DOUBLE WALLED, LOW REFLECTION WAVE BARRIERS

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Abstract

The effectiveness of a second perforated barrier seaward of a solid wave barrier in significantly reducing wave reflections and simultaneously improving wave protection is demonstrated in the paper. The indicated optimum seaward wall porosities and overall widths can be readily incorporated into practical structural designs for small craft facilities in relatively sheltered waters with limited wave periods. Results of an extended laboratory testing program and specific application to a recently designed and constructed structure are presented.

Introduction

Wave barriers (screens, curtains or skirts) have been found to offer cost effective and space efficient means of providing wave protection for small craft facilities in sheltered waterways where wave periods are restricted to locally wind generated seas.

The resultant wave reflections from a vertical barrier (as from other structures such as rubble mounds and floating breakwaters) often adversely impact on surrounding areas. Li (1995) demonstrated the significant reductions in wave reflection that may be achieved (for a full depth vertical seawall) by the seaward addition of a second perforated wall.

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In this paper, the design and effectiveness of a double wave barrier (with perforated seaward wall) in simultaneously satisfying low wave reflection and transmission requirements has been investigated in scaled laboratory wave flume and basin testing. Under design storm situations such structures experience significant wave overtopping and turbulent energy losses, conditions which are not conducive to analytical nor numerical solution.

Single Vertical Wave Barrier

Kriebel and Bollmann (1996) modified the original power transmission theory of Wiegel (1960) in obtaining an improved yet simple solution for estimating wave transmission for a single vertical wave barrier of the type shown in Figure 1.

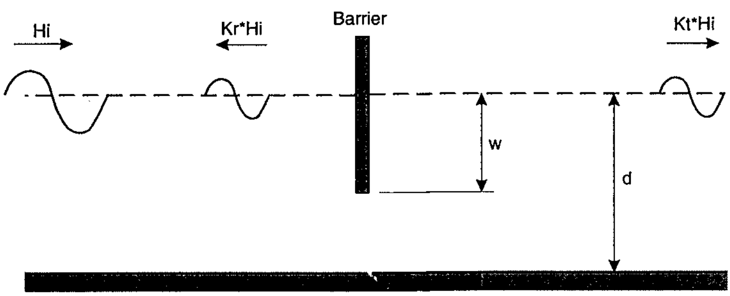

Figure 1. Definition sketch for single vertical wave barrier.

The Kriebel and Bollmann solution for wave transmission (H_t/H_i) is given by,

$$K_{ts} = 2\,T_F\,/\,(1+T_F) \tag{1}$$

where $$T_F = \frac{2\,k\,(d-w)+\sinh 2k\,(d-w)}{2\,kd\;+\;\sinh 2\,kd} \tag{2}$$

and the wavenumber $k = 2\pi\,/\,L$

Kriebel and Bollmann favourably compared predictions from the above solution with a range of test data and the mathematically derived eigenfunction expansion methods of Losada et al (1992).

Kriebel and Bollmann confirmed the findings of Peirson and Cox (1989) in that the Wiegel theory overestimated wave transmission in deepwater conditions whilst underestimating in shallow water. Peirson and Cox noted that the method of predicting forces on a single wave barrier as contained in the US Army Corps of

Engineers Shore Protection Manual (1984) was overly conservative due to the assumption that the transmitted wave is 180° out of phase with that of the incident wave – a restricted series of wave flume experiments resulted in phase lags not exceeding 60°. Over an extended range of conditions, Kriebel et al (1998) utilising eigenfunction expansion solutions and near prototype scale laboratory tests have found the phase lag to vary with wave period and be generally less than 90°. The eigenfunction predictions of wave forces were validated against the experimental data and found to provide a reasonable upper-bound solution – the Shore Protection Manual (1984) method of estimating forces again shown to be overly conservative.

Double Walled Low Reflection Wave Barrier

A double walled structure is effective at reducing the reflection coefficient because waves reflecting off the front barrier are out of phase with those reflecting off the rear barrier. The theoretical ideal separation between front and rear barriers can be readily shown to be *L/4, 3L/4 or 5L/4* where *L* is the wavelength. For a separation of *L*/2 there would be little to no effective reduction in wave reflection.

