CHAPTER 78

WAVE LOADS ON SEADYKES WITH COMPOSITE SLOPES AND BERMS

by
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Abstract

This paper deals with investigations on loads from wave-induced shock pressures on seadykes with composite slopes and berms. The investigations have been done with large scale laboratory tests, using different wave climate characteristics (regular waves, PM - spectra and field spectra). Two different types of dyke cross-sections have been investigated: one with an upper slope 1:6 and a berm in front, and the other one with composite slopes 1:3 in the lower part and 1:6 in the upper part. The presented results were discussed with respect to the influences of wave climate, of absolute waveheights and of geometrical conditions.

Introduction

Due to the increasing of storm surges and the supposed long-term rising of water levels at the coastlines of the North Sea, wave loads on seadykes have become again more important for savety analysis of excisting dykes. Air entrainment and wave climate characteristics under real sea state conditions play an important role both on shock pressure occurrence and on wave run-up process. Thus boundary effects and scale effects have to be minimized by using field data or large scale laboratory test data. The results presented in this paper were obtained from large scale laboratory tests in the "Large Wave Channel" (GWK) at Hannover, Germany, within an extensive research program on stability on sloping seadykes and revetments (supervision Prof. Führböter +), which had been supporting partly by the German Research Foundation (DFG) for more than 10 years. Previous results from this research program on wave loads on **uniform slopes** have been reported recently for example by Grüne (1992) for shock pressures and by Sparboom, Grüne, Haidekker & Grosche (1990) for wave run-ups.

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First results from the recent investigations with **composite slopes and berms** on loads from shock pressure occurrence will be presented in this paper. First results on loads from the wave-run-ups measured synchronously within the same testseries are reported by Schüttrumpf, Bergmann & Dette (1994).

Test equipment and data recording

The investigations have been conducted in the Large Wave Channel (GWK) at Hannover (Grüne, Führböter, 1976), which is a joint institution both of the University of Hannover and the Technical University of Braunschweig.

Two different types of dyke cross-sections were installed, which are shown in figure 1. A uniform slope of 1:6, which had been used for previous investigations, in its lower part, firstly was replaced by a berm up to 3.3 m above bottom (upper cross-section in Fig.1), then secondly replaced by lower slopes of 1:3 (middle and lower cross-section in Fig.1). To get a wide range for the vertical distance *Dc* between stillwaterlevel *SWL* and slope junction, the replacing by lower slopes of the composite slope cross-sections has been done in two steps. In the first step the lower slope was built up to the same level as the berm (3.3 m above bottom), in the second step up to 4.5 m above bottom.

Waves were measured with wire gauges in front of the wave generator and in front of the dyke cross-sections. The wave induced shock pressures were measured with pressure cells on the slope surfaces in vertical distances of roughly 10 cm. The areas on the dyke surface with installed pressure cells are indicated in figure 1. For the testseries with the berm and the composed slopes with a lower slope up to 3.3 m above bottom pressure cells only were installed on the upper slope 1:6. Furthermore wave run-up was recorded with a step run-up gauge.

The testseries for each of the three dyke cross-sections in figure 1 were conducted with two water levels (4.0 m and 5.0 m above bottom). For each testseries with one of these both waterlevels three different types of wave characteristics were generated: Regular waves, PM - spectra (narrow banded) and field spectra (wide banded); roughly 15 single tests with each of these three wave climate types. The generated field spectra had been measured in front of similar dyke cross-sections at the german coast during high storm surges.

For data collecting two different modes have been used: With the first one all analog signals from pressures cells, waves gauges and wave-run-up gauges were continuously digitized with 100 Hz and then storaged by the main processing computer. With the second mode only higher individual shock pressure events were storaged additionally by a personal computer, using 200 ms long time intervals of the pressure signals as uncontinuous windows with a digitation rate of 1 kHz. The advantage of this sample method is the high digitation rate, but due to that the disadvantage is, that the sample is time-restricted, which leads to lossings of total

