

WAVE TRANSMISSION AT SUBMERGED BREAKWATERS

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Abstract: Measurements of wave transmission at two trapezoidal submerged structures are analysed and discussed with respect to the design formula of d'Angremond et al.. Transmission coefficients agreed well within the given range of validity, however, an appropriate crest height and crest width from the rubble mound surface has to be used. Special interest has been put on results beyond the upper limit of the formula, e.g. relatively high water levels, the variation in the mean transmitted periods, and on some results from numerical modelling.

TEST SET-UP AND HYDRAULIC BOUNDARY CONDITIONS

Data of the following two test series were used:

The first series was investigated in a side channel of a wave basin. The idea was to perform tests without the increase of water level in the transmission area which mostly will occur in channel tests but not in the field case. The structure was completely from rubble 35 to 55 mm diameter, with slope 1 over 2. The height of the structure was 0.5 m, the crest width 0.2 m. Water levels were between 0.45 and 0.7 m, significant wave heights between 2.5 and 17.5 cm with peak periods from 1 to 1.75 sec.

The second series was investigated in the *Large Wave Channel* in Hannover. The structure was formed like a summer dike sloped 1 over 7, with a height of 1.5 m above horizontal sand beach and crest width of 3 m. The structure was impermeable, constructed as sand core covered with a mattress and filled with *Colcrete Solidur*, a mixture of fine sand and cement. Water levels were from crown height to 1.5 m above the crown. Significant wave heights from 0.6 to 1.2 m with peak periods of 3.5 to 8 sec.

THE DESIGN FORMULA OF D'ANGREMOND, VAN DER MEER AND DE JONG

In the design formula of d'Angremond, van der Meer and de Jong (1996) the transmission coefficient K_t is calculated as a function of

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relative freeboard R_c/H_s ,
relative crest width B/H_s ,

and the Iribarren parameter $\xi = \tan \alpha / \sqrt{s_{0p}}$ ($s_{0p} = \frac{g}{2\pi} \cdot \frac{H_s}{T_p^2}$) (1)

$$K_t = -a \cdot \frac{R_c}{H_s} + \left(\frac{B}{H_s} \right)^{-b} \cdot (1 - \exp(-c \cdot \xi)) \cdot d \quad (2)$$

For permeable structures the formula is given as

$$K_t = -0.4 \cdot \frac{R_c}{H_s} + \left(\frac{B}{H_s} \right)^{-0.31} \cdot (1 - \exp(-0.5 \cdot \xi)) \cdot 0,64 \quad (3)$$

for impermeable structures

$$K_t = -0.4 \cdot \frac{R_c}{H_s} + \left(\frac{B}{H_s} \right)^{-0.31} \cdot (1 - \exp(-0.5 \cdot \xi)) \cdot 0,80 \quad (4)$$

The formulae are limited to values of K_t between 0.075 and 0.80.

The formulae deliver transmission coefficients K_t for the relative freeboard $R_c/H_s = 0$ dependent on the relative crest width and the breaker number. The variation with R_c/H_s is then linear with slope -0.4 within the given limits. The general trend is sketched in Fig. 1.

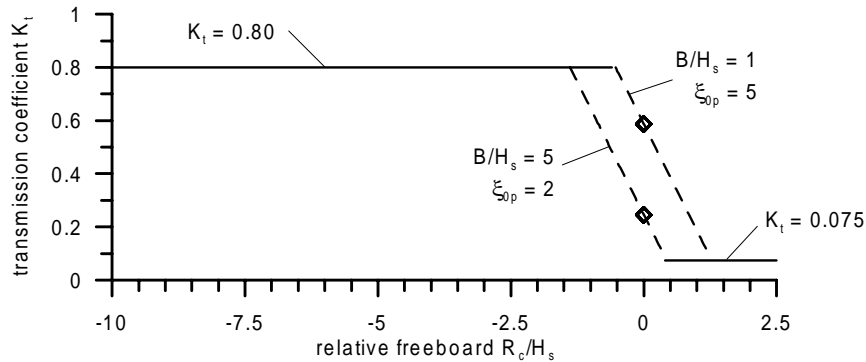


Fig. 1: Principle of the design formula of d'Angremond et al. with examples of results for given parameters B/H_s and ξ

DATA OF THE INVESTIGATIONS IN THE SIDE CHANNEL OF A WAVE BASIN (SERIES 1) IN COMPARISON TO THE DESIGN FORMULA OF D'ANGREMOND ET AL.

