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THE INFLUENCE OF WAVE CLIMATE ON WAVE PRESSURE AND WAVE RUN-UP

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Joachim Grüne[1] and Zeya Wang[2]

ABSTRACT

In this paper the influence of wave characteristic on wave loads acting on structures, will be demonstrated examplarily with results from a comprehensive research program on shock pressures and wave run-up with field investigations and with large - scale laboratory tests.

1. INTRODUCTION

It is well-known, that the influence of wave characteristic plays an important role on the magnitude of the wave induced loads on the structures. This is not only due to a different air entrainment between small - scale laboratory waves and real sea state waves, but also due to other boundary condition effects.

In the history of experimental research on wave induced loads on structures the first step was the use of small - scale laboratory tests with regular waves. Using the general scale laws one tried to transfer the results from such investigations to natural conditions. On the other hand results from first field investigations pointed out the much more complex physical processes including the often more complex boundary conditions in nature. The next step was to generate waves with a random sea state instead of pure regular waves, but this causes two problems to be solved for practical engineering purposes: firstly which type of random waves are representative for the specific problem, secondly which are the representative wave parameters to verify excisting approaches for calculation. The first problem mostly was solved by using a specific shape of spectral density distribution (e. g. PM - spectra) without any reference to structural behaviour of real sea state wave trains, the second problem mostly by replacing H by H1/3 and T by Tp and by changing the values of coefficients.

One further step was to include three-dimensional effects by using small-scale three-dimensional wave basins. Such basins may have a wave generation system only for longcrested random waves, but nowadays there are some with a system to generate as well short crested real sea state waves. Another step was to avoid scale effects by using large - scale laboratory

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facilities, but due to the necessary magnitude of such facilities there is the restriction to two-dimensionality. For using both types of facilities it becomes more important to generate a sea state which is in agreement with natural conditions.

The influences of wave climate on loads which will be demonstrated exemplarily with shock pressure data and wave run-up data. These data have been analyzed as well from field measurements at the coast of the German Bight as from large scale laboratory tests in the LARGE WAVE CHANNEL (GWK) at Hannover, Germany (GRÜNE & FÜHRBÖTER, 1976). Thus scale effects have been minimized. Structures with different cross - sections were used and different types of wave characteristics were generated for the investigations.

3. INFLUENCE OF WAVE CHARACTERISTIC ON SHOCK PRESSURES

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 shock pressure occurrence results in a rather complex physical process.

In the first example shock pressures measured in field are compared with those from large-scale laboratory tests (GRÜNE, 1992). All dyke profiles in field and laboratory have a sand core covered with a layer from asphalt concrete. The same type of sensors and data recording system were installed in the laboratory as used for the field measurements. The first tests on uniform slope 1:4 were done mostly with regular waves to produce a collective of at least 200 single shock pressure events for statistical considerations and to check the spatial width of pressure occurrence.

But for comparing regular test data with field data the following facts have to be considered:
- firstly one don't know, which wave height parameter should be used for coparison. This problem is an old and suffering one, since tests were run in laboratories.
- secondly one have to notice, that regular waves have a more or less constant breaker point and thus the zone, where the breaker tongue hits the slope surface, is a rather narrow one. Furthermore the thickness of the watersheets from the wave run-ups of the preceeding waves also are rather constant, mostly with a certain value. Both conditions are contrary to those of irregular wave conditions, where the thickness together with the hitting zone from the breakertongue have a broad spreading characteristic. These conditions can be attenuated by the three-dimensionality of real sea state waves and by non oblique wave attack. This may result in higher shock pressures, if the breaker tongue of a high wave hits the slope surface at a moment, when the waterfilm tends to zero. On the other hand, as demonstrated in Fig. 1, each regular wave gives a peak pressure value, which cannot be found for irregular waves. This leads to different statistical characteristics of the data.

In Fig. 2 the statistical peak pressure data P99,9 measured on slope 1:4 in field are compared with those measured in laboratory with regular waves on same slope. All data are related to the mean wave heights Hm. For all data the agreement is rather poor, but it must be mentioned, that there are also differences between the field data, due to different wave climate characteristics at the two locations. The laboratory tests have similar wave characteristics as

