CHAPTER 79

WAVE RUN-UP ON REVETMENTS WITH COMPOSITE SLOPES

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Abstract

The paper deals with wave run-up on revetments and seadykes with composite slopes. The presented data were obtained from large scale laboratory tests with different wave climate characteristics in the " Large Wave Channel " (GWK) at Hannover, Germany. The results are discussed with respect to slope angle transformation mode to be used in the well-known HUNT-formula.

Introduction

Savety analysis of excisting coastal protection works becomes again more important due to the world wide increasing of storm surges and the supposed long-term rising of water levels at the coastlines. Within such a savety analysis wave run-up and overtopping is the most important load factor.

Previous investigations on wave run-up have shown different results using different verifications of formulae to fit the boundary conditions with complex cross-sections and with real sea state wave conditions. Thus a research program has been established, which is focussed on the effects of non-uniform cross-sections and of real sea state wave characteristics. A part of this research program deals with cross-sections, which are composed from different uniform slopes. Results from investigations on run-up with such composed cross-sections are presented in the following.

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The most convenient formula for calculating wave run-up on gentle smooth slopes like seadykes and revetments normally have, is the well-known one derived by HUNT (1959). Although originally derived for regular waves on a uniforn slope the tendency of the HUNT-formula also agrees quite well with irregular data.

Usually the HUNT-formula is written in dependence of the breakerindex ξ in the following form:

$$R \,/\, H = C_\xi \cdot \xi \,, \quad \text{with} \qquad \xi = \frac{\tan\,\alpha}{\sqrt{\dfrac{2\pi \cdot H}{g \cdot T^2}}}$$

and with
R = run-up
C = coefficient
H = waveheight
T = wave period
α = slope angle ($\tan\alpha = 1 : N$, with N = slope value)

For using this formula in a savety analysis of dykes and revetments in field this general form has to be verified as well with respect to the irregular waveheight and wave period parameters of the real sea state conditions (see BATTJES, 1974) as with respect to the non-uniformly sloped seadyke cross-sections, which mostly occur in prototype. These verifications lead to different values C_ξ in dependence of used irregular wave parameters and/or the mode of slope angle α transformation for non-uniform cross-sections. In a lot of previous papers such verifications of the HUNT-formula have been reported, among them a few with data from field and/or from large scale laboratory tests. For example are those from GRÜNE (1982), FÜHRBÖTER et. al. (1989), SPARBOOM et. al. (1990), v. d. MEER & STAM (1992), d. WAAL & v. d. MEER (1992), WANG & GRÜNE (1995). The results shown in this paper will be discussed mainly with respect to the mode of slope angle transformation for composed slopes.

Only a few suggestions excist for slope angle α transformation approaches for slopes of composed cross-sections. SAVILLE (1958) proposed an equivalent gradient method, where the equivalent slope is defined by the linear interpolation between the breakerpoint and the maximum wave run-up on the non-uniform slope. But this mode is not necessarily representative for all types of non-uniform slopes, the method was not tested by SAVILLE (1958) with measurements on convex slopes. Some field data for composite slopes (1:4 and 1:6) have been reported by GRÜNE (1982), who found that the influence of slopes occur roughly in the range between 1.0 $H_{1/3}$ below and 2.0 $H_{1/3}$ above stillwaterlevel. A similar suggestion for an average slope was given by d. WAAL & v. d. MEER (1992) with a linear interpolation between the points 1.0 $H_{1/3}$ below and 1.0 $H_{1/3}$ above stillwaterlevel on the dyke surface.

Test equipment

The data, presented in this paper, are from large scale laboratory tests, which have been done in the Large Wave Channel (GWK) at Hannover (GRÜNE & FÜHRBÖTER, 1976). The GWK is a facility of the recently founded Coastal Research Center "Forschungszentrum Küste (FZK)" , which is a joint institution both of the University Hannover and the Technical University Braunschweig.

The cross-sections of the revetment used for the tests in the GWK are shown in Fig. 1. It has a sand core and is covered with asphalt-concrete. The composed slope consist of two different uniform slopes: a slope of 1:6 in the upper part and a slope of 1:3 in the lower part. The lower slope 1:3 was varied twice: for one testseries the slope junction level of both uniform slopes was 3.3 m above bottom, for the other testseries the slope junction level was 4.5 m above bottom.

