FIELD STUDY ON WAVE RUN-UP ON SEADYKES

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Abstract

This paper deals with a comprehensive field research program on wave run-up, which is ongoing at different locations at the landside borders of the wadden sea (tidal flats) and the tidal estuaries of the German Bight since 1991. The field measurement equipment is described and an overview about first results is given.

Introduction

Due to the increasing of storm surges and the supposed long-term rising of water levels at the coastlines of the North Sea, for savety analysis of excisting dykes in field a more exact knowledge is needed on wave run-up and overtopping process, especially with respect to non-uniform dyke cross-sections and to real sea state conditions. Air entrainment and wave climate characteristics under real sea state conditions play an important role 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.

Field measuring program and equipment

The ongoing research program is focussed on the influence not only of real sea state wave climate but also of complex non-uniform dyke cross-sections on wave run-up. The investigations have been doing for recent years at four different locations at the coast of Dithmarschen and at the Elbe river estuary (Fig. 1) in cooperation with the Regional State Board for Water Management (ALW Heide, supervision Dipl.-Ing. J. Gärtner) of the State of Schleswig-Holstein. At two locations (Heringsand and Stinteck) the measurements have started in 1991,

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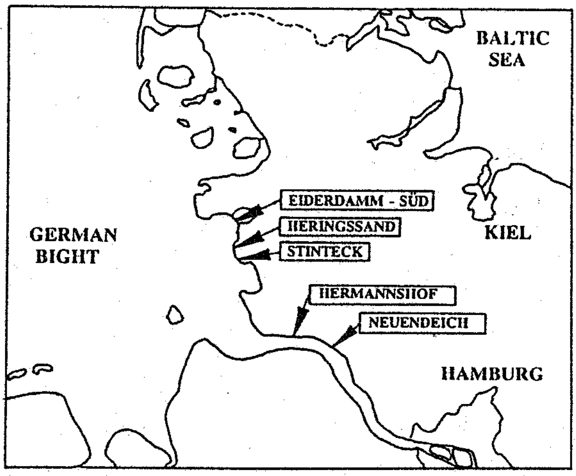

Fig. 1 Measuring locations at German Bight

at the two other locations in 1993. At another location (Eiderdamm-Süd) measurements already had been done during previous programs (Grüne, 1982).

Each of these locations represents one spezific type with respect as well to different characteristics of morphologic boundary conditions, which generally occur in wadden seas and estuaries as to different excisting non-uniform types of dyke cross-sections. Fig. 2 shows a scheme of the installed sensors at each location. The incoming wave climate has been measuring with a pressure cell for evaluation of surface elevation and with a two-component velocity meter for evaluation of the wave approach direction at the outhermost seewards position. At two locations additional pressure cells were installed between the outhermost position and the dyke. The wave run-up has been measured with a 70-step gauge. The aim of the program is to generalize all the measured relations between wave climate (in dependence of the morphologic boundary conditions) and wave run-up (in dependence of dyke cross-sections). The generalized results shall be used for savety analysis with extrapolated storm surge level conditions.

At the locations Heringsand and Stinteck (Fig. 3) occur a distinct wadden sea wave climate. At Heringsand location there are less wave energy parts dissipating from the closedby tidal gully compared to Stinteck. Furthermore at Heringsand the wave climate in front of the dyke is strongly influenced by the wave damping effect of the higher green foreland, which has a mean level of NN + 2.0 m and a width of roughly 500 m.

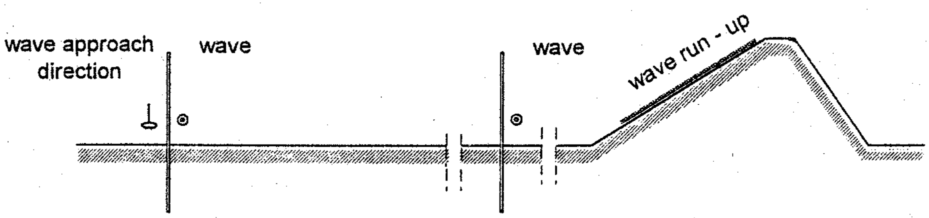

Fig. 2 Scheme of installed sensors at each location.