For many small craft facilities even a separation of *L*/4 can be cost prohibitive. The introduction of porosity in the front barrier has been found to assist in reducing wave reflections with separations significantly less than the theoretical optimum *L*/4. In studying a full depth solid rear wall with porous front wall structure, Li (1995) indicated that the optimum separation could be as low as *0·18L*. *For many small craft facilities* the concept of a double wave barrier structure as shown in Figure 2 is most appealing. Major benefits include: (i) little impact on water circulation which can continue below the penetration depth; (ii) the horizontal deck connecting the two barriers can be utilised for pedestrian and/or vehicular traffic; and (iii) control of wave reflections (optimised by incorporation of porosity in the front wall) and reduction of adverse impacts on surrounding areas.

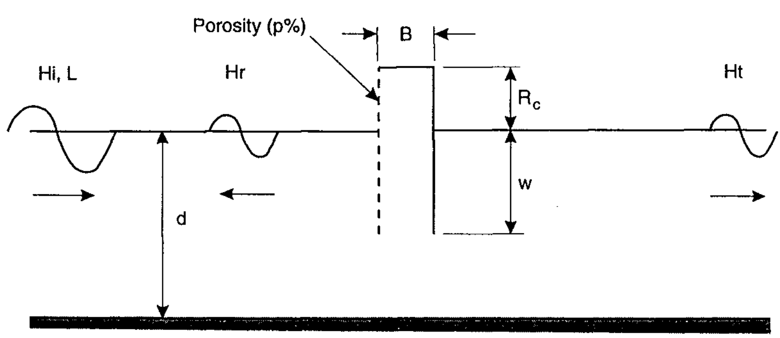

Figure 2. Definition sketch for double walled low reflection wave barrier.

Testing Program

To examine the behaviour of low reflection double wave barrier structures, an extensive experimental testing program was undertaken in the random wave flume at Water Research Laboratory, School of Civil and Environmental Engineering, University of New South Wales. The flume is 32 m long, 1 m wide and 1·2 m deep. Waves are generated by a single paddle hydraulic wave actuator at the upwave end. Wave energy absorption at the downstream end is achieved with porous plates and a sloping mat of synthetic hair. Double barrier structures for testing were mounted in a specially constructed force measurement rig located 24 metres away from the wave generator. The test rig with load cell arrangement is shown in Figure 7. Model double wave barriers were constructed from marine ply or transparent rigid acrylic for a range of vertical heights, widths/separations between front and rear walls and perforation porosities of the front wall.

The testing program examined transmitted and reflected wave behaviour for varying water depth (d), wavelength (L), incident wave height (H_i), barrier penetration (w), double barrier separation (B), and front wall porosity (p%). The above water crest level (R_c) was initially set above wave runup level to eliminate any overtopping.

Wave heights were measured with twin wire capacitance wave probes at various locations upwave and downwave of the test rig to determine incident (H_i) transmitted (H_t) and reflected (H_r) wave heights and thus the dependent parameters of wave transmission ($K_t = H_t / H_i$) and reflection ($K_r = H_r / H_i$) coefficients.

The range of the governing independent non-dimensional terms examined in the testing was:

porosity of front wall	$p\%$	10% to 30%
water depth to wavelength ratio	d/L	0.2 to 0.6
barrier penetration to depth ratio	w/d	0.2 to 0.6
barrier separation to wavelength	B/L	0.1 to 0.3
wave steepness	H/L	0.02 to 0.10

More than 250 independent conditions were tested for wave transmission and reflection behaviour. Force measurements were restricted to the reduced set of conditions directly related to the Royal Prince Alfred Yacht Club structure in which significant wave breaking and overtopping of the structure occurred due to the low deck crest level required.

Test Results

Preliminary testing for a selected range of *d/L*, *w/d* and *B/L* confirmed the results of Li (1995) in that reflections were minimised for an optimum front wall porosity of about 20%. A 20% porosity was also found to be optimum for practical construction and operational purposes such as incorporation of reinforcing steel in concrete panelled porous walls and minimising effects of marine growth. The majority of testing was subsequently carried out for front barrier porosity of 20%.

As indicated in Figure 3, wave steepness was found to have little effect on wave transmission and reflection coefficients.

