NUMERICAL PREDICTION OF WAVE OVERTOPPING ON COASTAL STRUCTURES

BY

NOBUHISA KOBAYASHI AND ANDOJO WURJANTO

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UNIVERSITY OF DELAWARE
NEWARK, DELAWARE
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ABSTRACT

Monochromatic wave overtopping over the crest of an impermeable coastal structure located on a sloping beach is predicted numerically by expanding the numerical model developed previously for predicting wave run-up on such a structure located on the horizontal seabed. The expanded numerical model predicts the temporal variations of the velocity and depth of the flow over the crest of the structure from which the average overtopping rate per unit width is computed. The model accounts for the effect of wave shoaling on the sloping beach in front of the structure located in relatively shallow water. The computed average overtopping rates are shown to be in agreement with available small-scale test data for which smooth impermeable structures were fronted by a 1:10 slope. The numerical model also predicts the decrease of wave reflection due to the increase of wave overtopping. However, more detailed measurements will be required to further calibrate and evaluate the numerical model which may be extended to examine the armor stability of overtopped breakwaters since the numerical model predicts the fluid velocity and acceleration required for the armor stability analysis.

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TABLE OF CONTENTS

NUMERICAL PREDICTION OF WAVE OVERTOPPING ON COASTAL STRUCTURES

PART I: INTRODUCTION

Background

Wave overtopping on a coastal structure is important for determining the required crest height of the structure. Prediction of wave overtopping on coastal structures is presently based on hydraulic model tests and empirical formulas. Only the volume of overtopped water during a specified time interval was measured in typical hydraulic model tests (e.g., Saville 1955; Jensen and Sorensen 1979). Accordingly, available empirical formulas based on the measured volume of overtopped water such as the formula proposed by Weggel (1976) and given in the Shore Protection Manual (U.S. Army CERC 1984), hereafter referred to as SPM, predict only the average rate of wave overtopping and do not give any information on the temporal variations of the water velocity and depth during wave overtopping.

The average overtopping rate may be sufficient for determining the required drainage capacity. However, the velocity and depth of the water overtopping the crest of the structure are required to assess the severity of the damage caused by wave overtopping (e.g., Lording and Scott 1971; Jensen 1983). Furthermore, empirical formulas are limited to the structural geometry and wave conditions examined in the model tests and are not versatile enough to deal with various combinations of different coastal structures and incident wave characteristics. As a result, it is desirable to develop a numerical model to fill the gap between empirical formulas and site-specific hydraulic model tests.

Scope

The numerical model developed by Kobayashi et al. (1987) for predicting the uprush and downrush of normally incident waves on rough impermeable slopes is expanded to predict wave overtopping over the specified crest geometry of an impermeable coastal structure located on a sloping beach. The related problem of wave transmission by overtopping (e.g., Cross and Sollitt 1972; Seelig 1980) and through a porous rubble-mound breakwater (e.g., Madsen and White 1976) is not considered herein. Moreover, the randomness of incident wind waves, the permeability of a rubble structure and the stability of armor units are not examined in this report.

Kobayashi et al. (1987) showed that their numerical model was in agreement with available test data on run-up, run-down and reflection of monochromatic waves plunging, collapsing and surging on uniform and composite riprap slopes. Kobayashi and Greenwald (1988) conducted small-scale tests using a 1:3 gravel slope with an impermeable base to further calibrate and evaluate the numerical model. The calibrated model was shown to be capable of predicting the measured temporal variations of the hydrodynamic quantities on the rough impermeable slope. Moreover, Kobayashi and Watson (1987) showed that the numerical model could also be applied to smooth impermeable slopes by adjusting the friction factor associated with the slope roughness.

The numerical model is expanded herein to allow wave shoaling on the beach in front of the structure as well as wave overtopping at the landward edge of the crest of the structure located above the still water level. The average overtopping rate is calculated from the predicted instantaneous overtopping rate. The expanded numerical model is then shown to yield agreement with the small-scale data of monochromatic wave overtopping on smooth impermeable structures summarized by Saville (1955). It should be stated that a concise version of this report will be published elsewhere (Kobayashi and Wurjanto 1989).

PART II: NUMERICAL MODEL

Governing Equations

The two-dimensional coordinate system (x', z') used in this report is defined in Fig. 1 in which the prime indicates the physical variables. Fig. 1 also shows the slope geometry for the tests of Saville (1955) with which the modified numerical model will later be compared. In the following, the problem is formulated in a general manner. The x'-coordinate is taken to be positive in the landward direction with x'=0 at the water depth d_t' below the still water level (SWL) where the incident wave train is specified as input. The z'-coordinate is taken to be positive upward with z'=0 at SWL. The water depth d_t' and the variation of the local slope angle θ' with respect to x' are used to specify any slope geometry in the computation domain $0 \leq x' \leq x_e'$ where x_e' is the x'-coordinate of the landward edge of the slope which is assumed to be located above SWL. In Fig. 1, $\tan\theta'$ is 0.1 in front of the structure, $\tan\theta_s'$ on the structure slope and zero on the crest of the structure.

Assuming that the pressure is hydrostatic below the instantaneous free surface located at $z'=\eta'$, Kobayashi et al. (1987) used the following equations for mass and x'-momentum integrated from the assumed impermeable bottom to the free surface

$$\frac{\partial h'}{\partial t'} + \frac{\partial}{\partial x'}(h'u') = 0 \tag{1}$$

$$\frac{\partial}{\partial t'}(h'u') + \frac{\partial}{\partial x'}(h'u'^2) = -gh'\frac{\partial \eta'}{\partial x'} - \frac{\tau_b'}{\rho} \tag{2}$$

in which t'=time; h'=instantaneous water depth; u'=instantaneous depth-averaged horizontal velocity; g=gravitational acceleration; η'= instantaneous free surface elevation above SWL; τ_b' = bottom shear stress; and ρ = fluid density, which is assumed constant.

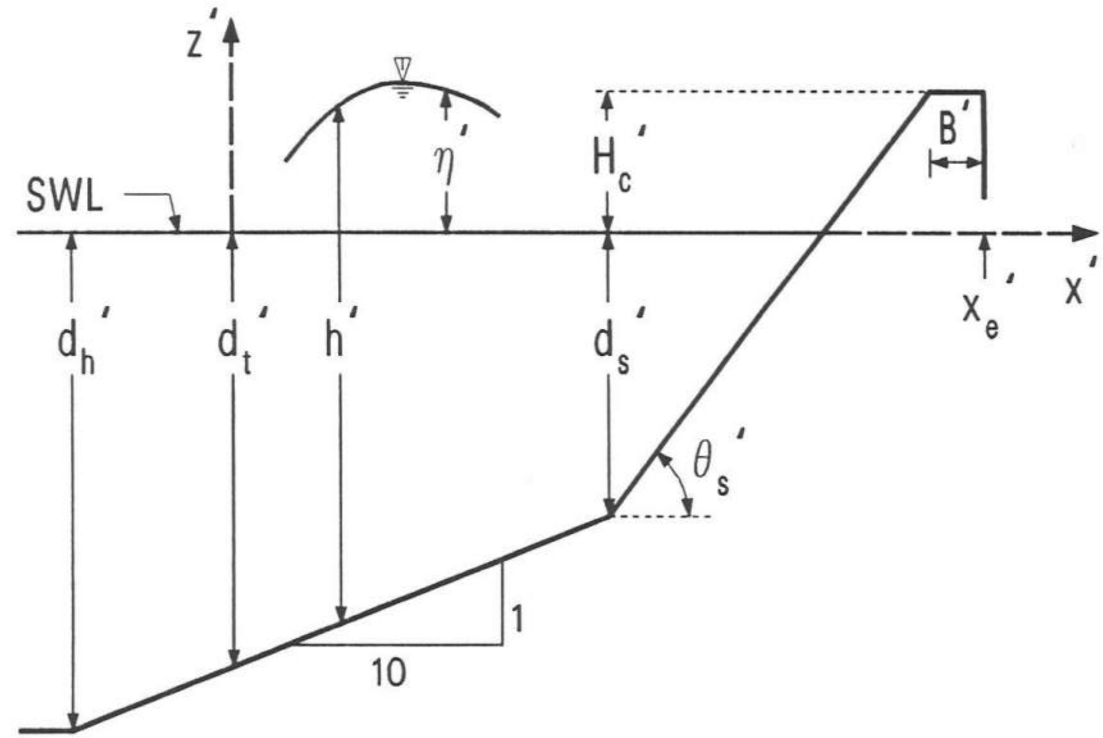

Figure 1. Definition sketch for numerical model and slope geometry for the tests of Saville (1955)

The bottom shear stress is expressed as

$$\tau_b' = \frac{1}{2}\,\rho f' |u'| u' \tag{3}$$

in which f'=bottom friction factor which is assumed to be constant for given slope roughness characteristics neglecting the effect of viscosity. Kobayashi and Watson (1987) compared the numerical model with the empirical formulas for wave run-up and reflection proposed by Ahrens and Martin (1985) and Seelig (1983), respectively. Their limited calibration indicated that f'=0.05 or less for small-scale smooth slopes, although the computed results were not very sensitive to the value of f'. Consequently, f' = 0.05 is used for the subsequent computation.

Numerical Method

Denoting the characteristic wave period and height by T' and H_o', respectively, the following dimensionless variables are introduced:

$$t = \frac{t'}{T'} \quad ; \quad x = \frac{x'}{T'\sqrt{gH_o'}} \quad ; \quad x_e = \frac{x_e'}{T'\sqrt{gH_o'}} \quad ; \quad u = \frac{u'}{\sqrt{gH_o'}} \tag{4}$$

$$z = \frac{z'}{H_o'} \quad ; \quad h = \frac{h'}{H_o'} \quad ; \quad \eta = \frac{\eta'}{H_o'} \quad ; \quad d_t = \frac{d_t'}{H_o'} \tag{5}$$

$$\sigma = T'\sqrt{\frac{g}{H_o'}} \quad ; \quad \theta = \sigma \tan\theta' \quad ; \quad f = \frac{1}{2}\,\sigma f' \tag{6}$$

in which σ=dimensionless parameter related to wave steepness; θ=normalized gradient of the slope; and f=normalized friction factor.

In terms of the normalized coordinate system, the slope geometry in the computation domain is given by

$$z = \int_0^x \theta\, dx - d_t \quad ; \quad \text{for } 0 \le x \le x_e \tag{7}$$

For normally incident monochromatic waves, the characteristic period and height used for the normalization are taken to be the period and height of the monochromatic wave. Since the wave height varies due to wave shoaling, it is required to specify the location where the value of H_o' is given. For a coastal structure located on the horizontal seabed, Kobayashi et al. (1987) used the wave height at the toe of the structure which was taken to be located at x=0, so that the normalized wave height at x=0 was unity. For the monochromatic wave overtopping tests of Saville (1955), the deep water wave height was given. As a result, the wave height H_o' used for the normalization is taken to be the deep water wave height in the following.

Substitution of Eqs. 3-6 into Eqs. 1 and 2 yields

$$\frac{\partial h}{\partial t} + \frac{\partial m}{\partial x} = 0 \tag{8}$$

$$\frac{\partial m}{\partial t} + \frac{\partial}{\partial x}(m^2 h^{-1} + \frac{1}{2} h^2) = - \theta h - f|u|u \tag{9}$$

in which m=uh is the normalized volume flux per unit width.