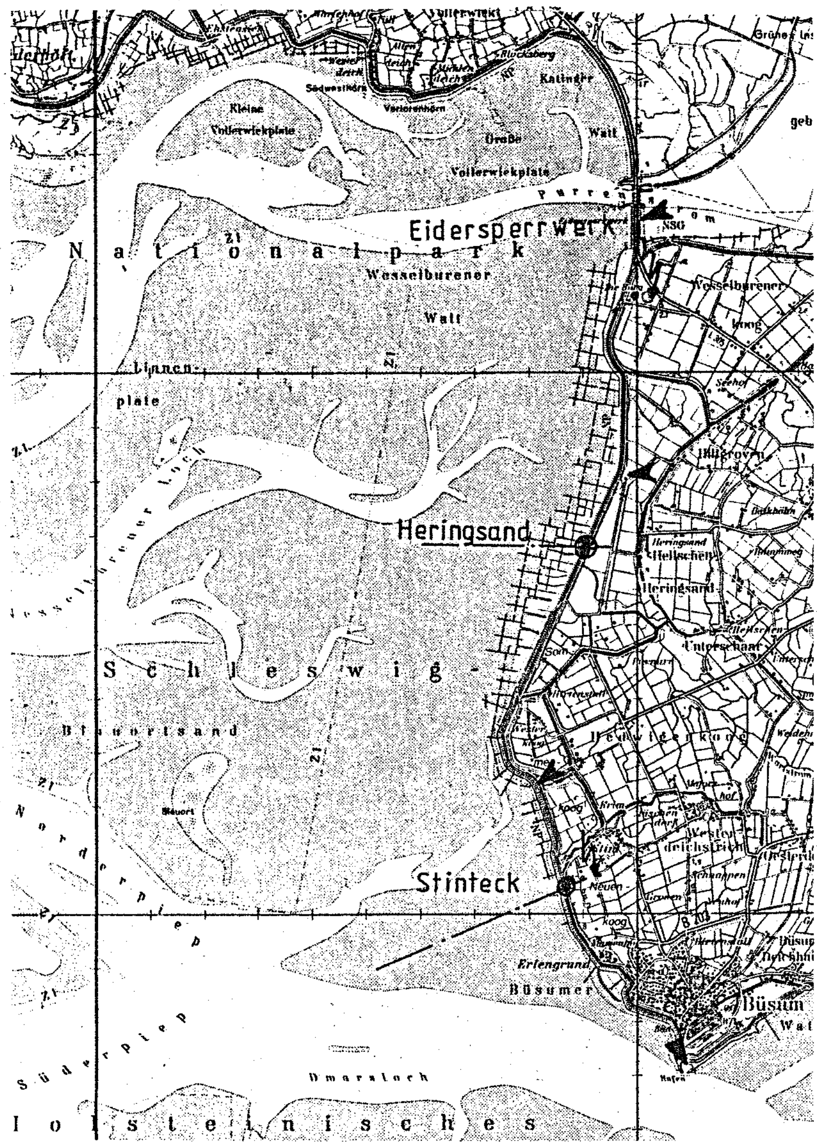

Fig. 3 Measuring locations Heringsand and Stinteck

The cross-section of the dyke at Heringssand is plotted in Fig. 4. Due to the relatively less intensive wave climate the dyke surface is covered totally with grass on clay and has a relatively gentle slope of roughly 1:10 in the lower part. In all cross-sections in Fig. 4 the dotted lines give the geodetic reference level (Normalnull). The upper waterlevels are the highest ones ever been recorded (HHThw), the lower ones are the Mean High Tide levels (MThw) and the water levels between HHThw and MThw are the highest ones, used for measurements within this program till today. The supports of the installed run-up step gauges (which are described in detail by Grüne, 1982) are marked with a solid line parallel on the dyke surface. The 70 steps of the gauge have different distances between each other in dependance of the slope. But all steps are calibrated in such way, that the signal is linear to the vertical component of the watertongue running up and down on dyke surface.

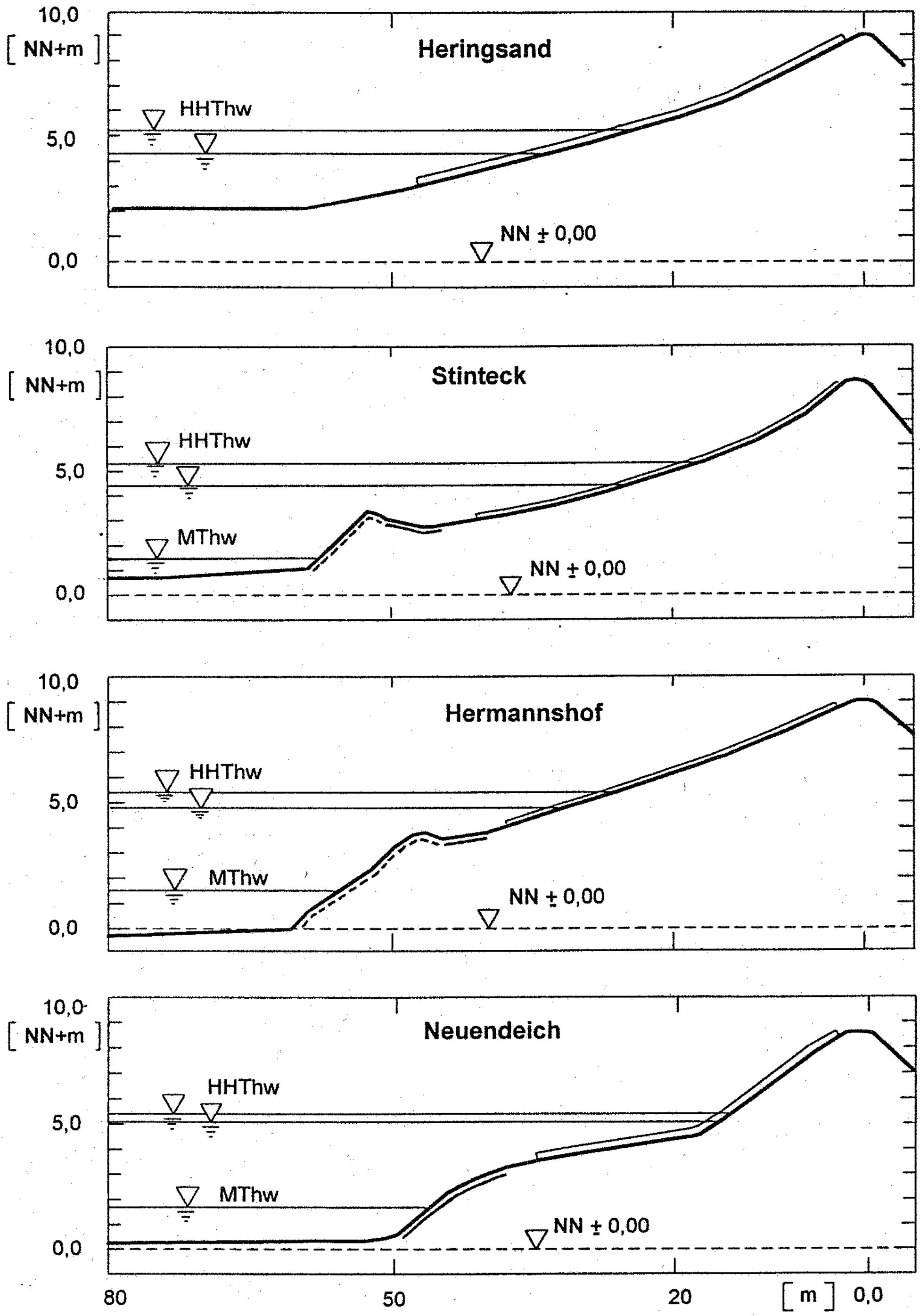

Fig. 4 Cross - sections of the dykes used for field measurements

The Mean High Tide level MThw at Heringsand lies roughly 0.5 m below the green foreland. Wave climate at Heringsand is measuring at three positions: 1040 m, 470 m and 50 m in front of the dykefoot. The vertical distances of the 70 run-up steps at Heringsand vary from 5 cm on the lower gentle slope to 12 cm on the higher steeper slope.

