

# Wave Transmission over Low Crested Geotextile Breakwater Structures

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## Abstract

This paper summarises an investigation undertaken by the Water Research Laboratory and International Coastal Management into wave transmission for low crested geotextile breakwater structures. Structures such as these are being used as an alternative to rock structures or as interim coastal protection structures. These low crested (submerged) detached breakwater structures are typically implemented to provide a milder nearshore wave climate, and to maintain or increase the beach width in the lee of the breakwater. The structures tested were built using a single layer of geotextile mega containers, and ranged in cross section from a single mega container of approximately 4 m width, up to three mega containers measuring approximately 12 m in total cross section width.

The two-dimensional physical modelling investigated the various breakwater structures under a range of monochromatic wave conditions, with wave periods varying from 5 to 10 seconds and wave heights ranging from small unbroken waves, up to depth limited breaking waves of approximately 2.5 m height. The test results determined that under shorter period wave conditions, a significant reduction in transmitted wave height was achieved even with a breakwater of only 4 m cross section width. Further reductions in transmitted wave conditions were recorded by increasing the breakwater width to 8 m, however, little additional reduction was achieved by further increasing the width to 12 m. During longer period wave conditions and slightly deeper submergence, the narrow 4 m breakwater width provided very little wave reduction, with increases in breakwater width to 8 m and 12 m providing more modest reductions in transmitted wave height. Following the physical modelling study, a range of empirical equations for wave transmission have been applied with the same hydraulic conditions as the physical model tests, and the predicted wave transmission compared to the physical model results.

## 1 Introduction

This paper summarises an investigation undertaken by the Water Research Laboratory (WRL) of the University of New South Wales and International Coastal Management to investigate wave transmission for low crested geotextile breakwater structures. Structures such as these are being used as an alternative to rock structures or as interim coastal protection solutions. These low crested detached breakwater structures are typically implemented to provide a milder nearshore wave climate, and to maintain or increase the beach width in the lee of the breakwater. The structures tested were built using a single layer of geotextile mega containers, and ranged in cross section from a single mega container of approximately 4 m width, up to three mega containers measuring approximately 12 m in total cross section width.

While the laboratory investigation was undertaken for a site specific study, useful data has been extracted from the results, which can be applied for other similar projects. A range of other empirical assessment techniques for considering wave transmission over low crested submerged structures have been used to make predictions and comparisons with the data obtained from the WRL physical modelling investigation.

## 2 Investigation Aims

The aim of this paper is to provide an indication of the effects of a range of parameters on wave transmission past low crested submerged breakwater structures. The parameters investigated include:

- Structure crest width
- Structure submergence
- Wave height
- Wave period

This conference paper also provides an assessment of the ability of several empirical equations to predict wave transmission for submerged breakwater structures with the same conditions as those tested in the physical model.

## 3 Physical Model Setup

### 3.1 Test Facility and Instrumentation

The two-dimensional physical model testing was undertaken in the 0.6 m wave flume at WRL. This flume measures approximately 40 m in length, 0.6 m in width, and 0.9 m in depth. For this particular study the site specific bathymetry was reproduced in the model using a false timber panel floor. Waves were generated in the 0.6 m flume using a piston type wave paddle, powered by an electrical servo motor. Both regular and irregular wave sequences were tested during the

study, with wave generation and wave data collection undertaken with the GEDAP/NDAC software suite.

Two capacitance wave probes were used to measure wave conditions in the flume during tests. One wave probe was located at the seaward edge of the bathymetry measuring offshore wave heights ( $H_0$ ), while the second wave probe was located on the leeward side of the model breakwater structures measuring the transmitted wave heights ( $H_t$ ). Figure 1 shows the basic flume setup for the study.