Eqs. 8 and 9 expressed in the conservation-law form of the mass and momentum equations except for the two terms on the right hand side of Eq. 9 are solved numerically in the time domain using the explicit dissipative Lax-Wendroff finite difference method based on a finite-difference grid of constant space size Δx and constant time step Δt as explained by Kobayashi et al. (1987). The damping coefficients determining the amount of damping high-frequency numerical oscillations at the rear of breaking wave crests are taken to be unity. For the subsequent computation for smooth slopes, the number of spatial grid points in the computation domain $0 \le x \le x_e$ is typically taken to be about 130. The number of time steps per wave period is taken to be on the order of 6,000, which is greater than the typical value of 2,000 used for rough slopes (Kobayashi et al. 1987) since the reduction of the friction factor for a smooth slope tends to cause more numerical instability at the moving waterline on the smooth slope (Kobayashi and Watson 1987). The CPU time using the IBM 3081D computer is on the order of 2 min per wave period (Wurjanto 1988).

Initial and Boundary Conditions

The initial time t=0 for the computation marching forward in time is taken to be the time when the specified incident wave train arrives at the seaward boundary located at x=0 and no wave action is present in the computation domain $0 \le x \le x_e$.

In order to derive appropriate seaward and landward boundary conditions, Eqs. 8 and 9 are rewritten in terms of the characteristic variables α and β (Kobayashi et al. 1987)

$$\frac{\partial \alpha}{\partial t} + (u + c)\frac{\partial \alpha}{\partial x} = -\theta - \frac{f|u|u}{h}; \quad \text{along} \quad \frac{dx}{dt} = u + c \tag{10}$$

$$\frac{\partial \beta}{\partial t} + (u - c)\frac{\partial \beta}{\partial x} = \theta + \frac{f|u|u}{h}; \quad \text{along} \quad \frac{dx}{dt} = u - c \tag{11}$$

with $c=\sqrt{h}$; $\alpha = u + 2c$; $\beta = -u + 2c$ (12)

The seaward boundary is taken to be located seaward of the breakpoint so that the flow at x=0 is subcritical and satisfies the condition $u<c$ at x=0, which is normally satisfied seaward of the breakpoint. Then α and β represent the characteristics advancing landward and seaward, respectively, in the vicinity of the seaward boundary. Kobayashi et al. (1987) expressed the total water depth at the seaward boundary in the form

$$h = d_t + \eta_i(t) + \eta_r(t) \; ; \; \text{at } x=0 \tag{13}$$

in which η_i and η_r are the free surface variations at x=0 normalized by the deep water wave height H_o'. The incident wave train outside the breakpoint is specified by prescribing the variation of η_i with respect to $t \geq 0$. The term $\eta_r(t)$ in Eq. 13 accounts for the difference between the actual variation $\eta=(\eta_i + \eta_r)$ at x=0 and the prescribed variation η_i. This difference $\eta_r(t)$ may be regarded as the normalized free surface variation associated with the wave train reflected from the structure. The variation of $\eta_r(t)$ at x=0 may be expressed in terms of the value of the seaward-advancing characteristics, $\beta=(-u + 2\sqrt{h})$, at x=0 which is obtained from Eq. 11 using a simple first-order finite difference scheme (Kobayashi et al. 1987). Then, Eq. 13 yields the value of h at x=0 for given η_i, while the value of u at x=0 is obtained from $u=(2\sqrt{h} - \beta)$ at x=0.

For incident monochromatic waves, the variation of $\eta_i(t)$ at x=0 may be specified using an appropriate wave theory since the finite-amplitude shallow-water equations given by Eqs. 1 and 2 with $r_b'=0$ do not have a periodic solution for the wave of constant form (e.g., Dean and Dalrymple 1984). It is convenient to introduce the following dimensionless parameters:

$$K_s = \frac{H'}{H_o'} \quad ; \quad L = \frac{L'}{d_t'} \quad ; \quad U_r = \frac{H'(L')^2}{(d_t')^3} = \frac{K_s L^2}{d_t} \qquad (14)$$

in which K_s=shoaling coefficient at x=0; H'=wave height at x=0; H_o'=deep water wave height used for the normalization; L=normalized wavelength at x=0; L'=wavelength at x=0; d_t'=water depth below SWL at x=0; and U_r=Ursell parameter at x=0. In this report, the normalized incident wave profile $\eta_i(t)$ for $t \geq 0$ is estimated using cnoidal wave theory for $U_r \geq 26$ and Stokes second-order wave theory for $U_r<26$ (e.g., Svendsen and Brink-Kjaer 1972; Dean and Dalrymple 1984). The period and height of the periodic variation of $\eta_i(t)$ are equal to unity and K_s, respectively. The wave reflection coefficient, r, may be estimated as the height of the computed periodic variation of $\eta_r(t)$ divided by K_s. It may be shown that the parameters K_s, L and U_r defined in Eq. 14 and the periodic variation of $\eta_i(t)$ specified as input can be computed for given values of the dimensionless parameters d_t and σ defined in Eqs. 5 and 6, respectively, for both cnoidal and Stokes second-order wave theories (Kobayashi and DeSilva 1987; Wurjanto 1988).

An appropriate value of d_t determining the seaward boundary location may be selected so that the computed wave overtopping rate will not be sensitive to the value of d_t, while $L \gg 1$ and $K_s \simeq 1$ at the seaward boundary. The condition of $L \gg 1$ is necessary to apply Eqs. 1 and 2 in the computation domain. The condition of $K_s \simeq 1$ may be required since the value of K_s estimated without regard to the effect of reflected waves may not be very accurate.

In summary, the input required for the computation based on the normalized variables introduced in Eqs. 4-6 consists of the parameters d_t and σ specifying the incident monochromatic wave profile at the seaward boundary, the friction factor f' associated with the slope roughness characteristics, and the normalized slope geometry in the computation domain $0 \le x \le x_e$ expressed by Eq. 7.

The landward boundary on the structure is located at the moving waterline where the water depth is essentially zero unless wave overtopping occurs at the landward edge located at $x = x_e$. For the actual computation, the waterline is defined as the location where the normalized water depth h equals an infinitesimal value, δ, where $\delta = 10^{-3}$ is used on the basis of the previous computation for smooth slopes (Kobayashi and Watson 1987). For the case of no wave overtopping at $x=x_e$, the waterline movement is computed using the predictor-corrector-smoothing procedure explained by Kobayashi et al. (1987).

Wave overtopping is assumed to occur when the normalized water depth h at $x=x_e$ becomes greater than δ. The computation procedure for the case of wave overtopping at $x=x_e$ essentially follows the procedure used by Packwood (1980) to examine the effect of wave overtopping on the measured wave transformation in the surf zone on the gentle slope whose height was less than wave run-up. It is assumed that water flows over the landward edge freely since a different boundary condition is required for a vertical wall (Greenspan and Young 1978). The flow approaching the landward edge can be supercritical as well as subcritical since the associated water depth is relatively small.

If $u \leq \sqrt{h}$ at the grid point next to the landward edge at $x=x_e$, the flow approaching the landward edge is subcritical or critical, and only the characteristics α given by Eq. 10 advance to the landward edge from the computation domain $0 \leq x \leq x_e$. For this case, the flow at $x=x_e$ is assumed to be critical, that is, $u=\sqrt{h}$ at $x=x_e$. An additional relationship required to find the values of u and h at $x=x_e$ is obtained from the value of $\alpha=(u + 2\sqrt{h})$ at $x=x_e$ computed using Eq. 10 with $f=0$ which is approximated by a simple first-order finite difference equation.

On the other hand, if $u > \sqrt{h}$ at the grid point next to the landward edge, the flow approaching the landward edge is supercritical, and both characteristics α and β given by Eqs. 10 and 11 advance to the landward edge from the computation domain. Since Eqs. 10 and 11 are equivalent to Eqs. 8 and 9, the values of u and h at $x=x_e$ are obtained directly from Eqs. 8 and 9 with $f=0$ which are approximated by simple first-order finite difference equations (Wurjanto 1988).

If the value of h at $x=x_e$ becomes less than or equal to δ, the wave overtopping at $x=x_e$ is assumed to cease and the computation of the waterline movement is resumed.

Average Overtopping Rate

For incident monochromatic waves, the normalized average overtopping rate per unit width, Q, is obtained from the computed temporal variation of m=uh at $x=x_e$

$$Q = \frac{Q'}{H_o' \sqrt{gH_o'}} = \int_{t_p}^{t_p+1} m \, dt \quad ; \quad \text{at } x=x_e \tag{15}$$

in which Q'=dimensional average overtopping rate per unit width; and t_p=normalized time when the flow at $x=x_e$ becomes periodic.

For the computation made in this report, $t_p = 4$ is found to be sufficient as will be shown later. The computed value of Q is hence the average value of m(t) at $x = x_e$ during $4 \leq t \leq 5$. It should be noted that Eq. 15 does not include the volume flux during the interval when the value of h at $x=x_e$ does not exceed δ since the values of h and u at the grid points landward of the computational waterline defined by $h=\delta$ are set to be zero during the computation.

PART III: COMPARISON WITH AVAILABLE DATA

Data Used for Comparison

The numerical model is compared with the extensive small-scale test data summarized by Saville (1955). The following comparison is limited to the structure geometry shown in Fig. 1 in which B'=crest width; H_c'=crest height above SWL; d_s'=water depth below SWL at the toe of the structure fronted by a 1:10 slope; θ_s'=angle of the structure slope; d_h'=water depth below SWL on the horizontal bottom in a wave flume. Among the tests conducted for the Beach Erosion Board, which were regarded as 1:17 undistorted scale models, the test results for smooth slopes with $\cot\theta_s'=1.5$ and 3.0 are analyzed herein. The number of the analyzed tests is 110 and 111 for the 1:1.5 and 1:3 slopes, respectively. For these tests, $B'=8.96$ cm, $(d_h' - d_s')=44.8$ cm, and the still water level in the flume was varied. Among the tests conducted as 1:30 undistorted scale models for the Jacksonville District, an analysis is made of the test results for smooth slopes with $\cot\theta_s'=3.0$ and 6.0 in which $B'=13.2$ cm, $d_s'=10.2$ cm, $d_h'=25.4$ cm and the crest height H_c' was varied. The number of the analyzed tests is 40 for each of the 1:3 and 1:6 slopes. The test results analyzed herein are tabulated in Appendix B.

For all these tests, monochromatic waves of known characteristics were generated in a burst. The volume of the overtopping water was measured for the stable portion of the incident wave train excluding the first three or four waves before reflected waves from the structure could reach the wave generator and return to the structure. The repeated tests indicated the measurement uncertainty of less than 10 percent. The wave heights for the Beach Erosion Board tests were referred to deep water, while those for the Jacksonville District tests were referred to the depth d_h'. These wave heights at the depth d_h' are converted to the corresponding deep water wave heights, where the shoaling analysis used in this paper has been discussed in connection with Eq. 14.

In order to select typical tests for the subsequent computation and comparison, the following dimensionless parameters together with the parameter σ defined in Eq. 6 and the measured average overtopping rate normalized in the form of Eq. 15 are calculated and tabulated for each test in Appendix C

$$\xi = \frac{\sigma \tan\theta_s'}{\sqrt{2\pi}} \quad ; \quad d_h = \frac{d_h'}{H_o'} \quad ; \quad d_s = \frac{d_s'}{H_o'} \quad ; \quad H_c = \frac{H_c'}{H_o'} \quad ; \; R = \frac{R'}{H_o'} \tag{16}$$

in which ξ=surf similarity parameter based on the deep water wave height and structure slope (Battjes 1974); and R'=dimensional wave run-up on the structure slope in the absence of wave overtopping. The normalized wave run-up R for each test is estimated using the figures in SPM which plot R as a function of $\cot\theta_s'$, σ^{-2} and d_s for smooth impermeable slopes fronted by a 1:10 slope. Five tests with σ=7.9 are excluded since $\sigma \geq 9$ for these figures.