The dyke at Stinteck location has a berm made with natural stones, which are placed irregular (marked in Fig. 4 with a dotted line under the dyke surface). The top of the berm partly is covered with smooth artificial concrete stones and is used as a working road (marked with a solid line under the surface). This area also has an inner slope partly, which creates an extended water basin for water levels around the berm top level. The dyke surface above this area is covered with grass. The wave climate is measuring 700 m and 50 m in front of the dykefoot. The run-up steps have vertical distances from 4 cm on the lower gentle slope to 12 cm on the higher steeper slope. An impression of waves acting on the dyke at Stinteck is given in Fig. 7. The photo was taken during a stormsurge with a water level roughly 2.0 m above Mean High Tide, where all waves break on top of the berm.

The wave climate at the locations Hermannshof (Fig. 5) and Neuendeich (Fig. 6) are influenced as well by the deepwater conditions in the Elbe river estuary as by the restricted depths due to flats in front of the dykes. But these flats only have a width of roughly 200 meters at Hermannshof and of roughly 400 meters at Neuendeich, respectively.

The berm of the dyke at Hermannshof (Fig. 4) is covered in the same way as at Stinteck with stones up to the top, but the top of the berm is smaller and has an outer slope, which is covered with asphalte concrete. The grass covered surface above the berm has a nearly uniform slope. Wave climate at Hermannshof only is measuring 50 m in front of the dyke. The vertical distances of the 70 run-up steps vary from 5 cm at the lower levels up to 9 cm at the higher levels.

