WAVES'97

THE EFFECT OF FORELAND ON WAVE CLIMATE CHANGES

BY

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Preprint of the Proceedings of the

3 rd International Symposium
on Ocean Wave Measurements and Analysis (WAVES'97)

November 1997, Virginia Beach, Virginia, USA

THE EFFECT OF FORELAND ON WAVE CLIMATE CHANGES

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Abstract

This paper deals with investigations on the influence of foreland in front of dykes and revetments on wave climate changes. The research program was carried out as well with large-scale laboratory tests as with field measurements. The test equipments are described and first results are discussed.

Introduction

The definition foreland in Germany usually means green foreland, well-known as salt marshes. Such salt marshes with a ground level above Mean High Tide have been built up in former times naturally or artificially for land reclamation. Nowadays they were protected for enviromental reasons, but still they are part of coastal protection system.

The effect of these salt marsh forelands on wave climate changes play an important role for the savety analysis of excisting dykes, which 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.

Results from investigations on the influence of foreland on wave climate are poor, which makes savety analysis very unsave, especially with extrapolated higher waterlevels. Thus further research is needed on this topic. With respect to the wave climate characteristics under real sea state conditions with mostly a high amount of air entrainment, for the investigations described in this paper, large scale laboratory tests and field measurements have been used to minimize boundary effects and scale effects.

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Equipment for field measurements and laboratory tests

The field measurements have been doing for recent years at the location Heringsand at the " Dithmarscher Küste " of the German Bight within a comprehensive research program on wave climate and wave run-up on dykes and revetments at different locations at the wadden sea and at the Elberiver estuary (Grüne, 1996 ; Grüne, 1997). Fig. 1 shows the coast with Heringsand location as far as to the 10 m deepwater line. The extended salt marshes (foreland) at the coastline around Heringsand (cross-hatched in Fig. 1) are supported by the shelter effect of enlarged tidal flats (wadden seas) in front of it.

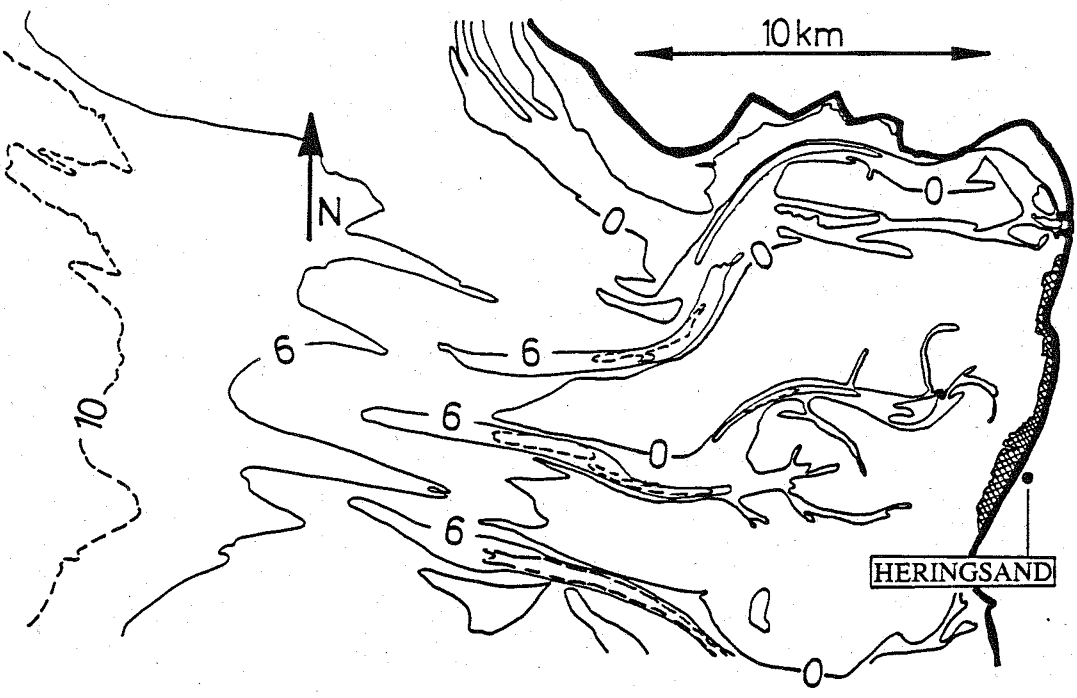

Fig. 1 Field measuring location at the coastline of " Dithmarscher Küste "

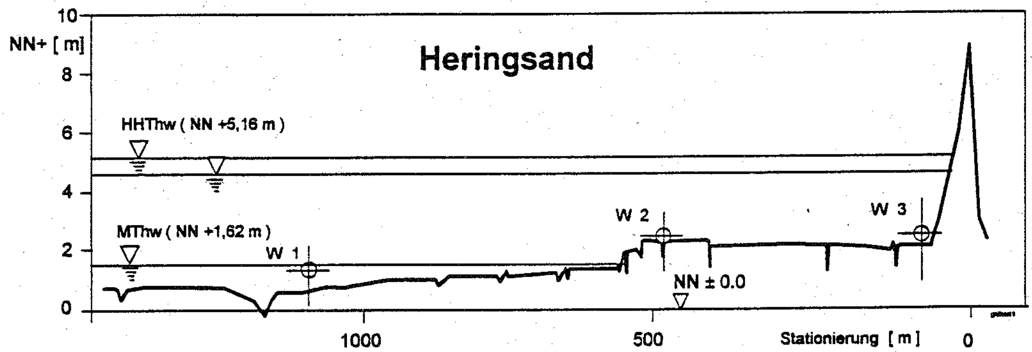

Fig. 2 Cross-section of the measuring profile at Heringsand

The cross-section of the measuring profile normal to the dykeline is plotted in Fig. 2. The green foreland extend up to roughly 500 m from dykefoot. The wave climate was recorded with pressure cells at three positions (W1, W2 and W3). The pressure data were evaluated to surface elevations by means of first order theory and empirical coefficients found from model tests and verified in field measurements. The waterlevel between Mean High Tide (*MThw*) and the highest ever recorded storm surge stillwaterlevel (*HHThw*) in Fig. 2 gives the highest level with measurements during this field program.