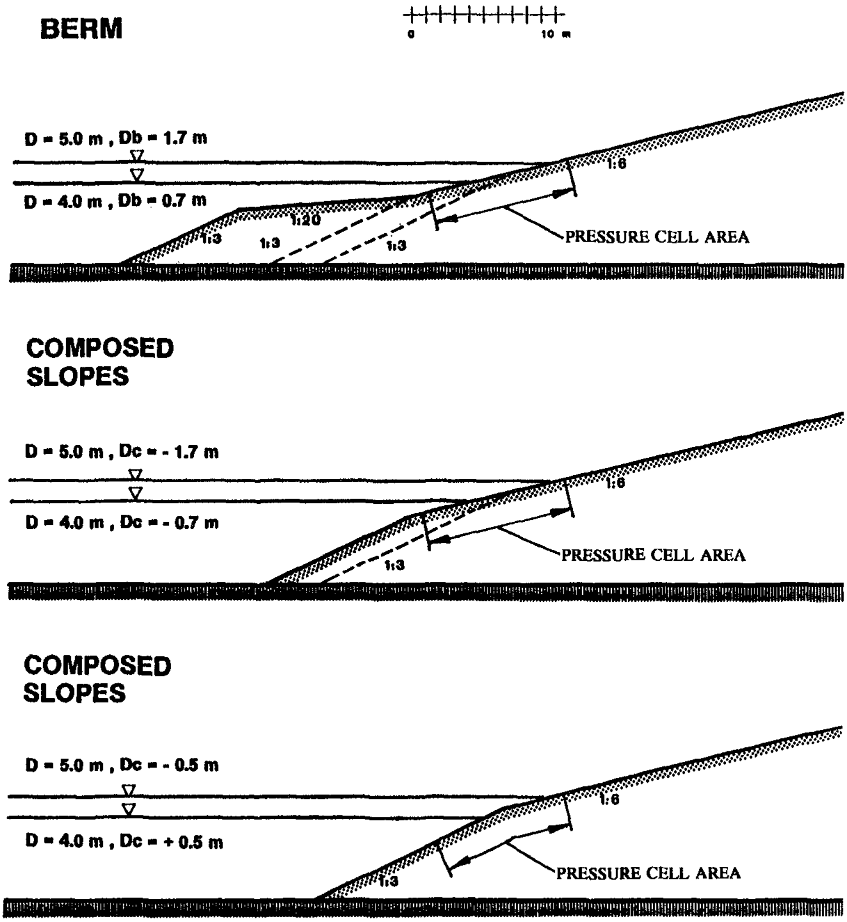

Fig. 1 Dyke cross-sections with berm and composed slopes, investigated in the LARGE WAVE CHANNEL (GWK)

events, especially if the threshold level is accomplished by high quasi-static pressures or by spikes from noises. Therefore a complete data analyzing of all testseries with all pressure cells was done from the 100 Hz digitized datafiles. It must be mentioned, that there were some reduced peak pressure values for higher shock pressure events compared with the 1 kHz-digitation-mode, depending on the peak pressure rising time. The reductions mostly were small, but some rare events were reduced up to approximately 30%. With respect to the stochastic behaviour the influence of partly reduced maximum peak pressure values on the general characteristics of shock pressure ocurrence seems to be small.

Analyzing of shock pressures, definitions

Shock pressures occuring on sloping dyke surfaces are damped more frequently compared to those on vertical walls. Furthermore, especially under real sea state conditions, partly they are mixed with pressure components from waves and wave run-ups. Thus it is often very difficult to distinguish the real shock pressures from the steep wavefronts or the wave run-up fronts, especially if one use normal speed records. In previous reports the author has described an detailed method of analyzing pressure-time histories from high-speed records, which allows a summerizing of the numberless different occuring shapes of pressure-time histories by anatomy parameters (Grüne 1988a, 1988b, 1992).

Using this parameterizing mode, it was possible to evaluate a generalized model of shock pressure occurrence with respect to deterministic and stochastic characteristics. The deterministic parts of the model are represented by local distributions of the anatomy parameters on dyke surface. The local distributions may be devided into different local ranges, which each of it represents a certain state during the breaking process.

For the stochastic part of the generalized model stands the superposition with the stochastic fluctuations of the anatomy parameters. Most data of the different anatomy parameters spread like stars at the sky. But nevertheless there are some clear tendencies and some envelope conditions. There are many possibilities of relating the parameters one with another, reasonable trends were found in dependence on the peak pressure values *Pmax*. In all cases the quality of correlation increase with increasing *Pmax*. Thus the higher peak pressures may be seen as indicators both for general shock pressure occurrence and for details of anatomy parameters.

The following definitions and notations have to be given with respect to the presentation of the results in this paper:

- The maximum pressure value (peak pressure) of an individual shock pressure event usually is defined as *Pmax* [10^4 Pa , (m waterhead)].
- The maximum value of all peak pressures *Pmax*, recorded during one single test is defined as *Max Pmax* and is either analyzed from the data of each pressure cell separately, when the results are presented as local distributions or analyzed from all pressure cells, when presented in dependence of the breakerindex ξ. All pressure data are related to waveheights *H* and are therefore dimensionless, using [m waterhead] for pressures and [m] for waveheights.
- The waves were generated with a closed loop system, to prevent rereflexion at the wave generator. Thus the generated waveheights have been used. A comparison with the waves, measured in front of the dyke shows sufficient agreements, especially for irregular waves. All waveheights *H* are defined as mean waveheights for regular waves and as significant waveheights *H* 1/3 for irregular waves.

