# CHAPTER 115

### ENERGY TRANSMISSION OVER BREAK WATER - A DESIGN CRITERION ? -

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#### 1. INTRODUCTION

The wave transmission from seaside to lee of break waters depends on structural parameters as well as on the initial wave climate. Transmission coefficients for special boundary: conditions are known, but information about wave paramters are often not available or they cover often only special cases. Again a case study, undertaken for the break water at the proposed deep water harbour at Scharhoern/Neuwerk, Germany, documented this lack. The results of the case study using conservative wave parameters did not answer the important questions of energy transmission sufficiently, thus we investigated the characteristics of the initial and transmitted wave spectra. A special case was treated initially and subsequently more general situations were examined. These tests were carried out using a physical model of a length scale of 1:10 under conditions described by Froude's law.

## 2. MODEL TESTS

The cross section of the proposed break water is seen in Figure 1. It consists of several layers with a cover layer of concrete cubes. The break water was built into the wave channel under simulated prototype conditions, i.e. under water and having waves in the flume. This was done to simulate also the settling of the structure.

The wave flume itself is about 90 m long, 4 m wide and has a water depth of 1.6 m. The model was located about 60 m away from the wave generator. A dividing wall was set up so that the width of the structure was only 2 m. Thus it was possible to measure the wave heights in front and beside the break water as well as behind in order to get information about the energy transmission and reflection.



Figure 1: Cross section of the break water Scharhoern/Neuwerk

In order to avoid misleading test results, wave groups which were reproducible but limited in time length were used. The main reason for using this kind of model waves is to compensate the effects of energy reflection. Figures 2 to 5 show four different wave trains with the timeamplitude relation of the wave board, initial wave and transmitted wave.

The wave train is generated by the superposition of different wave packets, which gives two advantages:

- The wave train can be limited in time to avoid the influence of reflection at the wave board, but all wave components are simulated.
- The oscillation of the water surface at any point of the channel can be predetermined in period and amplitude.

Assumption of this method is that the wave packet is describable by an analytical function. It was proved and



WG 903 C

Figure 2: Wave group 903 C



WG 903 D

Figure 3: Wave group 903 D

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WG 915 A

Figure 5: Wave group 915 A

analyzed by Coulson 1949 that the Gaussian wave packet does fulfill this assumption. Additionally it has the following characteristics:

- The energy peak is well marked and travels with the group velocity adequate to the wave length of the energy peak.
- The amplitudes in front of and behind the energy peak decay exponential. The wave length in front of the energy peak increases, and behind it the wave length decreases.
- This kind of Gaussian wave packet describes the surface motion of the sea in shallow waters pretty well, specially a wave train with a well marked energy peak. The energy spectra covers a wide frequency band and the amplitude distribution does follow the Rayleigh distribution.

The superposition of several of these wave packets results in the wave train which statistical and group properties can be varied in a wide range. But this variation is not random but predetermined.

The water depth was varied from h/d = 0.9 to h/d = 1.0 and h/d = 1.1 that is 10 % below break water crest even and 10 % over. Each test series consisted of 16 different wave trains (those four already shown but each of it with four different frequencies). The runs were controlled by an 'on line' computer. The data were collected and stored by magnetic tape for later analysis.

## 3. EVALUATION OF MODEL TESTS

The conventional evaluation of the damping efficiency of break waters relates the transmitted wave height to the initial wave height. But this method gives no information about possible relationships of wave period and steepness in the luv and lee of the structure. Thus, a frequency analysis was included in the programme for the data analysis. The spectral distribution of the wave energy gives some information about the transmission which is indeed dependent on the wave frequency. The transmission coefficient is defined as  $K_{\rm L} = H_{\rm L}/{\rm H_{\rm I}}$ . Using its regular waves the coefficient was calculated by comparing the mean values of waves, i.e.:

 $\overline{K}_{\downarrow} = \overline{H}_{\downarrow}/\overline{H}$  and in an analog manner, the transmission coefficient for 33 % and 10 % highest waves. The wave generation system enabled us to shift the energy maximum to different frequencies and to test the influence of wave grouping.

#### 4. RESULT OF MODEL TESTS

The transmission coefficients evaluated for different water depth and wave heights as a function of the normalized run-up  $\Delta h = 1 - h - d/H_{i(n)}$  is given in Figure 6.