The large scale laboratory tests have been carried out in the Large Wave Channel (GWK) at Hannover (Grüne & Führböter, 1976) of the Coastal Research Center (FZK), which is a joint institution of both the University Hannover and the Technical University Braunschweig. The cross-section of the test configuration is shown in Fig. 3. The foreland extend roughly 85 m long in front of the dykefoot. The step in front of the foreland has a slope of 1 : 2 and a depth of 1.4 m. The distance from the step up to the wave generator is roughly 175 m.

Totally 23 wave staffs (WP 1 to WP 23) of wire typ were used along the channel. The data from the wave staffs WP 5 to WP 9 were used to evaluate the incoming waveheights H_0 , the ones from WP 14 to WP 19 were used to evaluate the waveheights H_V on the foreland. The water levels SWL were varied for the tests in 10 steps in the range of D_V = 0.6 to 3.5 m or D_V / D_0 = 0.3 to 0.7, respectively. Both regular waves and irregular waves from PM-spectra were used for the tests.

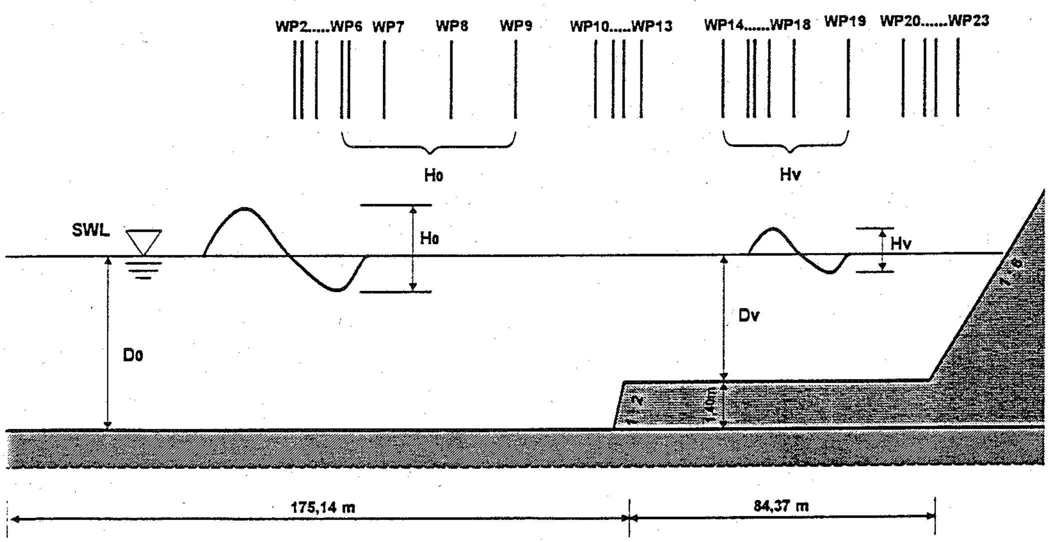

Fig. 3 Cross-section of the test configuration in the GWK

Results from field measurements

In Fig. 4 all significant waveheights $H_{1/3}$, measured at all three positions W1, W2 and W3 are plotted versus the stillwaterlevel *SWL*, which is refered to national geodetic level Normal Null (*NN*). It must be remarked, that most data in this paper will be presented in dependence of stillwaterlevel *SWL* as we found it the strongest indicator of wave climate in such shallow water areas (see e.g. Grüne, 1997). Furthermore the advantage of the stillwaterlevel *SWL* is, that it's value is equal at all three wave measuring positions. Because the foreland has a level of roughly *NN* + 2.2 m at the seawards area, waveheights on the foreland can be measured only with stillwaterlevels *SWL* higher than *NN* + 2.5 m, which is roughly 1 m above Mean High Tide *Thw*.