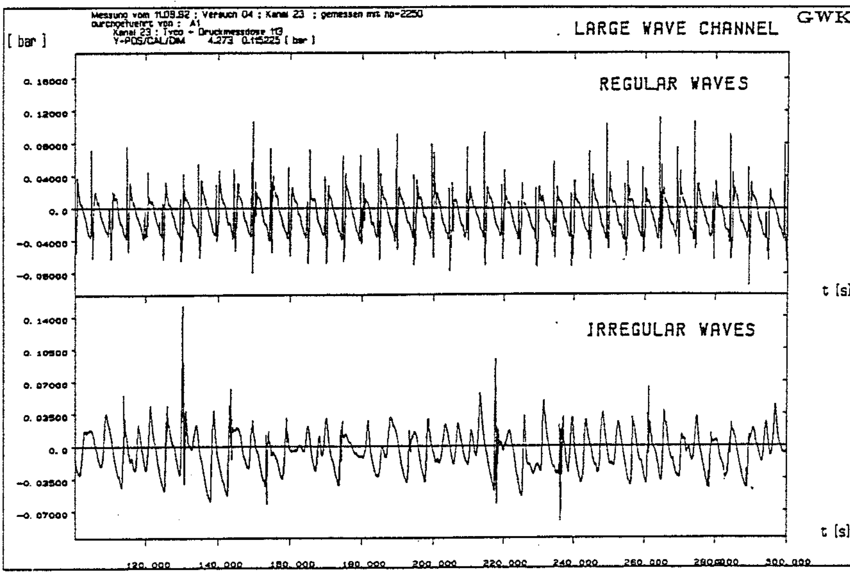

Fig. 1 Pressures on dyke surface induced by regular and irregular waves

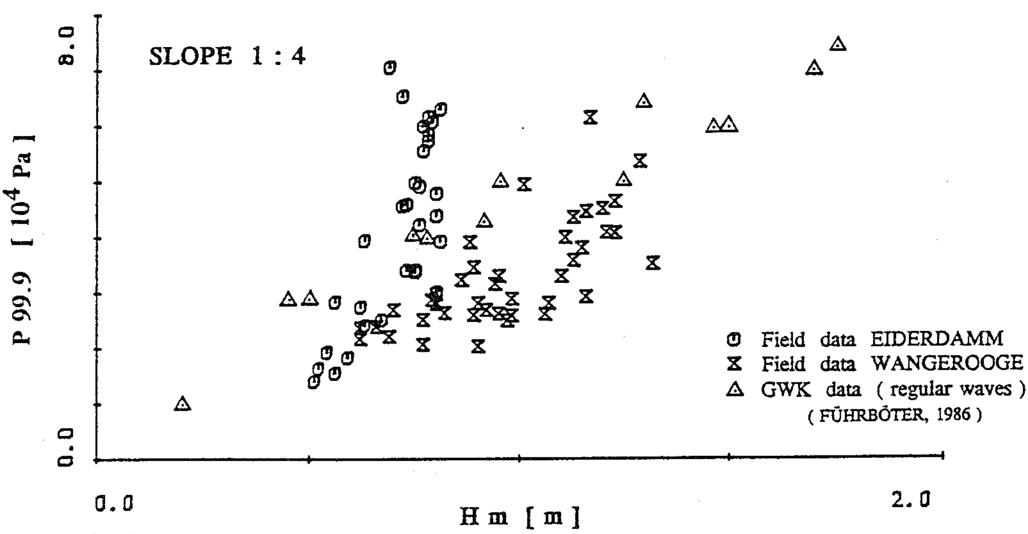

Fig. 2 Comparison between field and large-scale test data with regular waves

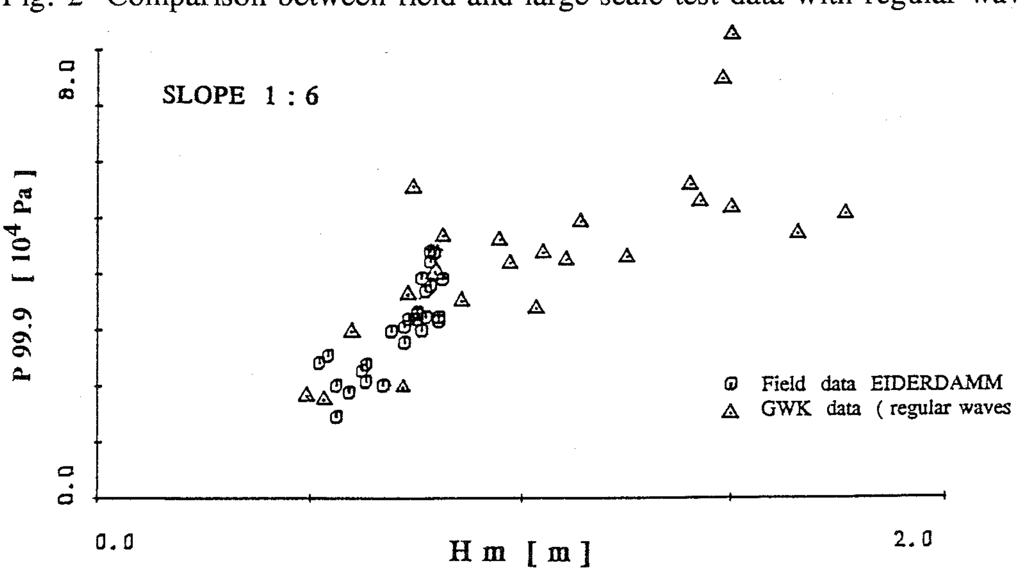

Fig. 3 Comparison between field and large-scale test data with regular waves

they exist at Eiderdamm location. It is obvious, that higher pressure values occur in field. Further comparisons, that even, if one relate the field data to significant wave height H1/3, there are higher pressure data in field. The data, measured on slope 1:6, are compared in Fig. 3. The agreement is fairly well, but the differences of the GWK data between both slopes are smaller compared to the field data. From this results one may state, that comparison between field data and laboratory data with regular waves both should be related to mean wave values Hm, which is also the cleanest way from the definition point of view.

The next examples are from large - scale tests (GRÜNE & BERGMANN, 1994), which have been done with seadykes, 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 (Fig. 4), and the other one with composite slopes 1:3 in the lower part and 1:6 in the upper part (Fig. 5).

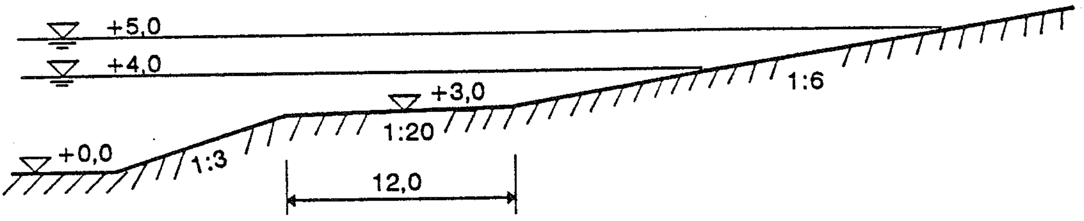

Fig. 4 Cross - section of the dyke with berm used for the tests in GWK

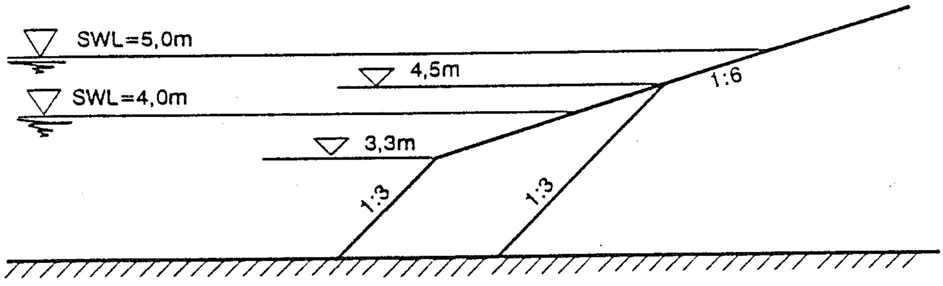

Fig. 5 Cross - section of the dykes with composed slopes used for the tests in GWK