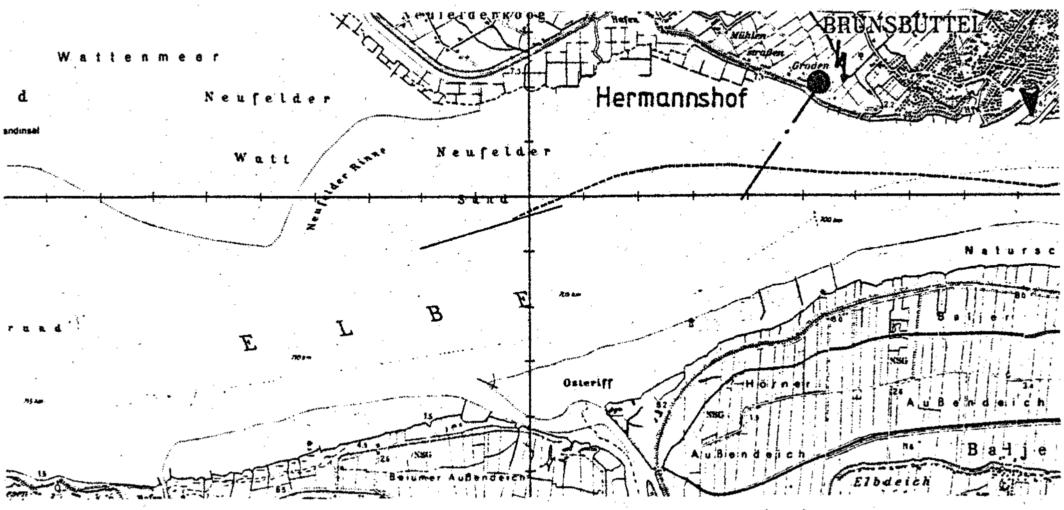

Fig. 5 Measuring location Hermannshof

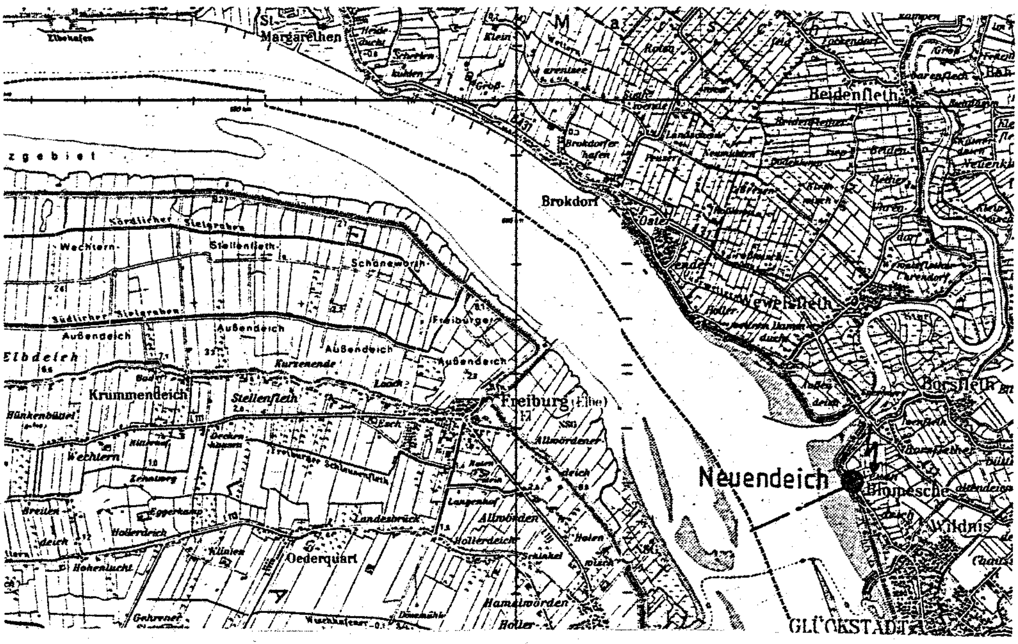

Fig. 6 Measuring location Neuendeich

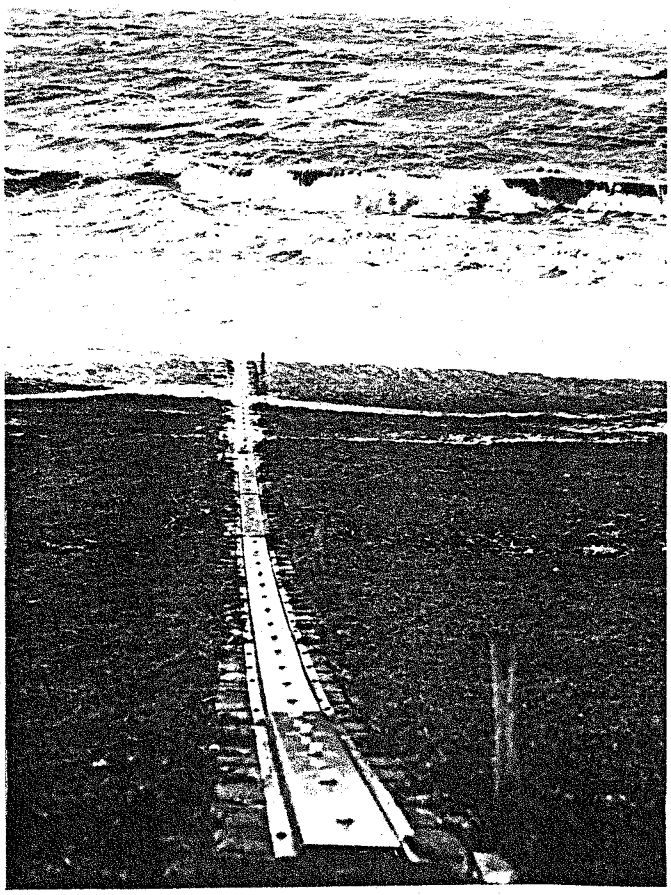

Fig. 7 Waves acting on the dyke at Stinteck location during a storm surge

The dyke profile at Neuendeich (Fig. 4) has an extended berm. The outer steep berm slope is covered with artificial smooth concrete stones (in Fig. 4 marked with a solid line under surface). The surface on the berm and on the higher steep slope is covered with grass. Wave climate is measuring also only at the positions 50 m in front of the dykefoot. The run-up steps have vertical distances between 3 cm on the lower gentle slopes and 11 cm on the higher steeper slope.

At all locations the sensors are connected by cables with a computer-contolled recording system in a shelter box at the backside of the dykes. Data recording is starting automatically in dependance of desired storm surge waterlevels (usually 1.5 m above MThw).

Data analysing

The wave parameters of the surface elevation were evaluated from the recorded pressure signals. Linear theory was used for transformation, modified with correctionfactors. These factors depend on relative depth of sensor and were found from laboratory and field experiments. Analysis has been done in time domain (modified Zerodowncrossing method) and in frequency domain.

Analyzing run-up records from field can be rather complicate, because characteristics of run-up signals may be strongly influenced by two main effects:
- Firstly by the physical breaking process on gentle slopes and on berms.
- Secondly by the kind of gauge with a relatively long distance on the slope between the steps for gentle slopes.

The first effect can be demonstrated in Fig. 8, where in the lefthand plot a short time history is given as an example of synchronous signals of waves and run - ups, recorded at Stinteck location. One won't find any direct linkage between both signals, as one may expect it from the literature according to small scale model tests with regular or irregular PM-spectra waves on uniform steep slopes. This effect comes out clearly, if one look on the cross-section in Fig. 4 with the extremely broad berm and on Fig. 7, where one can see the waves breaking in front of or on the berm, which create reduced and longperioded run-ups after passing the distance to the upper dyke surface. Furthermore the run-downs mostly stay above stillwaterlevel, which is a typical result of gentle slopes.

With other boundary conditions the run-up records may have other characteristics. Such an example from Neuendeich location is given in the righthand plot of Fig. 8 with same time scale as in lefthand plot. Due to a very high water level for these data the waves break mainly at the higher steep slope. Thus these run-ups are neigher affected by breaking of waves before they reach the dyke surface nor by breaking on gentle slopes. In the timeexpanded part of the righthand plot the different linkage behaviour between the run-up signals from these both locations comes out evident.

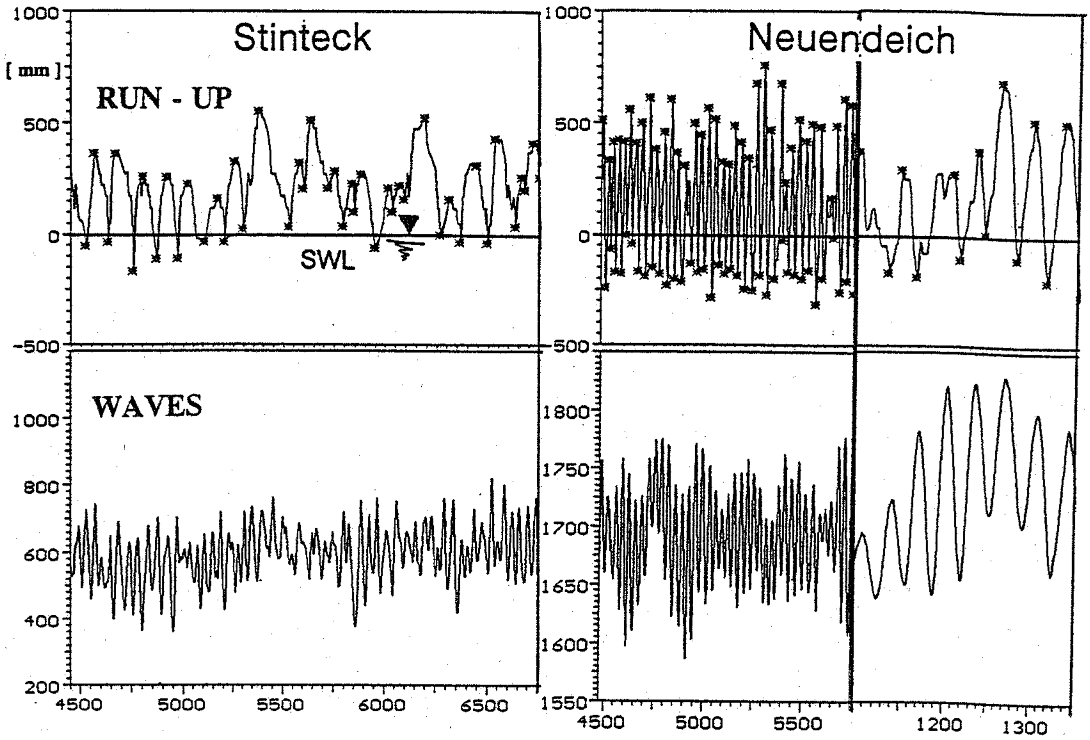

Fig. 8 Time histories of synchronously measured waves and run-ups

The second effect, mentioned before is caused by the kind of gauge. A step gauge on gentle slopes necessarily has long distances between the single steps. Together with longperioded and damped run-ups thus leads to signals, which are shown schematically in Fig. 9. Such signals may be processed with step identification and smoothening modes.