Empirical Formula

In addition, the normalized average overtopping rate Q for each test is calculated using the empirical formula given in SPM which can be rewritten as (Kobayashi and Reece 1983)

$$Q = \sqrt{Q_o^*} \left(\frac{R - H_c}{R + H_c} \right)^{\alpha_*} \tag{17}$$

in which Q_o^* and α_* are empirical coefficients. The values of Q_o^* and $(0.1085/\alpha_*)$ are given in SPM for specific values of d_s and σ^{-2} for the smooth 1:1.5, 1:3 and 1:6 slopes fronted by the 1:10 slope. Actually, the test results under consideration were used to develop the empirical formula for Q with the empirical coefficients calibrated to obtain good agreement (Weggel

1976). The tests for which the values of the empirical coefficients can not be found directly using the figures in SPM are excluded in the following. The excluded tests, most of which are the Jacksonville District tests, may not have been used for the calibration of the empirical formula. The calculated values of Q using Eq. 17 are tabulated in Appendix D.

Fig. 2 shows the comparison of the measured values of the normalized average overtopping rate per unit width, Q, with those calculated using SPM. Table 1 indicates the minimum and maximum values of the dimensionless parameters σ, ξ, d_h, d_s and H_c associated with the 1:1.5 and 1:3 smooth slope tests for the Beach Erosion Board, denoted by BE 1:1.5 and BE 1:3, respectively, as well as the 1:3 and 1:6 smooth slope tests for the Jacksonville District, denoted by JD 1:3 and JD 1:6, respectively. Table 1 also lists the number of data points plotted in Fig. 2 for each of the four different tests.

TABLE 1. - Ranges of Dimensionless Parameters for Different Tests

Smooth Slopes	No. of Tests	σ	ξ	d_h	d_s	H_c
BE 1:1.5	101	9.7-49.1	2.58-13.1	2.46-11.3	0.00-3.00	0.25-5.00
BE 1:3	97	9.7-49.1	1.29-6.54	2.46-11.3	0.38-3.00	0.25-4.00
JD 1:3	20	9.4-11.1	1.25-1.47	1.91-3.87	0.76-1.55	0.23-1.41
JD 1:6	16	9.4-11.1	0.63-0.74	1.91-2.87	0.76-1.15	0.11-0.53

Fig. 2 may be considered to show the comparison of the empirical formula in SPM with the data used for its calibration. As a whole, the empirical formula somewhat overestimates the average overtopping rate as may be expected

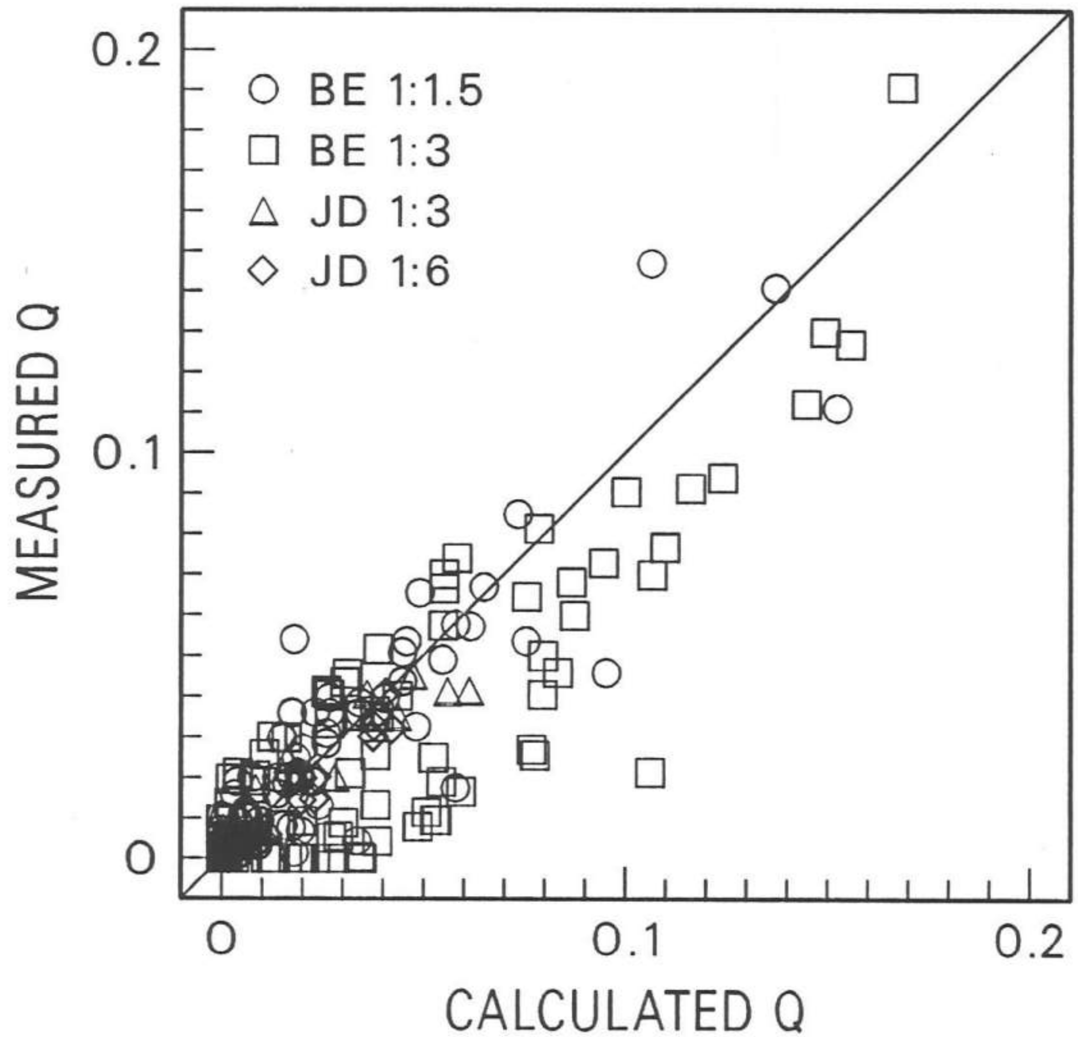

Figure 2. Comparison of measured values of normalized overtopping rate per unit width, Q, with those calculated using empirical formula in SPM

for the formula for a preliminary design. This empirical formula is very reasonable considering the number of parameters involved in the problem and the large sensitivity of the overtopping rate to the structure freeboard which needs to be determined for practical applications (Kobayashi 1985).

The empirical formula expressed in the form of Eq. 17 is suited for the regression analysis in which logQ is plotted against $\log[(R-H_c)/(R + H_c)]$ assuming that Q_o^* and α_* are constant. The plotted results have shown a large scatter of data points, indicating that the values of Q_o^* and α_* should be varied for different wave conditions and structure geometries. This regression analysis and additional regression analyses presented by Wurjanto (1988) indicate the difficulty of developing a simple empirical formula applicable to various wave conditions and structure geometries with little calibration of its empirical coefficients.

Comparison with Twenty Runs

Twenty runs representing the 234 data points shown in Fig. 2 are selected for the computation and comparison as summarized in Table 2. All the twenty runs are chosen from the Beach Erosion Board tests on the basis of the data statistics shown in Table 1. The test number listed for each run in Table 2 corresponds to that used for each data point in Appendices B, C and D. For these twenty runs, $14.8 \le \sigma \le 40.1$, $1.97 \le \xi \le 6.66$, $4.17 \le d_h \le 7.56$, $0 \le d_s \le 2.00$, and $0.50 \le H_c \le 2.67$. These ranges may be sufficient for the comparison with the data whose ranges are listed in Table 1.

TABLE 2. Summary of Computed Results for Twenty Runs

Run No.	Test No.	$\cot\theta_s'$	σ	ξ	d_h	d_t	d_s	H_c	r	$Q \cdot 10^2$		
										Data	Num.	SPM
1	122	3.0	14.8	1.97	4.92	3.00	0.75	0.50	0.27	6.6	2.7	5.5
2	148	3.0	14.8	1.97	4.92	3.00	0.75	1.00	0.30	4.1	0.3	2.6
3	136	3.0	14.8	1.97	5.67	3.00	1.50	0.50	0.29	6.4	5.3	7.6
4	160	3.0	14.8	1.97	5.67	3.00	1.50	1.00	0.29	3.6	1.4	3.8
5	132	3.0	20.5	2.72	7.56	4.00	2.00	0.67	0.49	9.0	8.1	10.0
6	123	3.0	25.0	3.33	4.92	4.00	0.75	0.50	0.44	6.0	5.4	8.7
7	149	3.0	25.0	3.33	4.92	4.50	0.75	1.00	0.48	1.7	1.6	5.9
8	172	3.0	25.0	3.33	4.92	4.00	0.75	1.50	0.49	0.4	0.2	3.9
9	137	3.0	25.0	3.33	5.67	4.00	1.50	0.50	0.53	9.4	9.1	12.4
10	161	3.0	25.0	3.33	5.67	4.00	1.50	1.00	0.60	4.0	4.5	8.0
11	184	3.0	25.0	3.33	5.67	4.00	1.50	1.50	0.65	0.8	1.6	4.9
12	120	3.0	40.1	5.34	6.56	6.00	1.00	0.67	0.60	9.1	9.8	11.6
13	134	3.0	40.1	5.34	7.56	6.00	2.00	0.67	0.60	13.0	11.3	14.9
14	158	3.0	40.1	5.34	7.56	6.00	2.00	1.33	0.70	7.7	5.1	11.0
15	181	3.0	40.1	5.34	7.56	6.00	2.00	2.00	0.76	2.5	1.6	7.8
16	198	3.0	40.1	5.34	7.56	6.00	2.00	2.67	0.77	1.1	1.5	5.1
17	13	1.5	25.0	6.66	4.92	4.92	0.75	0.50	0.45	4.9	6.6	5.5
18	55	1.5	25.0	6.66	4.92	4.92	0.75	1.50	0.63	1.3	0.8	2.4
19	7	1.5	25.0	6.66	4.17	4.17	0.00	0.50	0.16	3.9	4.0	4.1
20	29	1.5	25.0	6.66	4.17	4.17	0.00	1.00	0.28	2.0	0.7	2.0

The value of d_t for each run given in Table 2 satisfies the conditions of $d_h \geq d_t \geq d_s$ and $d_t \geq 3$. The 1:10 slope in front of the structure will influence wave run-up and overtopping if $d_s \lesssim 3$ on the basis of the figures given in SPM. The seaward boundary for the computation is hence taken to be located in the range $d_h \geq d_t \geq d_s$ as shown in Fig. 1. The condition of $d_t \geq 3$ is thought to reduce the effect of the seaward boundary location on the computed value of Q. The computed values of Q for different values of d_t for Runs No. 3, 10 and 14 are shown in Table 3. Table 3 lists the computed values

TABLE 3. - Sensitivity of Computed Values of Q to Seaward Boundary Location

Run No.	d_t	K_s	L	U_r	$Q \cdot 10^2$
3	3.00	0.95	7.8	19	5.3
	3.50	0.93	7.1	13	4.9
	4.00	0.92	6.5	10	3.8
	5.67	0.91	5.2	4	3.7
10	3.00	1.15	15.2	88	5.2
	3.50	1.08	13.6	57	5.2
	4.00	1.04	12.4	40	4.5
	4.40	1.04	11.6	32	4.5
14	4.00	1.47	21.7	174	8.0
	4.90	1.31	18.8	95	5.7
	5.50	1.21	17.4	66	5.4
	6.00	1.19	16.5	54	5.1
	7.00	1.14	15.0	37	5.0

of the parameters K_s, L and U_r defined in Eq. 14. These parameters depend on d_t only for the specified value of σ listed in Table 2. Considering the sensitivity of Q to d_t as well as the conditions of $L >> 1$ and $K_s \simeq 1$ required for the application of the numerical model, the value of d_t for each run is decided somewhat subjectively as listed in Table 2.