Wave run-up was measured with a run-up step gauge (GRÜNE, 1982), which was installed on the upper slope 1:6 for the testseries with the slope junction level 3.3 m above bottom and on both slopes for the other testseries. The steps of the run-up gauge had vertical distances of 6.5 cm on the slope 1:6. The waves in front of the revetment were measured with some wire gauges. The wire gauges had roughly constant distances between each other and reflexion effects had been minimized by using the data of four of these gauges. The analog signals from waves gauges and run-up step gauge were continously digitized with 100 Hz and storaged by the main processing computer.

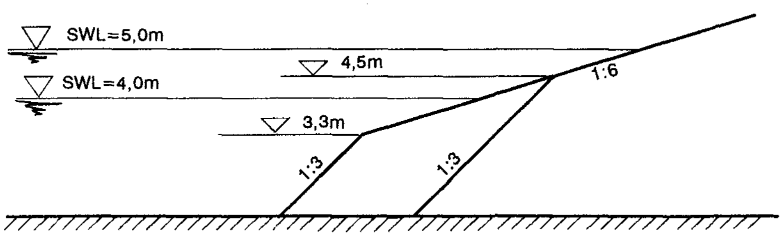


Fig. 1 : Cross-section of the revetment used for large scale tests in the GWK

All tests were conducted with two different water levels (4.0 m and 5.0 m above bottom), this results in altogether four different testseries with respect to the vertical distance *Dc* between still water level *SWL* and slope junction level (Dc = 1.7 m, 0.7 m, 0,5 m and - 0,5 m). Three different types of wave characteristics were generated: Regular waves, PM - spectra (narrow banded) and field spectra (wide banded). The generated field spectra had been measured in front of similar dyke cross-sections at the german coast during high storm surges. For each testseries roughly 15 single tests with each of these three different wave climate types were run. Fig. 2 gives an impression of wave acting on the revetment during a large scale test in the GWK.

Fig. 2 : Wave action on the revetment during a test in the GWK

Results

The results presented in this paper will be focussed on the approach of slope angle transformation with respect to HUNT-formula. All data are refferred to the mean period T_m from the time domain analysis. In a previous report on the results from the tests with the berm (WANG, GRÜNE, 1995), it was demonstrated, that the correlation using T_m is quite better than using the peak period T_p. This is due to the fact, that the estimation of a peak period from the spectral density distribution of real sea state shallow water waves is of problematic nature and can create confusion.

The first results to be discussed are from the testseries with regular waves, where the still water level *SWL* was 1.7 m above, 0.5 m above and 0.5 m below the junction level of the two slopes (Dc = +1.7 m, +0.5 m, and -0.5 m).

The measured run-up data R_{98} are related to the mean regular wave height and are plotted in Fig. 4 versus the breakerindex ξ, which is related to three different slopes separately (slopes of upper part of 1:6, lower part of 1:3 and average slope 1:N_{av}). 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. 3 (left hand). It is clear that due to the mode the data for N_{av} with Dc = +1.7 m (waterdepth of 1.7 m above junction level) are identical with those of the upper slope 1:6. This means, that the lower slope 1:3 has more or less no influence.

It must be remarked, that the average slope approach by de WAAL and v. d. MEER was evaluated for irregular waves, but there is no functional difference for regular waves. On the other hand, because the HUNT formula was originally evaluated from regular wave run-up data, thus fundamental trends may be demonstrated firstly with regular wave run-up data.

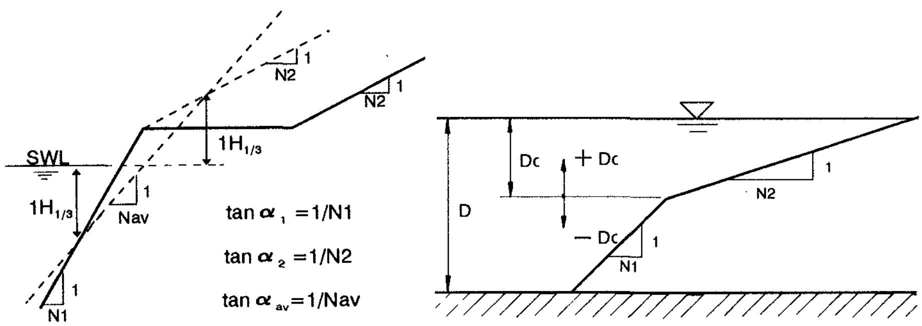


Fig. 3 : Definition of average slope N_{av} by de WAAL and v. d. MEER (left hand) and Definition of slope junction *Dc* (right hand)