The results are presented either as local distribution *Delta D/H* or in dependence of the breakerindex ξ, definitions and notations are given in Fig. 6. 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*. The vertical distance between the slope junction and *SWL* is defined as *Dc*. The waterdepth in front of the dyke is defined as *D* and the waterdepth

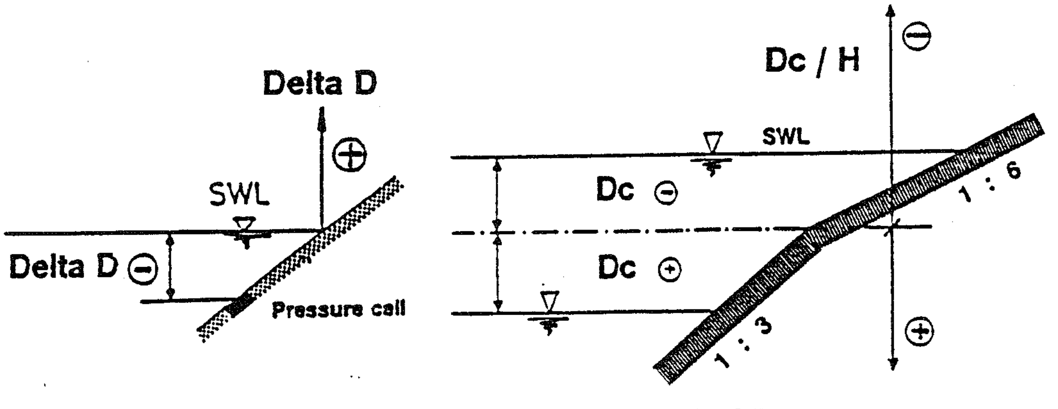

Fig. 6 Definition of *Delta D* and of *Dc*

on the berm as *Db*. All waveheights *H* are defined as mean waveheights for regular waves and as significant waveheights *H 1/3* for irregular waves.

The envelope curves for all test results with the berm - cross-section and an absolute waveheight *H (H1/3)* of 1.10 m are plotted for the different wave characteristics versus the local distribution in Fig. 7. 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 Fig. 8, where all test results are plotted versus the breakerindex ξ. Both the influence of wave characteristic and of restricted waterdepth can be seen distinctly.

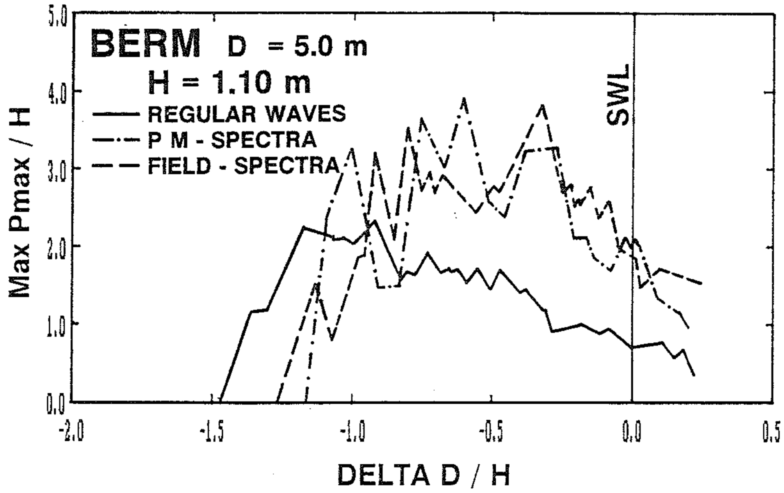

Fig. 7 Local distribution of *Max Pmax/H* for different wave characteristics

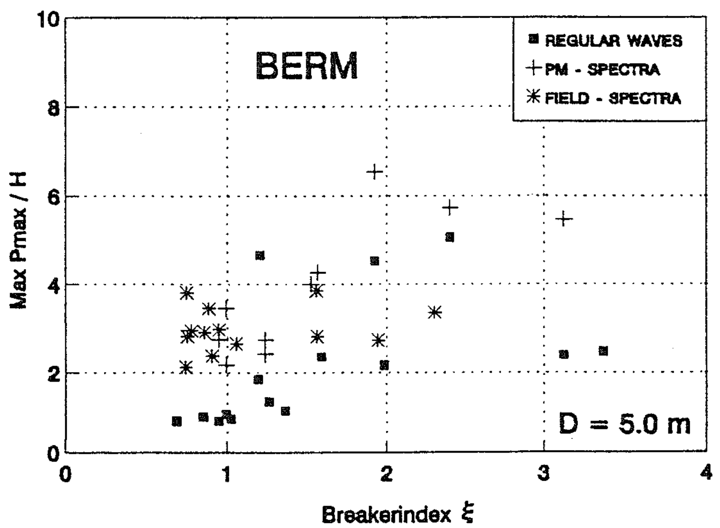

Fig. 8 *Max Pmax/H* versus breakerindex ξ for different wave characteristics

If one compare the influences of the different wave characteristics on the results from the tests with composite slopes, there is the same trend to lower pressure values *Max Pmax/H* for regular waves, which was found for the berm. This is demonstrated in Fig. 9 examplarily, where for two test series with different *Dc* all results with the absolute waveheight *H (H1/3)* of 1.10 m are plotted versus local distribution and in Fig. 10, where all results of these two test series are plotted versus the breakerindex ξ .