- The unit for the local distribution on the slope surface is definied as waveheight related vertical distance *Delta D/H* between pressure cell and stillwaterlevel *SWL* as shown in figure 2. The vertical distance between the slope junction and *SWL* is defined as *Dc*, as shown in figure 3. The waterdepth in front of the dyke is defined as *D* and the waterdepth on the berm as *Db*.
- The pressure data are either presented in dependence of the breakerindex

$$\xi = H * \tan \alpha \,/\, \sqrt{H/Lo}$$

with $H = Hm$, $T = Tm$ for regular waves and $H = H1/3$, $T = Tp$ for irregular waves or as local distributions. An example for a local distribution of the waveheight related maximum peak pressures *Max Pmax/H* is shown in figure 4. The lefthand plot shows for one single test the local distribution of *Max Pmax/H* for each pressure cell. In the righthand plot such local distributions from all tests within a testseries with constant boundary conditions (for this example: D = 5.0 m, Dc = - 0.5 m, PM - spectra, H = 1.10 m) have been summerized by an envelope curve.

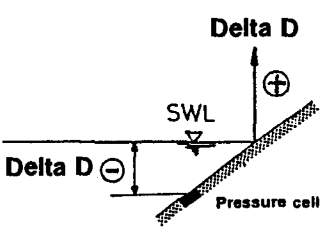

Fig. 2 Definition of *Delta D*

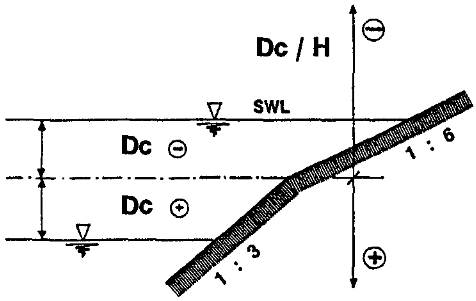

Fig. 3 Definition of *Dc*

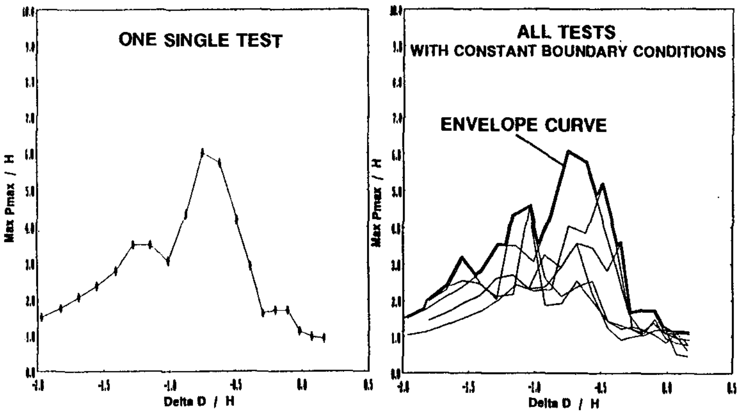

Fig. 4 Example for a local distribution of pressure data *Max Pmax/H*

Results for the dyke with a berm

Figure 5 shows the local distributions of the envelope curves for the testseries with regular waves. It is obvious, that for the testseries with a waterdepth of 5.0 m (lefthand plot) there is a clear trend of higher waveheight related pressures *Max Pmax/H* with decreasing absolute waveheight *H*, which may easily be explained by stronger breaking of higher waves on or in front of the berm due to restricted waterdepths *Db* on the berm. There is also a trend of shifting of the local maximum value area to smaller related waterdepths *Delta D/H* with increasing absolute waveheight *H*, which is also caused by the restricted waterdepth on the berm. A comparison with the corresponding results for the 4.0 m waterdepth in the left hand plot shows, that the trend to higher pressure values is only dominant for waveheights $H \leq 0.5$ m. With the waterdepth *Db* of 0.7 m all higher waves must be broken at least partly.