Table 2 lists the computed reflection coefficient r and the computed and measured values of Q together with those calculated using SPM. The computed value of r increases with the increase of ξ except for Runs No. 17-20 with d_s = 0.75 and 0.00 where the value of ξ for each run is listed in Table 2. Comparison of the values of r for the runs with the same values of $\cot\theta_s'$, σ, ξ, d_h, d_t and d_s but different values of H_c shows the slight increase of r with the increase of H_c, that is, as Q is decreased. The increase of r with the increase of ξ is consistent with the empirical formulas of Battjes (1974) and Seelig (1983) which do not account for the effects of d_s and wave overtopping. The increase of r with the increase H_c appears to be consistent with the limited data given by Seelig (1980).

On the other hand, the values of Q listed in Table 2 are plotted in Fig. 3 where for each measured value of Q, the numerically computed value of Q and that calculated using SPM are shown. The numerical model yields fairly good agreement with the data. It should be mentioned that the bottom friction factor $f' = 0.05$ is used for all the runs without any adjustment of f' for each run. The selection of the seaward boundary location affects the degree of the agreement somewhat. In order to eliminate the uncertainties associated with the seaward boundary location and the shoaling coefficient estimated without regard to the effect of reflected waves, it would be required to match the present numerical solution with that based on the Boussinesq equations for a sloping bottom (Abbott et al. 1984; Madsen and Warren 1984).

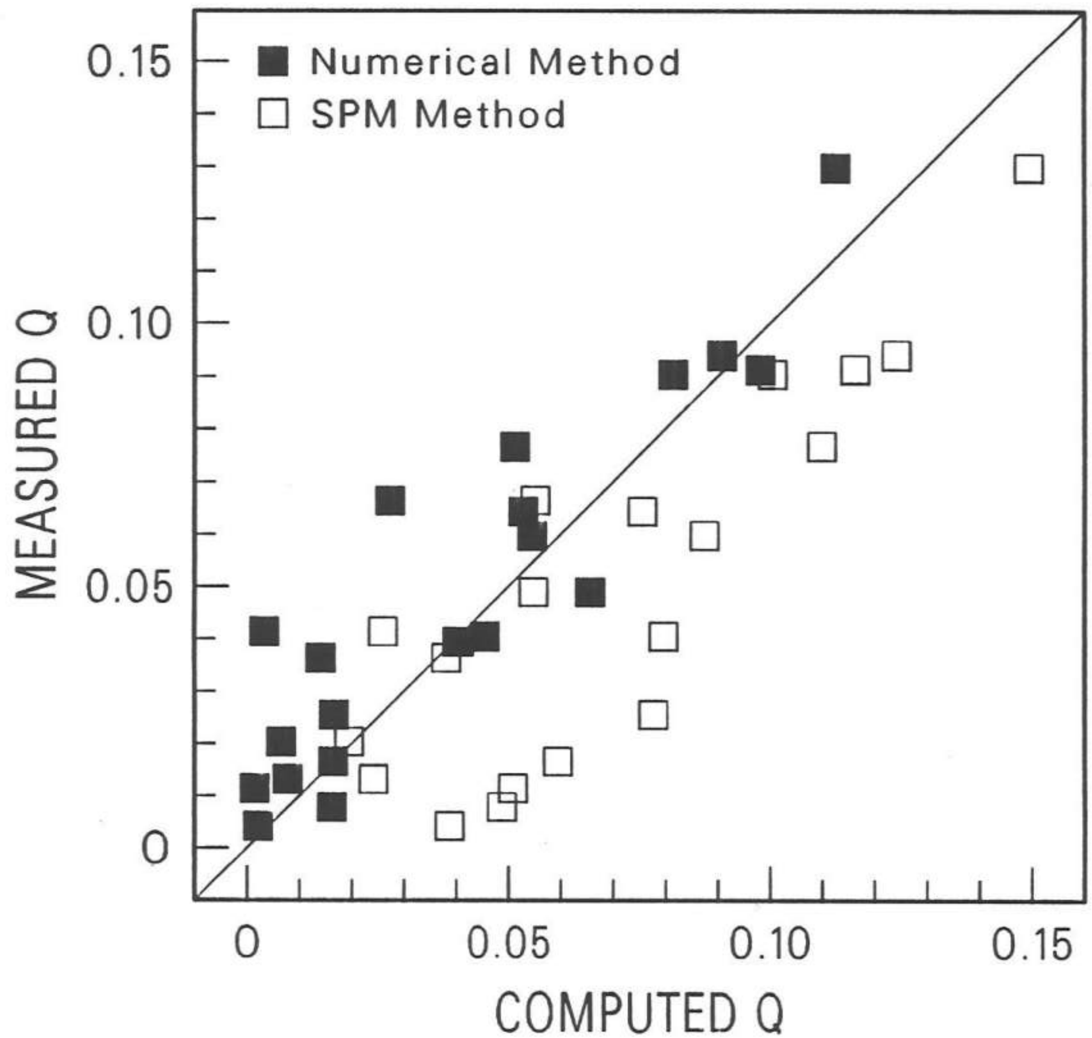

FIGURE 3. Comparison of computed and measured values of Q together with those calculated using empirical formula in SPM

Computed Flow Field

In addition to the average overtopping rate, the numerical model computes the temporal and spatial variations of the normalized water depth and horizontal velocity in the computation domain $0 \leq x \leq x_e$. The computed results for Run No. 3 with $\xi = 1.97$ are presented in the following since the numerical model predicts wave breaking in the vicinity of the toe of the 1:3 slope. Those for Run No. 10 with $\xi = 3.33$ and Run No. 14 with $\xi = 5.34$ included in the thesis of Wurjanto (1988) do not indicate wave breaking.

Fig. 4 shows the prescribed periodic variation of $\eta_i(t)$ and the computed variation of $\eta_r(t)$ at the seaward boundary located at x=0 for Run No. 3 with $d_t = 3$. For this run, the shoaling coefficient $K_s = 0.95$ and the Ursell parameter $U_r = 19$ as shown in Table 3. The incident periodic wave profile $\eta_i(t)$ whose period and height are unity and K_s, respectively, is specified using Stokes second-order wave theory. The computed reflected wave profile $\eta_r(t)$ becomes periodic before t=4. The computed reflection coefficient r = 0.29 for Run No. 3 is the height of $\eta_r(t)$ during $4 \leq t \leq 5$ divided by K_s. The asymmetry of the profile $\eta_r(t)$ is also noticed for the other runs and appears to be caused by wave overtopping since more symmetric profiles were predicted previously for the case of no wave overtopping (e.g., Kobayashi et al. 1987).

Fig. 5 shows the computed temporal variations of u and $c = \sqrt{h}$ at the landward edge located at $x = x_e$. Fig. 6 shows the corresponding variation of $m = uh$ at $x = x_e$. The computed results for the other runs are very similar to those shown in Figs. 5 and 6. Wave overtopping starts suddenly as a supercritical flow for which $u > c$ and decreases gradually as a critical flow for which $u = c$. The computed maximum value of u is on the order of unity. These figures show that the overtopping flow is highly unsteady. The

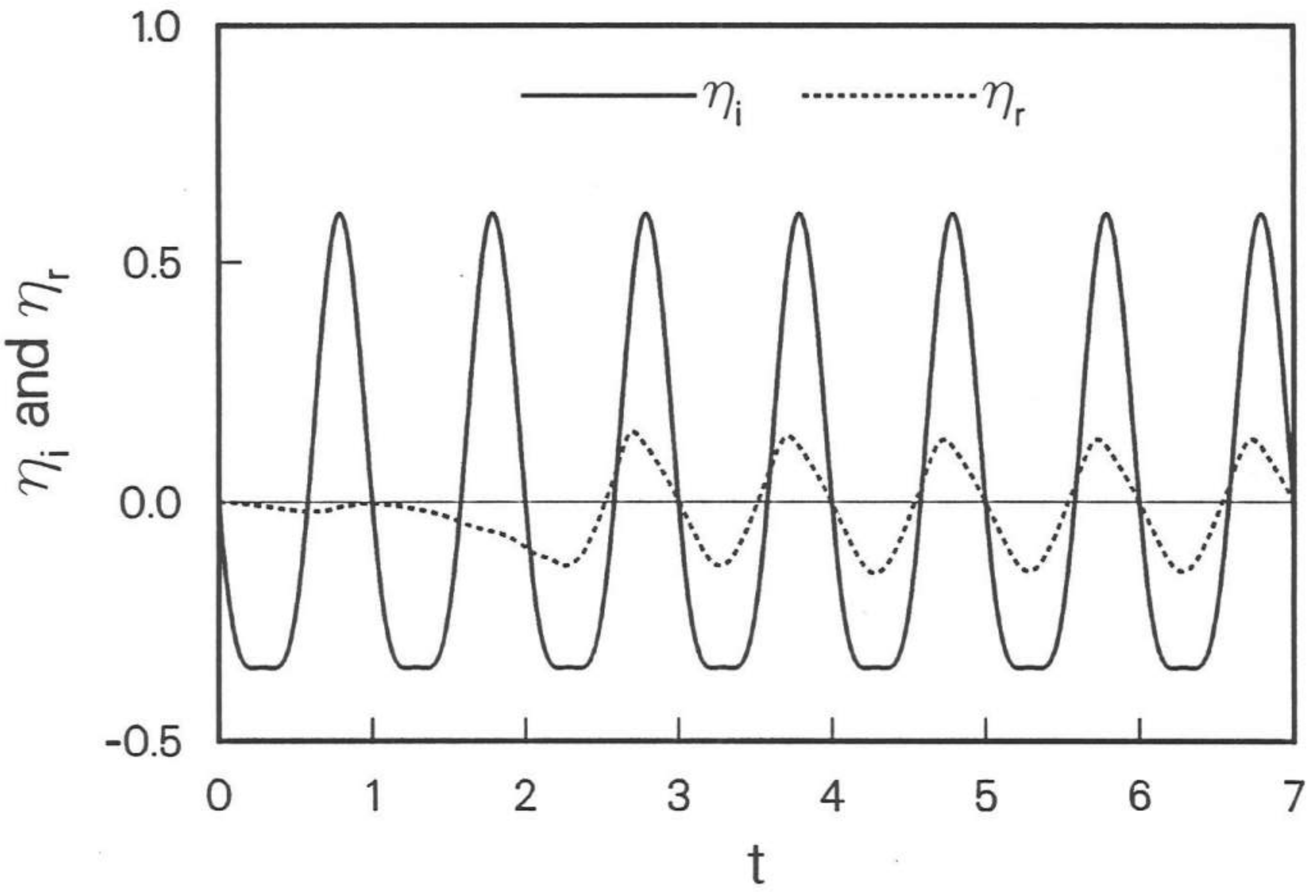

FIGURE 4. Specified incident wave profile $\eta_i(t)$ and computed reflected wave profile $\eta_r(t)$ at the seaward boundary as a function of normalized time t for Run No. 3