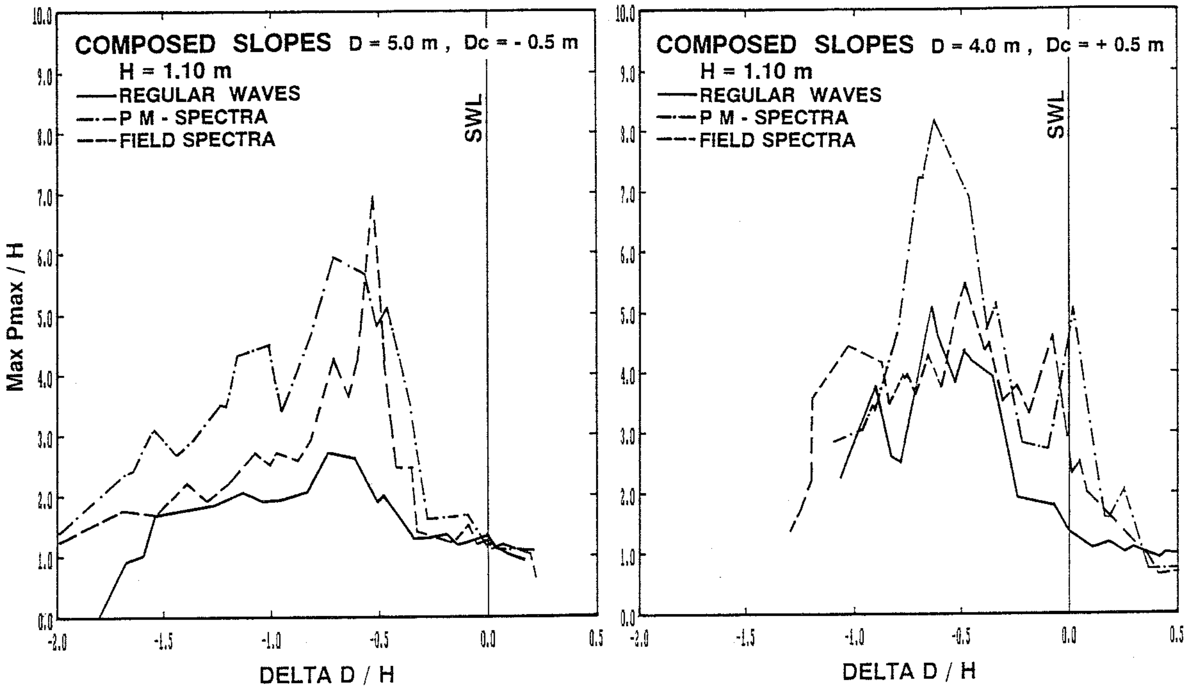

Fig. 9 Local distribution of *Max Pmax/H* for tests with different wave characteristics

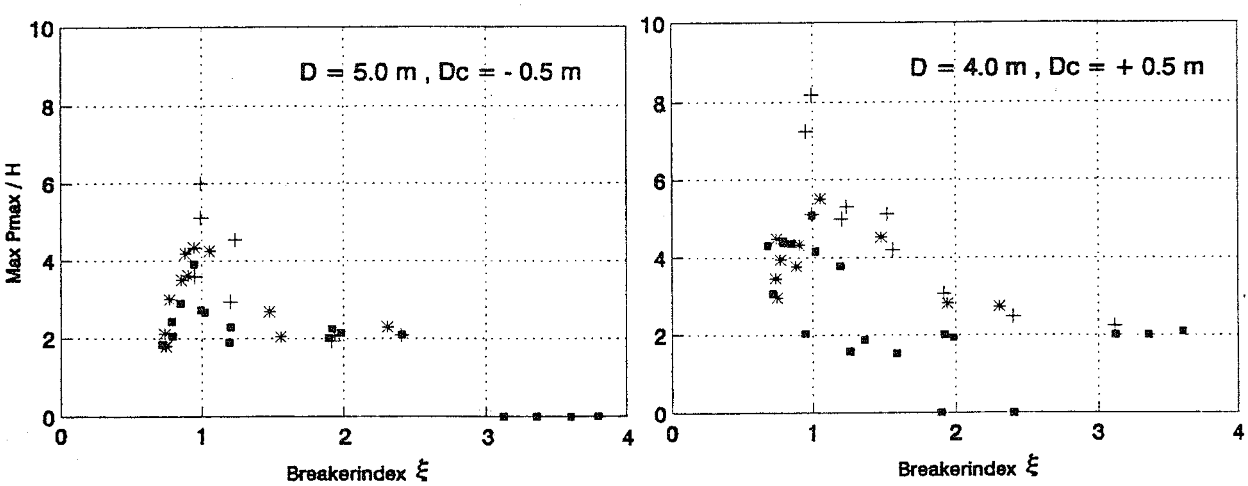

Fig. 10 *Max Pmax/H* versus breakerindx ξ for tests with different wave characteristics

4. INFLUENCE OF WAVE CHARACTERISTIC ON WAVE RUN - UP

From field investigations on wave run - up (GRÜNE, 1982) considerable differences were found for wave run - up data, measured under real sea state conditions, not only compared to data, calculated with common used formulae at that time, but also between two different locations due to different boundary conditions for wave climate.

In Table 1 some parameters and boundary conditions are listed for the two locations with different foreshore and wave climate conditions. The coefficient *C* in Table 1 belongs to the formula of HUNT (1959) $R98 = C * \sqrt{H1/3 * g} * \tan \alpha$. Due to different relative waterdephts *D/H* in front of the dykes the breakertypes play an important role on the wave run - up process. At Wangerooge location waves are breaking on the nearshore in front of the

Location	H1/3	Tm	D / H1/3	Breakerindex Xi	Breaker type	Cofficient C
	[m]	[s]	[-]	[-]		[-]
WANGEROOGE	0.6 to 1.6	4.5 to 7.3	1.9 to 3.2	0.1 to 0.15 (Nearshore) 1.4 to 2.0 (Dyke)	Spilling Plunging	0.71
EIDERDAMM	0.5 to 0.9	3.7 to 5.2	4.1 to 5.2	1.3 to 2.0 (Dyke)	Plunging	0.92

Table 1 Parameters and boundary conditions at the two locations in field

dyke as spilling breaker types and only smaller waves of the wave train are breaking on the dyke surface as plunging breakers. At Eiderdamm location breakers only on dyke surface occur, which are of the plunging type. It must be mentioned, that the calculated value of the breakerindex depends on the fact, whether one use the slope of nearshore or the slope of dyke surface. Thus the common use of the breakerindex is unsufficiently for such cases.