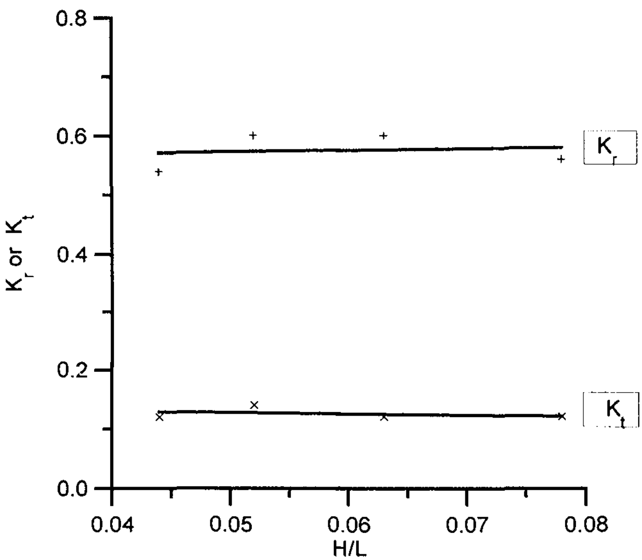

Figure 3: Double barrier transmission (K_t) and reflection (K_r) coefficients, varying H/L (porosity = 20%, d/L = 0.5, w/d = 0.5 and B/L = 0.21)

As indicated in Figures 4 and 5, wave reflections were minimised for barrier separations B less than 0·20L. The sensitivity of reflection coefficient to barrier separation was found to increase for reduced barrier penetrations in deeper water - conditions generally giving rise to increased wave transmission. In most applications *B/L* may be reduced to a suggested practical (and near optimum) value of 0·15 with little increase in reflected wave energy above the measured minimums. With near optimum 20% front wall porosity and double wall separation of 0.15L, reflection coefficients less than 0.3 were achievable for penetration ratios *w/d* less than 0.5.

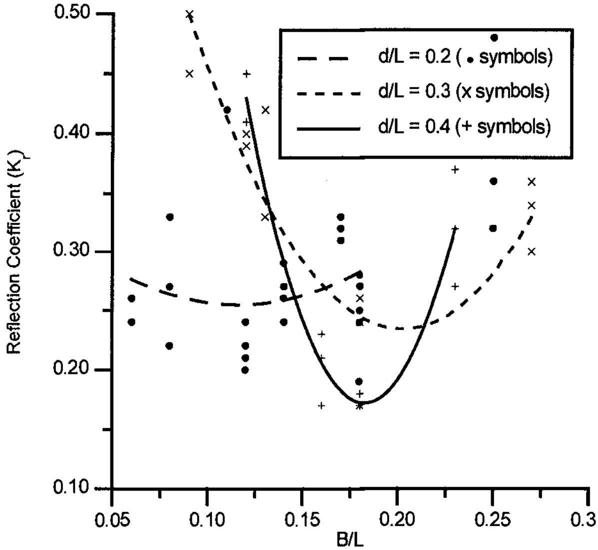

Figure 4: Double barrier, K_r variation with B/L and d/L (porosity = 20% and w/d = 0.3)

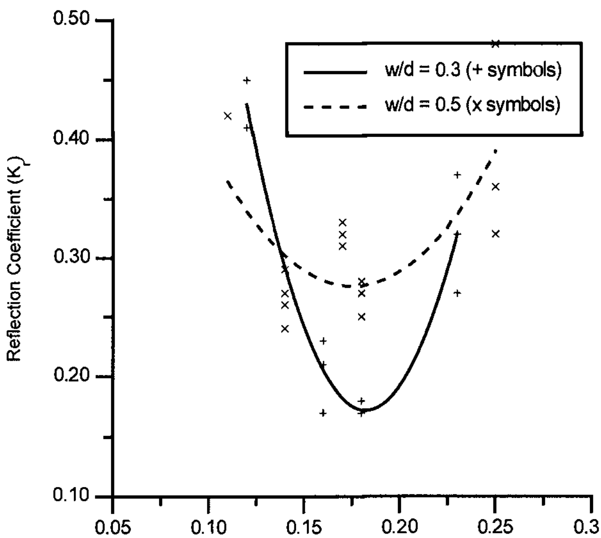

Figure 5: Double barrier, K_r variation with B/L and w/d (porosity = 20% and d/L = 0.4)

In Figure 6 the measured transmission coefficient K_t is compared to the value K_{ts} given by Kriebel and Bollmann (1996) in equation (1) for a single wave barrier. Over a wide range of *H/L*, *d/L*, *w/d* values the Kriebel and Bollman method was found to reasonably predict the wave transmission even for the porous front double barrier structures provided the barrier separation was less than the suggested optimum of 0·15*L*. With increasing barrier separations above 0·15*L* the double barrier can significantly further reduce wave transmissions below values achievable with a single barrier. It is, however, more efficient to achieve lower wave transmissions by increasing the penetration rather than widening the separation of the double barrier structure.