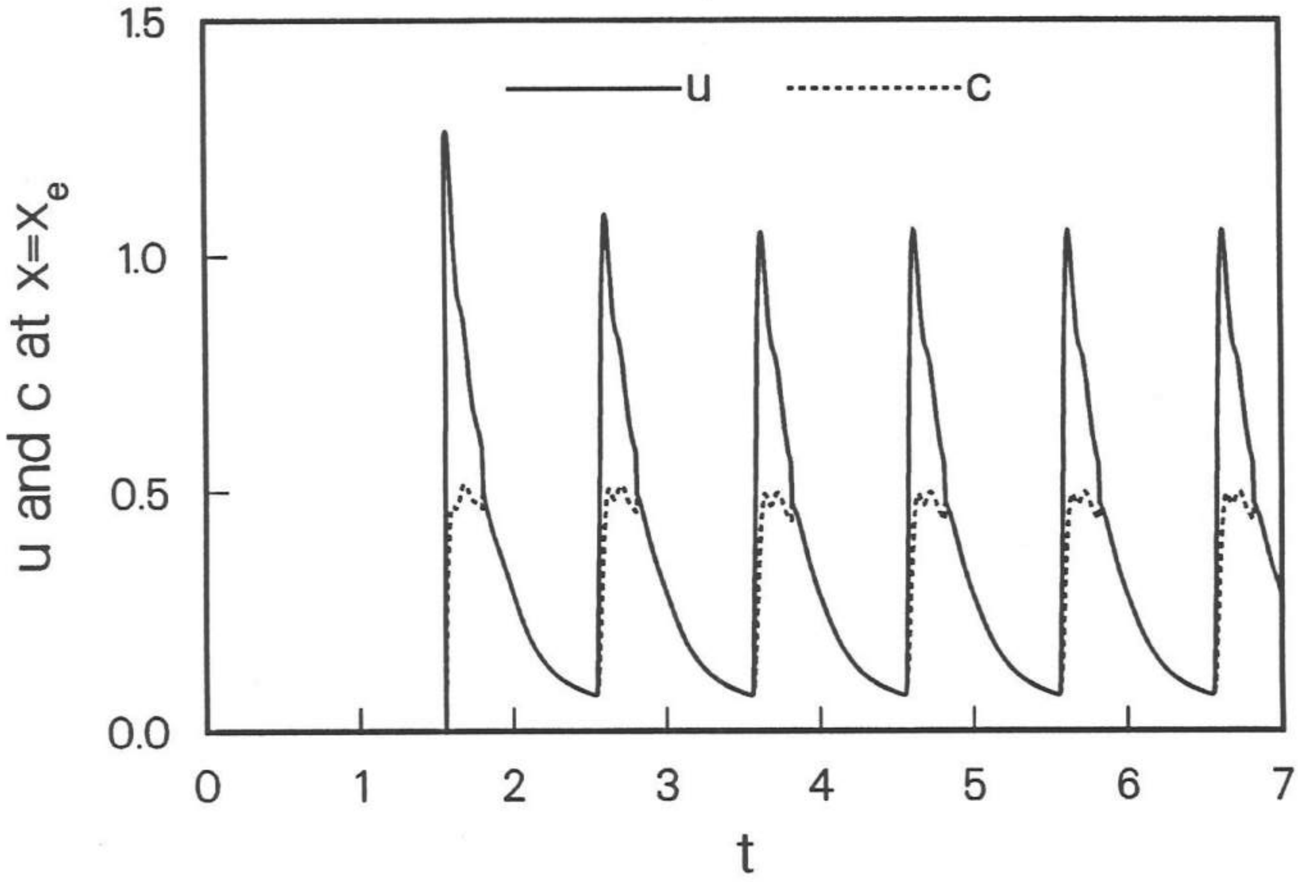

FIGURE 5. Temporal variations of u and $c = \sqrt{h}$ at the landward edge for Run No. 3

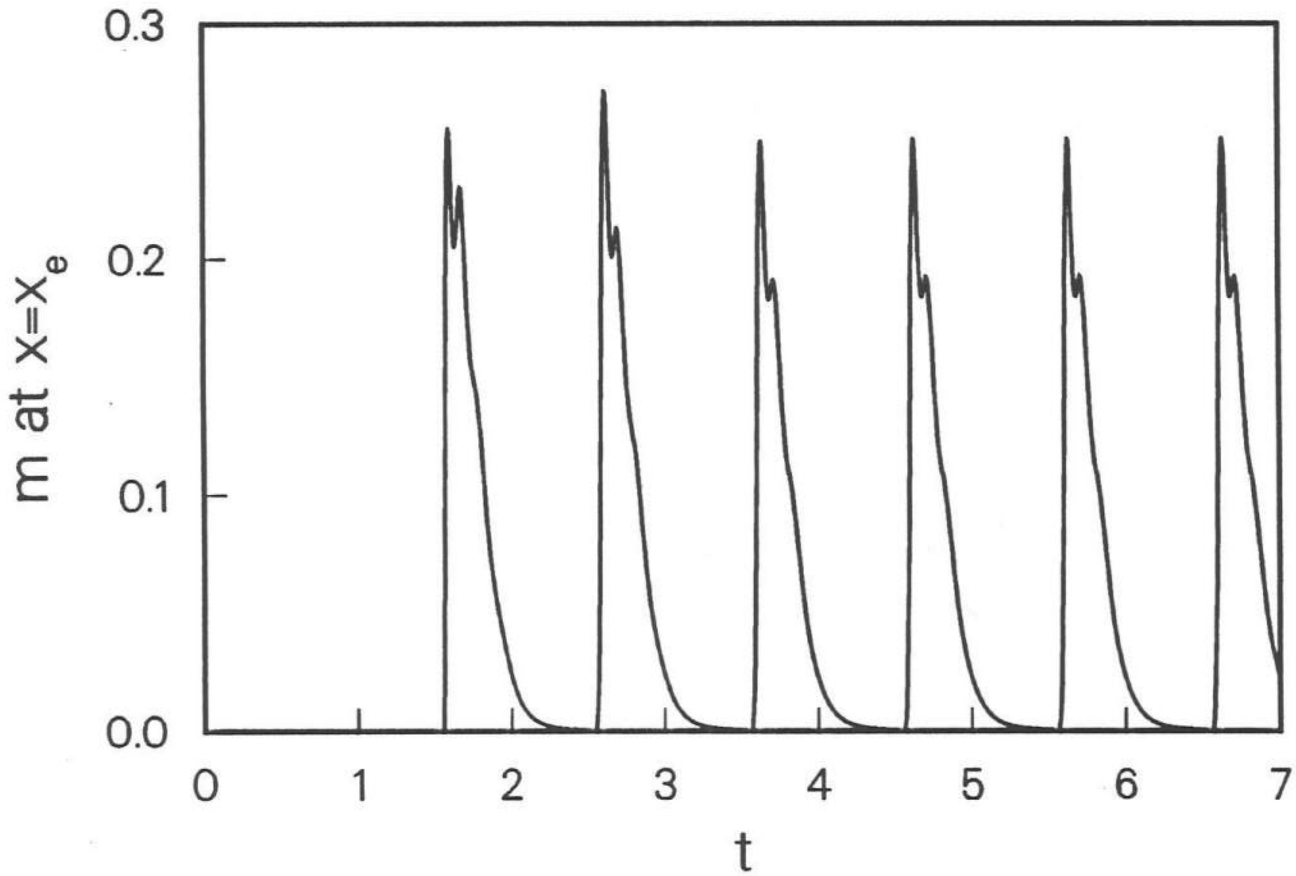

FIGURE 6. Temporal variation of normalized volume flux per unit width at the landward edge for Run No. 3

periodicity of the overtopping flow is established before $t = 4$, consistent with the experimental procedure of Saville (1955). The average value Q for m(t) during $4 \leq t \leq 5$ is 0.0528 and that during $6 \leq t \leq 7$ is 0.0529. Fig. 6 shows that the maximum value of m is much greater than Q. Since wave overtopping should cause the corresponding net flow directed landward at the seaward boundary, these values of Q at $x = x_e$ are compared with the average values of m(t) at x=0 which are 0.0639 for $4 \leq t \leq 5$ and 0.0598 for $6 \leq t \leq 7$. It appears to take more time to establish the steadiness of the net flow at x=0 perhaps because the flow at x=0 is highly oscillatory unlike the overtopping flow at $x=x_e$ directed landward only (Wurjanto 1988).

Figs. 7 and 8 show the spatial variations of the normalized free surface elevation η above SWL and the normalized horizontal velocity u, respectively, at t=4, 4.25, 4.5, 4.75, 5, 6.25, 6.5, 6.75 and 7. The normalized bottom and structure geometry given by Eq. 7 in the domain $0 \leq x \leq x_e$ is also plotted in Fig. 7. The periodicity of η and u is apparent in these figures. Fig. 7 indicates wave breaking in the vicinity of the toe of the structure. The numerical oscillations appearing at the rear of the wave crests could be reduced by increasing the values of the damping coefficients used for the computation (Kobayashi and DeSilva 1987). Fig. 8 indicates the large horizontal velocities associated with the wave uprush and downrush on the structure, which would determine the stability of armor units (Kobayashi and Otta 1987) if this structure were protected with armor units.

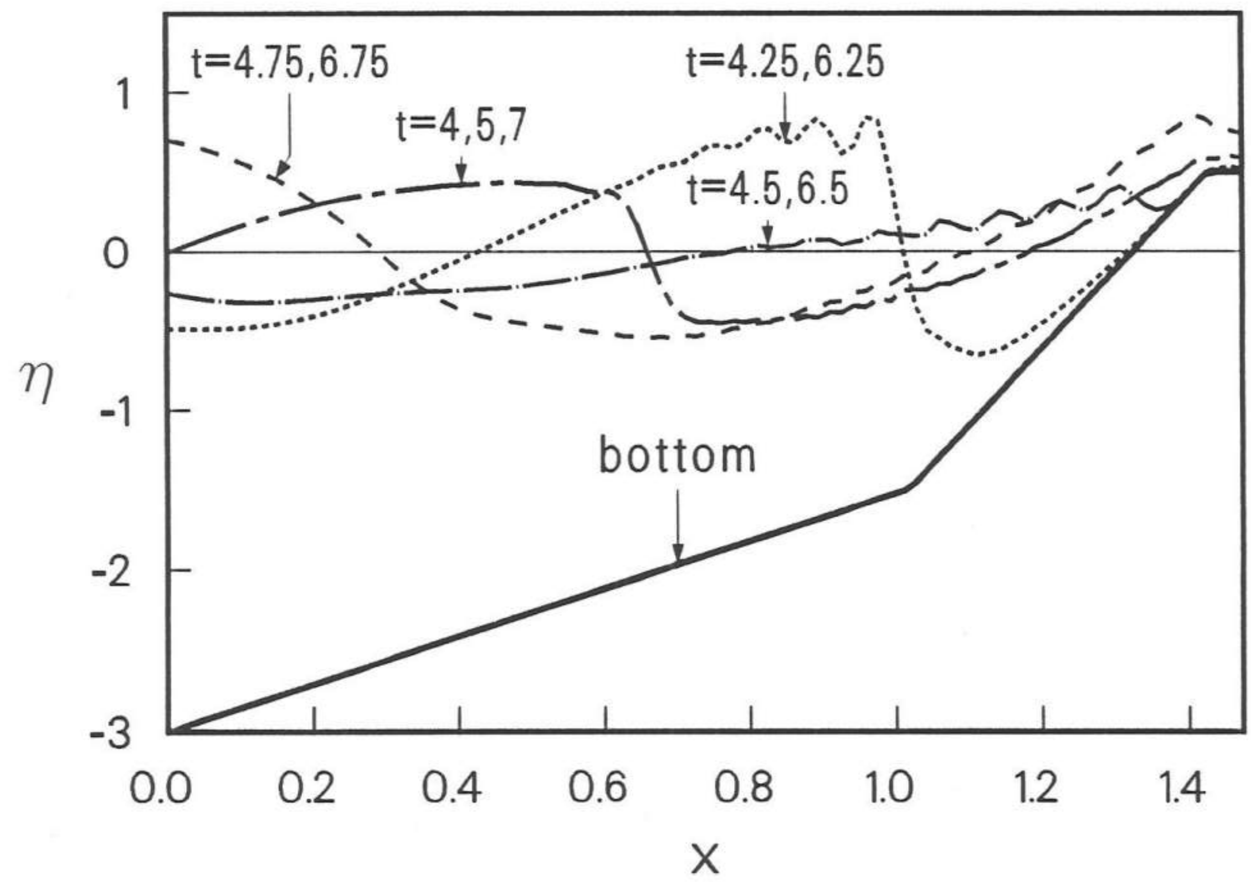

FIGURE 7. Spacial variations of normalized free surface elevation η at given normalized time t for Run No. 3