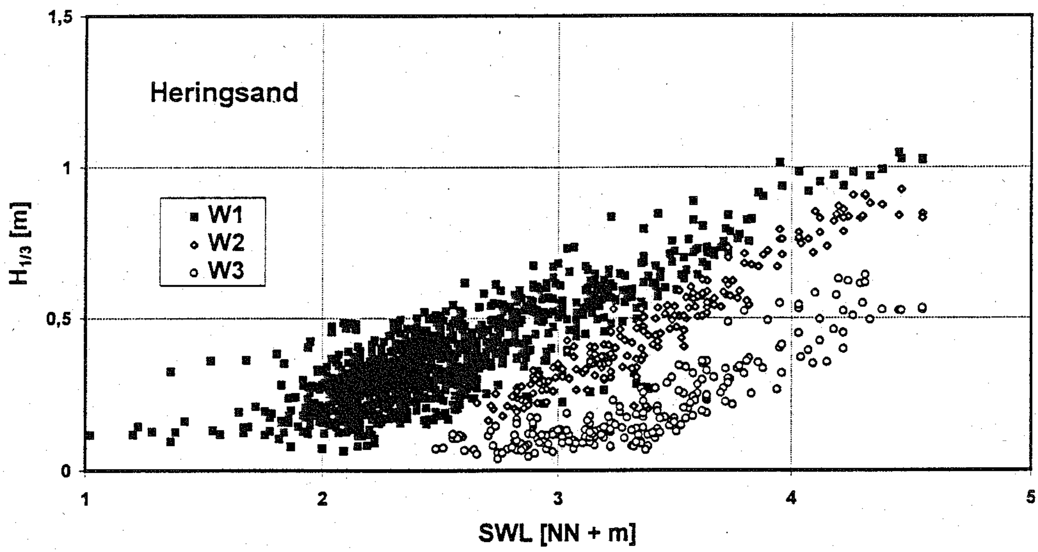

Fig. 4 Significant waveheights $H_{1/3}$ versus stillwaterlevel *SWL*

The waveheight data from Fig. 4 are plotted versus the local waterdepths *D* in Fig. 5. The most distinct correlation between waveheights $H_{1/3}$ and local waterdepths *D* occur for the data from W2 position, which also fit the zeropoint quite well. This indicates, that the critical waterdepth with respect to wave breaking has been achieved at W2 position. Thus one can suppose, that at W2 position strong wave-waterdepth interactions are dominant, whereas at W1 and W3 position weak interactions occur.

This is confirmed by the results listed in Table 1, where some waveheight and waveperiod parameter relations are compared. The waveheight parameter ratios agree quite well, except the ones for the higher waves at W2 position. All values for the ratios $H_{max} / H_{1/3}$, $H_{1/100} / H_{1/3}$ and $H_{1/10} / H_{1/3}$ are smaller at W2 position, compared with those at W1 and W2 position. Contrary to the ratios of the waveheight parameters the waveperiod parameter differ considerable, except those of the mean values from time and frequency domain (T_{m01} / T_m).

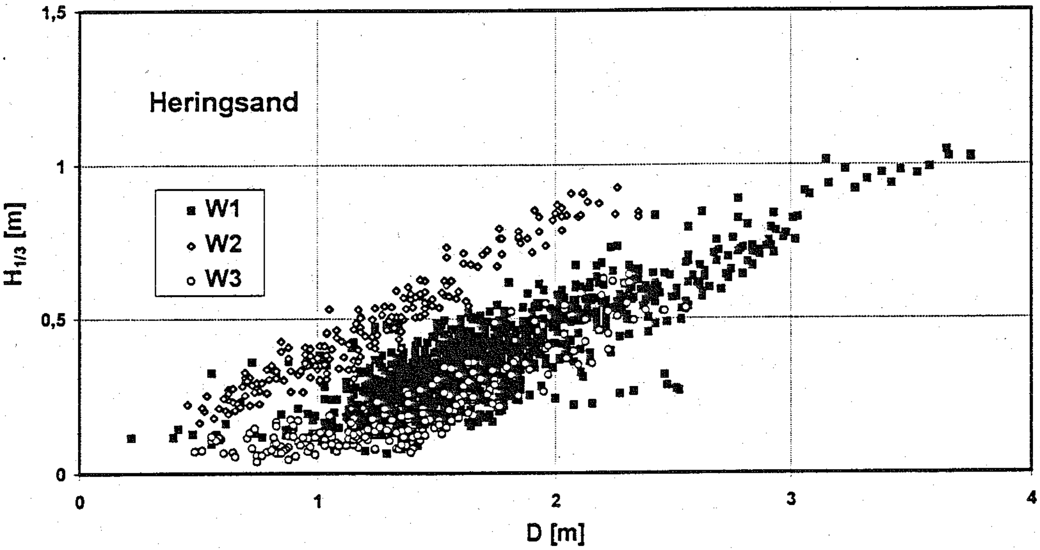

Fig. 5 Significant waveheights $H_{1/3}$ versus local waterdepth D

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	W 1	W 2	W 3
H m / H 1/3	0,690	0,708	0,703
H max / H 1/3	1,630	1,464	1,602
H 1/10 / H 1/3	1,225	1,183	1,223
H 1/100 / H 1/3	1,535	1,415	1,479
H rms / H 1/3	0,742	0,754	0,751
TH 1/3 / Tm	1,041	1,178	1,249
T m 01 / Tm	1,097	1,105	1,078
T m 02 / Tm	0,925	0,766	0,638

Table 1 Comparison of waveheight and waveperiod ratios

In this connection should be mentioned, that the peakperiods T_p differ even more, which will be investigated in detail within the ongoing research work. Generally it can be stated, that the use of peakperiods may be of problematic nature, due to the characteristics of wadden sea wave climate and to the sometimes necessary manipulation of evaluation mode with respect to occuring swell.

In the next figures the ratios of some parameter between the measuring locations are compared in dependence of the stillwaterlevel *SWL*. Fig. 6 shows the ratios of the significant waveheights $H_{1/3}$ between W2 position and W1 position (W2 / W1) and between W3 position and W1 position (W3 / W1). These data represent the main results of the investigations with respect to wave climate changes on foreland.

The data for the relation W2/W1 in Fig. 6 indicate a trend to same order of magnitude for waveheights at the seawards border of the foreland compared to those in front of the foreland (value W2/W1 = 1), if the stillwaterlevel *SWL* is higher than roughly *NN* + 5 m. Contrary to that, the relations W3/W1 lead to a waveheight reduction in front of the dykefoot of roughly 50% up to a stillwaterlevel of *NN* + 4.5 m. Because design waterlevels of dykes are higher, it would be desirable to extrapolate the trend more precisely, thus there is still some need for data with highest stillwater levels. The ratios for other waveheight parameters show similar results.