### 3.2 Model Scaling

Model scaling was based on geometric similarity between model and prototype. In designing the model and establishing the model scale, a range of parameters were taken into consideration such as:

- Wave conditions
- Capability of wave paddle
- Available depth
- Minimising scale effects

In considering these points, an undistorted length scale of 1:25 was selected for the model. The scaling relationship between length and time was determined by Froudian similitude, with the following scale ratios (prototype divided by model) being adopted:

- Length ratio  $L_R = 25$
- Velocity ratio  $V_R = L_R^{0.5} = 5$
- Time ratio  $T_R = L_R^{0.5} = 5$

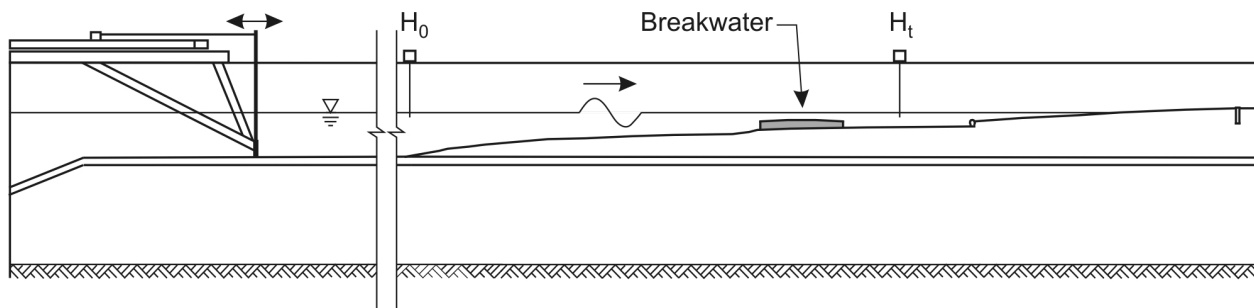


Figure 1. Wave flume setup for physical model investigation

### 3.3 Bathymetric Profile

The undistorted two dimensional profile for the site specific conditions reproduced in the flume is shown in Figure 1.

This profile represented a seawall fronted by a short beach, with the nearshore zone consisting of a shallow reef flat then a steep reef drop off (approximately 1V:13H). The bathymetric profile extended from the seaward limit at -6.1 m LAT (Lowest Astronomical Tide), to the landward limit at the crest of the beach seawall with an elevation of 3.54 m LAT. Breakwater structures were located at the seaward edge of the reef flat, such that the approaching bathymetry was the steep 1V:13H reef drop off slope. Approaching incident waves underwent significant shoaling and breaking across the 1V:13H slope, before passing over the breakwater.

## 4 Test Program

### 4.1 Overview

A summary of the different conditions and breakwater structures tested is shown in Table 1. A definition of terms is shown in Figure 2.

Table 1. Summary of Test Conditions

B (m)	$R_c$ (m)	$H_0$ (m)	T (s)
4, 8, 12	0, 0.44, 0.76	0.3 – 2.5	5.4, 7.7, 9.6

Where:

B = Breakwater crest width

$R_c$  = Breakwater submergence depth

$H_0$  = Offshore incident wave height at -6.1 m LAT

T = Incident wave period

See Figure 2 for explanation of terms.

### 4.2 Tested Breakwater Designs

The breakwater designs investigated in the wave transmission testing were low crested structures, with a crest level of approximately 1.8 m LAT. The crest of the breakwaters was at and just below the test water levels, such that for most tests, the breakwaters were submerged structures. The three different breakwater structures tested consisted of one, two, and three geotextile mega containers, placed side by side as shown in Figure 2. This provided breakwater structures with crest widths of 4 m, 8 m, and 12 m. As well as the wave transmission tests completed with the different breakwater structures in place, tests were also completed with the bathymetry only (no breakwater in place).

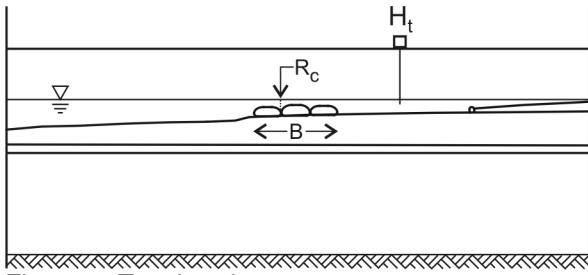


Figure 2. Test breakwater setup

### 4.3 Test Conditions

Three different water levels were tested in the modelling program, which corresponded to “typical”, 1 Year ARI and 10 Year ARI site specific conditions. The three test water levels were 1.84 m LAT, 2.28 m LAT, and 2.6 m LAT. With a breakwater crest level of approximately 1.8 m LAT, these test water levels corresponded to structure submergence depths ( $R_c$ ) of approximately 0 m, 0.44 m, and 0.76 m.