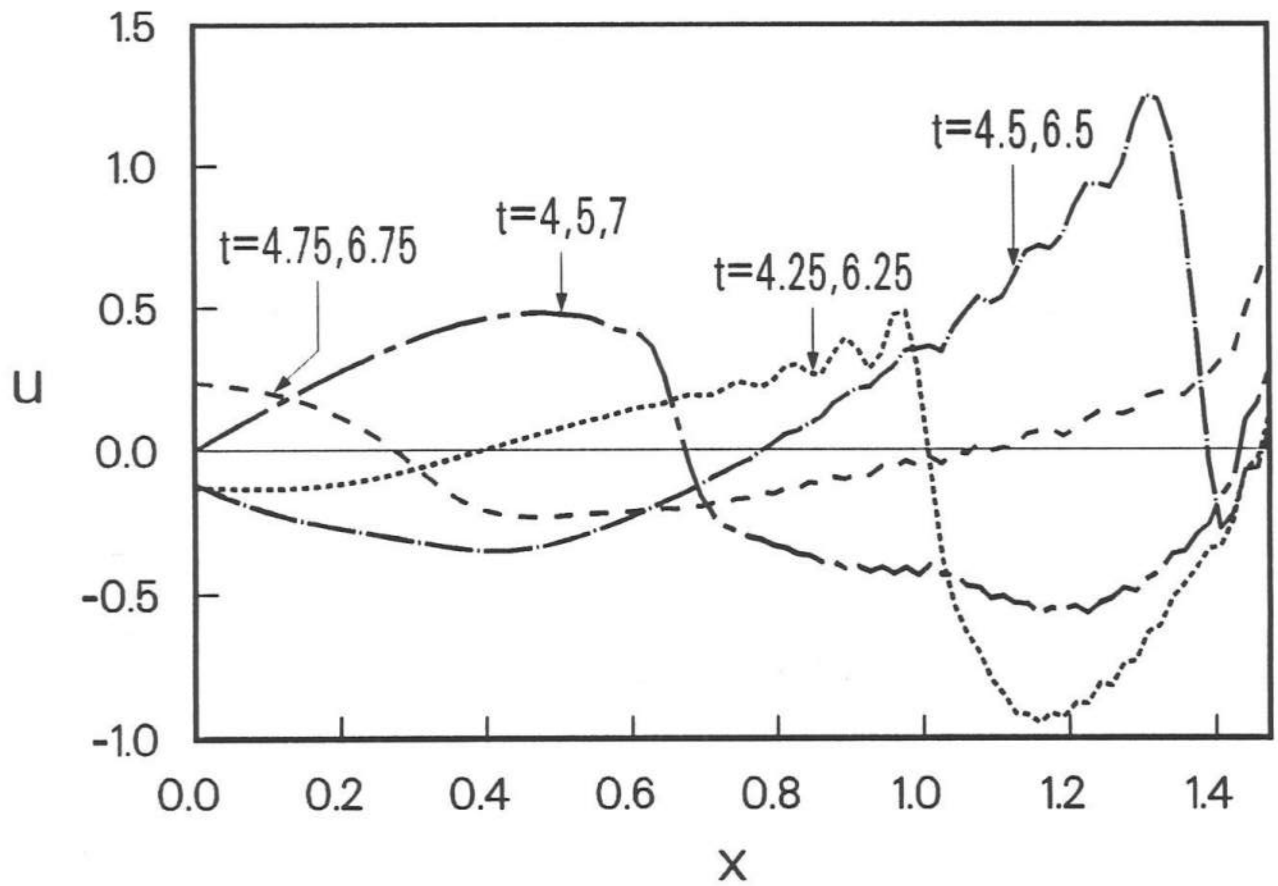

FIGURE 8. Spacial variations of normalized horizontal velocity u at given normalized time t for Run No. 3

PART IV: CONCLUSIONS

The numerical model expanded herein may be used to predict the fairly detailed hydrodynamics associated with wave overtopping over the crest of a smooth impermeable coastal structure located on a sloping beach. The comparison of the model with the data is limited to the average overtopping rates of monochromatic waves. More detailed evaluation and calibration of the model will require more sophisticated measurements. The numerical model may also be applied to rough impermeable structures by adjusting the friction factor associated with the surface roughness (Kobayashi et al. 1987).

In order to apply the model to overtopped rubble-mound breakwaters, the effects of random waves, permeability and wave action on the landward side of the breakwater may need to be taken into account. Such an extended numerical model combined with the armor stability model of Kobayashi and Otta (1987) could be used to investigate various design problems associated with rubble-mound breakwaters. In any case, it is desirable to improve the present design practices of coastal structures to the level of sophistication associated with the design of offshore structures performed using numerical models and hydraulic model tests.

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APPENDIX A: NOTATION

The following symbols are used in this report:

B' = dimensional crest width of structure;

c = $\sqrt{h}$;

d_h = water depth below SWL on horizontal bottom;

d_s = water depth below SWL at toe of structure;

d_t = water depth below SWL at seaward boundary;

f = bottom friction factor;

g = gravitational acceleration;

H' = dimensional wave height at seaward boundary;

H_c = crest height of structure above SWL;

H_o' = dimensional deep-water wave height;

h = instantaneous water depth;

K_s = shoaling coefficient at seaward boundary;

L = wavelength at seaward boundary;

m = normalized volume flux per unit width;

Q = average overtopping rate per unit width;

Q_o^* = empirical coefficient for wave overtopping formula;

R = wave run-up on structure in absence of overtopping;

r = wave reflection coefficient;

T' = dimensional wave period;

t = time

t_p = time when overtopping flow becomes periodic;

Δt = dimensionless time step used for computation;

U_r = Ursell parameter at seaward boundary;

u = instantaneous depth-averaged horizontal velocity;

x = horizontal coordinate with $x = 0$ at seaward boundary;

x_e = x-coordinate at landward edge;

Δx = dimensionless space size used for computation;

z = vertical coordinate with $z = 0$ at SWL;

α = characteristic variable defined as $\alpha = (u + 2c)$;

α_* = empirical coefficient for wave overtopping formula;

β = characteristic variable defined as $\beta = (-u + 2c)$;

δ = infinitesimal water depth defining computational waterline;

η = instantaneous free surface elevation above SWL;

η_i = free surface variation of incident wave train at $x = 0$;

η_r = free surface variation of reflected wave train at $x=0$;

θ = local slope angle in computation domain;

θ_s' = angle in degrees of structure slope;

ξ = surf similarity parameter based on structure slope;

ρ = constant fluid density;

σ = dimensionless parameter related to wave steepness; and

τ_b' = dimensional bottom shear stress.

Superscript

$'$ = prime indicating physical variables.

APPENDIX B: DIMENSIONAL DATA

The following quantities for each test are listed in the attached table:

$\cot\theta'_s$ = parameter related to the slope of the structure which is 1 on $\cot\theta'_s$;

H' = incident wave height given in the report of Saville (1955);

T' = incident wave period;

d'_h = water depth below SWL on the horizontal bottom;

d'_s = water depth below SWL at the toe of the structure whose slope is 1 on $\cot\theta'_s$;

H'_c = crest height of the structure above SWL; and

Q'_{TEST} = average wave overtopping rate per unit width measured for each test.

The dimensional quantities given in the report of Saville (1955) were for the prototype conditions. The model scale assumed in his report was as follows:

Test No.	Structure Slope	Model Scale	Description
1-110	1 on 1.5	1:17	Beach Erosion Board
111-221	1 on 3	1:17	Beach Erosion Board
222-261	1 on 3	1:30	Jacksonville District
262-301	1 on 6	1:30	Jacksonville District

It should be noted that the value of H' in the attached table is the deep water wave height, H'_0, for Test No. 1 to 221 and the measured wave height in the water depth d'_h for Test 222-301.

TEST NO.	$\cot\theta_s'$	H' *) (ft)	T' (sec)	d_h' (ft)	d_s' (ft)	H_c' (ft)	Q'_{TEST} (cfs/ft)
1	1.5	3.0	2.96	25.0	.0	3.00	.00
2	1.5	3.0	4.53	25.0	.0	3.00	.02
3	1.5	3.0	7.65	25.0	.0	3.00	.20
4	1.5	3.0	15.00	25.0	.0	3.00	2.50
5	1.5	6.0	4.19	25.0	.0	3.00	.11
6	1.5	6.0	6.40	25.0	.0	3.00	.83
7	1.5	6.0	10.81	25.0	.0	3.00	3.29
8	1.5	3.0	2.96	29.5	4.5	3.00	1.06
9	1.5	3.0	4.53	29.5	4.5	3.00	1.13
10	1.5	3.0	15.00	29.5	4.5	3.00	4.15
11	1.5	6.0	4.19	29.5	4.5	3.00	2.98
12	1.5	6.0	6.40	29.5	4.5	3.00	4.23
13	1.5	6.0	10.81	29.5	4.5	3.00	4.08
14	1.5	12.0	5.93	29.5	4.5	3.00	6.37
15	1.5	3.0	2.96	34.0	9.0	3.00	.73
16	1.5	3.0	4.53	34.0	9.0	3.00	.44
17	1.5	3.0	7.65	34.0	9.0	3.00	.80
18	1.5	3.0	15.00	34.0	9.0	3.00	4.33
19	1.5	6.0	4.19	34.0	9.0	3.00	5.45
20	1.5	6.0	6.40	34.0	9.0	3.00	5.57
21	1.5	6.0	10.81	34.0	9.0	3.00	4.46
22	1.5	6.0	15.00	34.0	9.0	3.00	9.26
23	1.5	12.0	5.93	34.0	9.0	3.00	12.60
24	1.5	12.0	9.05	34.0	9.0	3.00	13.55
25	1.5	3.0	7.65	25.0	.0	6.00	.00
26	1.5	3.0	15.00	25.0	.0	6.00	1.06
27	1.5	6.0	4.19	25.0	.0	6.00	.00
28	1.5	6.0	6.40	25.0	.0	6.00	.09
29	1.5	6.0	10.81	25.0	.0	6.00	1.70
30	1.5	3.0	2.96	29.5	4.5	6.00	.21
31	1.5	3.0	4.53	29.5	4.5	6.00	.31
32	1.5	3.0	7.65	29.5	4.5	6.00	.60
33	1.5	3.0	15.00	29.5	4.5	6.00	1.68
34	1.5	6.0	6.40	29.5	4.5	6.00	2.57
35	1.5	12.0	5.93	29.5	4.5	6.00	2.50
36	1.5	3.0	2.96	34.0	9.0	6.00	.08
37	1.5	3.0	4.53	34.0	9.0	6.00	.00
38	1.5	3.0	7.65	34.0	9.0	6.00	.00
39	1.5	3.0	15.00	34.0	9.0	6.00	1.59
40	1.5	6.0	4.19	34.0	9.0	6.00	2.98
41	1.5	6.0	6.40	34.0	9.0	6.00	2.99
42	1.5	6.0	10.81	34.0	9.0	6.00	2.71
43	1.5	6.0	15.00	34.0	9.0	6.00	3.82
44	1.5	12.0	5.93	34.0	9.0	6.00	9.36
45	1.5	12.0	9.05	34.0	9.0	6.00	10.28
46	1.5	3.0	15.00	25.0	.0	9.00	.26
47	1.5	6.0	6.40	25.0	.0	9.00	.00
48	1.5	6.0	10.81	25.0	.0	9.00	.45
49	1.5	3.0	2.96	29.5	4.5	9.00	.01
50	1.5	3.0	4.53	29.5	4.5	9.00	.02
51	1.5	3.0	7.65	29.5	4.5	9.00	.14
52	1.5	3.0	15.00	29.5	4.5	9.00	.56
53	1.5	6.0	4.19	29.5	4.5	9.00	.42
54	1.5	6.0	6.40	29.5	4.5	9.00	1.66
55	1.5	6.0	10.81	29.5	4.5	9.00	1.10
56	1.5	12.0	5.93	29.5	4.5	9.00	.78
57	1.5	3.0	15.00	34.0	9.0	9.00	.31
58	1.5	6.0	4.19	34.0	9.0	9.00	1.58
59	1.5	6.0	6.40	34.0	9.0	9.00	1.55
60	1.5	6.0	15.00	34.0	9.0	9.00	1.46
61	1.5	12.0	5.93	34.0	9.0	9.00	6.99
62	1.5	3.0	15.00	25.0	.0	12.00	.03
63	1.5	6.0	10.81	25.0	.0	12.00	.11
64	1.5	3.0	2.96	29.5	4.5	12.00	.00
65	1.5	3.0	4.53	29.5	4.5	12.00	.00
66	1.5	3.0	7.65	29.5	4.5	12.00	.00
67	1.5	3.0	15.00	29.5	4.5	12.00	.09
68	1.5	6.0	4.19	29.5	4.5	12.00	.20
69	1.5	6.0	6.40	29.5	4.5	12.00	.98
70	1.5	6.0	10.81	29.5	4.5	12.00	.68
71	1.5	12.0	5.93	29.5	4.5	12.00	.24
72	1.5	3.0	15.00	34.0	9.0	12.00	.00
73	1.5	6.0	4.19	34.0	9.0	12.00	.46
74	1.5	6.0	6.40	34.0	9.0	12.00	.45
75	1.5	6.0	10.81	34.0	9.0	12.00	.64
76	1.5	6.0	15.00	34.0	9.0	12.00	.36
77	1.5	12.0	5.93	34.0	9.0	12.00	4.72
78	1.5	12.0	9.05	34.0	9.0	12.00	6.68
79	1.5	3.0	15.00	29.5	4.5	15.00	.00
80	1.5	6.0	4.19	29.5	4.5	15.00	.06