In the next example test results from large - scale laboratory investigations on sloping seadykes with a berm (WANG & GRÜNE, 1995) are presented. The dyke cross-section with a berm is the same as used for the shock pressure tests and shown in Fig. 4. All tests were carried out as well with berm as without berm. The test series were done with two water levels (4.0 m and 5.0 m above bottom). For each test series three different types of wave characteristics were generated : Regular waves, PM - spectra (narrow banded) and field spectra (wide banded). The generated field spectra were recorded in front of similar dyke cross-sections at the german coast during high storm surges.

The measured data of the three different test series (without berm, berm with *SWL* = 4.0 m and berm with *SWL* = 5.0 m) with regular waves are plotted in Fig. 11, where the breakerindex ξ_{eq} is related to ξ_{eq} instead of ξ according to the proposal of d. WAAL & v. d. MEER (1992). For the data without berm ξ_{eq} is equal to ξ (γ_b = 1.0). For calculation of the equivalent slope value γ_b the approach has been modified for regular waves as follows:

$$r_{dB} = 0.45 \text{ dB/H} \quad \text{instead of} \quad r_{dB} = 0.5 \text{ (dB/H)}^2$$

All data are fitted fairly well by the regression line (dotted line) :

$$R_{98} / H = 1.0\, \xi_{eq} \quad \text{for} \quad \xi < 3.0 \quad \text{and} \quad R_{98} / H = 3.0 \quad \text{for} \quad \xi > 3.0$$

The results of the different test series with irregular wave tests using PM - spectra are given in Fig. 11 and those using field spectra are given in Fig. 12. All measured data are referred to the breakerindex ξ_{eq} (for data from the test series without berm ξ_{eq} is again equal to ξ), calculated with the wave period parameter T_m from the time domain analysis. The dotted line present the regression lines given by d.WAAL & v.d.MEER (1992) for peakperiod *Tp*:

$$R_{98} / H_{1/3} = 1.5 \cdot \xi_{eq} \quad (\xi_{eq} < 2.0) \qquad \text{and} \qquad R_{98} / H_{1/3} = 3.0 \quad (\xi_{eq} > 2.0)$$

The data of the three test series with PM - spectra agree quite well between each other due to the modification in calculating the equivalent slope value γ_b with r_{dB} as follows:

$$r_{dB} = 0.5 \text{ dB/H} \quad \text{instead of} \quad r_{dB} = 0.5 \text{ (dB/H)}^2$$

From a comparison between all irregular data from laboratory tests in Fig. 14 it comes out clearly, that the laboratory tests with field spectra generate generally higher run-up data $R_{98} / H_{1/3}$ compared to those with PM-spectra. This leads to the mean values of the coefficient $C_{\xi Tm}$ = 1.71 for PM - spectra and $C_{\xi Tm}$ = 2.04 for field spectra. Thus the value for the ratio $C_{Lab\,F} / C_{Lab\,PM}$ = 1.19, which means roughly 20 % higher run - ups occur with field spectra.

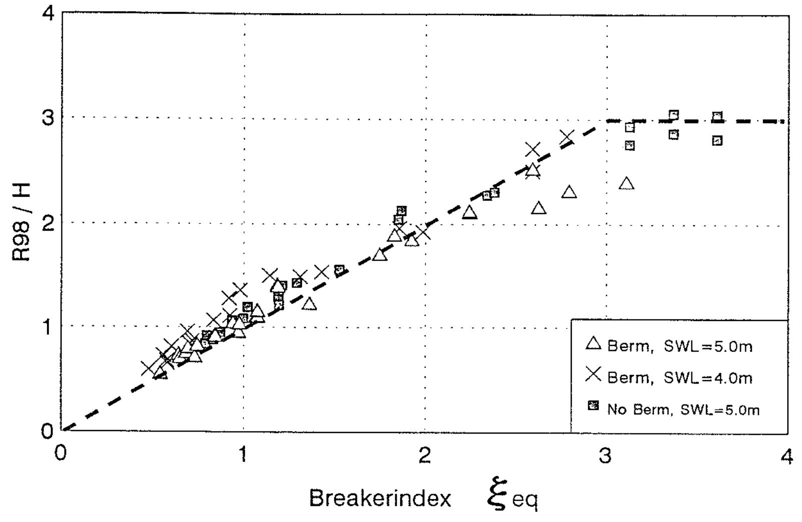

Fig. 11 R_{98} / H versus breakerindex ξ_{eq} from large scale tests with regular waves

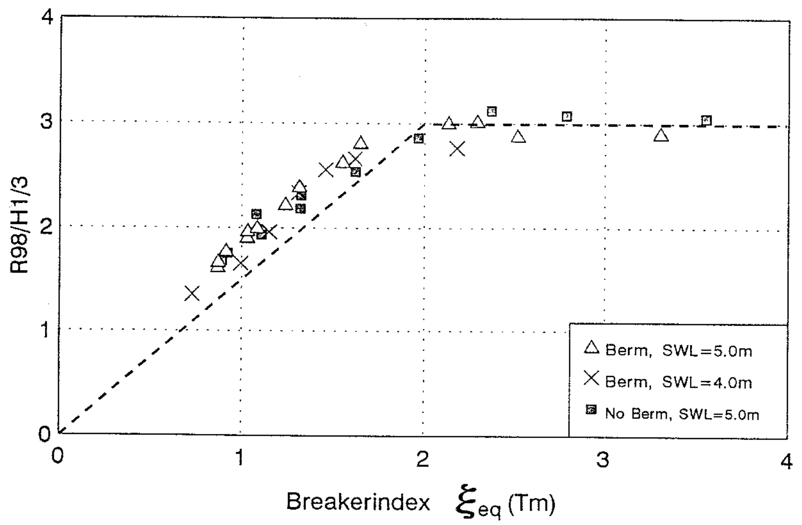

Fig. 12 R_{98} /$H_{1/3}$ versus breakerindex ξ_{eq} from large scale tests with PM-spectra