In the middle plot of Fig. 4 the data with *Dc* = +0.5 m (*SWL* only 0.5 m above the junction level) show similar trends and only small differences between the average slope N_{av} related data and those for the uniform upper slope 1:6, which means, that the lower slope 1:3 has only a small influence. Greater differences occur for the data with *Dc* = -0.5 m (*SWL* 0.5 m below the junction level). The average slope data agree much more to the 1:3 slope, but they all are fare away from a linear dependence with identic gradients.

A new mode for slope angle transformation of two composed uniform slopes is based on the rather old approach, derived by DROGOSZ-WAWRZYNIAK (1965) as follows with the definitions shown in Fig. 3 (right hand):

$$\frac{1}{N} = \frac{1}{N_1} + 2\cdot\frac{Dc}{L_o} * \left(\frac{1}{N_2} - \frac{1}{N_1}\right)$$

This formula was modified by the authors in the following manner: the original factor 2**Dc* / *Lo*, which is a function of position of junction level *Dc* and

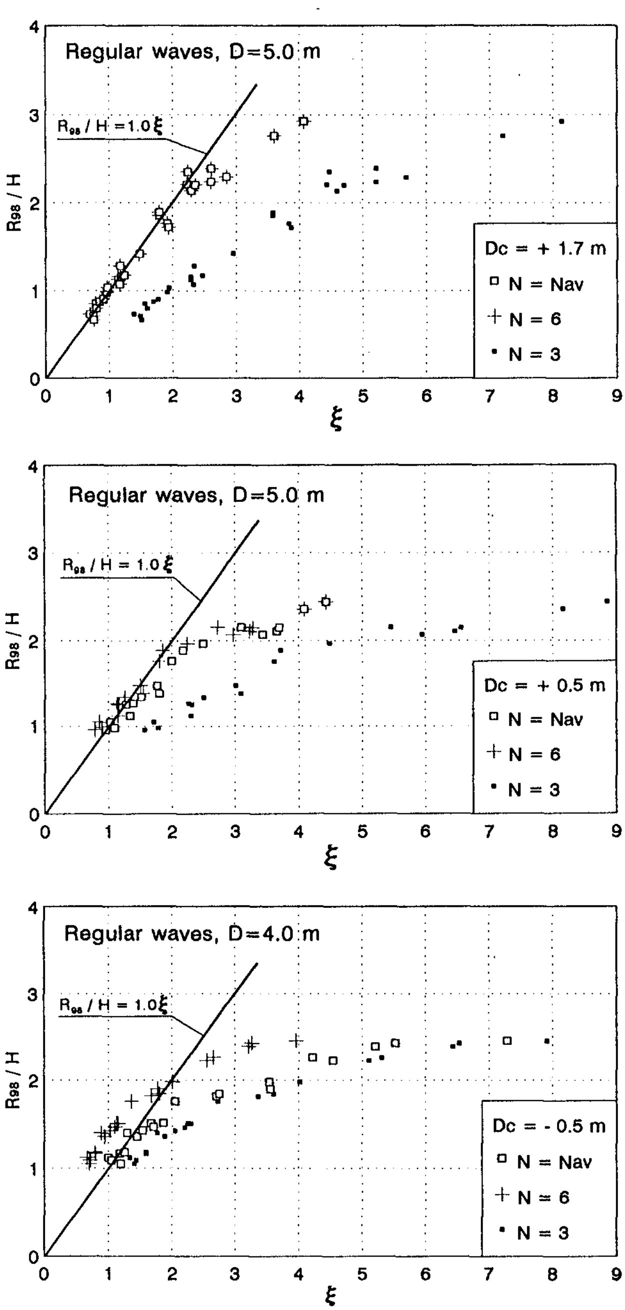


Fig. 4 : R_{98} / H versus breakerindex ξ for tests with regular waves

wavelenght Lo, has been extended, so that the new factor is a function of the dyke geometry in terms of the depth related position of junction level Dc / D and the deepwater wave steepness H / Lo or the wave period, respectively. Compared to the average slope approach of d. WAAL and v. d. MEER, this slope approach has been extended by the wave period:

$$2 * \frac{Dc}{L_o} \Rightarrow f\left(\frac{Dc}{D}, \frac{H}{L_o}\right)$$

Thus the modified formula is written:

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

with the following factors
for regular wave climate:

$$f\left(\frac{Dc}{D}, \frac{H}{L_o}\right) = \left(\frac{1}{2} - \frac{Dc}{D}\right) * \left(7 * \left(\frac{H}{L_o}\right)^{0.1} - 4.43 - \frac{Dc}{D}\right)$$

for irregular wave climate:

$$f\left(\frac{Dc}{D}, \frac{H_{1/3}}{L_o}\right) = 2 * e^{-\frac{Dc}{D}} * \left(3 * \left(\frac{H_{1/3}}{L_o}\right)^{0.2} - 1\right)$$

with Dc = distance between stillwaterlevel and junction level
D = waterdepth
H = waveheight
Lo = deepwater wave length = $g*T_m^2 / 2\pi$

The high accuracy of this slope angle transformation may be demonstrated in the best way by the plots in Fig. 5, where the results for waveheight related run-up data are plotted versus the deepwater steepnesses H / Lo for the testseries with regular waves and Dc = +0.5 m (upper plot) and Dc = -0.5 m (lower plot). The full line in Fig. 5 represents the HUNT-formula, using the new approach for slope angle transformation with $1{:}N = 1{:}N_{su}$. It is obvious, that the differences to the measured values are rather small. The two dotted straight lines, marked with $N = 3$ and $N = 6$, represents the original HUNT-formula, using one of the uniform slopes $N = 3$ or $N = 6$ respectively. If one of these slope angle approaches would be correct, all measured data should fit one of these dotted lines. The irregular dotted line, marked with $N = N_{av}$, which lies between the two others straight ones, represents the HUNT-formula, using the average slope N_{av} according to de WAAL & v. d. MEER. Whereas the agreement for higher wave steepnesses is quite well, there are considerable differences for lower steepnesses.

The accuracy of the new slope angle transformation also comes out clearly in Fig. 6, where the measured data are plotted versus the breakerindex ξ. The upper plot again is for the data with Dc = +0.5 m and the lower plot for the data with Dc = -0.5 m. It must be stated, that the measured data agree quite well with

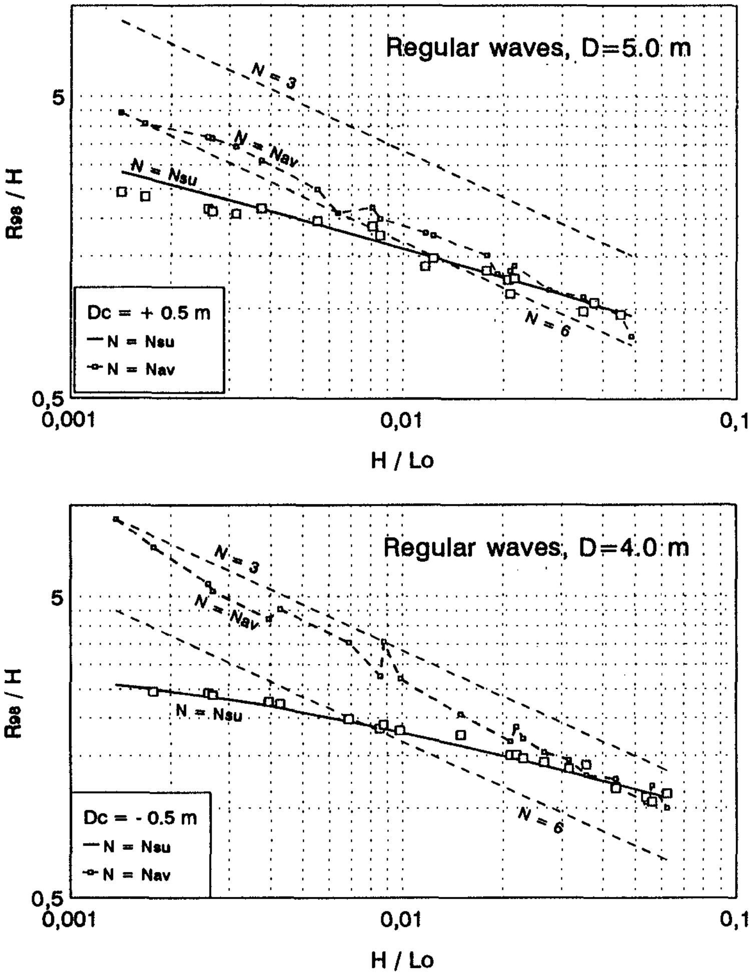


Fig. 5 : R_{98} / H versus steepness H / Lo for tests with regular waves

the HUNT-formula with the new mode of slope angle transformation, expecially no range with a constant value has to defined as it is necessary with previous slope angle transformation modes.

