CHAPTER 187

WAVE TRANSMISSION AT LOW-CRESTED STRUCTURES

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Abstract

Existing data on wave transmission have been critically examined to obtain a homogenous data base. These data have been re-analyzed, and an expression has been derived relating the transmission coefficient to structural parameters and wave parameters.

Introduction

One of the main aims of breakwaters is improving the tranquility in designated areas to facilitate cargo handling or to protect natural shorelines. Economic considerations often indicate that the structural integrity of the breakwater shall be such that the structure is able to survive severe weather conditions without major damage. The functional requirements, however, do not always require that absolute tranquility is maintained under such extreme conditions. Since the volume of material involved in the structure (and thereby it's cost) is proportional to the square of it's height, it is worthwhile to consider the minimum crest level as carefully as the structural strength of the armor layer. Therefore it is necessary to give a good prediction of wave transmission of low-crested structures. This is the main reason for the continued attention for wave transmission at Delft University and Delft Hydraulics.

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Run-up, Overtopping and Transmission

Before analyzing the phenomenon of wave transmission it may be wise to define the three related subjects, run-up, overtopping and transmission, since there seems to be a lot of misunderstanding about the meaning of these words.

Wave run-up is the phenomenon that when a wave approaches a sloping face, a wave tongue runs up the slope. The tongue reaches a maximum elevation above still water level, which is the run-up level. This is thus a vertical distance above the momentary sea level. When the crest of the slope is lower than the run-up level, the wave tongue will pass over the crest.

The average quantity of water passing over the crest is called wave transmission. It is expressed in m^3 per running meter crest per second, and it can therefore be compared with the specific discharge per unit width (q) in open channel flow. In case the area behind the sloping structure is dry land, the quantity of overtopping mat be used to design the capacity of the drainage system.

In case the area behind the structure is a plane of water, the masses of water spilling over the crest from time to time will generate waves in the basin. These waves will generally be smaller than the waves at the outside of the structure. The ratio between the wave height behind the structure (H_t) and the wave height in front of the structure (H_i) is the transmission coefficient K_t.

The governing parameters related to transmission are: structural geometry, permeability, crest freeboard, crest width, surface roughness, water depth and the hydraulic parameters wave height and wave period. A definition sketch is given in Figure 1.

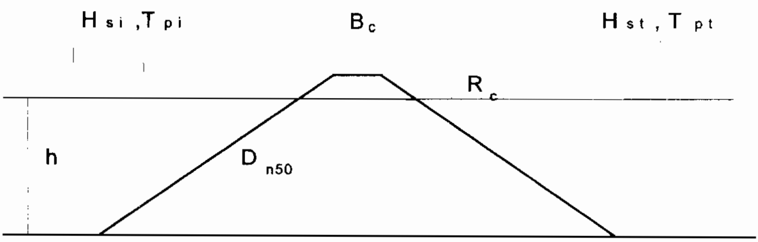

Figure 1. Definition Sketch

Existing Transmission Formulae

Two formulae describing wave transmission at low-crested structures have already been published by the authors in previous papers. In the first formula, derived by Van der Meer (1990, a and b), the transmission coefficient was related to the crest freeboard R_c, divided by the incident significant wave height H_{si}.

$$K_t = 0.46 - 0.3 \frac{R_c}{H_{si}}$$

K_t is limited between 0.8 and 0.1.

Figure 2 shows an indication of the scatter obtained in this way. In particular, it is remarkable that the transmission coefficient does not reach the value 1 for relatively low structures, and that it remains quite above 0 for structures with a considerable relative freeboard.

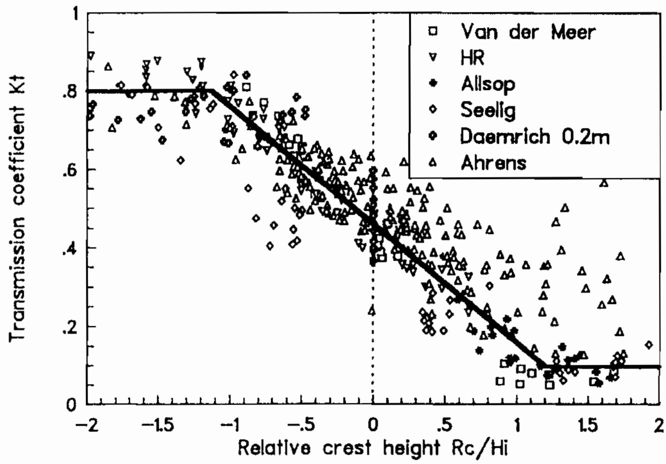

Figure 2. Wave transmission versus relative crest height R_c/H_i

The second formula was derived by Daemen in his Master's thesis (Daemen 1991) and published by Van der Meer et al (1991). Daemen attributed part of the scatter to permeability of the armor layer, specifically for those structures that had a crest slightly above MSL. It was concluded that the scatter could be reduced by introducing a different dimensionless expression for the freeboard i.e. R_c/D_{n50}, in which D_{n50} is the nominal stone diameter of the armor layer.