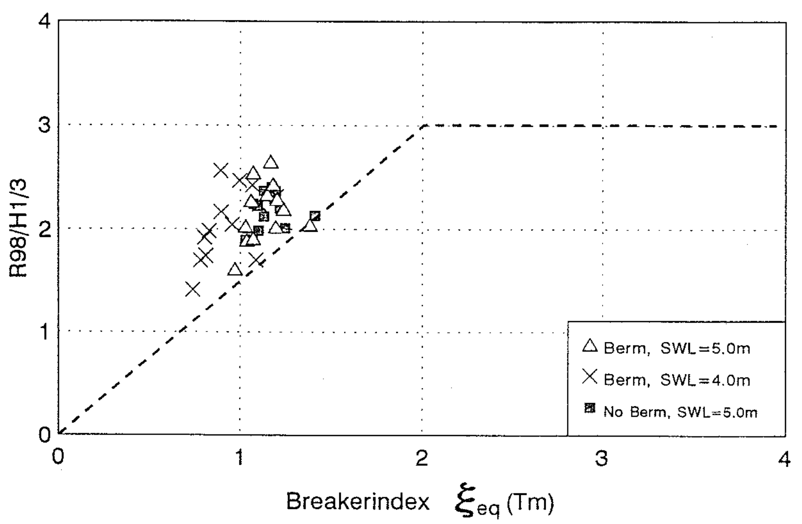

Fig. 13 R_{98} /$H_{1/3}$ versus breakerindex ξ_{eq} from large scale tests with field spectra

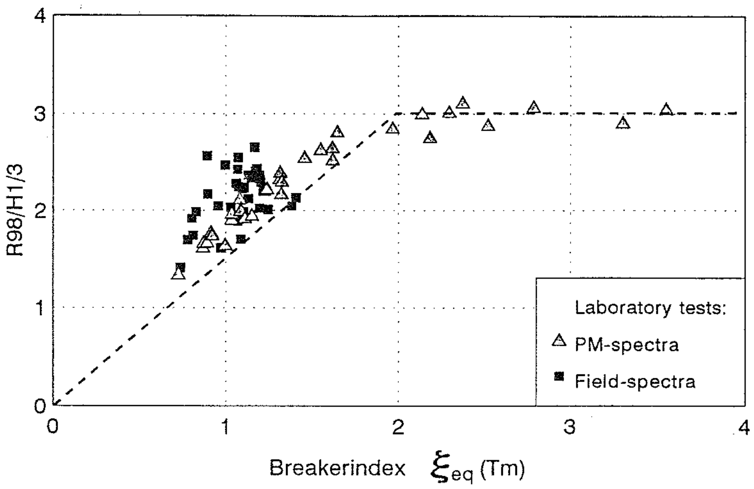

Fig. 14 : Comparison of run-up data measured in laboratory tests with irregular waves

The next data are from large scale laboratory tests in the GWK (WANG & GRÜNE, 1996) are done with the composed slopes, which already have been used for the tests on shock pressures described in chapter 3 and shown in Fig. 5. The slope junction level of both uniform slopes varied twice: 3.3 m and 4.5 m above bottom. All tests were conducted with two different water levels with three different types of wave characteristics.

The measured run-up data R_{98} are related to the mean regular wave height Hm and are plotted versus the breakerindex ξ, which is related to the period T_m from the time domain analysis and two different slope approaches separately ($1{:}N_{av}$ and $1{:}N_{su}$). The average slope N_{av} has been evaluated according to the mode, given by d. WAAL & v. d. MEER (1992), and is defined in Fig. 15 (left hand). N_{su} is a new mode for slope angle transformation of two composed uniform slopes, based on an approach, derived bý DROGOSZ-WAWRZYNIAK (1965) and modified by the authors in the following manner with the definitions shown in Fig. 15:

$$\frac{1}{N_{su}} = \frac{1}{N_2} + f\left(\frac{Dc}{D}, \frac{H}{L_o}\right) * \left(\frac{1}{N_1} - \frac{1}{N_2}\right)$$

The original factor $2*Dc/Lo$, which is a function of position of junction level Dc and wavelenght Lo, has been extended, so that the new factor is a function of the dyke geometryin terms of position of junction level Dc/D and the deepwater wave steepness H/Lo or the wave period, respectively.

The results from the testseries with Dc = + 0.5 m are plotted in Fig. 16 (regular waves), in Fig. 17 (PM - spectra) and in Fig. 18 (field spectra) all versus the breakerindex ξ.

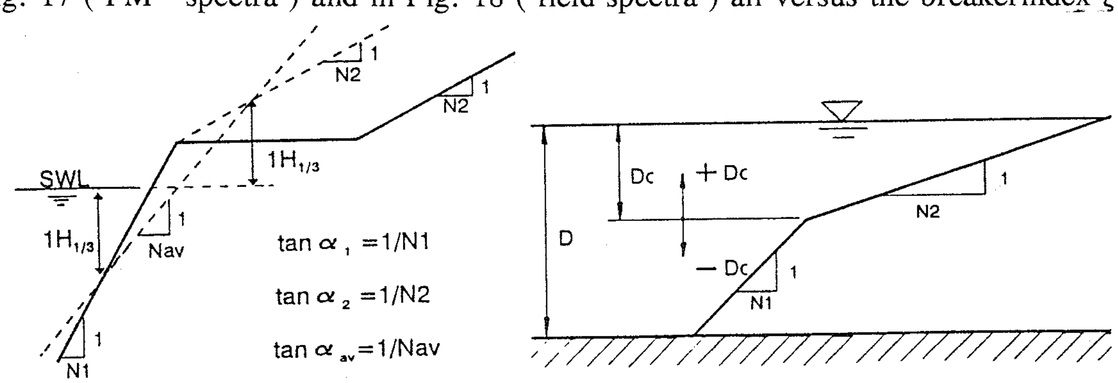

Fig. 15 : Definition of average slope N_{av} (left hand) and of slope junction Dc (right hand)