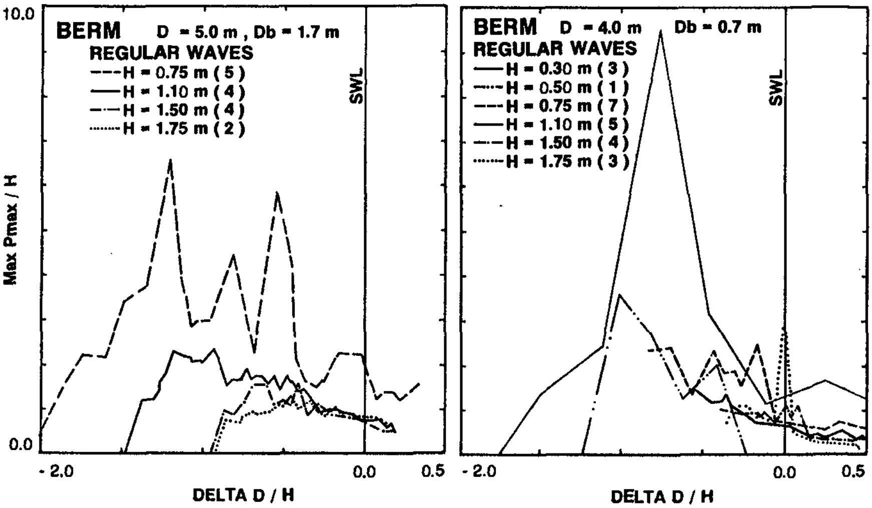

Fig. 5 Local distributions of *Max Pmax/H* for testseries with regular waves

The same trends were found for the results of the testseries with PM - spectra in figure 6, but the differences between the values *Max Pmax/H* of the different waveheights *H1/3* are smaller. That is caused by the fact, that not all waves in the irregular wave train were broken compared to a regular wave train with same waveheight *H* as *H1/3* in the irregular wave train. The same trend also is obvious in figure 7, where the data *Max Pmax/H* of all single tests with regular and irregular waves are plotted versus the breakerindex ξ.

The envelope curves of the local distribution for all tests with an absolute waveheight *H* (*H1/3*) of 1.10 m are plotted for the different wave characteristics in figure 8. The results indicate for all tests with regular waves smaller pressure values *Max Pmax/H* than for irregular waves. Similar results were found for other waveheights. The influence of wave characteristic also comes out in figure 9, where all test results are plotted versus the breakerindex ξ. Both the influence of wave characteristics and of restricted waterdepth can be seen distinctly.