To investigate the wave transmission characteristics for different wave heights, testing was predominantly undertaken using monochromatic waves. A small number of irregular wave tests were undertaken to verify the monochromatic results.

Three different wave periods of 5.4 s, 7.7 s, and 9.6 s, were tested in the modelling program. These wave periods corresponded to the site specific “typical”, 1 Year ARI and 10 Year ARI conditions. That is, tests completed with the “typical” water level, were also tested with the “typical” wave period, and likewise for the 1 Year ARI and 10 Year ARI test conditions.

Wave heights were varied incrementally from very small unbroken waves (approximately 0.3 m height), up until depth limited breaking waves occurred well seaward of the breakwater structure. Wave heights were generally increased in increments of approximately 0.25 m.

## 5 Test Results

### 5.1 Effect of Breakwater Crest Width on Wave Transmission

To investigate the effect of breakwater width ( $B$ ) on wave transmission, monochromatic wave tests were completed for breakwaters of 4 m, 8 m, and 12 m crest width. Each breakwater was tested for three wave period/water level combinations.

Both offshore ( $H_0$ ) and transmitted ( $H_t$ ) wave heights were measured during each test. Waves were affected by the processes of shoaling and breaking over the bathymetry, as well as breaking on the breakwater, as they passed from the offshore ( $H_0$ ) to the transmitted ( $H_t$ ) location. As such, the wave height coefficient,  $K$  (determined

as  $H_t/H_0$ ), presented in this analysis considers the combination of these processes.

To identify the effects of wave shoaling and breaking on wave transmission, tests were initially completed with no breakwater in place. Results for the three different test water level and wave period conditions are shown in Figures 3 – 5.

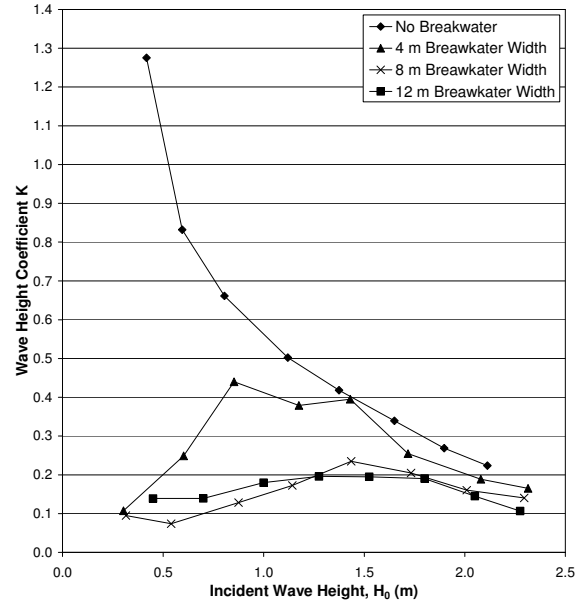


Figure 3. Effect of breakwater width ( $B$ ) on wave transmission for submergence depth,  $R_c = 0$  m and wave period,  $T = 5.4$  s

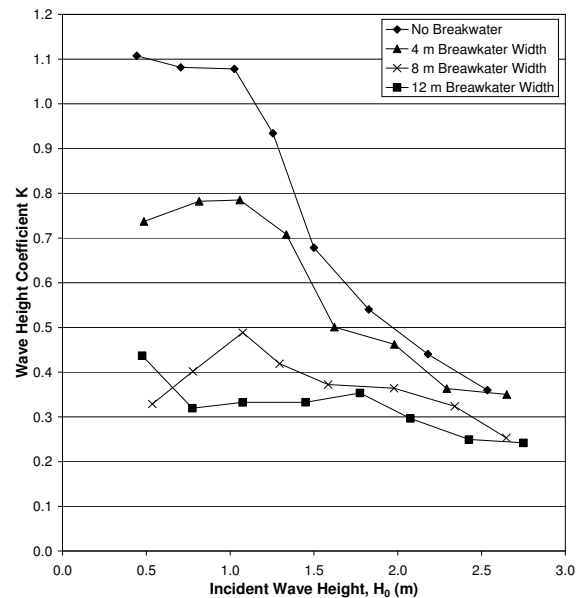


Figure 4. Effect of breakwater width ( $B$ ) on wave transmission for submergence depth,  $R_c = 0.44$  m and wave period,  $T = 7.7$  s