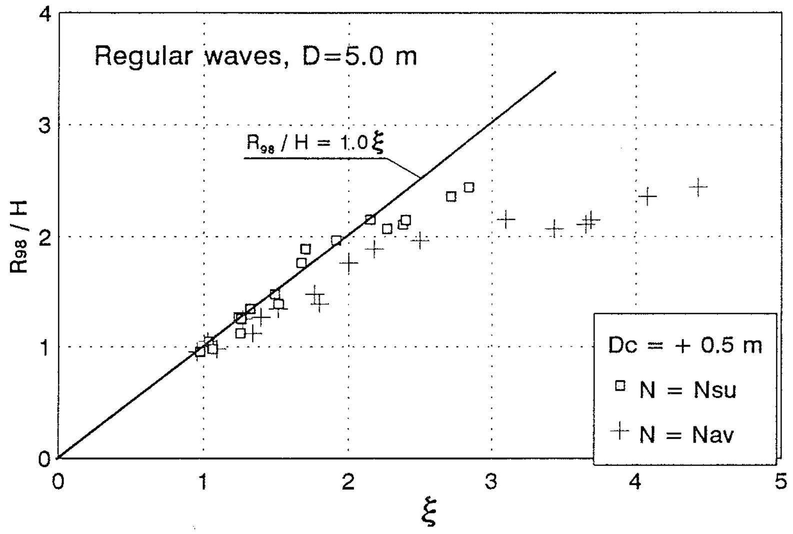

Fig. 16 : R_{98} / H versus breakerindex ξ for tests with regular waves

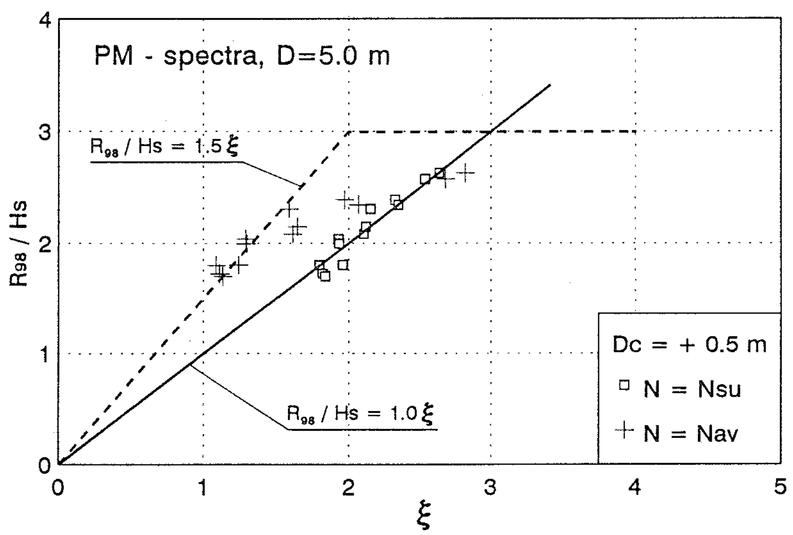

Fig. 17 : R_{98} / $H_{1/3}$ versus breakerindex ξ for tests with PM-spectra

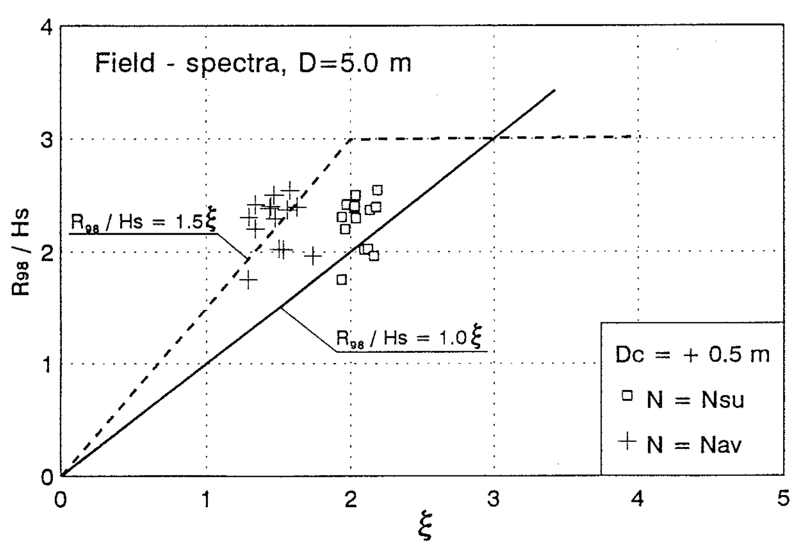

Fig. 18 : R_{98} / $H_{1/3}$ versus breakerindex ξ for tests with field-spectra

As well as for tests with regular waves the linear correlation of the test data with irregular waves is much stronger (PM - and field spectra) with the new slope approach $N = N_{su}$, in comparison with the average slope approach. This is due to the fact, that a better fitting of the influence of wave characteristik on wave run - up process is possible by using the wave period parameter additionally in the slope angle approach. The field spectra in Fig. 18 data scatter a little bit more, but without any distinct trend. Further they have a much smaller range of deepwater steepnesses, which is normal for a wadden sea wave climate.

The last example is focussed on the influence of three - dimensional sea state on wave run - up with respect to wave approach direction in field (GRÜNE, 1998). When wind waves coming in from deeper parts of the shelf in areas with extremely restricted water depths, they keep their general three-dimensional characteristic with respect to the water particle movement. Even when the breaking wave crests seem to be transformed into a considerable two-dimensional behavior, the wave-induced velocities keep their three-dimensionality. This comes out clearly in Fig. 19 examplarily, where the evaluated values for the wave approach directions of consecutive waves in a wave train are plotted as time history for a period of 15 minutes, measured in field. A_{TsC} is defined as the mean wave approach direction between trough and crest, and A_{CTe} as the one between crest and trough, respectively.