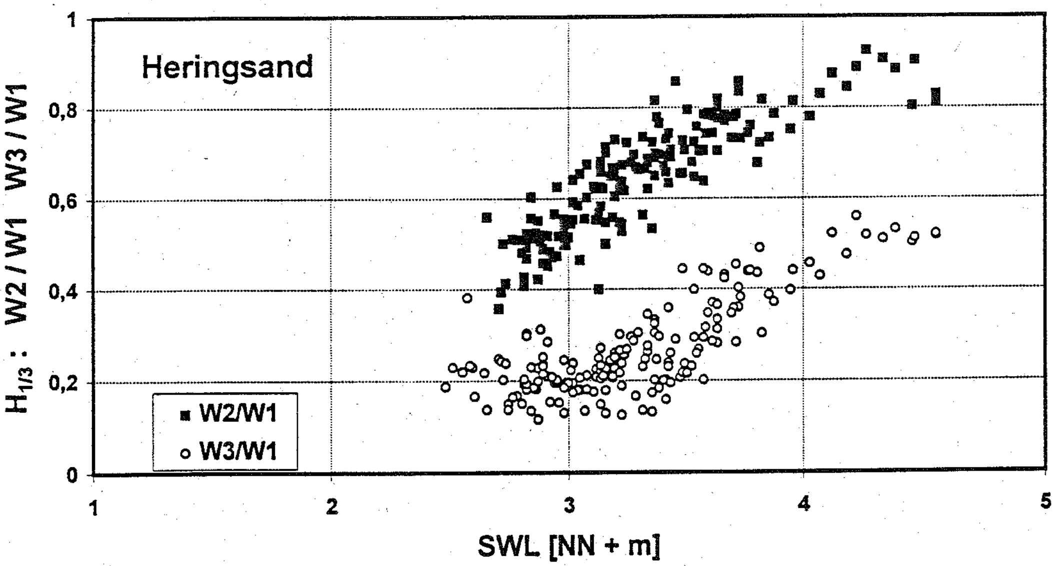

Fig. 6 Comparison of ratios W2/W1 and W3/W1 for significant waveheights $H_{1/3}$

Completely different relations occur for the waveperiods. The ratios of the mean waveperiods T_m from the time domain analysis are plotted in Fig. 7 versus *SWL*. Whereas the relation W2/W1 is closely constant in dependence of *SWL*, the W3/W1 relation varies distinctly. With lower stillwaterlevels *SWL* just above the ground level of the foreland the period values at W3 position tend to 50% compared to those at the wadden sea position W1. Then with increasing *SWL* the ratios increase up to 150% to 200% and then again with subsequently rising waterlevel the ratio decrease down to the value of roughly 100% of that at W1 position. This is caused by different wave decay and wave propagation in dependence of waterdepth on foreland, which will be discussed briefly in the following. Similar relations as for mean periods occur for the peakperiods T_p as shown in Fig. 8: roughly constant ratios between W2 and W1 positions, but a broad scattering of the ratios W3/W1 with slightly decreasing values for higher stillwaterlevels *SWL*.