Eventually, an expression was developed of the shape:

$$K_t - a \frac{R_c}{D_{n50}} + b$$

in which

$$a = 0.031 \frac{H_{si}}{D_{n50}} - 0.24$$

and

$$b = -5.42\, s_{op} + 0{,}0323\, \frac{H_{si}}{D_{n50}} - 0.0017\, \left(\frac{B}{D_{n50}} \right)^{1.84} + 0.51$$

Boundaries were set at K_t max. = 0.75 and K_t min = 0.075, while the validity of the formulae was limited for $1 < H_s/D_{n50} < 6$ and $0.01 < s_{op} < 0.05$.

Daemen further noted that the data by Ahrens, based on the behavior of reef-type breakwaters were so much different that other formulae were required to describe transmission over such structures. A comprehensive analysis of the background of the tests by Ahrens justifies the separation of reef type structures from regular breakwaters. At the same time, Daemen suggested a modified expression valid for reef type breakwaters. The results obtained by Daemen for regular breakwaters are presented in Figure 3.

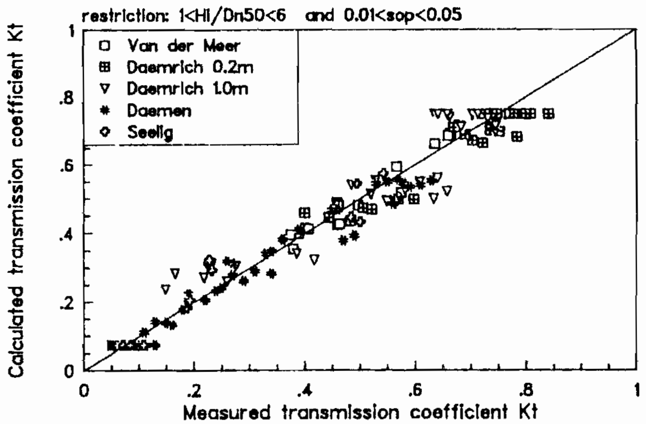

Figure 3. Calculated and measured transmission for conventional breakwaters (Daemen)

Although the result of Daemen looks quite promising considering the scatter, there is one obvious disadvantage: the formula is not valid for structures that have no characteristic diameter, or that have a low or zero permeability in the region around MSL. Examples of such structures are asphalt grouted breakwaters and groynes, caisson type breakwaters, and breakwaters with large solid superstructures. It was therefore decided to continue the work by Daemen and to try and find an expression for the transmission that is primarily based on the outer dimensions of the structure, with correction factors for roughness and permeability. Before starting the new analysis, it was decided to examine existing data sets critically to obtain a homogenous data base.

Existing Data Sets

Van der Meer and Daemen both used various sets of data that were gathered and published by various researchers. It was mentioned already that the test results by Ahrens were omitted by Daemen because of the completely different character of the reef type breakwater. The test series by Seelig (1980), Allsop (1983), Daemrich and Kahle (1985), Powell and Allsop (1985), Van der Meer (1988) and Daemen (1991) that had been used by both, van der Meer and Damen, were studied again for the present work, and new data from site specific model investigations by Delft Hydraulics (mainly carried out in 1993 and 1994) could be added. In these series also impermeable submerged breakwaters were included.

All data, however, have there specific character. Seelig used waves with an extremely large wave steepness of 0.10, which could not be reproduced in other laboratories due to wave breaking. Allsop restricted his studies to structures with a relatively high crest level. Daemrich and Kale used tetrapods as armor units, instead of quarry stone used by many other authors. Probably, the permeability is thus slightly larger, which results in a larger transmission. Powell and Allsop carried out their tests at extremely shallow water depths. Some of the recent investigations by Delft Hydraulics were also on armor layers with Tetrapods and Accropods, with consequences for the permeability. All authors are a little ambiguous about the definition of the crest level. This may explain systematic deviations between various data sets.