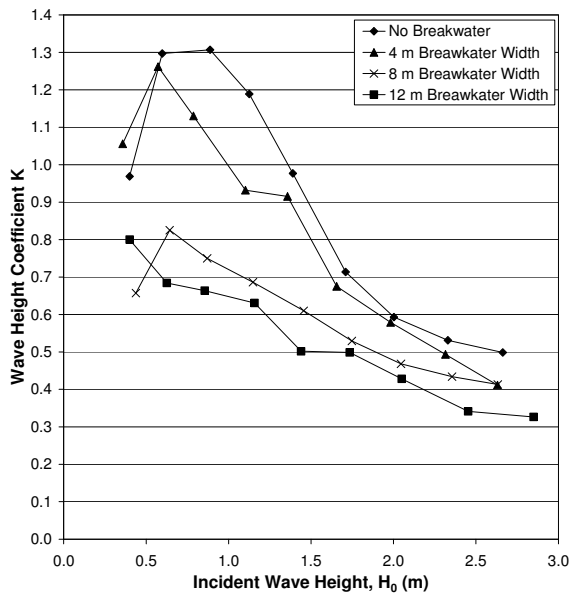


Figure 5. Effect of breakwater width ( $B$ ) on wave transmission for submergence depth,  $R_c = 0.76$  m and wave period,  $T = 9.6$  s

The results shown in Figure 3 indicate that with short period wave conditions and the breakwater crest at the water level, a reasonable reduction in wave transmission is achieved by having a narrow breakwater with crest width of only 4 m. The reduction in transmission coefficient achieved by increasing the breakwater width from 4 m to 8 m varies from very little up to a maximum of approximately 0.2. However, there is very little reduction in wave transmission achieved by further increasing the crest width to 12 m.

For longer wave period and deeper submergence levels (Figures 4 and 5), the most significant reduction in wave transmission is achieved by increasing the crest width from 4 m to 8 m. However, modest reduction of transmitted wave height is still achieved by further increasing the breakwater crest width to 12 m. As expected these results demonstrate that for effective reduction of longer period waves (10 second period), a wider breakwater is required. However, for shorter period conditions (5 second period), there is very little additional wave reduction achieved by increasing the width of the breakwater crest beyond approximately 5 m.

## 5.2 Effect of Submergence and Wave Period on Wave Transmission

To investigate the effect of wave period ( $T$ ) and breakwater submergence ( $R_c$ ) on wave transmission, the physical model results have been re-presented in Figures 6 – 8, to be independent of the breakwater crest width ( $B$ ). The results shown in these figures all indicate a clear trend of higher wave transmission associated with higher breakwater submergence and longer wave period. As the two parameters

were not investigated independently during this investigation, the individual effects of each have not been defined.

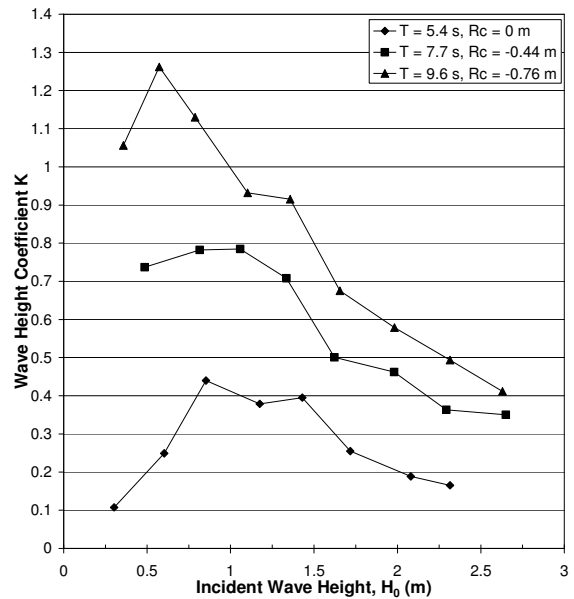


Figure 6. Effect of wave period ( $T$ ) and submergence ( $R_c$ ) on wave transmission for breakwater width  $B = 4$  m