Similar relations were found for the data from the testseries with PM-spectra and field spectra, using the slope angle transformation mode $N = N_{su}$ in the HUNT-formula. The measured run-up data R_{98} / $H_{1/3}$ from the testseries with PM-spectra are plotted versus the significant waveheight related deepwater stepnesses $H_{1/3}$ / Lo in Fig. 7 for the testseries with Dc = +0.5 m and with Dc = -0.5 m. The notations for N are the same as used in Fig. 5.

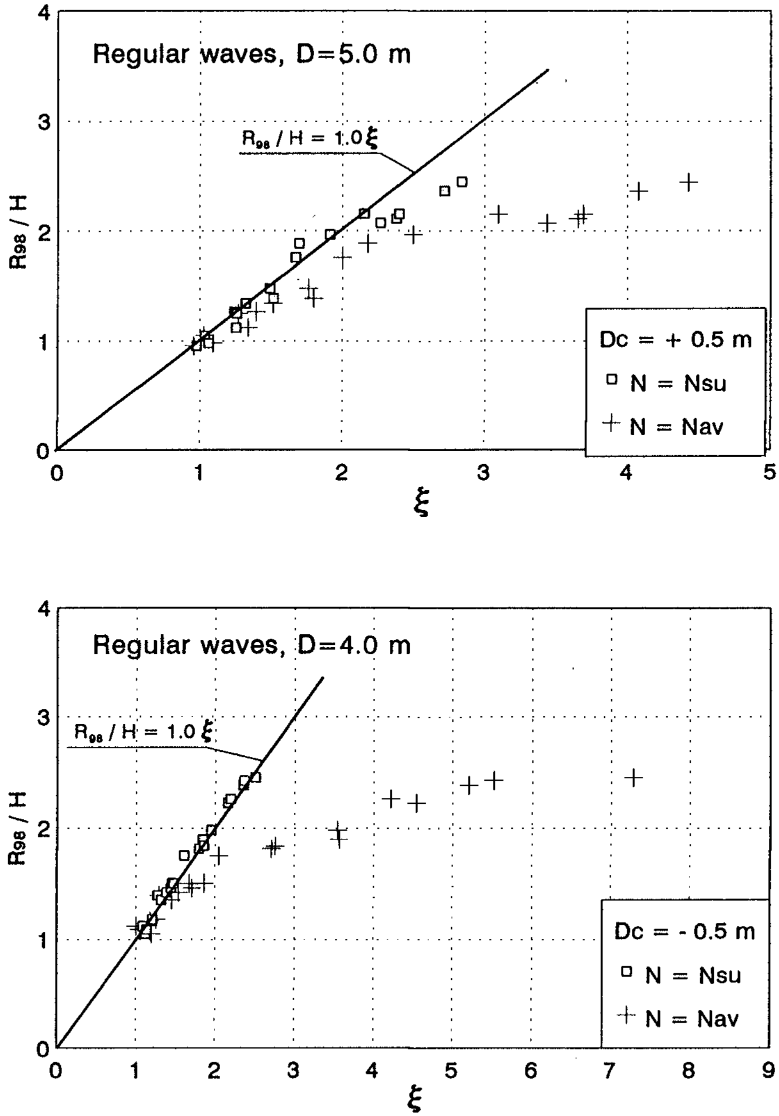
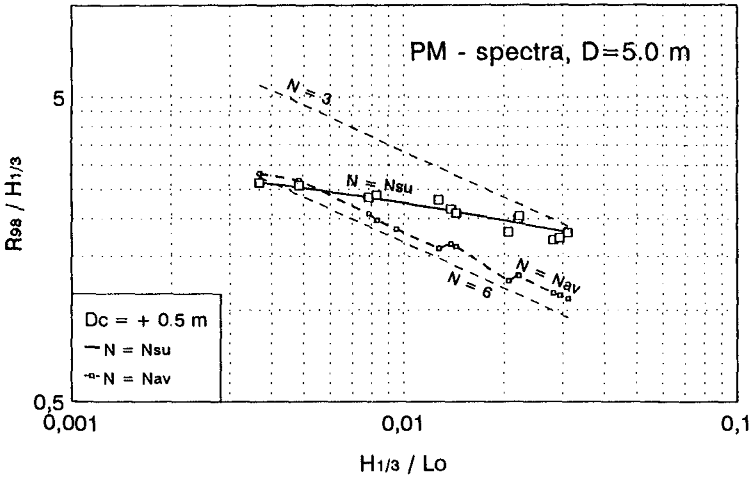