Figure 6: The results and regression of the transmission coefficient  $K_{\mathrm{T}\,(n)}$  for the normalized run-up

This graph includes the linear regression, which has an interesting behaviour, particularly at  $\Delta h = 0.88$ . At values of  $\Delta h < 0.88$ , the transmission coefficient drops for extreme values of  $H_1 = H_{1/3}$  faster than for  $H_1 = H_{1/3}$ . At higher values of  $\Delta h$  the depending is vice versa.

That means, that if h-d = 12 % of H. (which is H<sub>1/3</sub>, H<sub>1/10</sub> or H) the transmission coefficient has the same value of about 0.4 no matter of the kind of significant wave we ware looking at. In front of this point, the  $K_{\rm T}$ values are smaller for higher significant waves when the difference (h-d) is about 60 % of H. This is a quite amazing result, but it may be explained by the energy dissipation of the breaking waves which are of course the higher ones. If (1 - h-d/H) raises, that is if the break water crest is not significantly above the still water level, the assumed result can be found: the higher the waves, the higher the K<sub>T</sub>-values.

The scatter of  $K_m$ -values is considerable and does not allow an exact calculation of the influence of wave grouping, but the trend is obvious, i.e. wave trains of significant grouping characteristic create higher  $K_m$ -values. Because the wave train portions of different frequency and different energy percentage do not provide useful results by means of an extreme value analysis, a spectral analysis became necessary. The test results showed a strong amplitude and energy damping near the energy maximum of the initial wave train but the damping rate depends on the mean frequency of the wave train. An example is given in Figure 7, h/d = 1.0



Figure 7: Transmission function  $K_{T(f)}$ of one wave train generated by four different frequencies, h/d = 1.0

All tested wave trains had almost an equal character of the C<sub>1/3</sub>-quotient H<sub>1/3</sub>/ $\overline{H}$  = 1.5, but the frequency of the maximum energy was different. The transmission function K<sub>m(f)</sub>, assumed to be linear in the range of the energy peak, increases with decreasing frequency.

Taking a brief look to the spectra analysis we will see on Figure 8 to 11 the energy spectra of the initial and the transmitted waves and the transmission function.

The higher curve in the first graph is the auto spectrum which is the magnitude squared of the linear: spectrum which is the Fourier transform of the signal x(t), thus  $S_v(f) = F(x(t))$ , that is

$$G_{xx}(f) = S_{x}(f) \cdot S_{x}(f) = conjugate of function$$

The second curve in the first graph and the second graph shows the cross power spectrum which is a measure of the mutual power between two signals at each frequency and it is defined as:

$$G_{y x}(f) = S_{y}(f) \cdot S_{x}(f)^{*}$$

The transfer function in the third graph is the mathematical description of the input - output relationship of a system. For single inputs and outputs it is defined to:

$$H(f) = \frac{\overline{G_{y x}(f)}}{\overline{G_{xx}(f)}}$$

The frequency range, which includes about 95 % of the wave energy is marked. Each wave train gives a different transfer function. They are taken together to show the frequency behaviour of the transmission function and are plotted in Figure 12 to 15.

There seems to be a general tendency. In case of relative low water (h/d = 1.1) the group characteristic dominates the wave transmission in such a way, that wave trains of strong grouping create higher  $K_{T(f)}$  values, and there is also the frequency related tendency for the transmission

1892



8. 8

Energy spectra of the initial and trans-mitted waves and the transmission function, wave group 903 C Figure 8:



Energy spectra of the initial and transmitted waves and the transmission function, wave group 903  $\rm D$ Figure 9:



Figure 10: Energy spectra of the initial and transmitted waves and the transmission function, wave group 912 A



Figure 11: Energy spectra of the initial and transmitted waves and the transmission function, wave group 915 A







coefficient. In case of high water (h/d = 0.9) the frequency relation is not obvious. This may be explained by energy fronts, which are more marked in wave trains of high waves and strong grouping. These energy groups transmit a large amount of wave energy during a small time range. Additionally, the peak of energy density function is shifted to higher frequencies.

As  $H/gT^2$ , the so called normalized wave period, is an indicator of frequency dependence, the test results were evaluated to prove a frequency relationship.



It could be shown that the normalized wave period  $H/gT^2$  of the significant wave height  $H_{1/3}$  is not a sufficient parameter to indicate the frequency behaviour, see Figure 15.



Figure 15: Wave transmission depending on normalized wave period, wave group 903 C

The results for the other wave groups look more or less the same.

Summarizing, it may be stated that the damping efficiency of overtopped break waters is related to the wave height and its distribution as well as the frequency of the energy maximum. Moreover, a grouping characteristic of the initial wave train is of influence. More research on this phenomenon is of high interest.