In Fig. 2 the data from the first series are plotted according to the above mentioned scheme (transmission coefficient as a function of the relative freeboard).

The tendency, compared to the design formula, is reasonable around $R_c/H_s = 0$, but the deviation from the straight line for $R_c/H_s > 1$ or transmission coefficients higher than about 0.7 can be clearly stated.

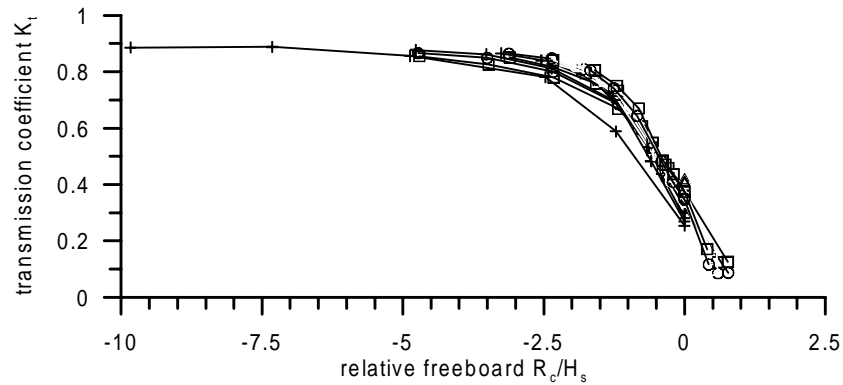


Fig. 2: Data of the investigations in the side channel of a wave basin (series 1)

Fig. 3 gives a direct comparison of measured and calculated transmission coefficients, however, without considering the range of validity, to highlight the trend near and beyond the upper limit of validity.

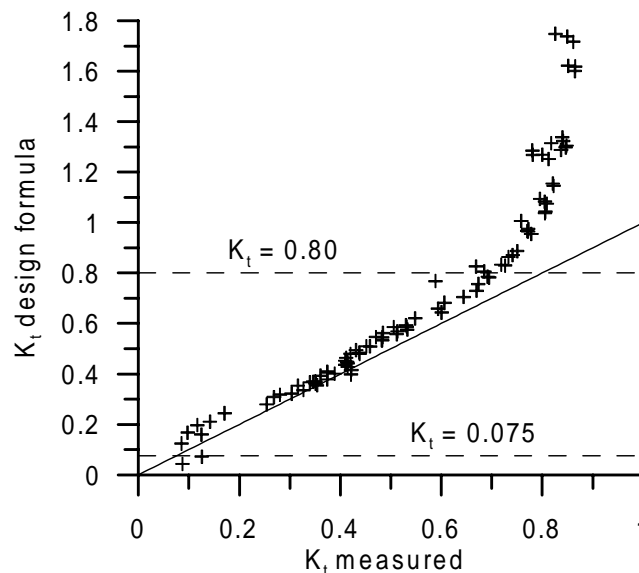


Fig. 3: Comparison of measured transmission coefficients with results from the design formula

The results can be characterised as follows:

1. the scatter is relatively low,
2. within the range of validity of the design formula there is a clear trend with nearly constant too high theoretical values,
3. outside the range of validity the deviation between measured and calculated transmission coefficients is continuously increasing.

Discussing in detail the deviation of the data within the range of validity, the definition of the crest height in rubble was found as source of possible uncertainties with a strong effect on R_c as the most important parameter. Some calculations with slightly changed crest heights were performed and it was found, that with a calculated increase of the structure height of

only 1 cm the overall agreement was much better, however, with slightly increased scatter, as to be seen in Fig. 4.