Fig. 6 : R_{98} / H versus breakerindex ξ for tests with regular waves



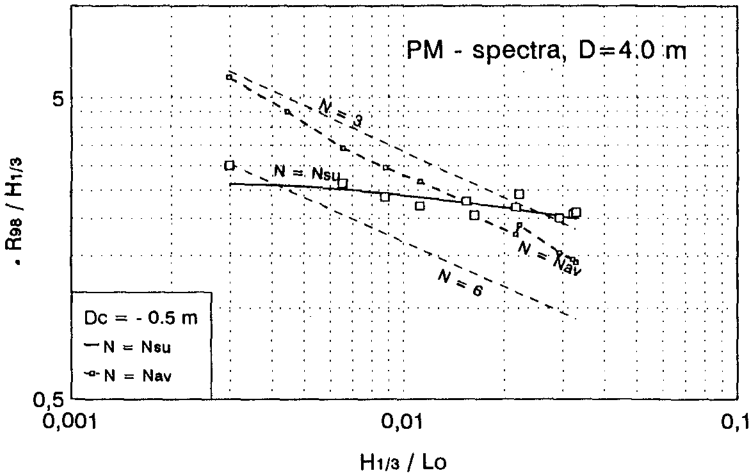
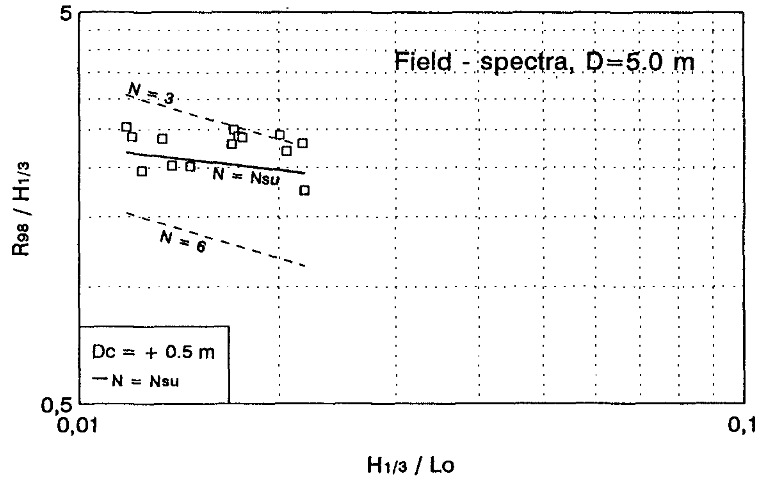


Fig. 7 : R_{98} / $H_{1/3}$ versus steepness $H_{1/3}$ / Lo for tests with PM-spectra

The data from the testseries with field spectra in Fig. 8 indicate similar relations, but they have a much smaller range of deepwater steepnesses, which is normal for a wadden sea wave climate.

The same data from Fig. 7 and 8 are plotted versus the breakerindex ξ in Fig. 9 (PM-spectra) and 10 (field spectra), respectively. 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), using the new slope approach $N = N_{su}$, in comparison with using the average slope approach. The field spectra in Fig. 10 data scatter a little bit more, but without any distinct trend.