*) Deep-water wave height for tests no. 1 to 221, wave height at the beach toe for others.

TEST NO.	$\cot\theta'_s$	H' *) (ft)	T' (sec)	d'_h (ft)	d'_s (ft)	H'_c (ft)	Q'_{TEST} (cfs/ft)
81	1.5	6.0	4.19	29.5	4.5	18.00	.00
82	1.5	6.0	6.40	29.5	4.5	15.00	.46
83	1.5	6.0	6.40	29.5	4.5	18.00	.11
84	1.5	6.0	6.40	29.5	4.5	21.00	.02
85	1.5	6.0	10.81	29.5	4.5	15.00	.26
86	1.5	6.0	10.81	29.5	4.5	18.00	.09
87	1.5	6.0	10.81	29.5	4.5	21.00	.00
88	1.5	12.0	10.90	29.5	4.5	15.00	.04
89	1.5	12.0	10.90	29.5	4.5	18.00	.00
90	1.5	6.0	4.19	34.0	9.0	15.00	.09
91	1.5	6.0	4.19	34.0	9.0	18.00	.00
92	1.5	6.0	6.40	34.0	9.0	15.00	.09
93	1.5	6.0	6.40	34.0	9.0	15.00	.00
94	1.5	6.0	10.81	34.0	9.0	15.00	.35
95	1.5	6.0	10.81	34.0	9.0	18.00	.07
96	1.5	6.0	10.81	34.0	9.0	21.00	.00
97	1.5	6.0	15.00	34.0	9.0	15.00	.11
98	1.5	12.0	5.93	34.0	9.0	15.00	3.72
99	1.5	12.0	5.93	34.0	9.0	18.00	2.38
100	1.5	12.0	5.93	34.0	9.0	21.00	1.39
101	1.5	12.0	5.93	34.0	9.0	24.00	.94
102	1.5	12.0	5.93	34.0	9.0	30.00	.35
103	1.5	12.0	5.93	34.0	9.0	33.00	.12
104	1.5	12.0	5.93	34.0	9.0	36.00	.00
105	1.5	12.0	9.05	34.0	9.0	15.00	4.98
106	1.5	12.0	9.05	34.0	9.0	18.00	3.76
107	1.5	12.0	9.05	34.0	9.0	21.00	2.18
108	1.5	12.0	9.05	34.0	9.0	24.00	1.64
109	1.5	12.0	9.05	34.0	9.0	27.00	1.28
110	1.5	12.0	9.05	34.0	9.0	33.00	.37
111	3.0	3.0	2.96	29.5	4.5	3.00	.09
112	3.0	3.0	4.53	29.5	4.5	3.00	.75
113	3.0	3.0	7.65	29.5	4.5	3.00	1.47
114	3.0	3.0	10.50	29.5	4.5	3.00	.63
115	3.0	3.0	15.00	29.5	4.5	3.00	3.74
116	3.0	4.5	2.96	29.5	4.5	3.00	.31
117	3.0	4.5	4.53	29.5	4.5	3.00	1.45
118	3.0	4.5	7.65	29.5	4.5	3.00	4.40
119	3.0	4.5	10.50	29.5	4.5	3.00	3.94
120	3.0	4.5	15.00	29.5	4.5	3.00	4.94

TEST NO.	$\cot\theta'_s$	H' *) (ft)	T' (sec)	d'_h (ft)	d'_s (ft)	H'_c (ft)	Q'_{TEST} (cfs/ft)
121	3.0	6.0	4.19	29.5	4.5	3.00	2.77
122	3.0	6.0	6.40	29.5	4.5	3.00	5.54
123	3.0	6.0	10.81	29.5	4.5	3.00	4.98
124	3.0	12.0	5.93	29.5	4.5	3.00	10.25
125	3.0	3.0	2.96	34.0	9.0	3.00	.12
126	3.0	3.0	4.53	34.0	9.0	3.00	.94
127	3.0	3.0	7.65	34.0	9.0	3.00	1.03
128	3.0	3.0	10.50	34.0	9.0	3.00	1.18
129	3.0	3.0	15.00	34.0	9.0	3.00	5.62
130	3.0	4.5	2.96	34.0	9.0	3.00	.31
131	3.0	4.5	4.53	34.0	9.0	3.00	1.90
132	3.0	4.5	7.65	34.0	9.0	3.00	4.89
133	3.0	4.5	10.50	34.0	9.0	3.00	3.68
134	3.0	4.5	15.00	34.0	9.0	3.00	7.03
135	3.0	6.0	4.19	34.0	9.0	3.00	3.79
136	3.0	6.0	6.40	34.0	9.0	3.00	5.36
137	3.0	6.0	10.81	34.0	9.0	3.00	7.83
138	3.0	6.0	15.00	34.0	9.0	3.00	9.35
139	3.0	12.0	5.93	34.0	9.0	3.00	13.49
140	3.0	3.0	2.96	29.5	4.5	6.00	.00
141	3.0	3.0	4.53	29.5	4.5	6.00	.00
142	3.0	3.0	7.65	29.5	4.5	6.00	.15
143	3.0	3.0	10.50	29.5	4.5	6.00	.28
144	3.0	3.0	15.00	29.5	4.5	6.00	1.35
145	3.0	4.5	2.96	29.5	4.5	6.00	.00
146	3.0	4.5	4.53	29.5	4.5	6.00	.00
147	3.0	6.0	4.19	29.5	4.5	6.00	.46
148	3.0	6.0	6.40	29.5	4.5	6.00	3.45
149	3.0	6.0	10.81	29.5	4.5	6.00	1.38
150	3.0	12.0	5.93	29.5	4.5	6.00	7.07
151	3.0	3.0	2.96	34.0	9.0	6.00	.00
152	3.0	3.0	4.53	34.0	9.0	6.00	.00
153	3.0	3.0	7.65	34.0	9.0	6.00	.11
154	3.0	3.0	10.50	34.0	9.0	6.00	.62
155	3.0	3.0	15.00	34.0	9.0	6.00	2.18
156	3.0	4.5	2.96	34.0	9.0	6.00	.08
157	3.0	4.5	10.50	34.0	9.0	6.00	1.35
158	3.0	4.5	15.00	34.0	9.0	6.00	4.15
159	3.0	6.0	4.19	34.0	9.0	6.00	.48
160	3.0	6.0	6.40	34.0	9.0	6.00	3.03

*) Deep-water wave height for tests no. 1 to 221, wave height at the beach toe for others.

TEST NO.	$\cot\theta'_s$	H' *) (ft)	T' (sec)	d'_h (ft)	d'_s (ft)	H'_c (ft)	Q'_{TEST} (cfs/ft)
161	3.0	6.0	10.81	34.0	9.0	6.00	3.37
162	3.0	6.0	15.00	34.0	9.0	6.00	5.82
163	3.0	12.0	5.93	34.0	9.0	6.00	9.54
164	3.0	12.0	9.05	34.0	9.0	6.00	16.48
165	3.0	3.0	7.65	29.5	4.5	9.00	.00
166	3.0	3.0	10.50	29.5	4.5	9.00	.00
167	3.0	3.0	15.00	29.5	4.5	9.00	.39
168	3.0	4.5	10.50	29.5	4.5	9.00	.48
169	3.0	4.5	15.00	29.5	4.5	9.00	1.03
170	3.0	6.0	4.19	29.5	4.5	9.00	.00
171	3.0	6.0	6.40	29.5	4.5	9.00	1.60
172	3.0	6.0	10.81	29.5	4.5	9.00	.35
173	3.0	12.0	5.93	29.5	4.5	9.00	4.63
174	3.0	3.0	7.65	34.0	9.0	9.00	.00
175	3.0	3.0	10.50	34.0	9.0	9.00	.00
176	3.0	3.0	15.00	34.0	9.0	9.00	.62
177	3.0	4.5	2.96	34.0	9.0	9.00	.00
178	3.0	4.5	4.53	34.0	9.0	9.00	.00
179	3.0	4.5	7.65	34.0	9.0	9.00	.50
180	3.0	4.5	10.50	34.0	9.0	9.00	.30
181	3.0	4.5	15.00	34.0	9.0	9.00	1.38
182	3.0	6.0	4.19	34.0	9.0	9.00	.14
183	3.0	6.0	6.40	34.0	9.0	9.00	.68
184	3.0	6.0	10.81	34.0	9.0	9.00	.66
185	3.0	6.0	15.00	34.0	9.0	9.00	2.24
186	3.0	12.0	5.93	34.0	9.0	9.00	6.04
187	3.0	12.0	9.05	34.0	9.0	9.00	12.16
188	3.0	3.0	15.00	29.5	4.5	12.00	.00
189	3.0	4.5	7.65	29.5	4.5	12.00	.02
190	3.0	4.5	10.50	29.5	4.5	12.00	.00
191	3.0	4.5	15.00	29.5	4.5	12.00	.02
192	3.0	6.0	6.40	29.5	4.5	12.00	.06
193	3.0	6.0	10.81	29.5	4.5	12.00	.00
194	3.0	12.0	5.93	29.5	4.5	12.00	2.27
195	3.0	3.0	15.00	34.0	9.0	12.00	.00
196	3.0	4.5	7.65	34.0	9.0	12.00	.00
197	3.0	4.5	10.50	34.0	9.0	12.00	.00
198	3.0	4.5	15.00	34.0	9.0	12.00	.62
199	3.0	6.0	4.19	34.0	9.0	12.00	.00
200	3.0	6.0	6.40	34.0	9.0	12.00	.00