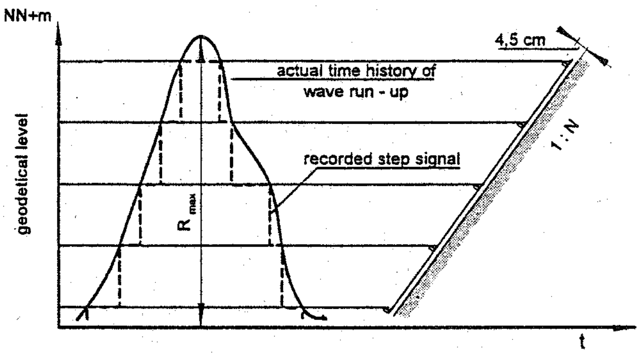

Fig. 9
Scheme of signals from a step gauge

Furthermore a definition mode far from the zerocrossing mode is necessary, due to the fact, that the run-down mostly stay above stillwaterlevel. An overview about the definitions and analysing modes used in this paper for the run-ups R_u, run-downs R_d (R_{dR} is used) and periods T_R is given in Fig. 10. The mode for separating single run-up events from a sequence is shown schematically in Fig. 11. Separated run-ups were analyzed, if the relation *a/b* don't exceed the threshold value *G* within a certain time window. The used treshold value is in the order of magnitude of 10 to 20. As conclusion it must be stated that run-up records from field measurements have to be analysed very carefully and seriously.

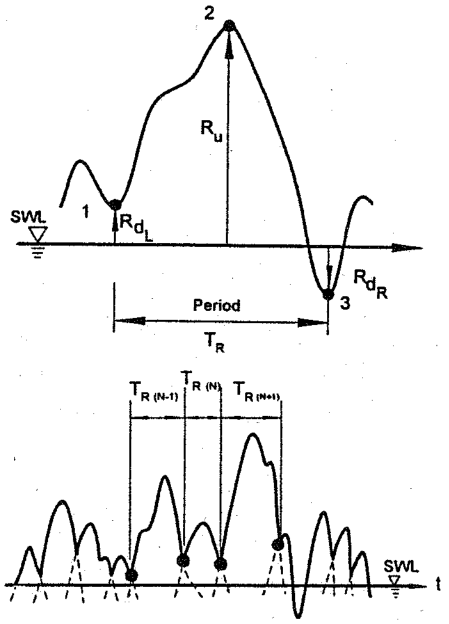

Fig. 10 Definition of run-up and run-down parameters

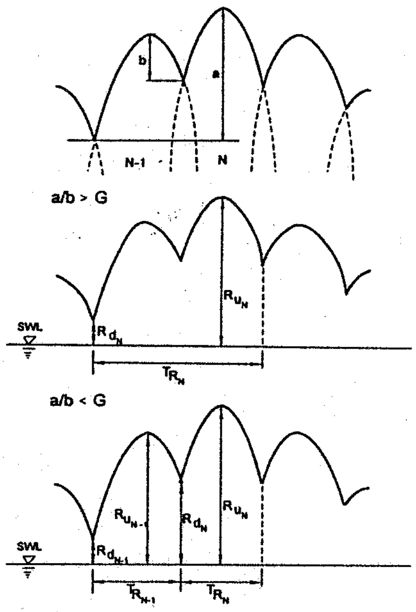

Fig. 11 Mode for separating of single run-up events

First results

Data were recorded during strong wind and storm surge conditions. A part of the data were measured at the different locations during same storm surge events. A comparison of the first data from all different types of cross-sections show distinct differences, which are both influenced by the different wave climates and by the different shapes of cross-sections. Due to restricted space in this paper only an overview of some first results can be given. More detailed results will be published in following papers.

The maximum run-up and run-down values, measured at all four locations, are shown in Fig. 12. The values are added on the stillwaterlevel *SWL* and are plotted versus the stillwaterlevel *SWL*, which is refered to geodetic level Normal Null. The full line represents the stillwaterlevel, the dotted line shows the geodetic level of the lowest step of the run-up gauge. Obvious are the small run-down values (except for higher waterlevels at Neuendeich), mostly around the stillwaterlevel, which is caused by the gentle slopes mainly, as already mentioned before.

In Fig. 13 the run-ups R_{98u} and run-down R_{98d} are related to significant waveheights $H_{1/3}$ and are again plotted versus the stillwaterlevel *SWL*. No run-up data are presented for Hermannshof location, because a part of those were measured without recording wave climate due to sensor defects. The data from Heringssand and Neuendeich have a trend of higher values for smaller waterdepths. This is contrary to that, which could be expected, but has simple reasons, which will be explained later.