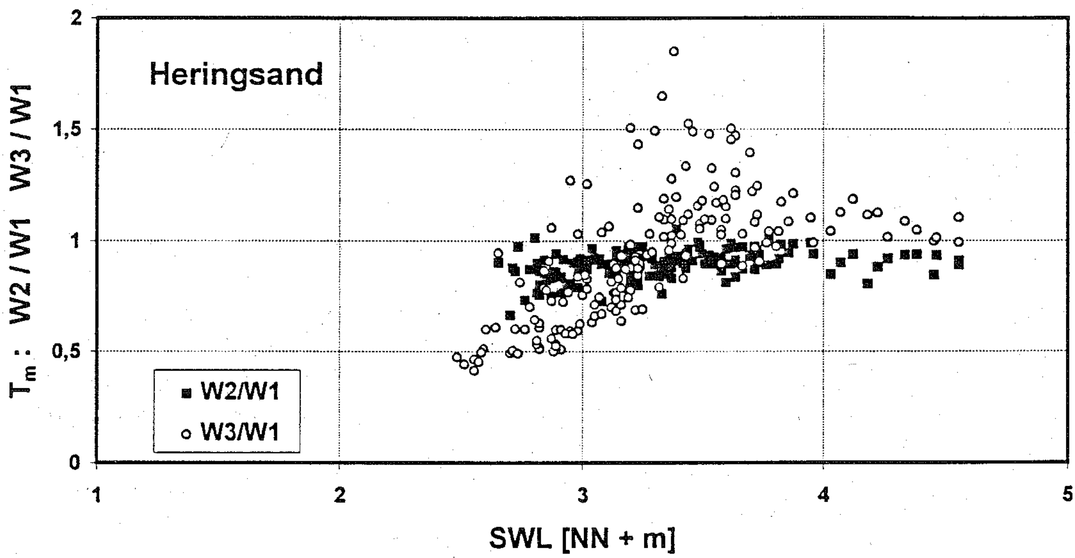

Fig. 7 Comparison of ratios W2/W1 and W3/W1 for mean waveperiod T_m

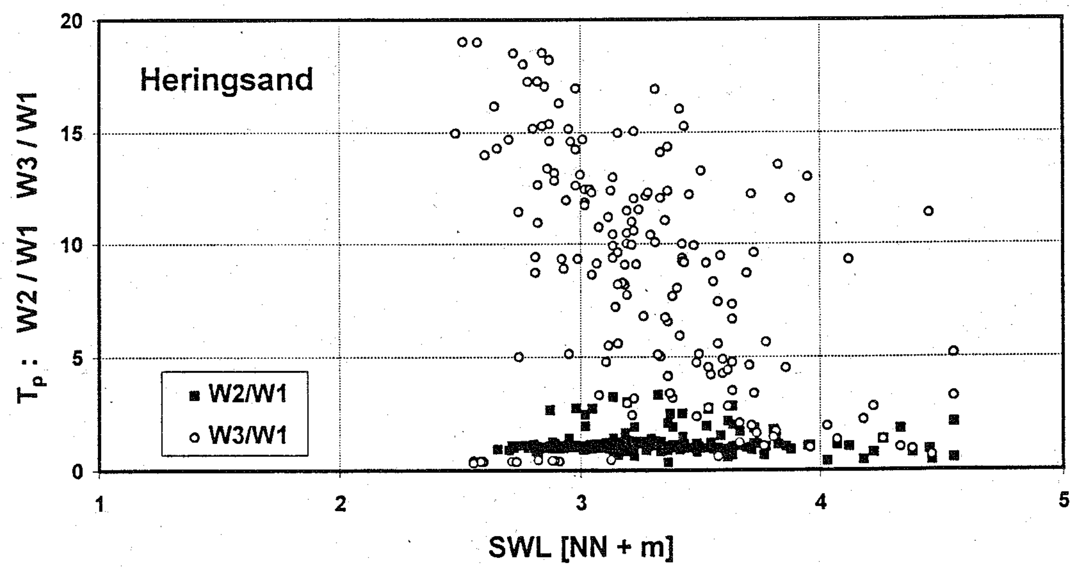

Fig. 8 Comparison of ratios W2/W1 and W3/W1 for peakperiod T_p

Fig. 9 shows an example of synchronously measured energy spectra at all wave measuring positions. The wave energy decay between W1 and W2 position may be classified as a weak one, whereas the decay at W3 position is strong compared to W1 or W2, respectively. The peakperiod at W2 position is longer and at W3 it is shorter, each compared with the one at W1 position, but this is more or less a result of smoothenning the energy spectra.

The ratios for the peakenergy values E_p in dependence of stillwaterlevel *SWL* are plotted in Fig. 10. The ratios show a similar trend as those of the waveheights in Fig. 6 consequently.

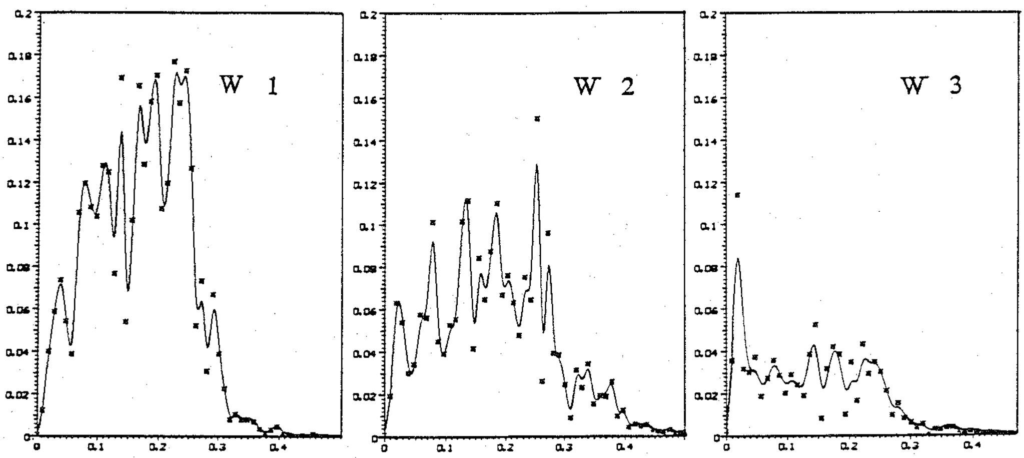

Fig. 9 Example of synchronously measured energy spectra

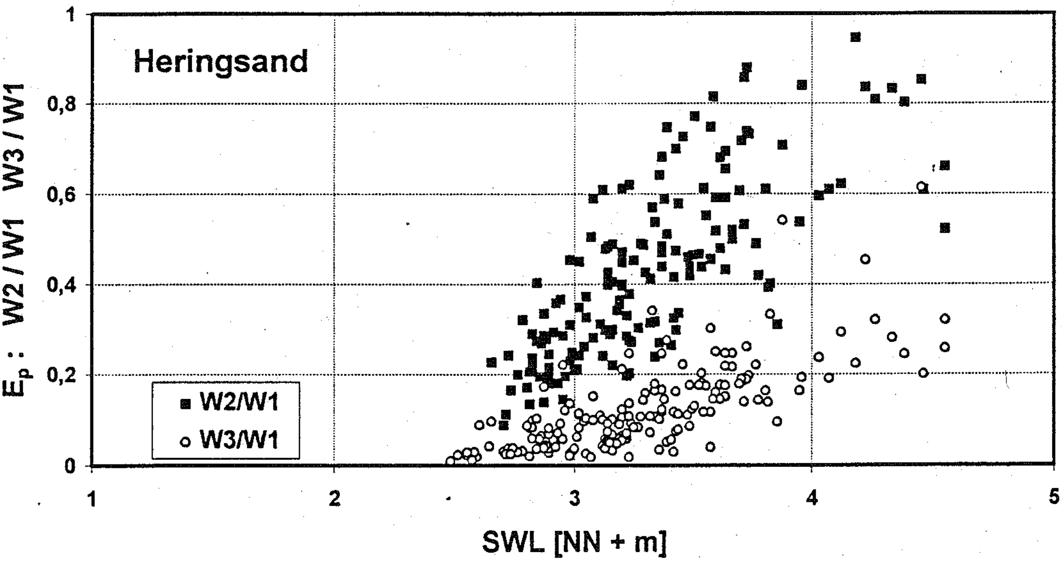

Fig. 10 Comparison of ratios W2/W1 and W3/W1 for peakenergy values E_p

More informations about wave decay and generation give the data for the spectral width parameter E_{ps}, which are plotted in Fig. 11. At W1 position the values of spectral width parameters have an increasing trend with increasing stillwaterlevel *SWL*. This indicates, that with lower waterlevels waves may be generated more or less only by local windfields and further, that the waves break partly with higher waterlevels. The spectral width parameters measured at W2 position indicate, that the waves always are breaking partly. From the data at W3 position it may be supposed, that the waves with small waterdepths on the foreland are generated by local windfields, either with normal values for spectra width parameter E_{ps} or with very high values, if the actual windspeeds are too high with respect to wave growth for these waterdepths. For higher stillwaterlevels *SWL* above *NN* + 4 m the data of all positions tend to a value