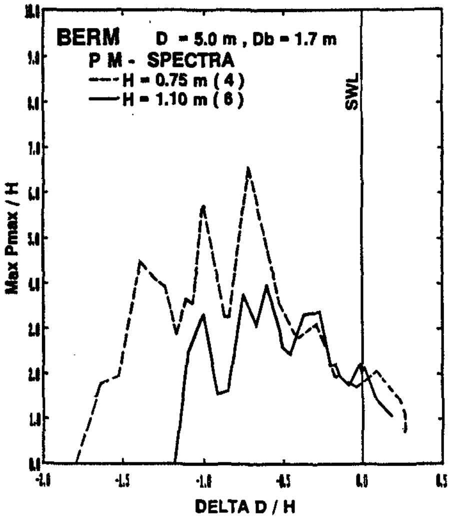

Fig. 6 Local distribution of *Max Pmax/H* for testseries with PM - spectra

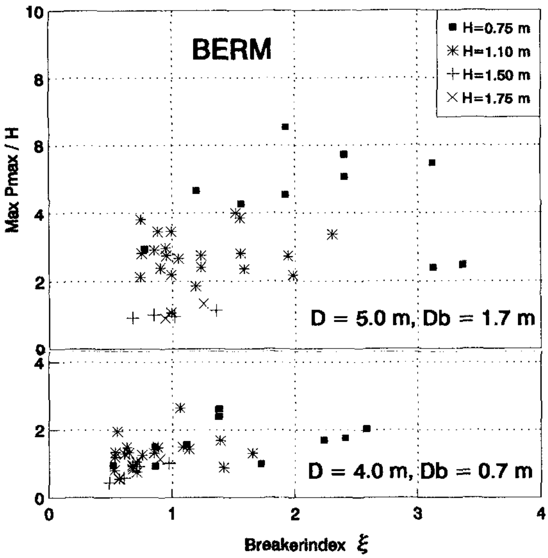

Fig. 7 *Max Pmax/H* versus breakerindex ξ for of regular and irregular waves

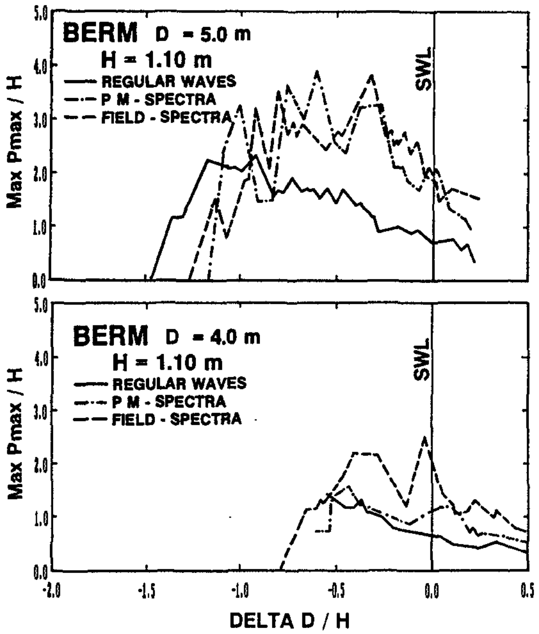

Fig. 8 Local distribution of *Max Pmax/H* for different wave characteristics

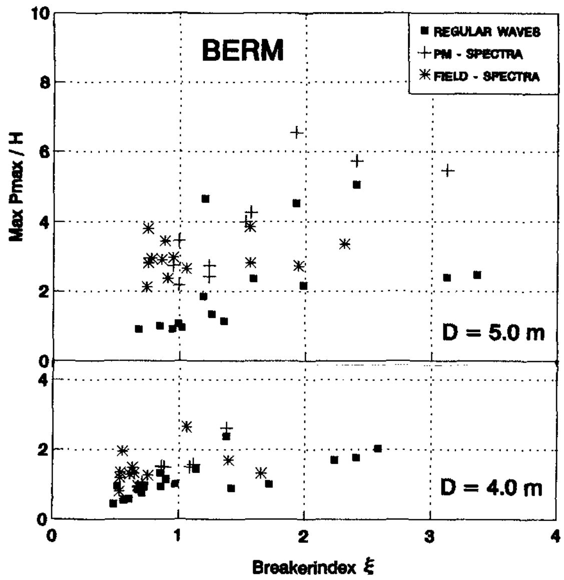

Fig. 9 *Max Pmax/H* versus breakerindex ξ for different wave characteristics

The mentioned trends lead to summerizing all test results as shown in figure 10, where the maximum peak pressures *Max Pmax/H* are plotted versus the waveheight related waterdepth *Db/H* on the berm. Both for regular and for irregular waves the same tendency comes out clearly, but with a different mean or upper value gradient. The corresponding maximum value *Max Pmax/H* for an uniform slope 1:6 is plotted in figure 10 as a dotted line. This value is a constant one due to much higher waterdepth and was estimated from previous field and large scale laboratory investigations.

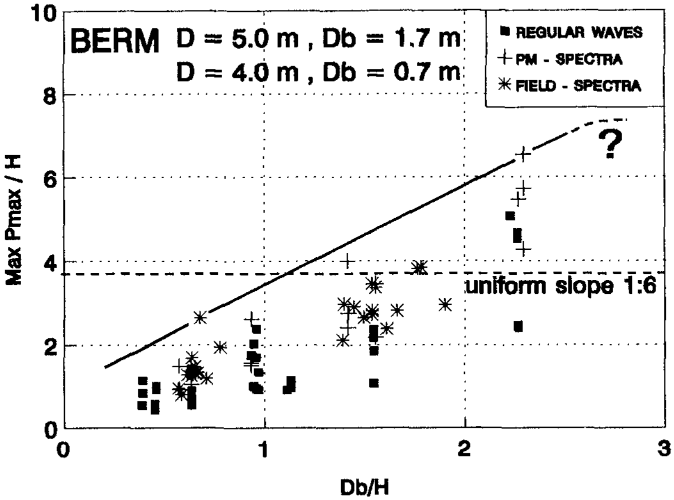

Fig. 10 *Max Pmax/H* versus waveheight related waterdepth *Db/H* on the berm

It is obvious, that compared to the uniform slope value for the berm, there are as well lower as higher pressure values, depending on the waveheight related waterdepth *Db/H* on the berm. Both effects may be explained either by the wave breaking effect in front of the berm (slope 1:3) for lower *Db/H* or by the wave shoaling effect on the 1:20 slope of the berm for higher *Db/H*. Further it can be expected, that the increasing effect due to shoaling is limited by higher related waterdepths and that the upper value curve goes finally back to the uniform slope 1:6 value. Finally it must be remarked, that decreasing pressure values on upper slope 1:6 due to wave breaking automaticly cause higher pressure values on the berm slopes 1:20 and 1:3, which could be recognized during the tests visually and acuostically.

Results for the dyke with composed slopes

The trends with respect to absolute waveheight and to wave characteristics differ for the results of the testseries with composite slopes between the testseries in dependence on the level of slope junction and stillwaterlevel. In contrast to the results for the berm the trend of higher peak pressures *Max Pmax/H* in dependence on the absolute waveheights *H* for the testseries, which is most influenced by the upper slope 1:6 (D = 5.0 m, Dc = -1.7 m), is negligible for regular waves and only small for irregular waves, respectively, as shown in figure 11.