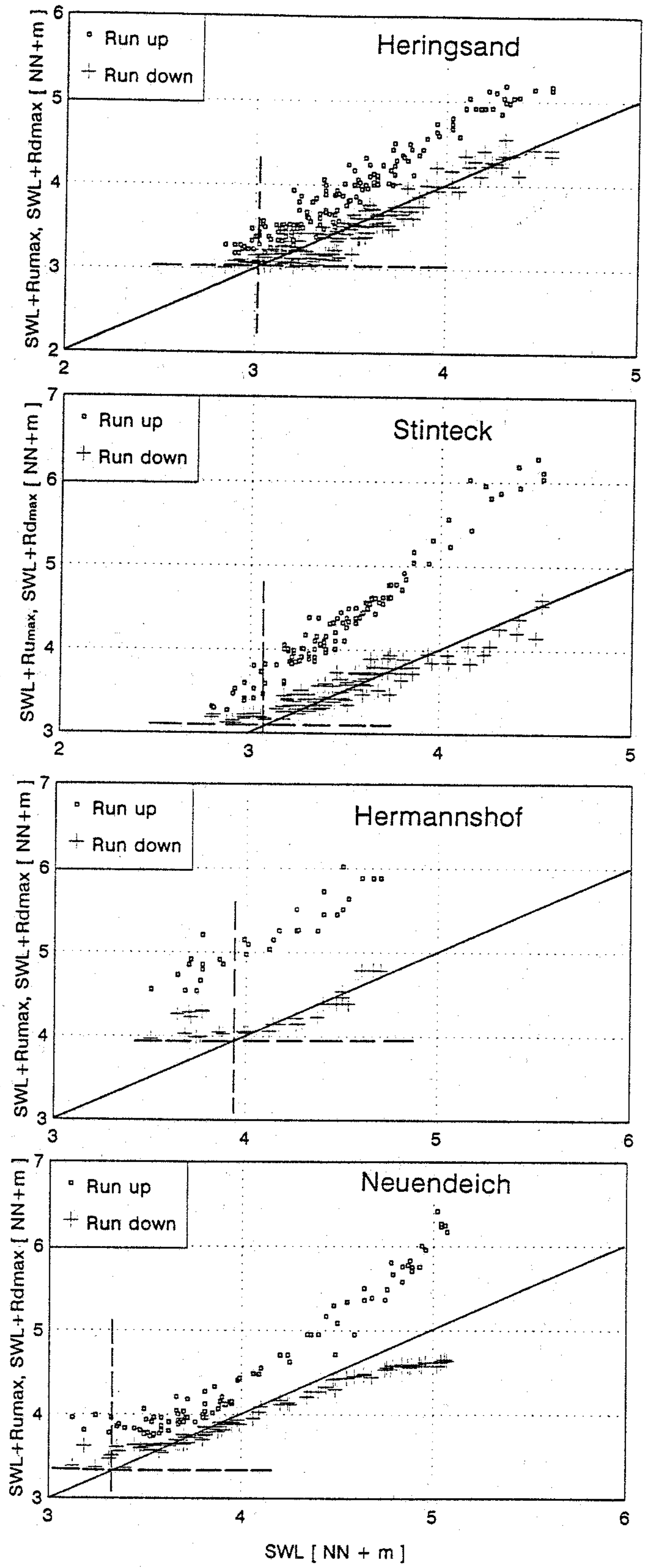

Fig. 12 Maximum run-up and run-down levels versus stillwaterlevels

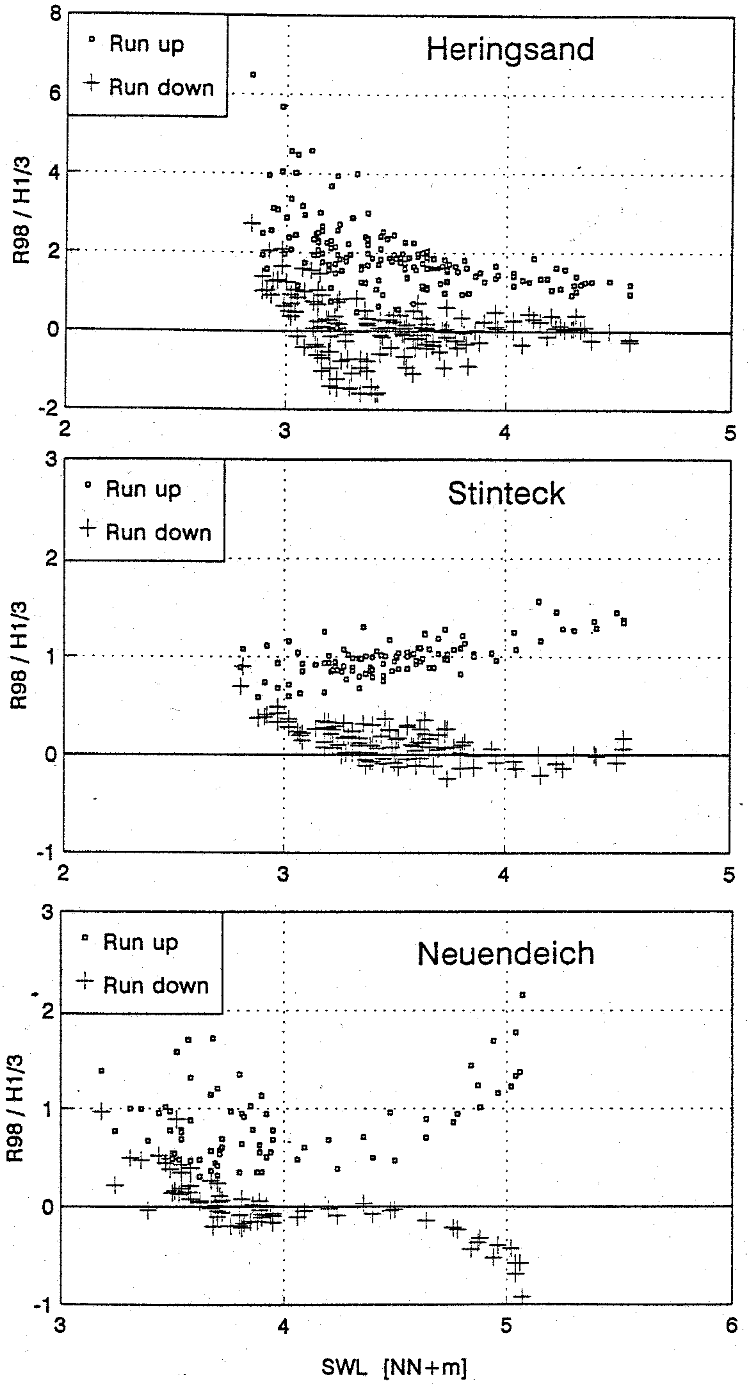

Fig. 13 R_{98} / $H_{1/3}$ versus stillwaterlevel *SWL*

Similar confusions come out from Fig. 14, where the relations between the mean wave periods T_{Hm} and the mean run-up periods T_{Rm} are plotted versus the stillwaterlevel *SWL*. Considerable differences are obvious between the different locations. Whereas at Heringsand location with higher stillwaterlevels above NN + 4.0 m only 20% of the waves create a run-up, at Stinteck there are 40% and at Neuendeich up to 100% of the waves, which create a run-up.