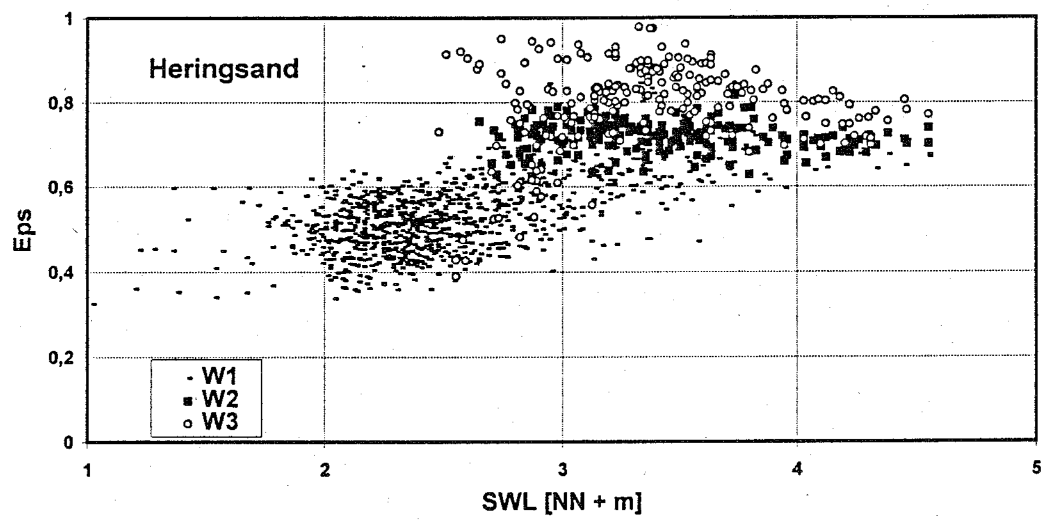

Fig. 11 Spectral width parameters E_{ps} versus stillwaterlevel *SWL*

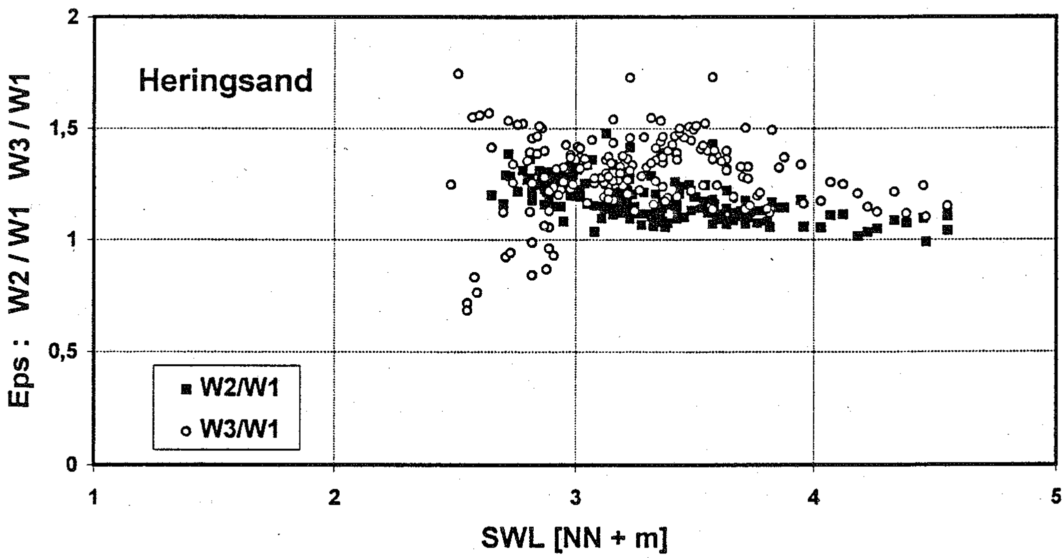

Fig. 12 Ratios W2/W1 and W3/W1 for spectral width parameters E_{ps}

of 0.65 to 0.8 and consequently in Fig. 12 the ratios W2/W1 tend to roughly 1.1 and the ratios W3/W1 to roughly 1.2 respectively.

Results from large-scale tests

Examples of the results from some tests in the large wave channel GWK are plotted in Fig. 13 (tests with regular waves) and in Fig. 14 (tests with irregular waves from PM-spectra). The measured waveheights (mean regular wave height H in Fig. 13, significant waveheight $H_{1/3}$ in Fig. 14) from all wavestaffs are plotted versus their positions along the wave channel. All tests