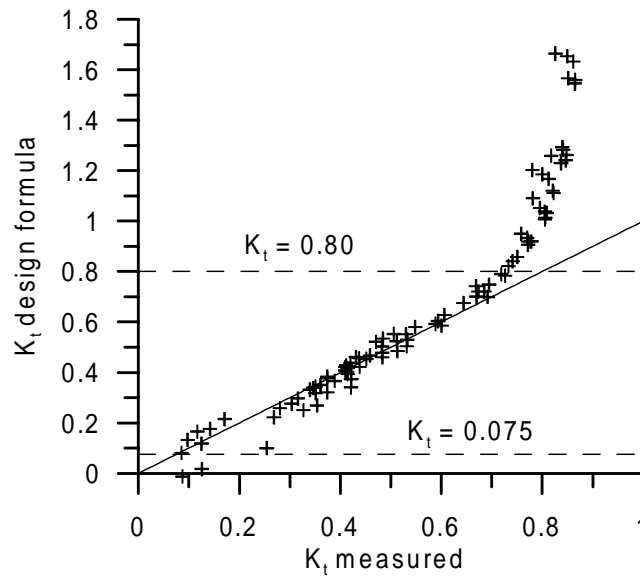


Fig. 4: Comparison of measured transmission coefficients with results from the design formula (crest height + 1 cm)

If the crest height is under discussion, the same has to hold for the crest width. And of course slightly different coefficients in the design formula could be expected for different data sets. With non-linear regression calculations the possible deviations of crest height and width as well as the coefficients of the design formula were determined. For this calculations only data from measurements with water levels from 50 to 55 cm, where the design formula should give best results (within the range of validity), were used. Results from calculations with modified coefficients and corrected crest height and crest width are shown in Fig. 5.

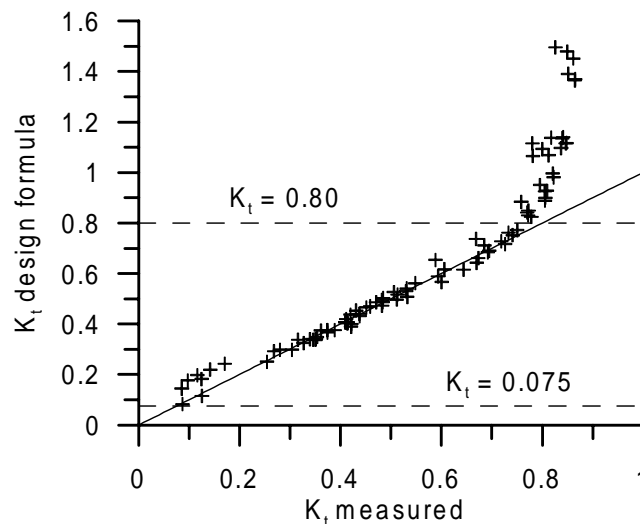


Fig. 5: Comparison of measured transmission coefficients with results from the design formula with modified coefficients and corrected crest height and width

It came out from this calculations that the crest height should be selected some 4 mm higher, the width some 8 mm wider. The differences of the coefficients are not too big:

Design formula with coefficients of d'Angremond et al.:

$$K_t = -0.4 \cdot \frac{R_c}{H_s} + \left(\frac{B}{H_s} \right)^{-0.31} \cdot (1 - \exp(-0.5 \cdot \xi)) \cdot 0,64 \quad (5)$$

Design formula with coefficients calculated for this data set:

$$K_t = -0.33 \cdot \frac{R_c}{H_s} + \left(\frac{B}{H_s} \right)^{-0.225} \cdot (1 - \exp(-0.44 \cdot \xi)) \cdot 0,632 \quad (6)$$

To examine, how good the expressions for the influence of the Iribarren number and the relative crest width fit to the data, the design formula was rearranged and the influences extracted. The result, which confirms that the used function for the influence of the relative crest width is reasonable for the range of the data, is given on the left hand side of Fig. 6. The same holds for the influence of the Iribarren number (right hand side of Fig. 6).