If one compare the influences of the different wave characteristics on the results in figure 12, there is the same trend to lower pressure values *Max Pmax/H* for regular waves, which was found for the berm, but with a smaller magnitude.

The maximum values of all single tests of this testseries are plotted in dependence on the breakerindex ξ in figure 14a. There is a certain influence of the wave characteristics, but the influence of the absolute waveheights was found to be more or less negligible.

A different trend was found for the testseries, which is mostly influenced by the lower slope 1:3, as the junction of the slope is 0.5 m above *SWL* (D = 4.0 m, Dc = +0.5 m). The tendency on the influence of absolute waveheights in figure 13 changes to higher values *Max Pmax/H* with higher absolute waveheights, less clear for regular waves, but very clear for the PM - spectra.

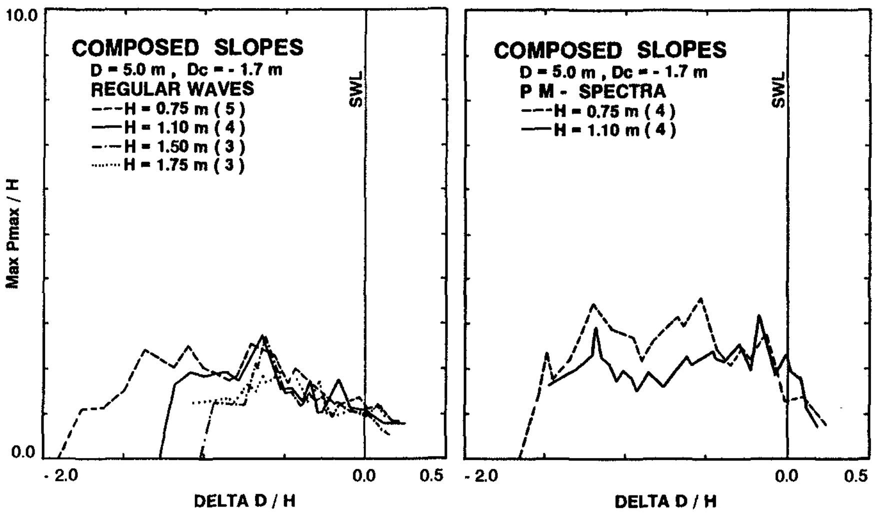

Fig. 11 Local distribution of *Max Pmax/H* for testseries with regular waves.

For the different wave characteristics in figure 15 still a trend was found to higher pressure values with irregular wave trains, which also comes out clearly with the plot of all results versus the breakerindex ξ in figure 14d.