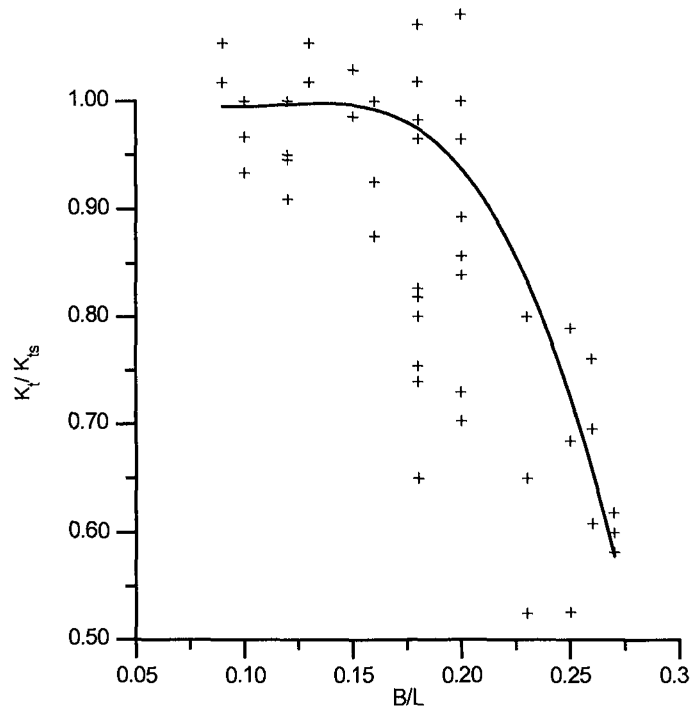

Figure 6: Ratio of double barrier transmission coefficient (K_t) to single barrier transmission coefficient of Kriebel and Bollmann (K_{ts}), versus B/L

The experimental test program clearly indicated the ability of a porous front walled double wave barrier in providing low wave reflections concurrent with adequate wave protection (low wave transmission). The concept has been recently utilised at Royal Prince Alfred Yacht Club.

Royal Prince Alfred Yacht Club – double walled low reflection wave barrier

Royal Prince Alfred Yacht Club (RPAYC) on Pittwater in Sydney's north required a new breakwater as part of an upgrade of its marina facilities. The breakwater was to provide protection for a system of floating marina units and replaces an aging slatted timber structure. To gain construction approval the structure had to meet the requirements of Pittwater Council. These included minimisation of wave reflections, visual impact (structure crest to be not more than 1.25 m above Mean Sea Level) and impact on current or sediment flows. Waves at the site are boat wakes or locally generated short period wind waves, with the longest fetch being at an angle of 55° to the required breakwater alignment. For the established design wave conditions (significant height 1 m and period 2.8 seconds), both the wave transmission and reflection coefficients were required to be less than 0.3. Bed materials consist of sands and silts over rock. Water depths range up to 11 m.

Following a design process that considered a number of options a double walled low reflection wave barrier was chosen as the best solution. The basic concept described above was refined for the particular application with detailed 2D wave flume and 3D wave basin modelling at Water Research Laboratory. The 2D testing was used to optimise the configuration of the double wave barrier - specifically the front wall porosity, the penetration depth and separation width. 2D detailed wave loading measurements by load cells incorporated hydrostatic and dynamic impact force components acting on both the seaward porous and rear solid barrier walls. The 3D testing was carried out to determine wave attenuation and reflection characteristics of the structure under angled wave attack. 3D wave induced forces (perpendicular and axial load components) on an instrumented 5 metre double barrier panel were measured under angled wave attack. The force testing arrangements of load cells are shown in Figure 7.