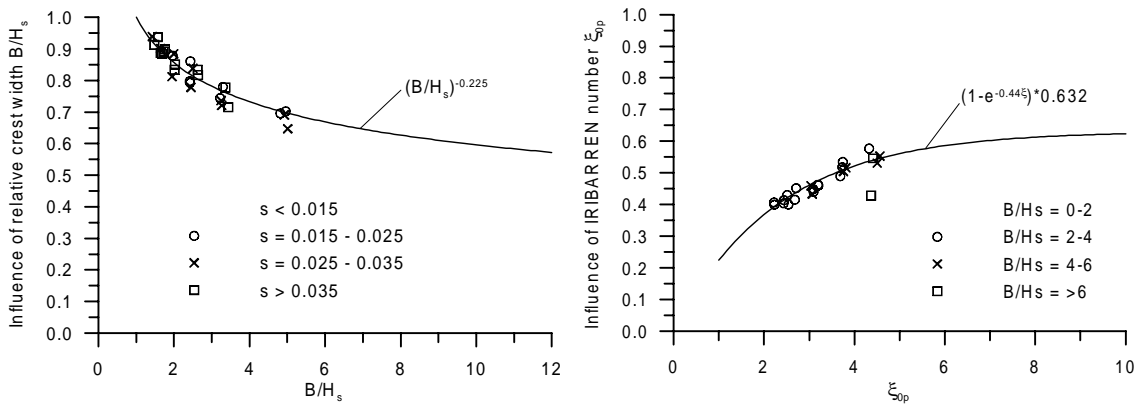


Fig. 6: Function for the influence of the relative crest width B/H_s (left hand side) and of the Iribarren number (right hand side)

DATA FROM HIGH WATER LEVELS BEYOND THE UPPER LIMIT OF VALIDITY OF THE DESIGN FORMULA

There is still the problem that the design formula does not hold for the high water levels and transmission coefficients (Fig. 3, 4 and 5).

For the range of data in this series it was not too difficult to include hyperbolic terms in the R_c/H_s term. Using hyperbolic tangent and hyperbolic arc sine in the following combination (determined by non linear regression)

$$-0.33 \cdot \left(0.99 \tanh \frac{R_c}{H_s} + 0.28 \operatorname{arc} \sinh \frac{R_c}{H_s} \right) \quad (7)$$

resulted in the scatter plot shown in Fig. 7 when using all data.

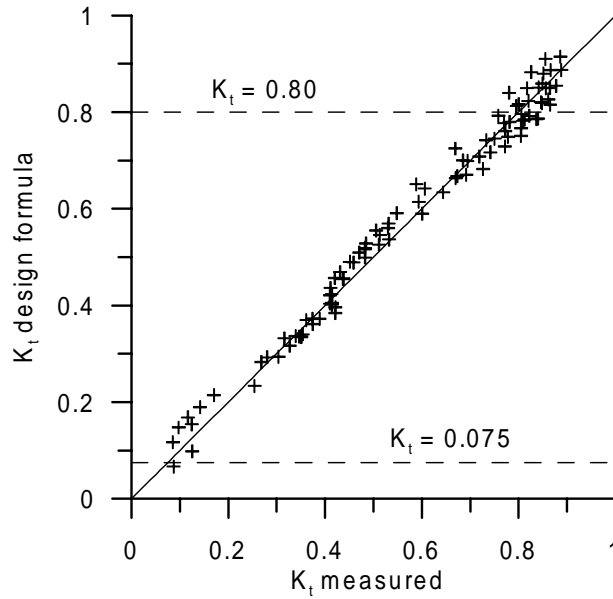


Fig. 7: Comparison of measured transmission coefficients with results from a design formula with hyperbolic term

