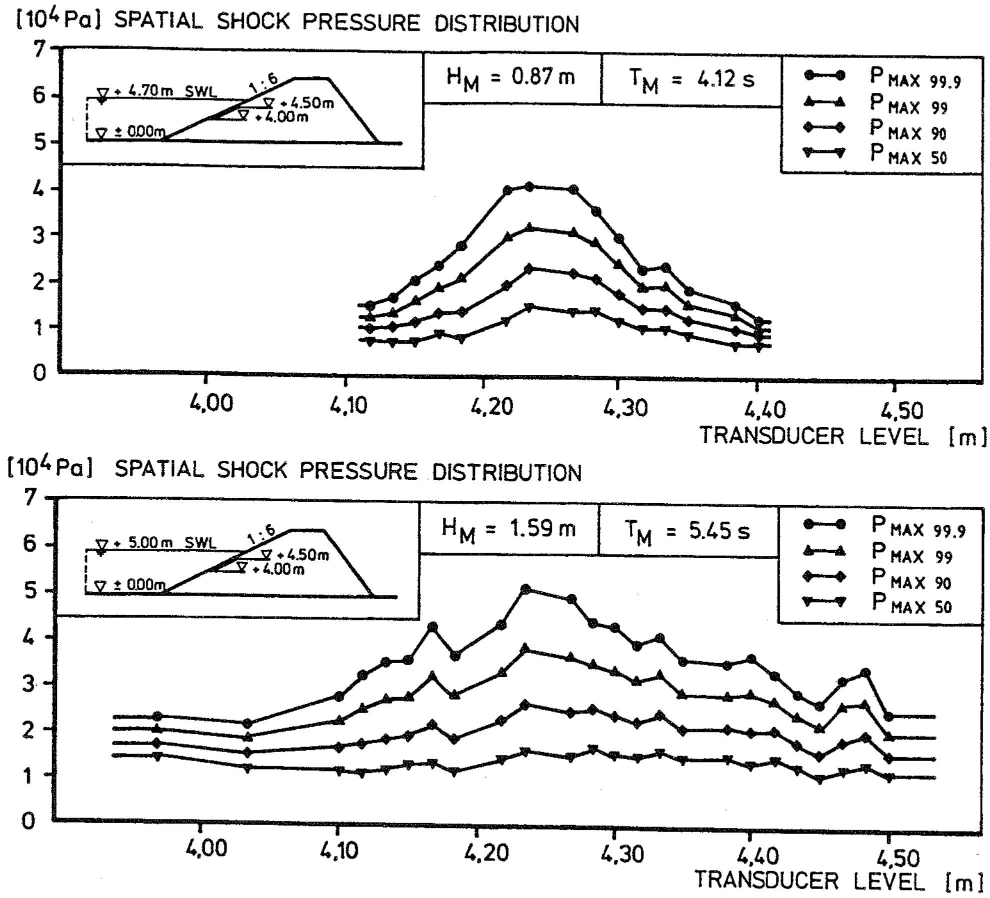

Fig.10 Spatial distributions of shock pressures on the slope 1:6

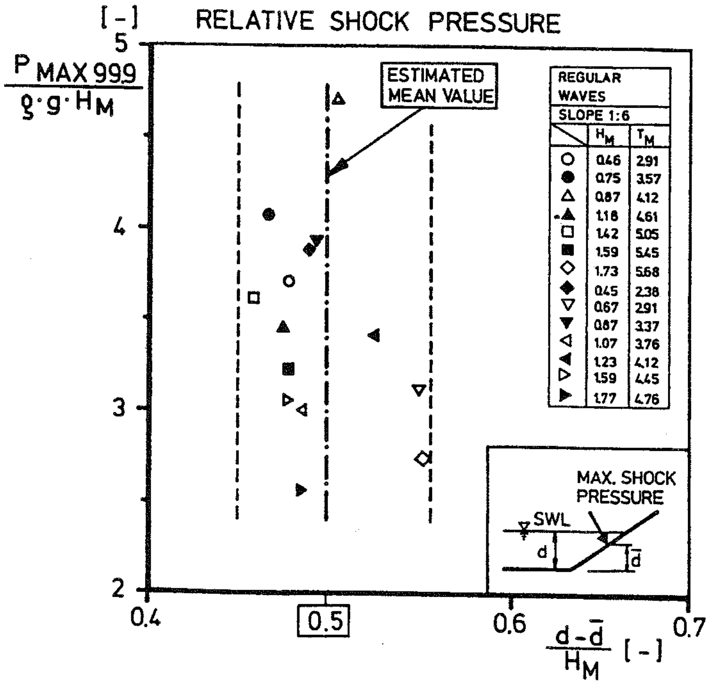

Fig.11 Area of maximum shock pressure occurrence for the slope 1:6

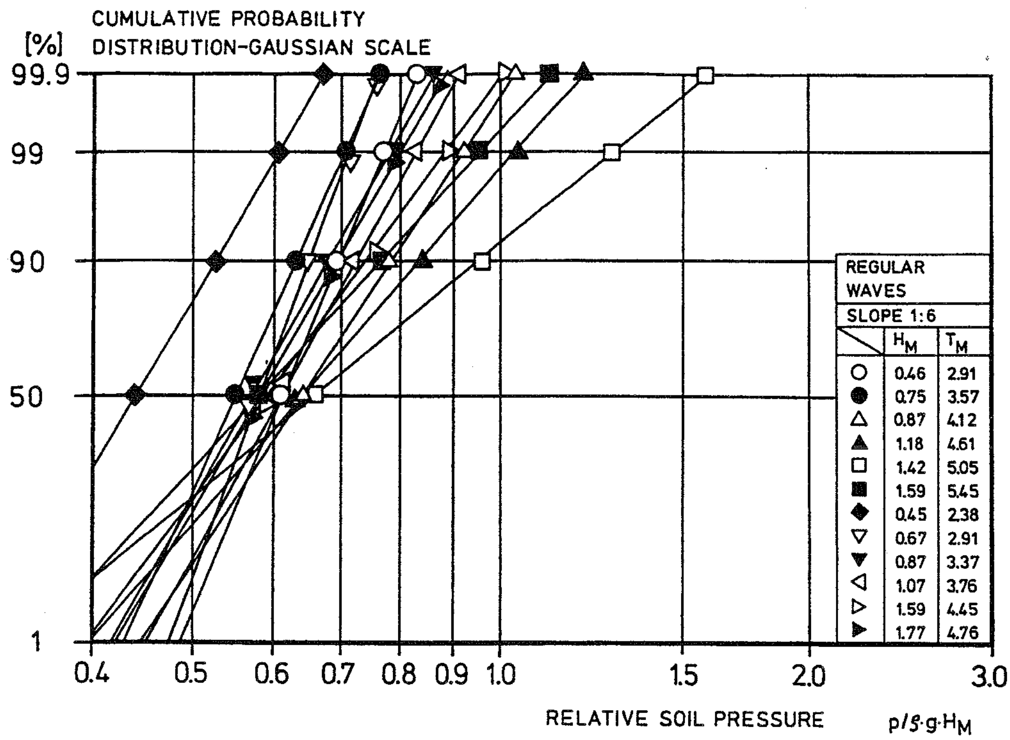

Fig.12 Soil pressure results 0.50 meter below the asphalt cover layer

Simultaneous measurements of soil pressures below the compact layer were also evaluated statistically like the shock pressures on the slope surface. The results are given in Fig.12. Comparing the results with those in Fig. 5 it can be stated that only about 30 per cent of the original shock pressures on the slope surface were transferred to the subsoil, due to damping effects of the compact asphalt layer. This relation is an important margin for soil-mechanical aspects in the design of sea dykes with impermeable cover layers on sandy cores.

4 CONCLUSIONS

As already stated by Führböter (1986), shock pressure phenomena due to breaking waves acting on dyke slopes can only be described probabilistically by the Log-Normal distribution.

The thickness of the backrush-water has an important influence of the shock pressure occurrence. Prototype and field investigations (slope 1:4 and 1:6) show that a proportionality exists for shock pressures and slope angles (equation (6)). For mostly used sloping faces of sea dykes in shallow water regions the following maximum shock pressures, acting nearly 0.50 H below SWL on the slope surface are to be expected:

SLOPE 1:4 $p_{max} \cong 6\,\rho\,g\,H$,

SLOPE 1:6 $p_{max} \cong 4\,\rho\,g\,H$.

The value for slope 1:4 is definitely greater than that found by Stive (1984).

In the case of compact cover layers the shock pressure transfer to the subsoil is characterized by a strong reduction of the original value at the slope surface. 0.50 m below the cover layer there are to be expected 30 per cent of the original shock pressure amplitudes.

Full-scale experiments on wave breaking phenomena are indispensible, because small-scale models are always influenced by scale effects. Together with field investigations under real sea state conditions (Grüne(1988 full-scale measurements guarantee highly reliable results for future design on sea dyk

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