In spite of the inconsistency of the various data sets, all data, except those of Ahrens for reef type breakwaters were used. From the data sets, some tests were discarded, however, i.e. those sets with extremely steep or breaking waves ($s_{op} > 0.6$ and $H_{si}/h > 0.54$). Tests with $R_c/H_{si} > 2.5$ and with $R_c/H_{si} < -2.5$ were considered less relevant and therefore not taken into account either.

The complete set of data used during the present study is compiled in Figure 4, which gives the raw relation between R_c/H_{si} and K_t.

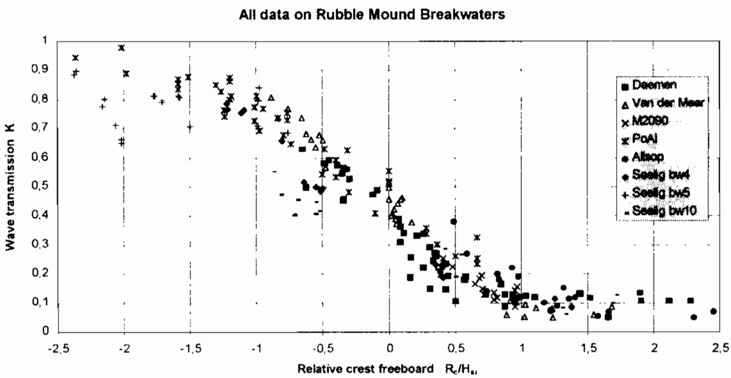

Figure 4. Homogenous Data on Transmission

Analysis

The analysis of data was taken up in a similar way as was done originally by van der Meer. This resulted in a relation of the form:

$$K_t = a \frac{R_c}{H_{si}} + b$$

in which

a determines the slope of the curve, and appears to be independent of any of the parameters considered, and

b determines the value of the transmission coefficient K_t when the relative crest height equals zero. This coefficient appears to be a function of crest width and breaker parameter.

Because of the trend in all data, the coefficient *a* could be set at -0.4. The coefficient b was expected to depend on crest width and breaker parameter ξ. It was attempted to find a dimensionless expression for the crest width by combining it with wave height and wave length respectively. Eventually, the best result was obtained by the expression

$$0.54 \left(\frac{B}{H_{si}}\right)^{-0.31}$$

The coefficient 0.54 in this expression could, however, not be considered a real constant yet. Because of the similarity between wave transmission and wave run-up, it was expected that the Iribarren parameter, $\xi = \tan\alpha / \sqrt{H/L}$ would play a role. It was found that the expression $(1 - e^{-0.5\xi}) * C$, (with C = 0.64) yielded optimum results.

The remaining scatter is due to the influence of the stone size D_{n50}. This influence becomes noticeable for values of $H_{si}/D_{n50} < 2$. The influence, however, is two-fold and works in different ways, depending on the crest level: small values of H/D indicate the presence of relatively large armor stones, which increase the permeability and thus increase the transmission by water flowing through the breakwater, but which increase the surface roughness at the same time and thus reduce transmission by water flowing over the breakwater. There were insufficient data to establish a final relation. Therefore, it is suggested to maintain the coefficient 0.64 for the time being. The deviation by this choice mainly influences the results for extreme values of K_t and thus of R_c/H_{si} (see figure 5).

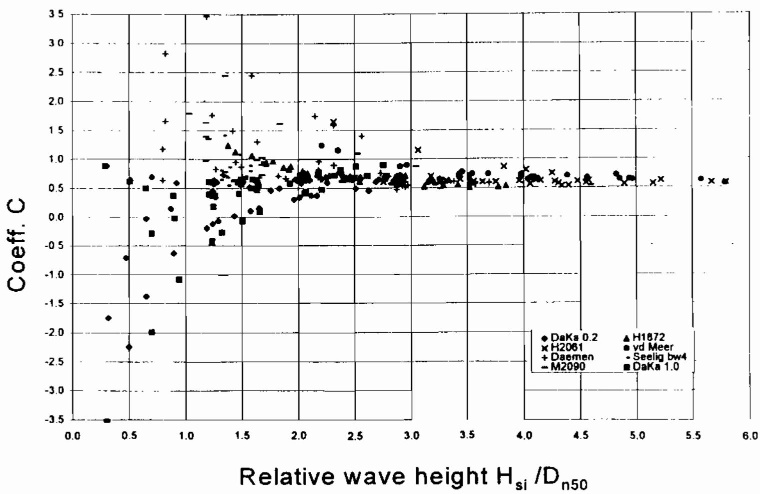

Figure 5. Remaining scatter due to armor size

Conclusions

In conclusion, the expression proposed for permeable breakwaters is:

$$K_t = -0.4\frac{R_c}{H_{si}} + \left(\frac{B}{H_{si}}\right)^{-0.31} * (1 - e^{0.5\xi}) * 0.64$$

with limits for the value of K_t:
$0.075 < K_t < 0.80$.