However, we are aware of the fact that such a fit is very much dependent on the range of wave parameters investigated and should be seen as a first step only to incorporate transmission coefficients beyond $K_t = 0.8$ in a design formula. As a first theoretical approximation to the upper ran

$$K_t = \tanh\left(2\pi \cdot R_c / L_{0p}\right)^{0.262} \quad (8)$$

In Fig. 8 this function is shown together with the data as a function of R_c/L_{0p} . For our range of data the application of the Power Transmission Theory was not really successful, but we still think that a possibly modified Power Transmission Theory could be of some value in selecting physical more conclusive fits of the hyperbolic terms mentioned above. For comparison the numerical model *Odiflocs* (van Gent 1992) has been used for the high water levels 0.6 m to 0.7 m. The results are shown in Fig. 9.

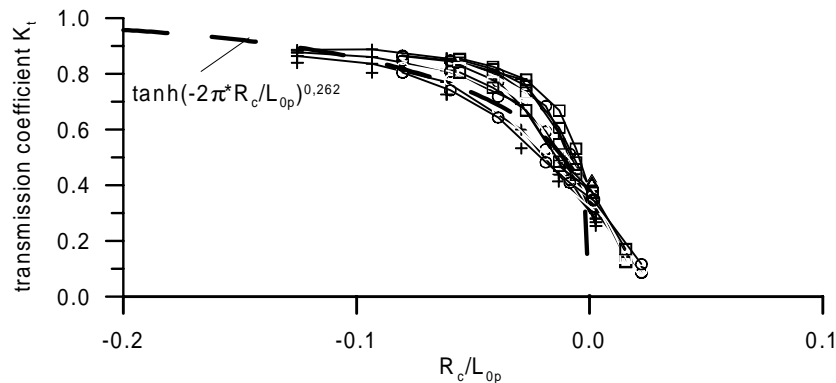


Fig. 8: Data of series 1 in comparison to Power Transmission Theory

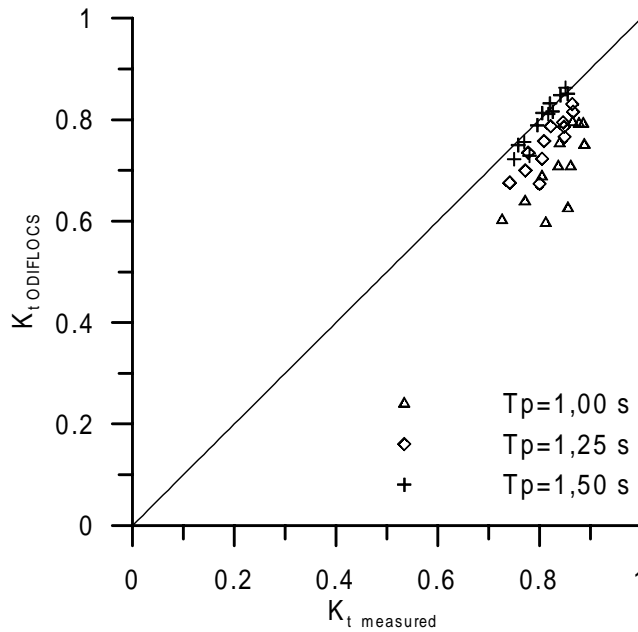


Fig. 9: Comparison of measured transmission coefficients with numerical calculations from *Odiflocs*

For our calculations there was the trend that the longer periods fitted quite well. With decreasing periods the results become too low, but have in principle a reasonable trend. The testing with *Odiflocs* and search for the reasons for these tendencies will go on.

VARIATION OF MEAN TRANSMITTED PERIODS

As a last point of the analysis of this data set, the change in the transmitted wave periods is treated. Plotting the relation of the mean periods of transmitted and incident waves as a function of the relative freeboard it can be seen that the reduction is strongest when the still water level is close to the crest, with a rapid increase with increasing crest height (Fig. 10).

