Auszug aus: Book of Abstracts of the Conference Physics of Estuaries and Coastal Seas (PECS), Hamburg, 2002

Numerical Simulation of Wave Transmission at Submerged Breakwaters compared to Physical Modeling

STEPHAN MAI *(Franzius-Institut for Hydraulic, Waterways and Coastal Engineering, Nienburger Str. 4, D-30167 Hannover, Germany,* smai@fi.uni-hannover.de*)*

NINO OHLE *(Franzius-Institut for Hydraulic, Waterways and Coastal Engineering, Nienburger Str. 4, D-30167 Hannover, Germany,* Nino.Ohle@fi.uni-hannover.de*)*

KARL-FRIEDRICH DAEMRICH *(Franzius-Institut for Hydraulic, Waterways and Coastal Engineering, Nienburger Str. 4, D-30167 Hannover, Germany,* daekf@fi.uni-hannover.de*)*

CLAUS ZIMMERMANN *(Franzius-Institut for Hydraulic, Waterways and Coastal Engineering, Nienburger Str. 4, D-30167 Hannover, Germany,* zi@fi.uni-hannover.de*)*

1 Introduction

The design of sea dikes requires knowledge about the wave parameter right in front. Especially the wave propagation along the foreland with structures like summer dikes or submerged breakwaters, determines the wave characteristics at the toe of the dike. Shoaling, refraction, wave breaking, bottom friction and wave transmission are the predominant processes within this area.

Standard numerical models, like SWAN (see *Ris. et al.* [1994]), are good tools for the simulation of these processes. Nevertheless physical model tests are still needed to calibrate the parameter and validate the numerical models.

This paper deals with the wave transmission at summer dikes respectively submerged breakwaters using the numerical model SWAN as well as laboratory tests in the *Large Wave Channel (GWK)* of the *Coastal Research Center (FZK)* and in the *Wave Basin Marienwerder (WBM)* of the *Franzius-Institute*, both located in Hannover, Germany. The focus is put on the analysis of wave spectra influenced by wave transmission.

2 Physical and Numerical Model Test

The model tests in the wave flume GWK with dimensions of 324 m x 5 m x 7 m were carried out at prototype scale. Figure 1 (left) shows the experimental set-up with a summer dike build on a foreland (top) and the wave breaking induced by the summer dike (bottom). The height of the foreland is 1.4 m. The summer dike had a crest height of 1.6 m above the foreland, a crest width of 3 m and a slope of 1:7. The parameters of the incoming wave field were varied from 0.6 m to 1.2 m for the significant wave height and from 3.5 s to 8.0 s for the peak wave period at water levels from 3 m to 4.5 m. The wave propagation was measured at 26 locations along the flume. A detailed description of the experiments in the GWK is given by *Mai et al.* (1999a).

The model tests in the wave basin WBM with dimensions of 40 m x 24 m x 1.1 m were carried out in a side channel with a width of 1.7 m. Figure 1 (right) shows the experimental set-up with a submerged rubble mound breakwater with a height of 0.5 m, a crest width of 0.2 m and a slope of 1:2 (top) and the wave breaking at the breakwater (bottom). The parameters of the incoming wave field were varied from 2.5 cm to 17.5 cm for the significant wave height and from 1 to 1.75 s for the peak wave period at water levels of 0.45 m to 0.7 m. Further information on the experiments in the WBM is given by *Daemrich et al.* (2002).

The data, i.e. time series of water level elevation, collected in both experiments was analyzed in time domain and also in frequency domain. An example of this analysis is given in figure 2 and figure 3.

In addition to the physical model tests numerical model tests were carried out using the phase – averaged model SWAN (see *Ris,* 1997) applying the same boundary conditions (bathymetry, water level and wave spectrum). A description of the calibrated model parameter is given by *Mai* (1999b). An example of the results of the numerical analysis is given in figure 2 and 3.