The adopted design double wave barrier is shown in Figure 8. The double barrier structure is supported by raking piles capped with concrete blocks at 5 m spacings. Panels (5 m long x 3.12 m deep) and decking (2 m wide) straddle the space between the supports. The total length of the structure is approximately 200 m. The front (seaward) wall panel is perforated with thirteen 500 mm holes, resulting in 17% porosity. This arrangement was arrived at after consideration of marine growth as well as code requirements for reinforcing steel and concrete cover. Two small holes are located in the rear wall at about the high water level to reduce buildup of floating debris.

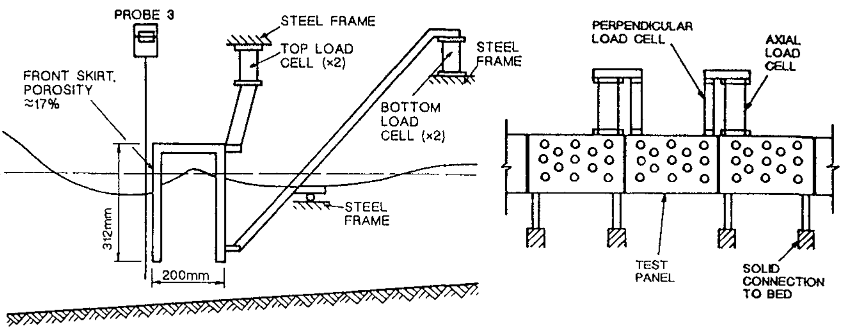

Figure 7. 2D force testing rig (scale 1:10) 3D force testing rig (scale 1:30)

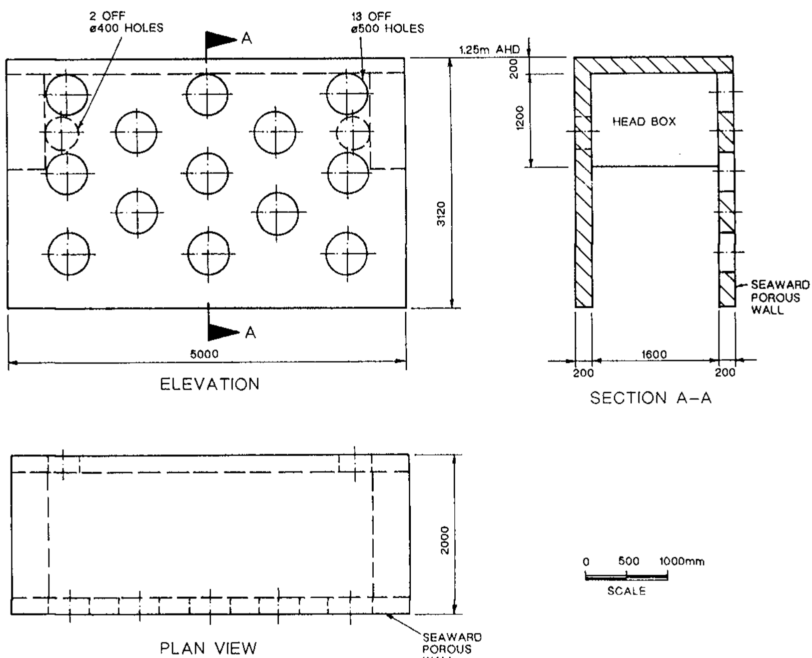

Figure 8. Royal Prince Alfred Yacht Club adopted double barrier structure.

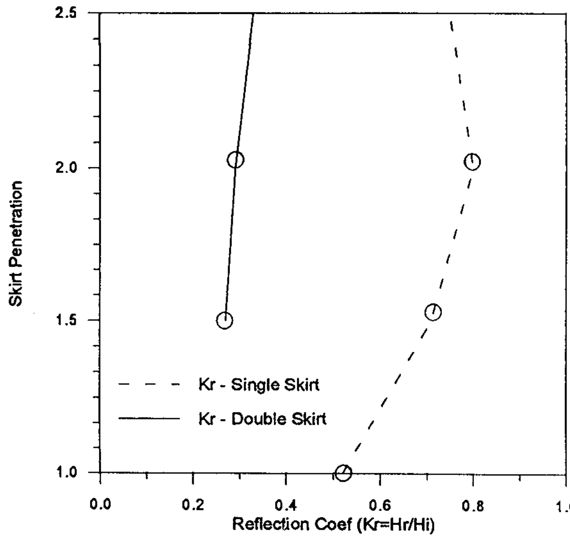

Figure 9. Impact of double barrier/skirt on reflections (H=1m, T=2.8s, 90°)