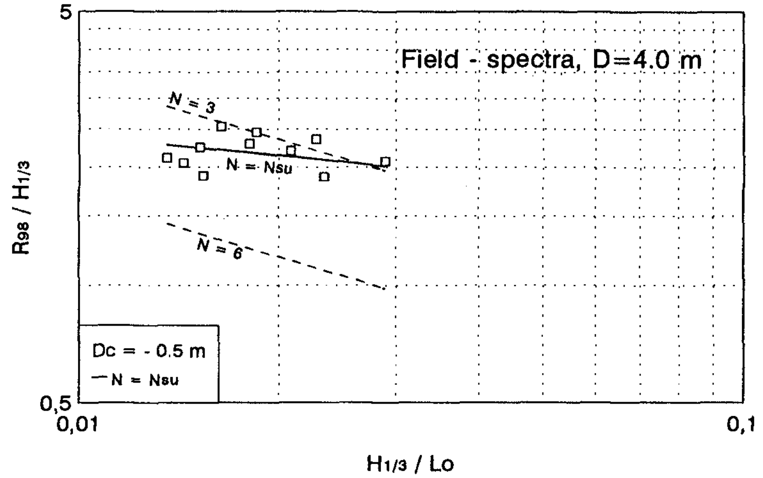
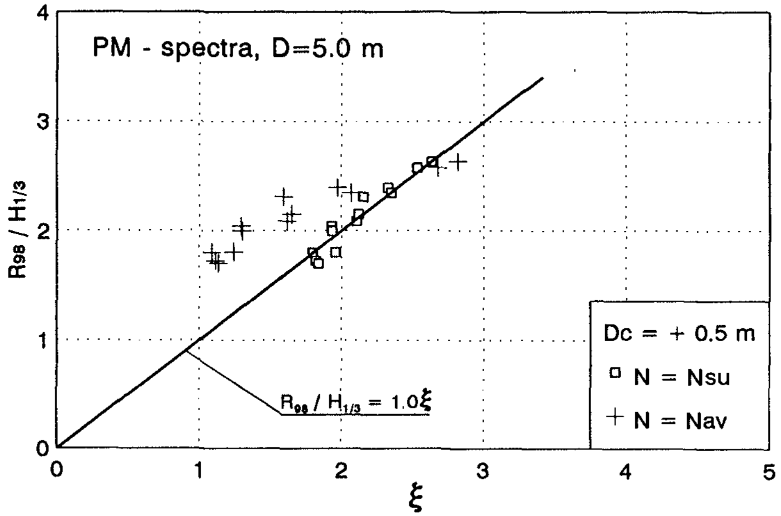


Fig. 8 : R_{98} / $H_{1/3}$ versus steepness $H_{1/3}$ / Lo for tests with field-spectra

Conclusion

The HUNT-formula has been verified with respect to slope angle transformation. Data from large scale laboratory tests with regular waves and irregular waves (PM-spectra and field spectra) were used. The wave run-up data on revetments with composite slopes are well presented with the HUNT-formula, using a new slope angle transformation, which takes not only the depth related position of junction point Dc / D but also the wave steepnesses H / Lo into account.