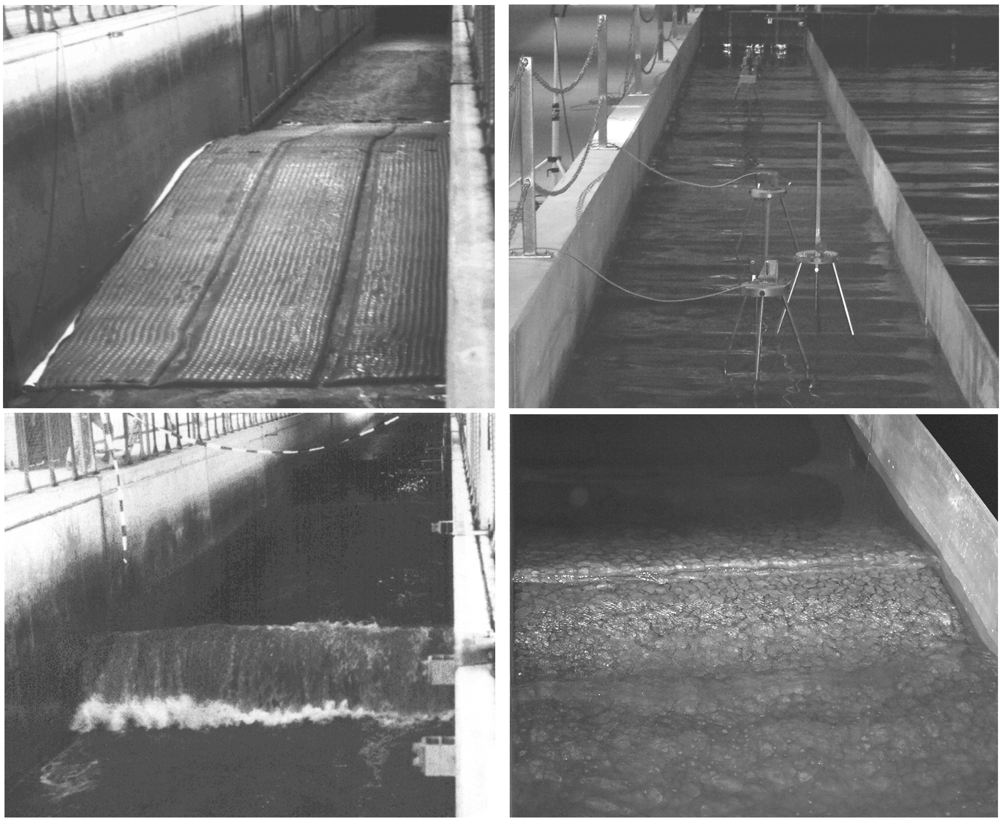

Figure 1: Experimental set-up in scale in the *Large Wave Channel* and the *Wave Basin Marienwerder* at the University of Hannover

3 Results

As shown in previous studies (see *Mai et al.* [1999b]) the characteristic wave parameters (significant wave height and peak wave period) were reproduced correctly by the numerical model. Figure 2 exemplifies this for the significant wave height measured in the GWK at a water level of 4 m and incoming waves with a significant wave height of 1 m and a peak period of 8 s. Besides that, the analysis of the wave spectra at two positions (see figure 2) in the flume also reveals a quite good agreement for the spectral properties as shown in figure 3. On the left hand side of figure 3 the non influenced wave spectrum in front of the submerged breakwater is shown. The right hand side of figure 3 gives a comparable chart for the influenced wave spectrum behind the breakwater.

Due to the transmission at the breakwater the wave spectrum is changed not only with respect to the total energy but also with respect to the spectral shape. The loss of total energy results in the decrease of significant wave height (see figure 2) while the change in the spectral shape results in lower mean wave periods. The change in the wave spectrum is caused by non-linear wave transformation over the submerged breakwater resulting in a transfer of energy from the spectral peak to the higher harmonics (see *Isobe et al.* [1996]). However the spectral peak remains nearly constant (see *van der Meer et al.* [2000]).

A measure for the energy transfer is the change in the ratio of the energy of the second harmonic (2H) and the energy of the spectral peak (1H). Figure 4 (left) shows the increase of this ratio E_{2H}/E_{1H} directly at the summer dike for a water level of 4 m and incoming waves with a significant height of 1 m and a peak period of 8 s. The energy of the spectral peak with a frequency f_p was calculated by integration of the power spectral density from 0.5 f_p to 1.5 f_p. The energy of the second harmonic was set to the integral of the spectral density from 1.5 f_p to 2.5 f_p.

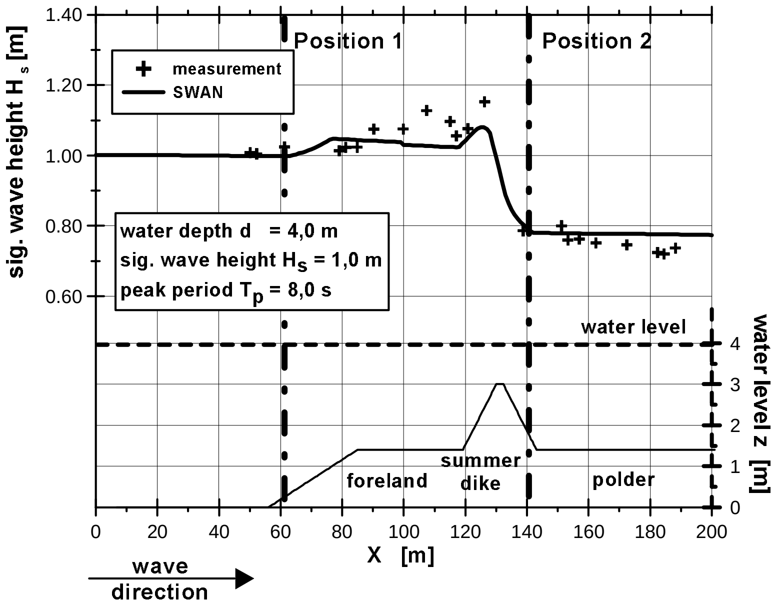

Figure 2: Change of the significant height of waves propagating over a foreland with summer dike - comparison of physical modelling (GWK) and numerical modelling (SWAN) (see *Mai et al.* [1999b]).