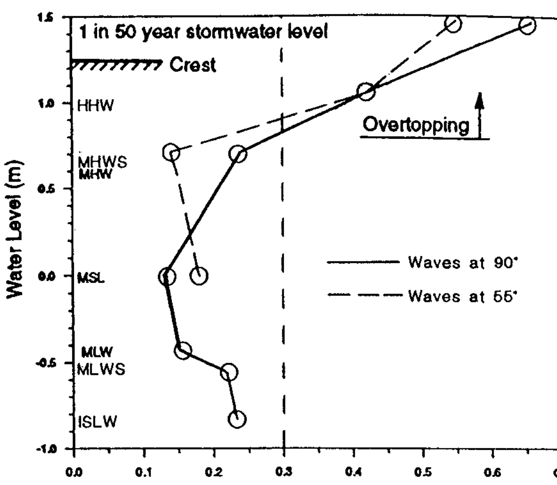

Figure 10. Wave transmission vs water level (H=1m, T=2.8s)

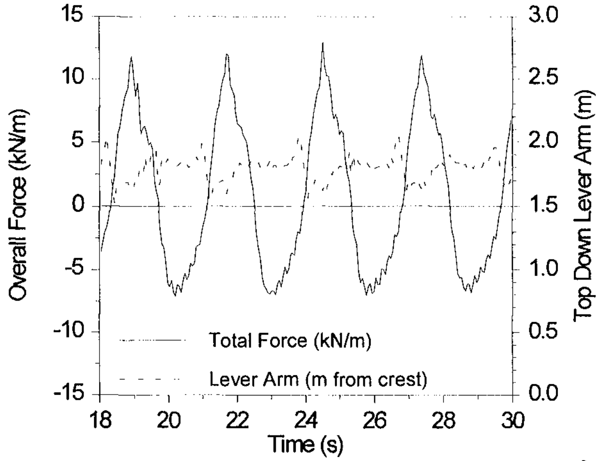

Figure 11. 2D wave force trace on total structure (H=1m, T=2.8s, 90°, WL=0m)

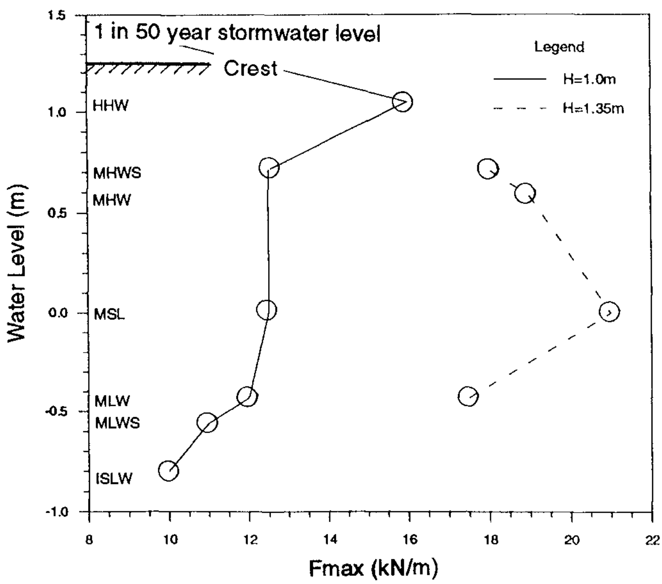

Figure 12. Maximum wave force vs water level (T=2.8s, 90°)