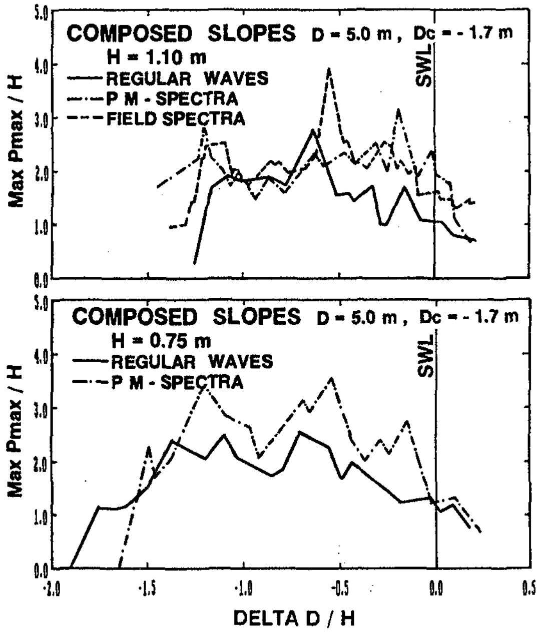

Fig. 12 Local distribution of *Max Pmax/H* for different wave characteristics

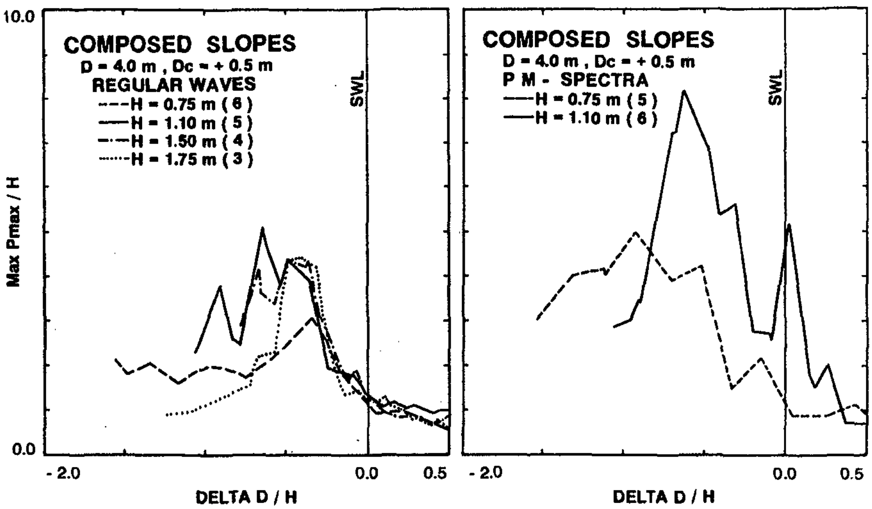

Fig. 13 Local distribution of *Max Pmax/H* for regular waves and PM - spectra

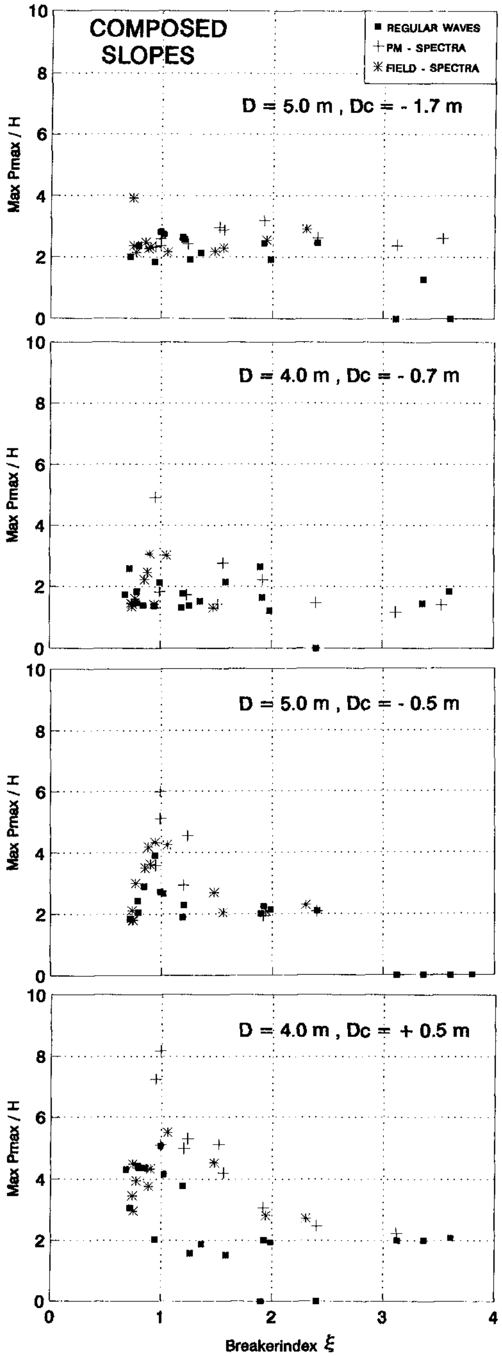

Fig. 14 a

Fig. 14 b

Fig. 14 c

Fig. 14 d

Fig. 14 *Max Pmax/H* versus breakerindx ξ for all testseries with composed slopes

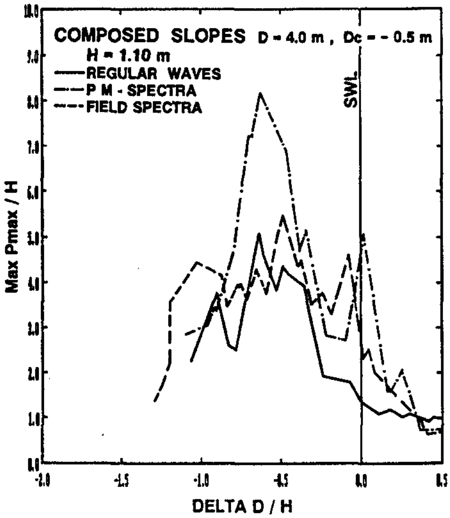

Fig. 15 Local distribution of *Max Pmax/H* for different wave characteristics

Similar results were found with the other both testseries (D = 4.0 m, Dc = - 0.7 m; D = 5.0 m, Dc = - 0.5 m): Firstly, no distinct trend for the dependence on absolute waveheight H for regular waves, but a small one for irregular waves. Secondly, the influence of the wave characteristics is evident as shown in figure 14b and 14c, where all test results are plotted versus the breakerindex ξ. Smaller pressure values *Max Pmax/H* were found for regular waves, as well as in all other testseries.