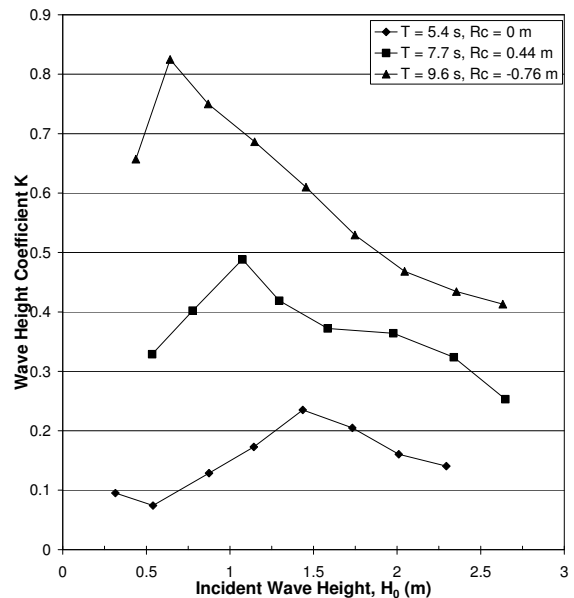


Figure 7. Effect of wave period ( $T$ ) and submergence ( $R_c$ ) on wave transmission for breakwater width  $B = 8$  m

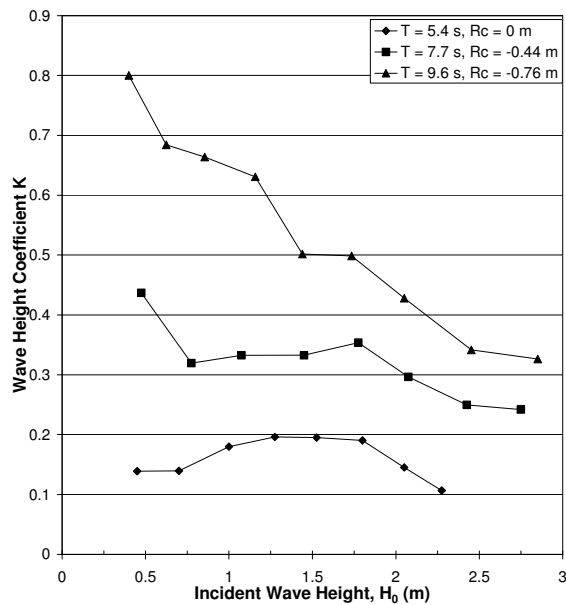


Figure 8. Effect of wave period ( $T$ ) and submergence ( $R_c$ ) on wave transmission for breakwater width  $B = 12$  m

## 6 Empirical Estimations of Wave Transmission

### 6.1 Overview of Empirical Analysis

While physical modelling is known to reproduce wave transmission over low crested submerged breakwater structures with good accuracy, the ability of empirical techniques is not as clearly understood. To investigate the effectiveness and use of empirical equations to simulate wave transmission, the same conditions simulated in the physical model study have been analysed using several common empirical wave transmission techniques. This empirical assessment has been undertaken for only one wave period ( $T = 9.6$  s) and water level (2.6 m LAT) condition.

### 6.2 Empirical Estimate of Wave Shoaling and Breaking

Most commonly available empirical equations used to estimate wave transmission past a breakwater are based on physical model studies where waves have been measured directly seaward and leeward of the test structure. As a result, the published equations for wave transmission coefficients ( $K_t$ ) include only the effects of the breakwater on wave reduction. For the physical model study documented in this paper, waves underwent significant changes due to shoaling and breaking between the deepwater measurement location ( $H_0$ ) and the transmitted wave measurement location ( $H_t$ ).

To allow for these shoaling and breaking effects, the first step in the empirical analysis approach was to simulate the wave shoaling and breaking processes caused by the bathymetry at the site.

The surf zone model of Dally, Dean, and Dalrymple (1984) was initially used to reproduce the conditions measured in the flume with no breakwater in place. The results of this simulation are shown in Figure 9, and clearly demonstrate that for most incident wave heights, the Dally, Dean, and Dalrymple (1984) model works with reasonable accuracy. For wave heights greater than 1 m, the empirical technique reproduces the measured wave transmission coefficient within approximately 10%.