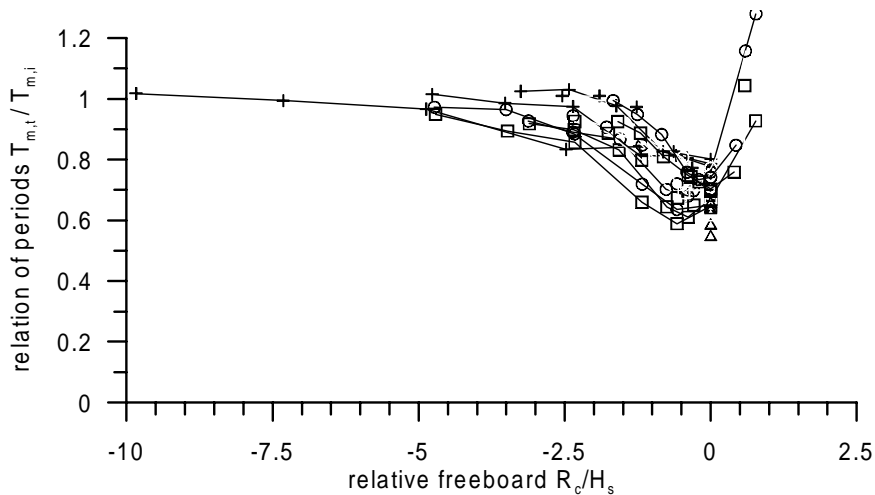


Fig. 10: Variation of periods T_m with R_c/H_s

Plotting the same data as a function of the freeboard related to the peak wave length gives an idea of a function for this data set for negative freeboards (Fig. 11). A rough estimate for

the range $R_c/L_{0p} < 0$ can be taken from the formula in Fig. 12, but this is not seen as a general design recommendation without further tests and more detailed analysis.