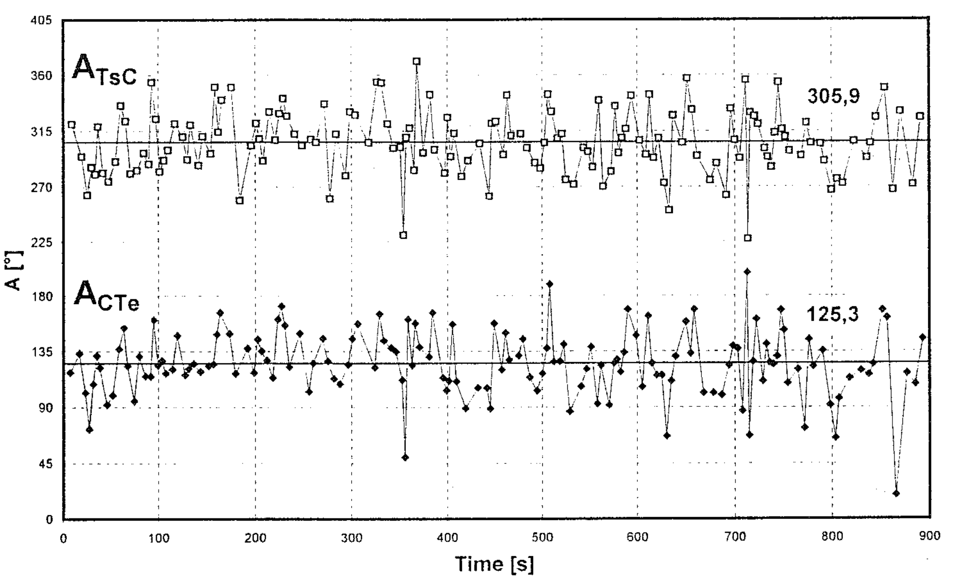

Fig. 19 Fluctuations of A_{TsC} and A_{CTe} during a period of 15 minutes

The values for A_{TsC} and A_{CTe} from Fig. 19 are plotted as frequency distributions in Fig. 20. The mean values of A_{TsC} and (A_{CTe} + 180°) for the total period differ only 0.6 degrees from each other. The agreements with the calculated Normal - distributions are quite good. The total range of fluctuation of the evaluated approach directions is roughly ± 70° and the standarddeviation is roughly 26°.

Similar wide sectors of fluctuation of wave approach were found for other measurements. This means, that if an oblique wave approach has a mean value of β = + 20° to normal dyke direction (β = 0°), there are still many approaches of single waves with β = - 20° and more. With respect to the influence on wave run-up these results indicate, that a possible reduction on wave run-up values due to oblique wave approach should be smaller than expected by excisting formulae, verified with long-crested sea state.

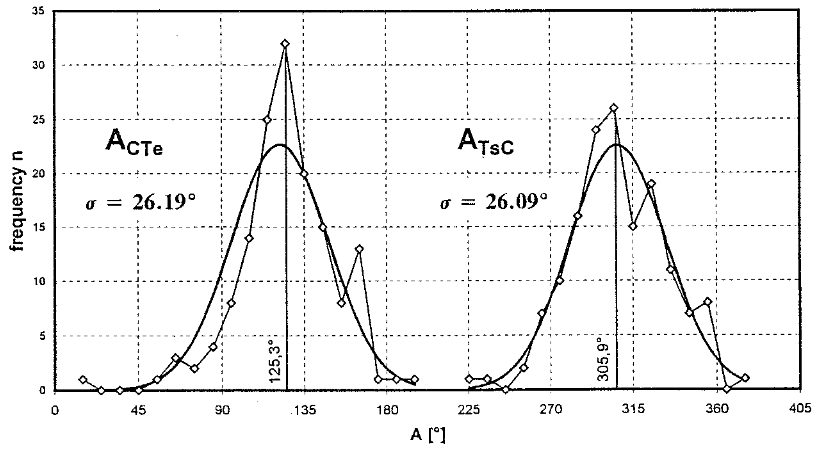

Fig. 20 Frequency distributions of A_{TsC} and A_{CTe} from the time history in Fig. 19

3. CONCLUSIONS

With some examples from field measurements and large - scale laboratory tests the influence of wave characteristics on measured wave loads could be confirmed.

- Regular waves always lead to smaller related pressure values *Max Pmax/H.* For comparison one should use mean waveheights both for regular and irregular waves.
- Field spectra in laboratory tests generate higher wave run - up values.
- Field data itself are strongly influenced by local boundary conditions and three - dimensional effects have to be considered.

4. REFERENCES

DE WAAL, J.P.; VAN DER MEER, J.W. (1992): Wave runup and overtoping on coastal structures. Proc. 23rd Intern. Conf. on Coast. Eng., Venice, Italy.

DROGOSZ-WAWRZYNIAK, L. (1965): in "Wave run-up and overtopping", Technical advisory committee on protection against inundation, Goverment publishing office - The Hague 1974, The Netherlands.

GRÜNE, J., FÜHRBÖTER, A. (1976): Large Wave Channel for "full-scale modelling" of wave dynamics in surf zones. Proc of Symp. on Modelling Techniques, San Francisco, USA.

GRÜNE, J.; BERGMANN, H. (1994): Wave loads on seadykes with composite slopes and berms. Proc. 24th Intern. Conf. on Coast. Eng., Kobe, Japan.

GRÜNE, J. (1982): Wave run-up caused by natural storm surge waves. Proc. 18th Intern. Conf. on Coast. Eng., Kapstadt, South Africa.

GRÜNE, J. (1992): Loads on sloping seadykes and revetments from wave-induced shock pressures. Proc. of the 23rd International Conference on Coastel Engineering (ICCE '92), Venice, Italy.

GRÜNE, J., (1998): Wave propagation directions under real sea state conditions
Proc. of 26th. Intern. Conf. on Coastal Eng. (ICCE'98), Copenhagen, Denmark

HUNT, I.A.jr. (1995): Design of seawalls and breakwaters. Journal of the Waterways and Harbors Division, Proc. ASCE, Vol. 85, WW3.

WANG, Z.Y.; GRÜNE, J. (1995): Influence of berms on wave run-up on sloping seadykes, Proc. 4th Intern. Conf. on Coast. and Port Eng. in developing countries (COPEDEC IV), Rio de Janeiro, Brazil, 1995

WANG, Z.Y.; GRÜNE, J. (1995): Wave run-up on revetments with composite slopes. Proc. 25th Intern. Conf. on Coast. Eng., Orlando, USA