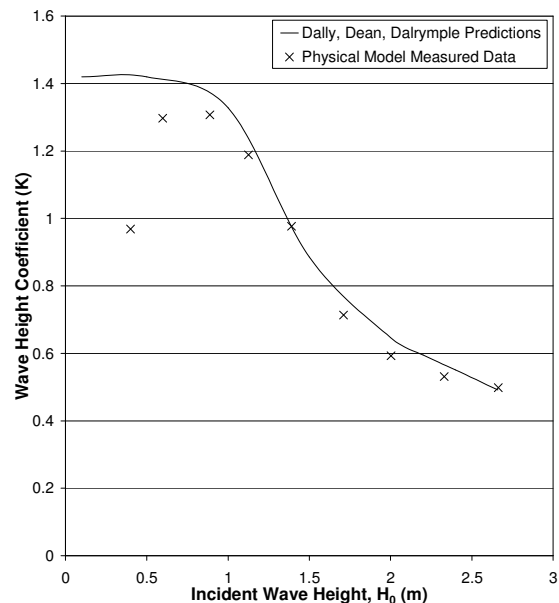


Figure 9. Comparison of physical model measurements with predictions made using the Dally, Dean, and Dalrymple (1984) surf zone model for the case with no breakwater, wave period  $T = 9.6$  s, water level = 2.6 m LAT (wave shoaling and breaking processes only)

### 6.3 Empirical Estimates of Wave Transmission past a Submerged Breakwater

Following the initial analysis of wave breaking and shoaling using the Dally, Dean, and Dalrymple (1984) surf zone model, a range of empirical wave transmission equations have been used to further predict the wave reduction generated by the submerged breakwater. Empirical analysis techniques used for wave transmission calculations include:

- Application of Dally, Dean, and Dalrymple with the inclusion of the breakwater in the bathymetric profile
- van der Meer (1991)
- van der Meer and d'Angremond (1991) in CEM (2008)
- Briganti *et al* (2004), in CIRIA (2007)

The process of applying these empirical techniques involved initially calculating the wave

height at the seaward edge of the breakwater using the Dally, Dean, and Dalrymple (1984) surf zone model, and then applying a transmission coefficient for the breakwater, determined from the empirical equations. Figures 10 – 12 show the empirical predictions of wave transmission past a submerged breakwater, compared with the measured physical model results.

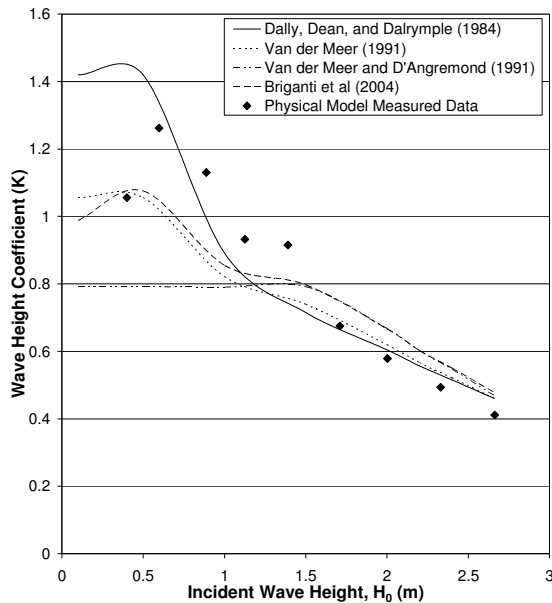


Figure 10. Comparison of physical model measurements with empirical predictions of wave transmission for a breakwater with crest width  $B = 4$  m, wave period  $T = 9.6$  s, water level = 2.6 m LAT

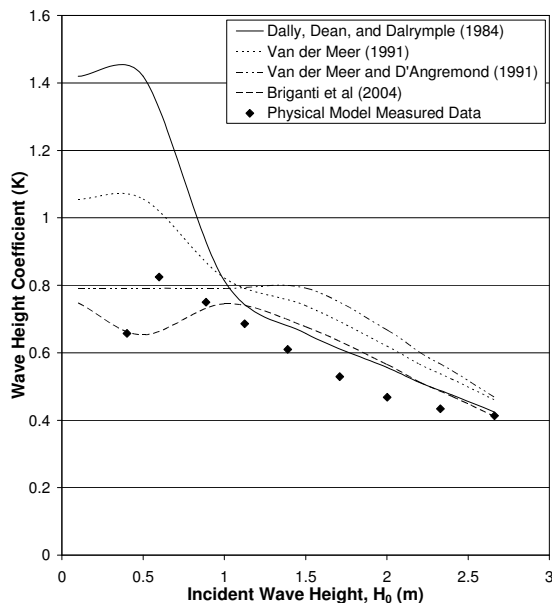


Figure 11. Comparison of physical model measurements with empirical predictions of wave transmission for a breakwater with crest width  $B = 8$  m, wave period  $T = 9.6$  s, water level = 2.6 m LAT