To summerize the pressure results from all 4 testseries with composed slopes, the pressure values *Max Pmax/H* of all single tests have been plotted versus the waveheight related vertical distance *Dc/H* between slope junction and stillwaterlevel *SWL* as shown in figure 16 for regular waves (upper part) and irregular waves (lower part). If the slope junction lies below *SWL*, the slope 1:6 seems to be dominant. If the slope junction lies above *SWL*, the lower slope 1:3 with higher pressure values is dominant. The transition range has a high gradient, if the slope junction is around till roughly half a waveheight below *SWL*. The eye-fitted upper value distributions are plotted as dotted lines in figure 16. A qualitative generalisation is given in figure 17. The asymetry of the influences from both slopes with respect to the distance *Dc/H* between slope junction and *SWL* is distinct.

Also peak pressure values smaller than for any of both slopes occur at *Dc/H* roughly half a waveheight below *SWL* from the testseries with D = 4.0 m, Dc = - 0.7 m. From the local distributions of the results it was found, that these results may be partly effected by the restricted pressure cell area below *SWL*, because for this testseries pressures only have been measured on the upper slope 1:6.

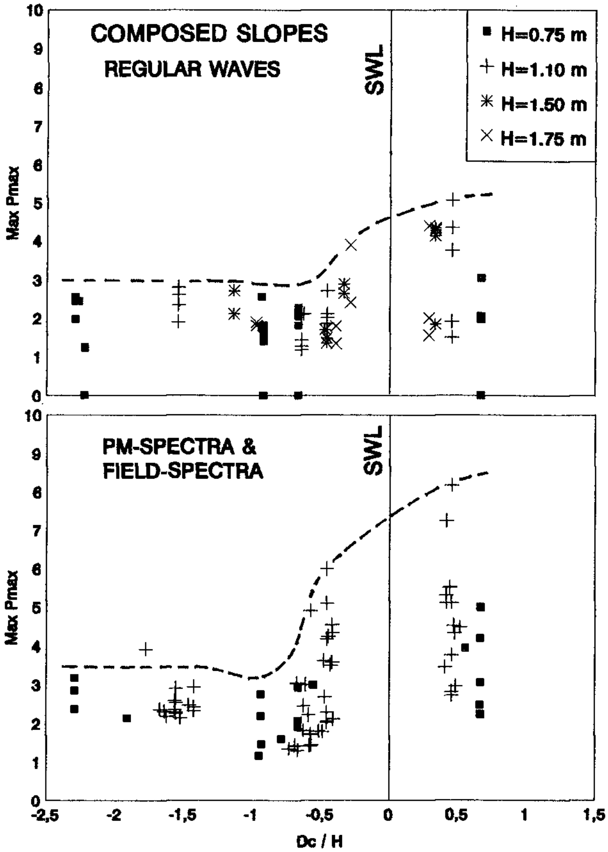

Fig. 16 *Max Pmax/H* versus *Dc/H* for all tests with composed slopes

SLOPE 1 : 3	SLOPE 1 : 6
NO	EXCLUSIVE
MODEST	DOMINANT
STRONG	STRONG
DOMINANT	MODEST
EXCLUSIVE	NO

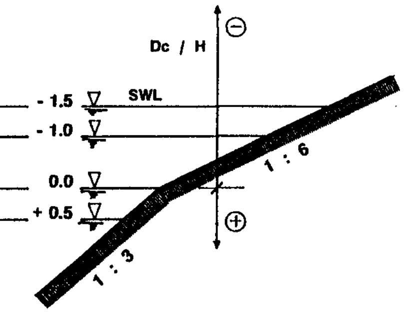

Fig. 17 Scheme of influence of slopes on shock pressure occurrence

Conclusion

From the results the following statements on the maximum peak pressure occurrence may be concluded:

- There are trends in dependence of the absolute waveheight, but in different ways:
a.) Where wave trains are broken at least partly, before they reach the slope (for instance at the berm), the waveheight related maximum pressure values *Max Pmax/H* increase with decreasing absolute waveheights *H*.
b.) Where waves trains are broken completely by the slope (for instance at composed slopes), the pressure values *Max Pmax/H* may increase with increasing absolute waveheights *H*.

- There are strong influences of the wave characteristics:
Regular waves always lead to smaller related pressure values *Max Pmax/H*, if regular waveheights *H* are compare with irregular waveheights *H1/3*. This confirmed previous results for the uniform slopes, that for comparison one should use mean waveheights both for regular and irregular waves. Nevertheless one should not use regular wave results for design of coastal protection works generally.

- Some special effects of geometrical conditions can be stated:
a.) For a slope with a berm in front, the peak pressures *Max Pmax/H* may decrease due to breaking effect or increase due to shoaling effect depending on waterdepth on the berm.
b.) For composed slopes there is a transition range, which is asymetric with respect to the distance *Dc* between slope junction level and stillwaterlevel *SWL*.

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