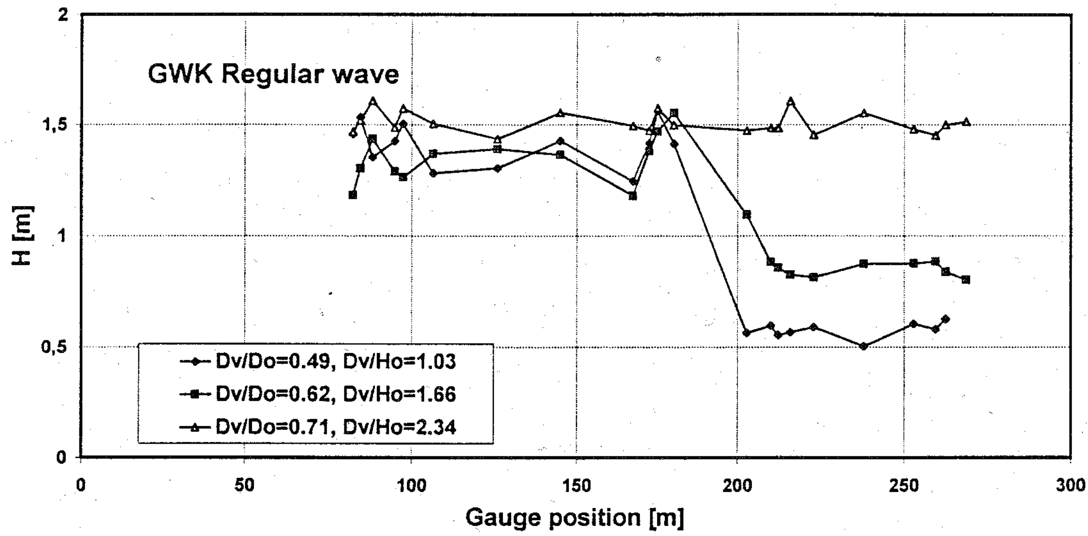

Fig. 13 Waveheights H (regular waves) measured along the GWK

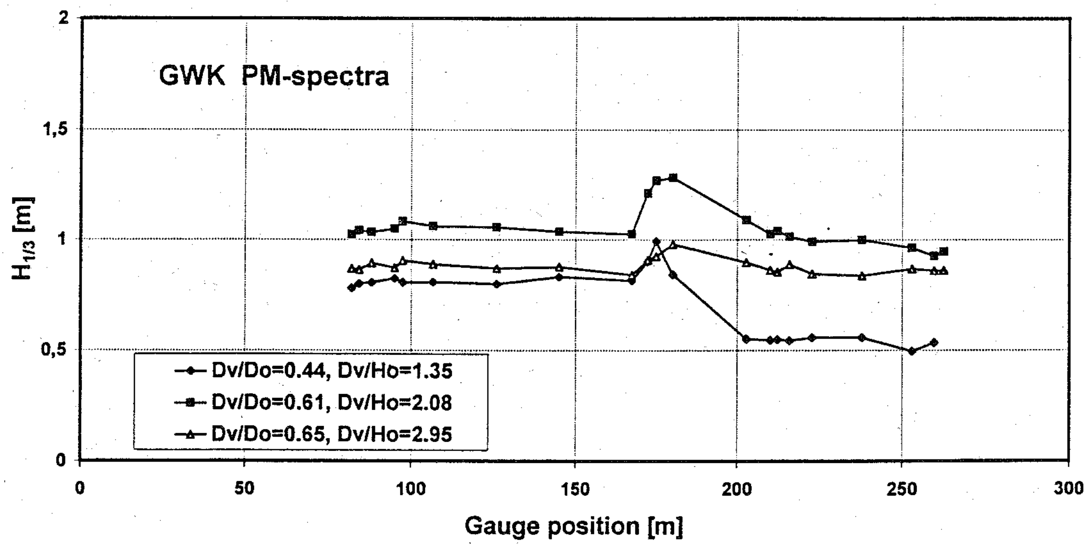

Fig. 14 Waveheights $H_{1/3}$ (irregular waves) measured along the GWK

have been done with different waterlevels. With a depth ratio D_v / D_o of more than roughly 0.6 or a depth-waveheight ratio D_v / H_0 of more than roughly 1.6 the foreland seems to have has no effect on wave damping. But in nearly all tests a distinct enhacement of the waveheights have been occured at the 1 : 2 sloping step, where the foreland begins.

The data from regular wave and irregular wave tests are compared in Fig. 15, where the ratios between the incoming waveheight and the waveheight on the foreland H_v / H_0 are plotted versus the depth ratios D_v / D_o. The wave damping effect increase with decreasing depth ratio. The trends both for regular waves and for irregular waves agree quite well, but the wave damping effect is stronger for regular waves.

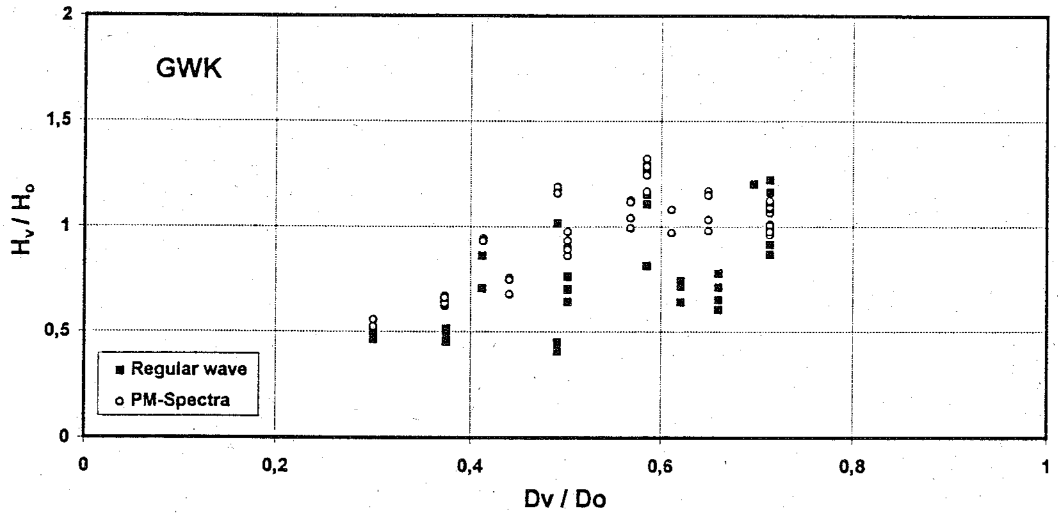

Fig. 15 Waveheight ratios H_v / H_0 versus depth ratios D_v / D_0

The waveheight ratios H_v / H_0 agree much better, if they are plotted in dependence of the waveheight related depths D_v / H_0, as shown in Fig. 16. Both for regular waves and irregular waves from PM-spectra the wave damping effect occur up to the D_v / H_0 ratios of roughly 2 (decreasing with increasing ratio D_v / H_0). Between D_v / H_0 = 2 to 3 there is an enhacement of H_v / H_0 up to 30%. With subsequently increasing D_v / H_0 > 3 the waveheight ratios H_v / H_0 tend to a constant value around 1.