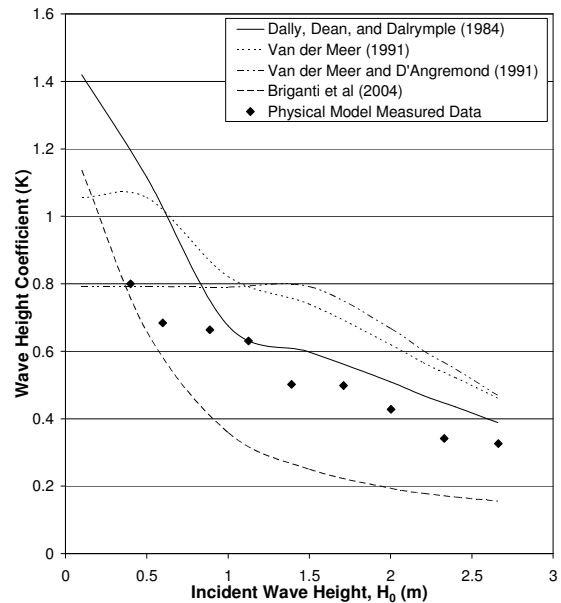


Figure 12. Comparison of physical model measurements with empirical predictions of wave transmission for a breakwater with crest width  $B = 12$  m, wave period  $T = 9.6$  s, water level = 2.6 m LAT

In general, the empirical approaches can be seen to have predicted wave transmission with a reasonable degree of accuracy. All techniques provide better predictions for larger incident wave heights ( $H_0$  greater than 1 m). For small incident waves, the process of wave shoaling has not been reproduced well with the Dally, Dean, and Dalrymple (1984) surf zone model (see Figure 9). As the other empirical equations have been coupled with this model for the transmission assessment, this has also resulted in less accurate predictions of wave transmission from these other empirical equations.

The Dally, Dean, and Dalrymple (1984) model, with the submerged breakwater implemented as a mound in the bathymetric profile, has produced wave transmission predictions that are as accurate (if not better) than the surf zone model coupled with other well known empirical wave transmission equations. From this analysis it can be concluded that a good first pass estimate of wave transmission over submerged geotextile breakwater structures, can be obtained using the Dally, Dean, and Dalrymple (1984) model, with a fine enough resolution to adequately simulate the breakwater structure.

## 7 Conclusions

A two dimensional physical modelling investigation into wave transmission over low crested geotextile breakwater structures has been undertaken by WRL and International Coastal Management. The results of the physical modelling have been presented in this paper, including the effects of a range of parameters on wave transmission such as:

- Structure crest width
- Structure submergence
- Wave height
- Wave period

The measurements from the physical modelling show a clear trend of increased wave transmission for higher breakwater submergence and longer wave period. The results also indicate that for short period wave conditions (of the order of 5 second wave period), a reasonable reduction in wave transmission can be achieved with a breakwater having a crest width as narrow as 4 m. Increasing the crest width to 8 m provided a small additional reduction in wave transmission, while further increases in crest width provided no additional wave reduction. For longer period wave conditions (10 second period), very little wave reduction is achieved with a 4 m breakwater, with modest increases in wave reduction achieved with wider 8 m and 12 m breakwater structures.

A range of empirical wave transmission techniques were used to simulate the conditions tested in the physical model, to test their effectiveness for transmission predictions for low crested geotextile structures. The analysis compared measurements from the flume model with predictions made using the Dally, Dean, and Dalrymple (1984) surf zone model, as well as predictions made using several wave transmission coefficient formulations. The results of the simple analysis showed that all of the empirical techniques provided good predictions of wave transmission, especially for wave heights greater than approximately 1 m. The Dally Dean and Dalrymple (1984) model provided the best all round predictions of wave transmission, and is a good first pass technique for estimating wave transmission over submerged geotextile breakwater structures.

## 8 References

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