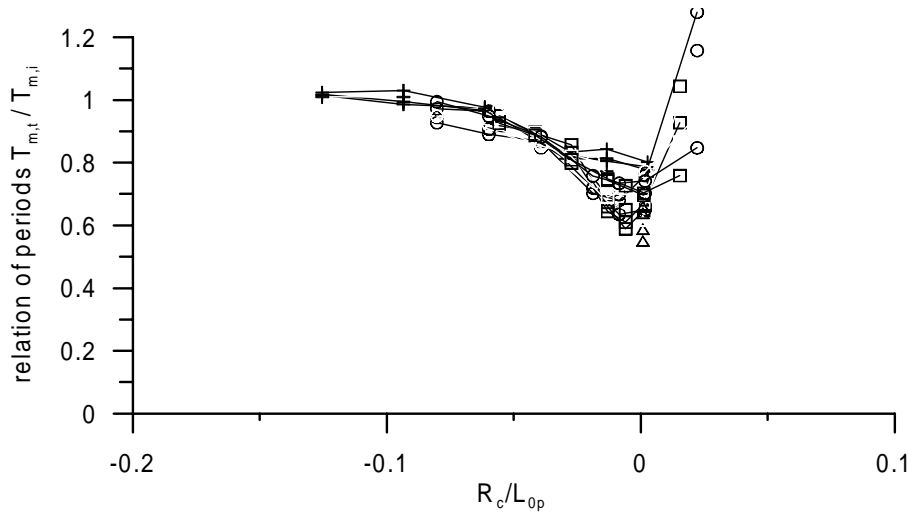


Fig. 11: Variation of periods T_m with R_c/L_{0p}

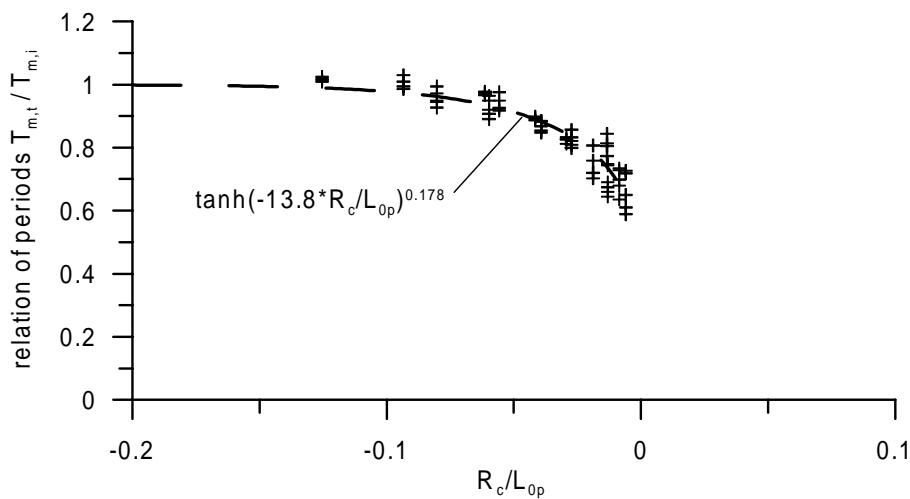


Fig. 12: Fitting function for $R_c/L_{0p} < 0$

It has to be mentioned that this relationship is based on an average from 3 wave gauges in different distances (3 m, 6 m, and 9 m) from the structure, and that there is also a trend, that the reduction of periods is stronger closer to the structure.

DATA FROM MEASUREMENTS IN THE LARGE WAVE CHANNEL (TEST SERIES 2)

In these tests the submerged structure was situated on a foreland. A sketch of the test set-up and an example of measured wave data along the channel are given in Fig. 13.

For the calculation of transmission coefficients incident waves were taken from a wave gauge 52 m in front of the structure. Transmitted waves were from a wave gauge 78 m behind the structure. Incoming significant wave heights were corrected for the shoaling influence from the deeper water to the water depth at the structure.