The data from field measurements at Heringsand and large scale laboratory tests in the GWK are compared in Fig. 17. With respect to the different absolute lengths of foreland in field and in laboratory the laboratory test data have to be compared with the field data from W2 position at Heringsand. These data agree only reasonable, whereas the data from W3 position in field show a much greater extend of wave damping on the foreland compared to the laboratory data. Thus

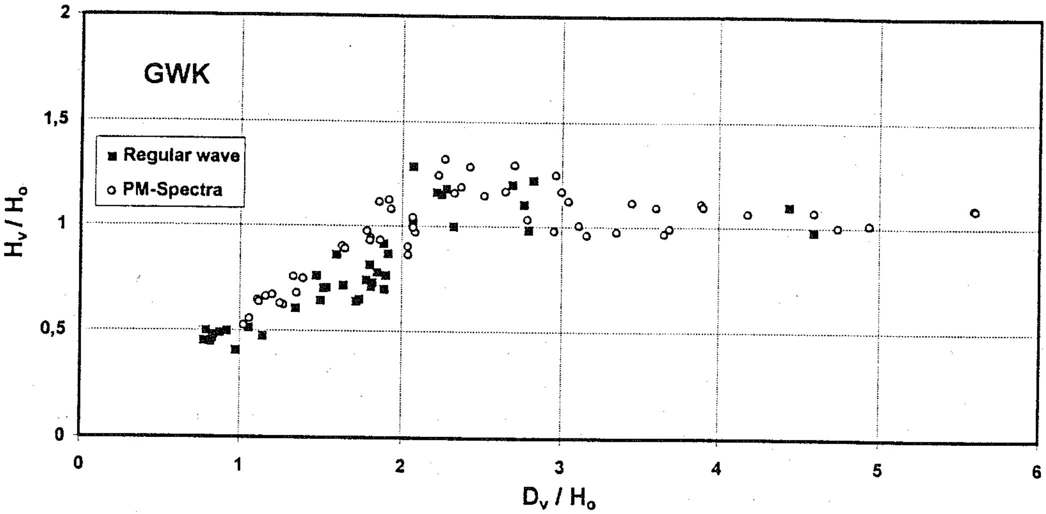

Fig. 16 Waveheight ratios H_v / H_0 versus depth-waveheight ratios D_v / H_0

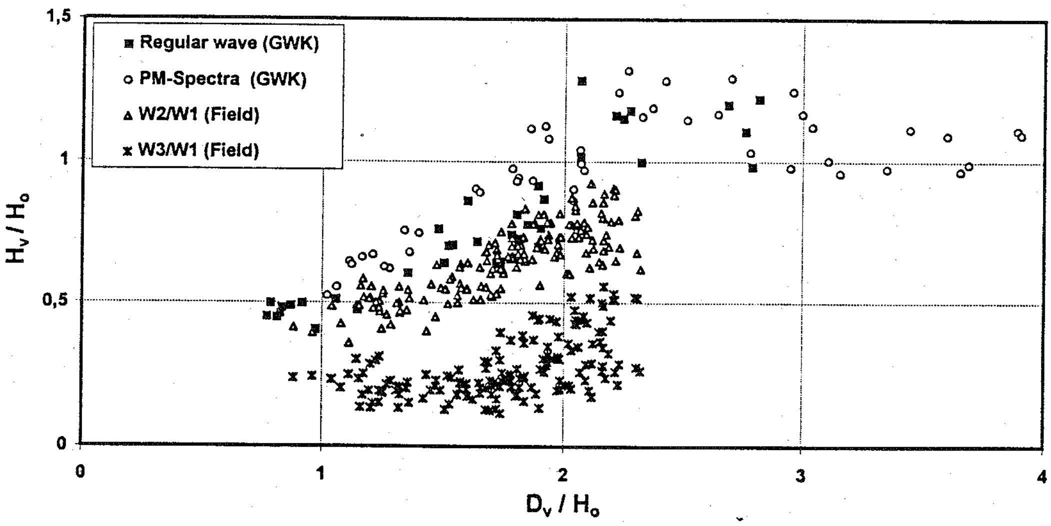

Fig. 17 Comparison of field data and large scale laboratory data

the effect of foreland on wave climate change seems to be strongly influenced by the length of foreland, which needs further research. But it must be mentioned, that the steps at the beginning of the foreland were different, the slope in field has a much more gentle mean slope of roughly 1 : 20 compared with the one in the GWK tests with only 1 : 2, possibly the different damping effect may be influenced partly by this effect.

Conclusion

Investigations on the effect of foreland on wave climate changes have confirmed, that waves were damped distinctly by the foreland. The distinct order of magnitude of wave height reduction in front of the dyke, found from the field measurements indicate a substantial effect also for highest storm surge stillwaterlevels.

Further research is needed with respect to the influence of occuring swell on evaluation of peakperiods and to the influence of foreland width on wave damping.

Acknowledgements

The authors would like to give their severe thanks to the following projects for leaving data: The large scale laboratory data have been leaving from the research program of SFB 205/A1 (supervision Prof. Dr.-Ing. A. Führböter †, Dr.-Ing. Dette), which was supported by the German Research Foundation (DFG). The field data have been leaving from a research program in cooperation with the Regional State Board for Water Management (ALW Heide, supervision Dipl.-Ing. Gärtner) of the State of Schleswig-Holstein.

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