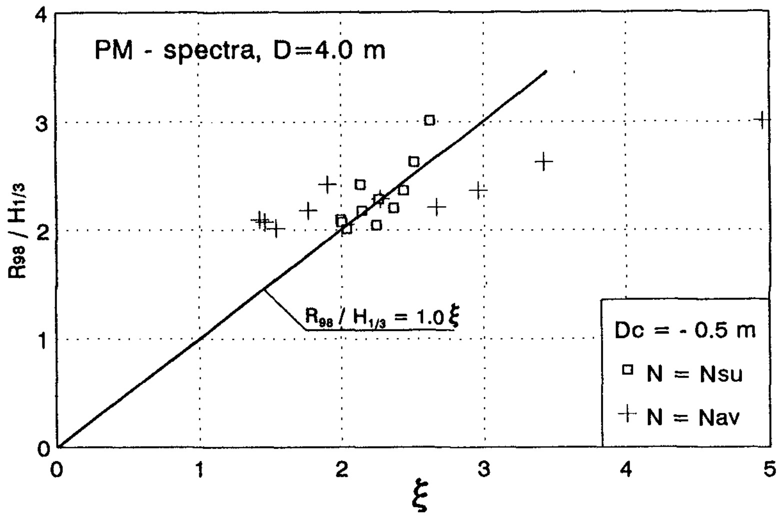


Fig. 9 : R_{98} / $H_{1/3}$ versus breakerindex ξ for tests with PM-spectra

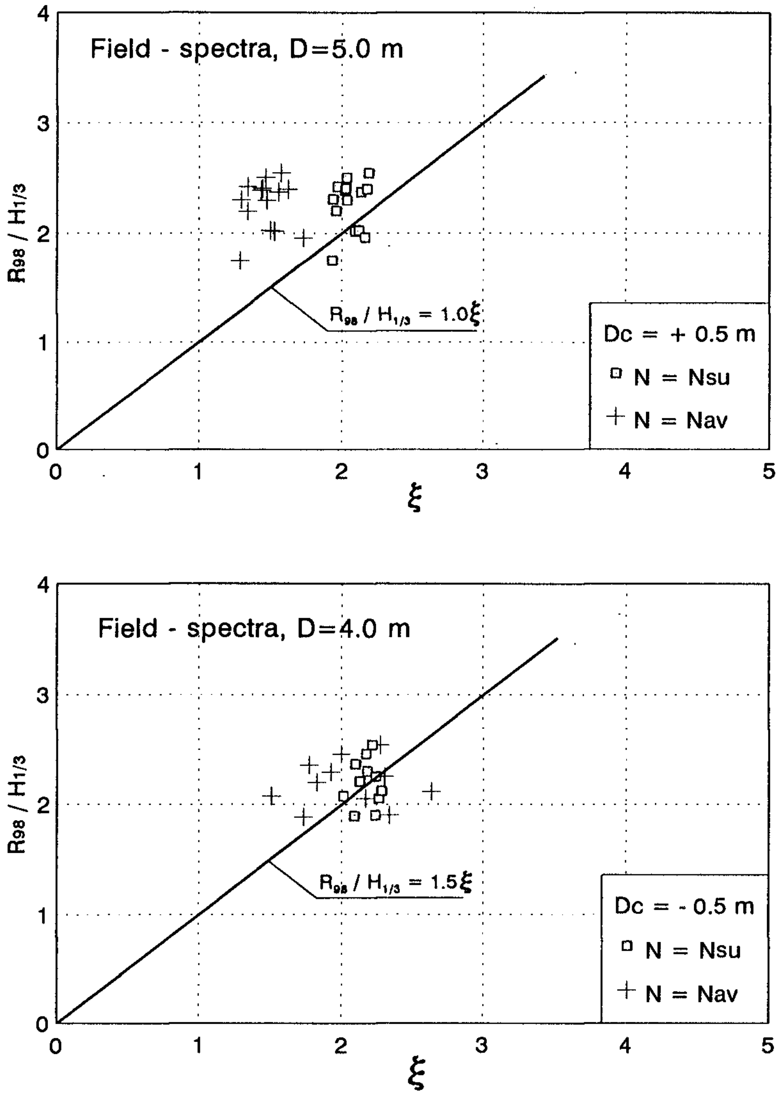


Fig. 10 : R_{98} / $H_{1/3}$ versus breakerindex ξ for tests with field-spectra

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References

BATTJES, J.A. : Computation of set-up, longshore currents, run-up and overtopping due to wind-generated waves, Dept. of Civil Engineering, Delft University of Technology, Report Nr. 74-2, 1974

DE WAAL, J.P.; VAN DER MEER, J.W. : Wave run-up and overtoping on coastal structures. Proc. 23rd Intern. Conf. on Coast. Eng., Venice, 1992

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

FÜHRBÖTER, A.; SPARBOOM, U.; WITTE, H.-H. : Großer Wellenkanal Hannover: Versuchsergebnisse über den Wellenauflauf auf glatten und rauhen Deichböschungen mit der Neigung 1:6. Die Küste, Heft 50, 1989 (in German)

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

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

HUNT, I.A.jr. : Design of seawalls and breakwaters. Journal of the Waterways and Harbors Division, Proc. ASCE, Vol. 85, WW3, 1959

SAVILLE, T. jr. : Wave run-up on composite slopes. Proc. 6th Conf. on Coast. Eng., 1958

SPARBOOM, U.; GRÜNE, J.; GROSCHE, S.; HAIDEKKER, M. : Full-scale measurements of wave run-up at sea dykes. Proc. 22nd Intern. Conf. on Coast. Eng., Delft, 1990

VAN DER MEER, J.W.; STAM, C.J.M. : Wave run-up on smooth and rock slopes of coastal structures. Journal of Waterways, Ports, Coastal and Ocean Engineering, Proc. ASCE, Vol. 118, WW4, 1992

WANG, Z.Y.; GRÜNE, J. : 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