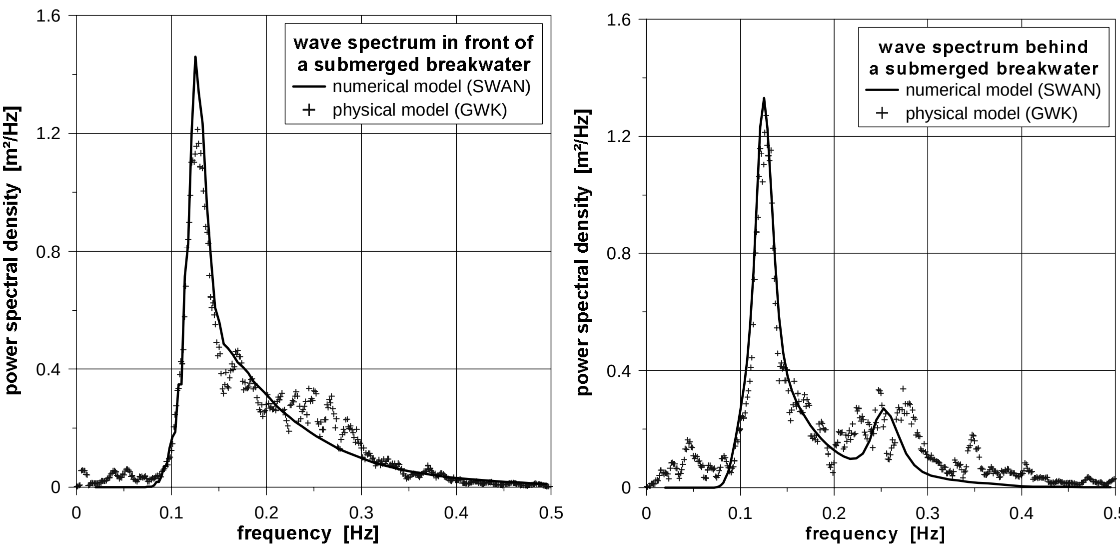

Figure 3: Spectrum of the incoming (left) and the transmitted (right) wave spectrum - comparison of physical modelling (GWK) and numerical modelling (SWAN).

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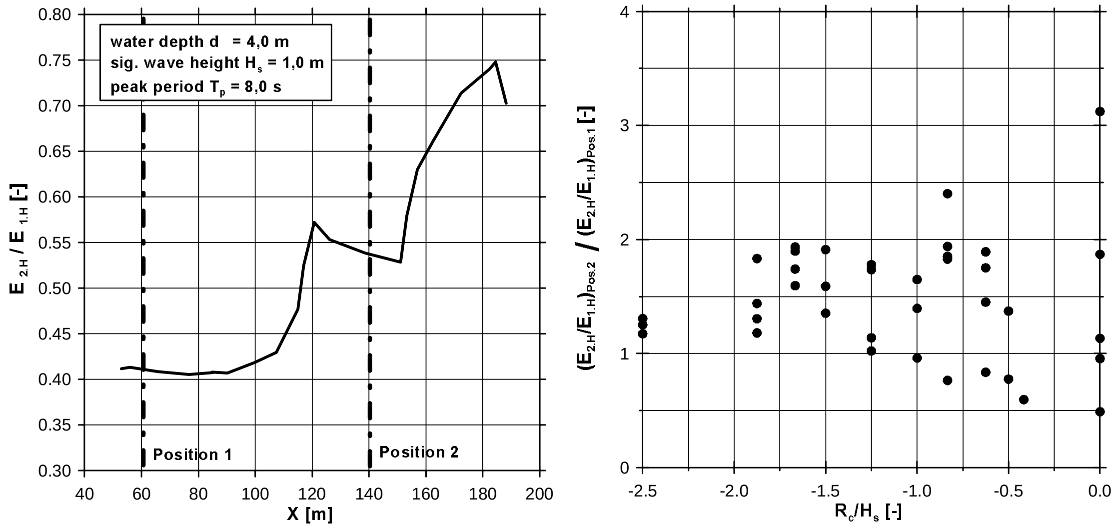

Figure 4: Ratio of the energy content of the first and second spectral peak (left) and normalised relative ratio of the energy content as a function of relative freeboard (right)

The change in the ratio E_{2H}/E_{1H} due to wave transmission is given in figure 4 (right) as a function of the relative freeboard, i.e. the ratio of negative water depth over the crest of the breakwater and the significant wave height. Except for small relative freeboards, i.e. very small transmission coefficients, the ratio E_{2H}/E_{1H} always exceeds unity. Similar results were also given by *van der Meer et al.* [2000]. The influence of wave transmission on the spectral shape diminishes for high relative freeboards.

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