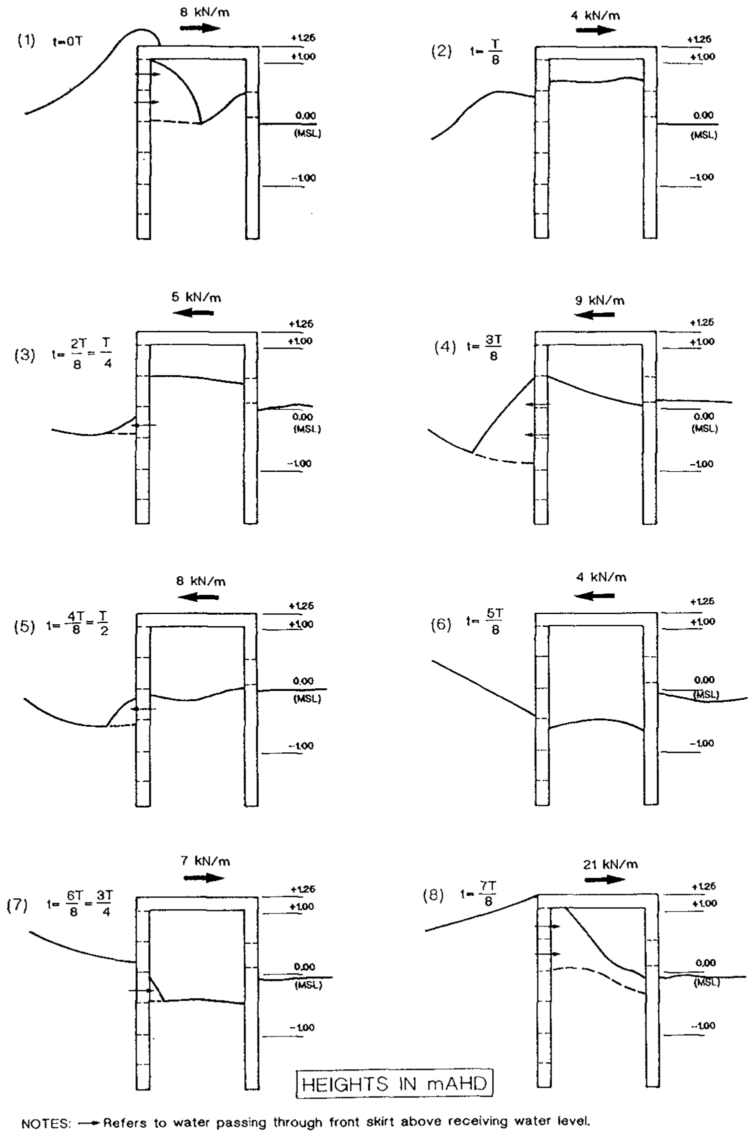

Figure13. Wave forces within a wave period (H=1.35m, T=2.8s, 90°, WL=0m)
Selected T/8 time steps do not necessarily coincide with peak forces

In Figure 9 the single solid barrier/skirt reflection coefficients of 0.7 to 0.8 were reduced to 0.3 by the addition of a second barrier/skirt (porosity 17% placed L/6 seaward in 10m water depth). As indicated in Figure 9, wave reflection was relatively insensitive to the water level/penetration depth. In contrast, as indicated in Figure 10, wave transmission varied markedly with water level. The transmission coefficient Kt was maintained at less than the design required value of 0.3 for water levels within the spring tide range and for approach wave angles from 55 to 90 (orthogonal) degrees. The increased wave transmission at water levels above High High Water resulted from overtopping of the deck at the imposed low crest level of 1.25m MSL.

An example 2D total force test trace under monchromatic waves is given in Figure 11. The variation of total force with water level is shown in Figure 12. Under design wave conditions the recorded maximum shoreward force (water levels between MLWS and MHWS) was 12 to 13 kN/m whilst the seaward forces (not shown) peaked at 8 kN/m. Sensitivity testing for waves more extreme than the design 1m was undertaken. The resulting total 2D forces and distribution of wave forces on the double barrier structure are included for 1.35m wave conditions in Figures 12 and 13.

Conclusions

The effectiveness of a second perforated barrier seaward of a solid wave barrier in reducing wave reflections and simultaneously improving wave protection has been demonstrated. The resulting indicated optimum seaward wall porosities and overall widths can be readily incorporated into practical structural designs for small craft facilities in relatively sheltered waters with limited wave periods. For longer wave periods the width required to provide low wave reflections (as well as low transmission) will generally become structurally and cost prohibitive.

The ability to reduce wave reflections to low levels was paramount in the acceptance and success of the recently constructed double walled low reflection wave barrier structure at Royal Prince Alfred Yacht Club.

The double walled wave barrier structure is clearly suited to reinforced concrete fabrication techniques similar to those already widely used in precasting of culverts. In addition to vessels being able to berth at the structure, the connecting deck can be readily utilised for pedestrian and/or vehicular traffic.

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