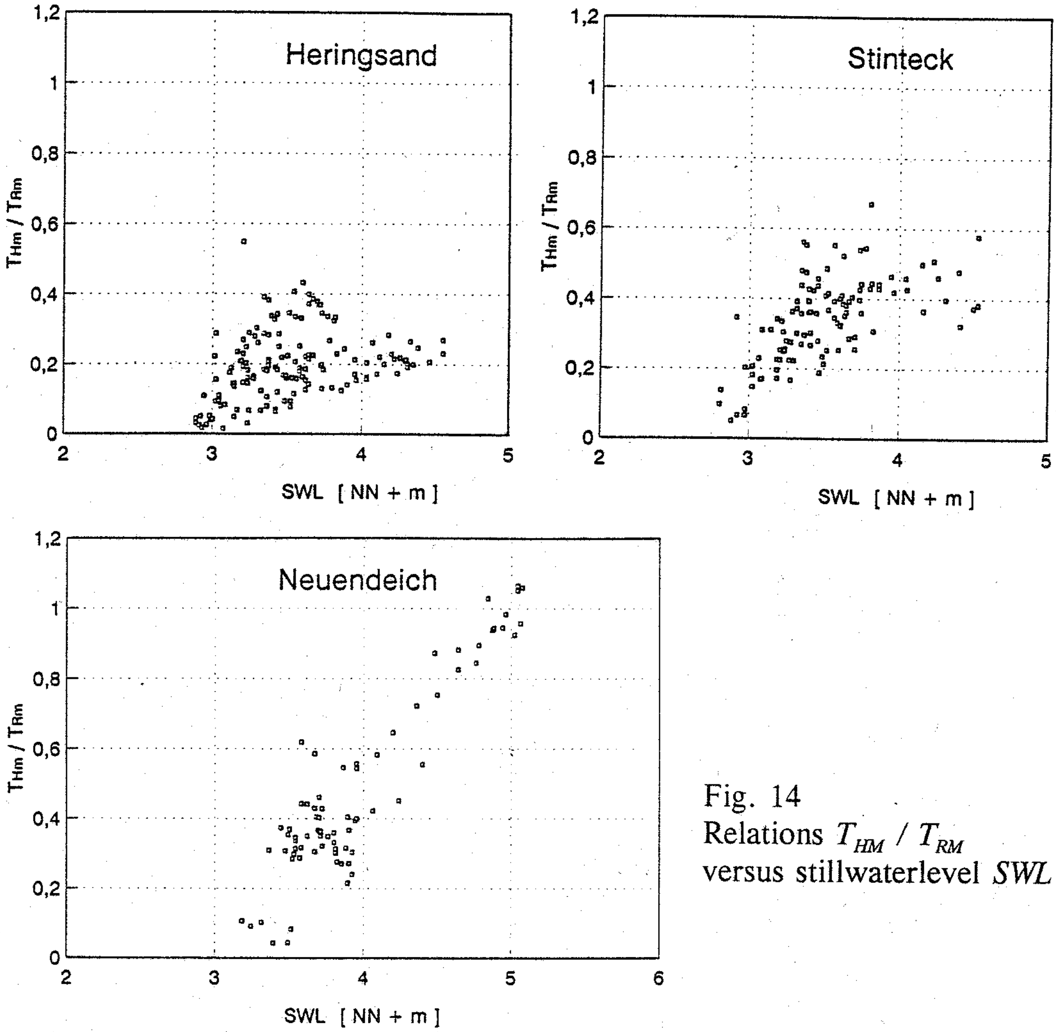

Fig. 14
Relations T_{HM} / T_{RM}
versus stillwaterlevel *SWL*

Other results with confusing different trends for the different locations occur for other parameters and relations, as shown in Fig. 15, where all data R_{98} / $H_{1/3}$ are plotted versus the breakerindices ξ . But all these trends can be explained by the different boundary conditions at the different locations. The boundary conditions also are changing in dependence of the stillwaterlevel *SWL*. One example is the occurrence of relatively high values R_{98} / $H_{1/3}$ up to 6 at Heringsand (upper plot in Fig. 15). From detailed analysis it was found, that the relative higher run-ups are created by longperioded parts of the surface elevations, which are eleminated for wave analysis, but have amplitudes up to roughly 0.3 m.

Another example can be demonstrated by the results, found for Neuendeich location and plotted in the lower parts of Figs. 13 and 15. In both plots one can distinguish the data into two groups, each with a more or less distinct trend. In Fig. 16 the appertaining mean waterdepths on the berm d_{BE} / $H_{1/3}$ (related to $H_{1/3}$) of these data are plotted versus stillwater level *SWL* and breakerindex ξ , respectively. From this figure and comparison with Figs. 13 and 15 the separation comes