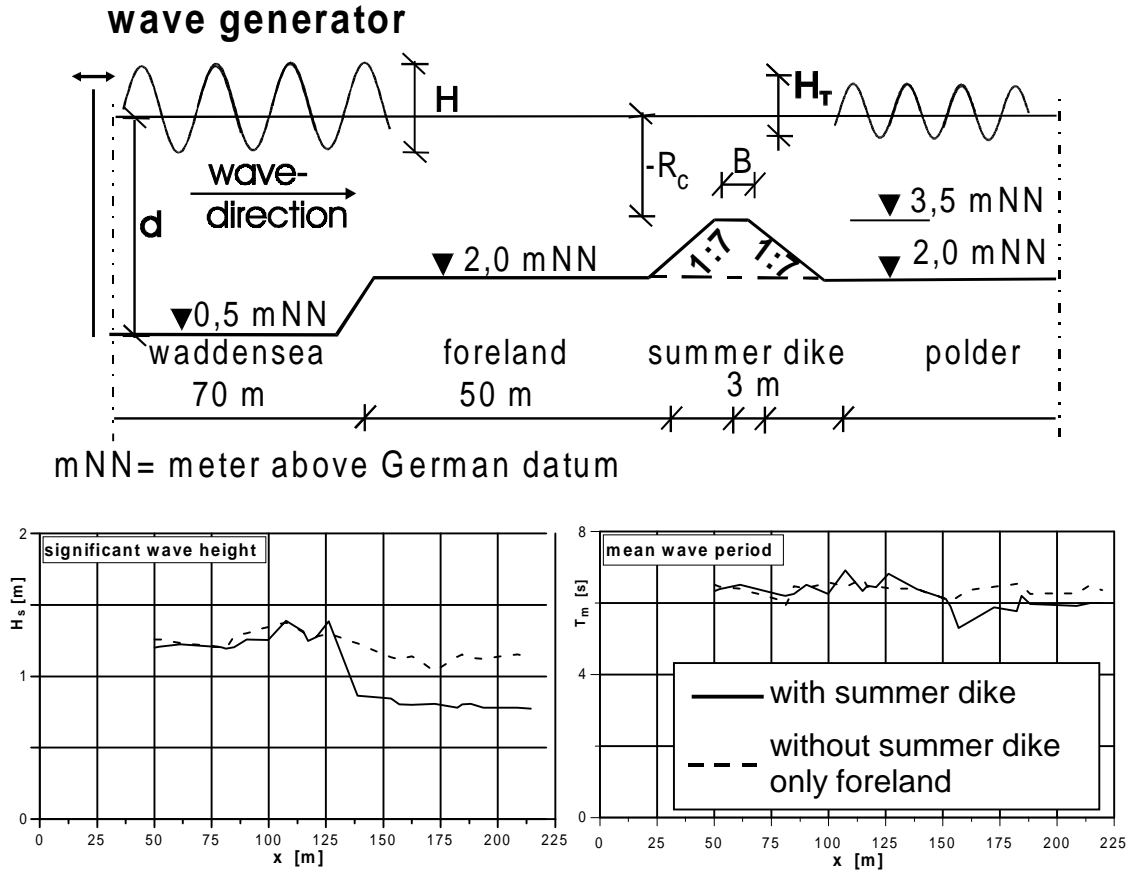


Fig. 13: Experimental set-up and example of measurements in the Large Wave Channel

Results from the design formula of d'Angremond et al. in comparison to calculated transmission coefficients are shown in Fig. 14.

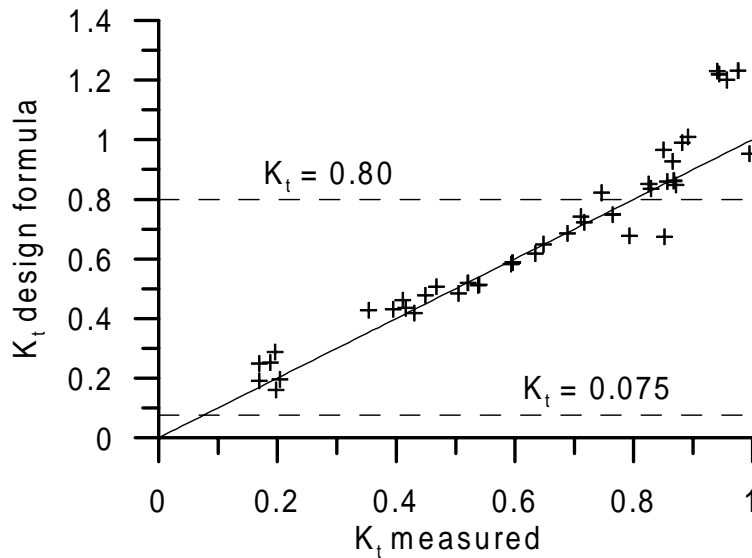


Fig. 14: Comparison of measured and calculated transmission coefficients at the Summer dike measured in the Large Wave Channel

There is relative good agreement in the usual range of validity of the design formula and also the typical trend in the high transmission coefficients. As this is from tests with a very flat sloped structure, this can be seen as one prove for the quality of the term with the Iribarren parameter.

For the investigations various numerical models have been used for comparison. These models with breaker terms according to Battjes / Janssen came up with really good results. These results can be found in the literature (Mai et al., 1998, 1999a, 1999b).

CONCLUDING REMARKS

From the two test series it can be stated that the design formula of d'Angremond et al. is a good basis for analysis and control of measurements on wave transmission at submerged structures within the given range of validity. However, an appropriate crest height and width has to be used. To enable the determination of appropriate values for the effective crest height (and therewith R_c) it is strongly recommended to perform enough measurements around $R_c = 0$ with small steps of variations in the water level.

Some methods are discussed in the paper to deal with the range of high water levels beyond the up to now range of validity of the design formula, however, there is still a need for better theoretical or empirical description.

Concerning the test set-up of the experiments in the side channel of the wave basin, it is believed that investigations without model dependent increase of water level in the transmission area may be more realistic than channel tests, where the increase often is influenced by the channel dimensions.

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