In a similar way, an expression for impermeable structures was derived:

$$K_t = -0.4\frac{R_c}{H_{si}} + \left(\frac{B}{H_{si}}\right)^{0.31} * (1 - e^{-0.5\xi}) * 0.80$$

with the same limits.

Measured and calculated results for compared for permeable and impermeable structures respectively. The results are presented in Figures 6 and 7. For permeable structures, the standard deviation σ was 0.060, resulting in a 90% confidence band of $K_t \pm 0.10$. For impermeable structures, the standard deviation was found to be 0.053, with 90% confidence level for $K_t \pm 0.087$.

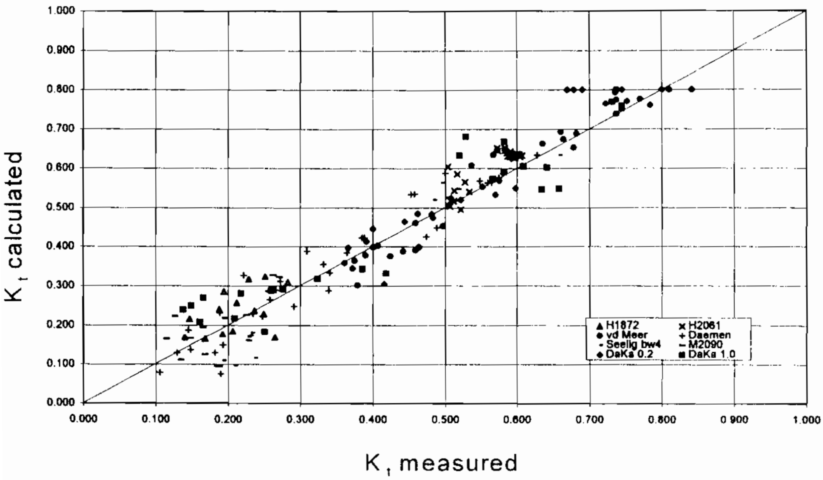

Figure 6. Measured and calculated transmission
permeable structures

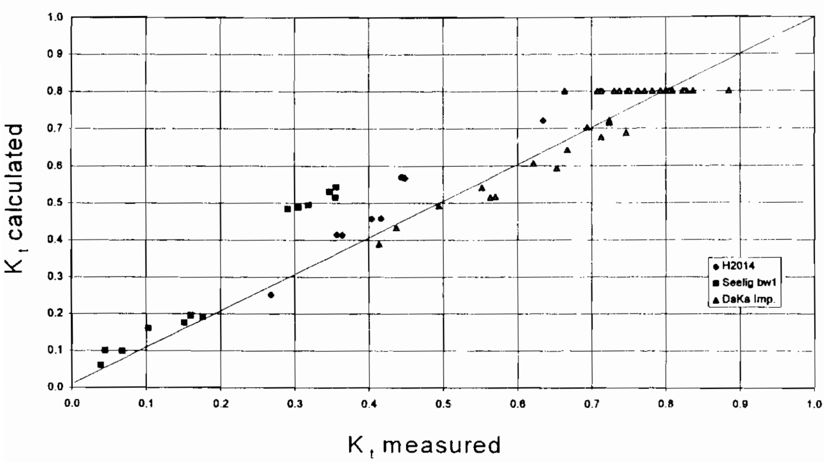

Figure 7. Measured and calculated transmission
impermeable structures

Recommendations

The main problem in finding a reliable expression for wave transmission is the fact that available data do not form a homogenous data base. Model tests have been carried out by several different laboratories, where it is not certain that always the same definitions have been used. This mainly applies to the crest level. Further, many model tests were carried out with emphasis on other aspects of structural behavior. It is therefore recommended that special tests be carried out with the main aim to establish a homogenous data base for transmission of permeable and non-permeable breakwaters.

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