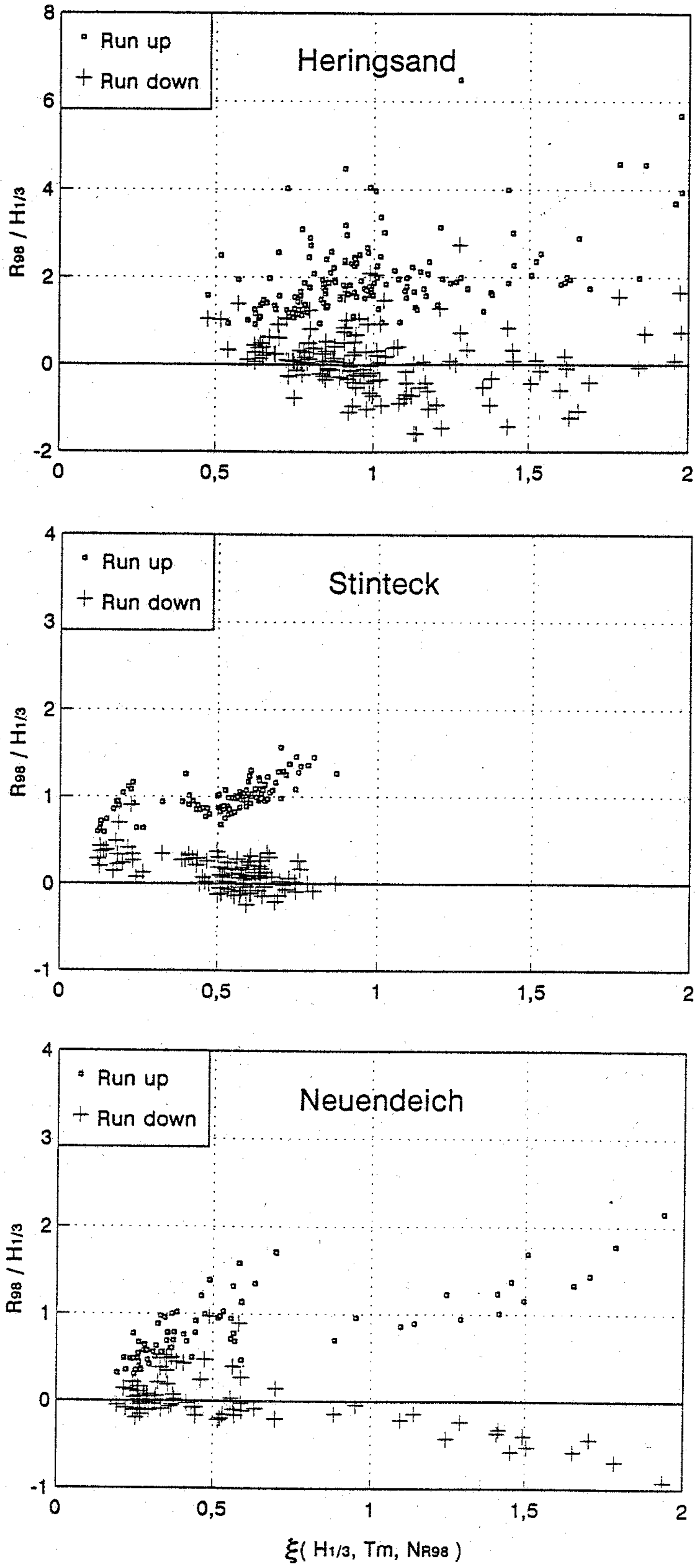

Fig. 15 R_{98} / $H_{1/3}$ versus breakerindex ξ

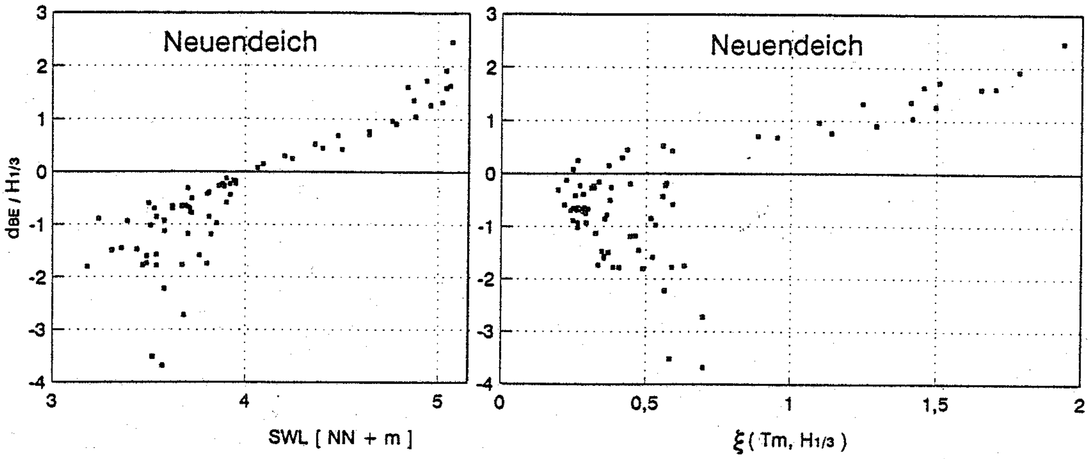

Fig. 16 d_{BE} / $H_{1/3}$ versus *SWL* (lefthand) and breakerindex ξ (righthand)

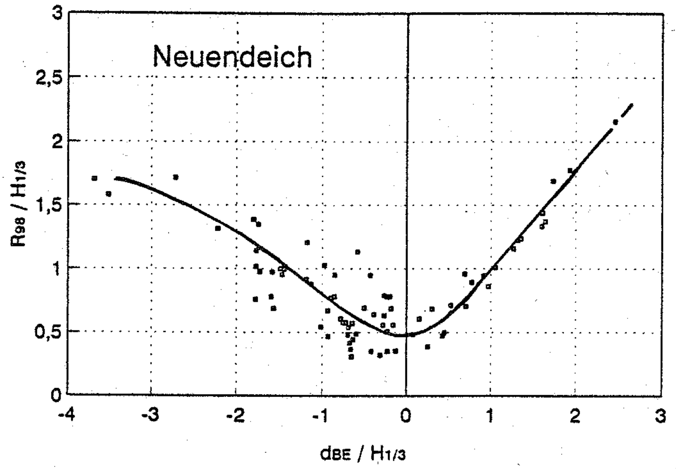

Fig. 17 R_{98} / $H_{1/3}$ versus d_{BE} / $H_{1/3}$

out clearly: one group with waterlevels below and one group with such above mean berm level. It can be stated that R_{98} / $H_{1/3}$ increase with increasing distance d_{BE} / $H_{1/3}$ as well for *SWL* below as for *SWL* above the mean berm level, which is shown distincly in Fig. 17. The data in this plot confirm the well-known effect, that run-up reduction is most effective for waterlevels around the berm level.

Conclusion

Analyzing of run-up measured in field and on complex cross-sections can be complicate, therefore the analysis has to be done very carefully and seriously. All the different influences have to be separated and quantified in detail.

Reference

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