TEST NO.	$\cot\theta'_s$	H' *) (ft)	T' (sec)	d'_h (ft)	d'_s (ft)	H'_c (ft)	Q'_{TEST} (cfs/ft)
201	3.0	6.0	10.81	34.0	9.0	12.00	.00
202	3.0	6.0	15.00	34.0	9.0	12.00	.79
203	3.0	12.0	5.93	34.0	9.0	12.00	3.23
204	3.0	12.0	9.05	34.0	9.0	12.00	9.65
205	3.0	4.5	7.65	29.5	4.5	15.00	.00
206	3.0	4.5	15.00	29.5	4.5	15.00	.00
207	3.0	6.0	6.40	29.5	4.5	15.00	.00
208	3.0	12.0	10.90	29.5	4.5	15.00	.15
209	3.0	12.0	10.90	29.5	4.5	18.00	.14
210	3.0	12.0	10.90	29.5	4.5	21.00	.00
211	3.0	4.5	15.00	34.0	9.0	15.00	.00
212	3.0	6.0	15.00	34.0	9.0	15.00	.00
213	3.0	12.0	5.93	34.0	9.0	15.00	1.15
214	3.0	12.0	5.93	34.0	9.0	18.00	.19
215	3.0	12.0	5.93	34.0	9.0	21.00	.00
216	3.0	12.0	9.05	34.0	9.0	15.00	7.01
217	3.0	12.0	9.05	34.0	9.0	18.00	4.82
218	3.0	12.0	9.05	34.0	9.0	21.00	2.20
219	3.0	12.0	9.05	34.0	9.0	24.00	1.05
220	3.0	12.0	9.05	34.0	9.0	27.00	.54
221	3.0	12.0	9.05	34.0	9.0	30.00	.10
222	3.0	4.0	4.50	25.0	10.0	1.58	2.60
223	3.0	4.0	5.50	25.0	10.0	1.98	2.62
224	3.0	6.0	4.50	25.0	10.0	2.28	4.20
225	3.0	6.0	5.50	25.0	10.0	3.00	4.58
226	3.0	8.0	5.00	25.0	10.0	2.97	5.94
227	3.0	8.0	6.00	25.0	10.0	3.58	6.60
228	3.0	10.0	5.50	25.0	10.0	2.92	7.21
229	3.0	10.0	6.50	25.0	10.0	3.65	8.88
230	3.0	12.0	6.00	25.0	10.0	3.05	11.10
231	3.0	12.0	7.00	25.0	10.0	3.80	10.80
232	3.0	4.0	4.50	25.0	10.0	3.15	1.60
233	3.0	4.0	5.50	25.0	10.0	3.95	1.15
234	3.0	6.0	4.50	25.0	10.0	4.55	1.80
235	3.0	6.0	5.50	25.0	10.0	6.00	1.80
236	3.0	8.0	5.00	25.0	10.0	5.95	2.52
237	3.0	8.0	6.00	25.0	10.0	7.15	3.45
238	3.0	10.0	5.50	25.0	10.0	5.85	4.42
239	3.0	10.0	6.50	25.0	10.0	7.30	5.00
240	3.0	12.0	6.00	25.0	10.0	6.10	5.40

*) Deep-water wave height for tests no. 1 to 221, wave height at the beach toe for others.

TEST NO.	$\cot\theta_s'$	H' *) (ft)	T' (sec)	d_h' (ft)	d_s' (ft)	H_c' (ft)	Q_{TEST}' (cfs/ft)
241	3.0	12.0	7.00	25.0	10.0	7.60	6.43
242	3.0	4.0	4.50	25.0	10.0	4.73	.20
243	3.0	4.0	5.50	25.0	10.0	5.93	.16
244	3.0	6.0	4.50	25.0	10.0	6.83	.40
245	3.0	6.0	5.50	25.0	10.0	9.00	.33
246	3.0	8.0	5.00	25.0	10.0	8.92	1.08
247	3.0	8.0	6.00	25.0	10.0	10.73	1.35
248	3.0	10.0	5.50	25.0	10.0	8.77	1.31
249	3.0	10.0	6.50	25.0	10.0	10.95	1.53
250	3.0	12.0	6.00	25.0	10.0	9.15	1.95
251	3.0	12.0	7.00	25.0	10.0	11.40	2.32
252	3.0	4.0	4.50	25.0	10.0	6.30	.00
253	3.0	4.0	5.50	25.0	10.0	7.90	.00
254	3.0	6.0	4.50	25.0	10.0	9.10	.00
255	3.0	6.0	5.50	25.0	10.0	12.00	.00
256	3.0	8.0	5.00	25.0	10.0	11.90	.18
257	3.0	8.0	6.00	25.0	10.0	14.30	.45
258	3.0	10.0	5.50	25.0	10.0	11.70	.65
259	3.0	10.0	6.50	25.0	10.0	14.60	.14
260	3.0	12.0	6.00	25.0	10.0	12.20	.90
261	3.0	12.0	7.00	25.0	10.0	15.20	.51
262	6.0	4.0	4.50	25.0	10.0	.88	1.80
263	6.0	4.0	5.50	25.0	10.0	.98	2.13
264	6.0	6.0	4.50	25.0	10.0	1.05	2.20
265	6.0	6.0	5.50	25.0	10.0	1.50	4.25
266	6.0	8.0	5.00	25.0	10.0	1.15	4.68
267	6.0	8.0	6.00	25.0	10.0	1.70	5.85
268	6.0	10.0	5.50	25.0	10.0	1.27	6.71
269	6.0	10.0	6.50	25.0	10.0	1.75	7.20
270	6.0	12.0	6.00	25.0	10.0	1.50	8.10
271	6.0	12.0	7.00	25.0	10.0	1.83	10.69
272	6.0	4.0	4.50	25.0	10.0	1.75	.80
273	6.0	4.0	5.50	25.0	10.0	1.95	.98
274	6.0	6.0	4.50	25.0	10.0	2.10	1.40
275	6.0	6.0	5.50	25.0	10.0	3.00	1.64
276	6.0	8.0	5.00	25.0	10.0	2.30	2.16
277	6.0	8.0	6.00	25.0	10.0	3.40	2.25
278	6.0	10.0	5.50	25.0	10.0	2.55	4.09
279	6.0	10.0	6.50	25.0	10.0	3.50	3.05
280	6.0	12.0	6.00	25.0	10.0	3.00	3.90

TEST NO.	$\cot\theta_s'$	H' *) (ft)	T' (sec)	d_h' (ft)	d_s' (ft)	H_c' (ft)	Q_{TEST}' (cfs/ft)
281	6.0	12.0	7.00	25.0	10.0	3.65	5.27
282	6.0	4.0	4.50	25.0	10.0	2.63	.20
283	6.0	4.0	5.50	25.0	10.0	2.93	.16
284	6.0	6.0	4.50	25.0	10.0	3.15	.40
285	6.0	6.0	5.50	25.0	10.0	4.50	.16
286	6.0	8.0	5.00	25.0	10.0	3.45	.72
287	6.0	8.0	6.00	25.0	10.0	5.10	.30
288	6.0	10.0	5.50	25.0	10.0	3.82	1.47
289	6.0	10.0	6.50	25.0	10.0	5.25	.83
290	6.0	12.0	6.00	25.0	10.0	4.50	1.50
291	6.0	12.0	7.00	25.0	10.0	5.48	1.54
292	6.0	4.0	4.50	25.0	10.0	3.50	.00
293	6.0	4.0	5.50	25.0	10.0	3.90	.00
294	6.0	6.0	4.50	25.0	10.0	4.20	.00
295	6.0	6.0	5.50	25.0	10.0	6.00	.00
296	6.0	8.0	5.00	25.0	10.0	4.60	.00
297	6.0	8.0	6.00	25.0	10.0	6.80	.00
298	6.0	10.0	5.50	25.0	10.0	5.10	.49
299	6.0	10.0	6.50	25.0	10.0	7.00	.28
300	6.0	12.0	6.00	25.0	10.0	6.00	.60
301	6.0	12.0	7.00	25.0	10.0	7.30	.51

*) Deep-water wave height for tests no. 1 to 221, wave height at the beach toe for others.

APPENDIX C: NORMALIZED DATA

The following dimensionless parameters for each test are listed in the attached table:

$\cot\theta_s'$ = parameter related to the slope of the structure which is 1 on $\cot\theta_s'$;

d_h = (d_h'/H_0') = normalized water depth below SWL on the horizontal bottom where H_0' = deep water wave height;

d_s = (d_s'/H_0') = normalized water depth below SWL at the toe of the structure whose slope is 1 on $\cot\theta_s'$;

H_c = (H_c'/H_0') = normalized crest height of the structure above SWL;

R = (R'/H_0') = normalized wave run-up on the structure slope in the absence of wave overtopping estimated using the figures in SPM where R' = dimensional wave run-up;

σ = $T'(g/H_0')^{1/2}$ = parameter related to wave steepness;

ξ = $(\sigma \tan\theta_s'/\sqrt{2\pi})$ = surf similarity parameter based on the deep water wave height and structure slope; and

Q_{TEST} = $[Q_{TEST}'/(H_0'\sqrt{gH_0'})]$ = normalized average wave overtopping rate per unit width based on the measured value Q_{TEST}' for each test.

It should be noted that for Test No. 1 to 221, the deep water wave height H_0' is the wave height given in the report of Saville (1955), whereas for Test No. 222-301, the value of H_0' for each test is calculated from that referred to the depth d_h'.

TEST NO.	$\cot\theta_s'$	d_h	d_s	H_c	R	σ	ξ	$Q_{TEST} .10^3$
1	1.5	8.33	.00	1.00	.65	9.70	2.58	.00
2	1.5	8.33	.00	1.00	1.08	14.84	3.95	.68
3	1.5	8.33	.00	1.00	2.14	25.06	6.67	6.78
4	1.5	8.33	.00	1.00	4.02	49.14	13.07	84.79
5	1.5	4.17	.00	.50	.65	9.71	2.58	1.32
6	1.5	4.17	.00	.50	1.08	14.83	3.94	9.95
7	1.5	4.17	.00	.50	2.13	25.04	6.66	39.45
8	1.5	9.83	1.50	1.00	1.99	9.70	2.58	35.95
9	1.5	9.83	1.50	1.00	2.78	14.84	3.95	38.32
10	1.5	9.83	1.50	1.00	4.68	49.14	13.07	140.75
11	1.5	4.92	.75	.50	1.79	9.71	2.58	35.73
12	1.5	4.92	.75	.50	2.85	14.83	3.94	50.72
13	1.5	4.92	.75	.50	4.33	25.04	6.66	48.92
14	1.5	2.46	.38	.25	1.02	9.71	2.58	27.00
15	1.5	11.33	3.00	1.00	1.96	9.70	2.58	24.76
16	1.5	11.33	3.00	1.00	1.99	14.84	3.95	14.92
17	1.5	11.33	3.00	1.00	2.08	25.06	6.67	27.13
18	1.5	11.33	3.00	1.00	2.38	49.14	13.07	146.85
19	1.5	5.67	1.50	.50	1.99	9.71	2.58	65.35
20	1.5	5.67	1.50	.50	2.77	14.83	3.94	66.79
21	1.5	5.67	1.50	.50	3.78	25.04	6.66	53.48
22	1.5	5.67	1.50	.50	4.34	34.75	9.24	111.03
23	1.5	2.83	.75	.25	1.79	9.71	2.58	53.42
24	1.5	2.83	.75	.25	2.85	14.82	3.94	57.44
25	1.5	8.33	.00	2.00	2.14	25.06	6.67	.00
26	1.5	8.33	.00	2.00	4.02	49.14	13.07	35.95
27	1.5	4.17	.00	1.00	.65	9.71	2.58	.00
28	1.5	4.17	.00	1.00	1.08	14.83	3.94	1.08
29	1.5	4.17	.00	1.00	2.13	25.04	6.66	20.38
30	1.5	9.83	1.50	2.00	1.99	9.70	2.58	7.12
31	1.5	9.83	1.50	2.00	2.78	14.84	3.95	10.51
32	1.5	9.83	1.50	2.00	3.78	25.06	6.67	20.35
33	1.5	9.83	1.50	2.00	4.68	49.14	13.07	56.98
34	1.5	4.92	.75	1.00	2.85	14.83	3.94	30.82
35	1.5	2.46	.38	.50	1.02	9.71	2.58	10.60
36	1.5	11.33	3.00	2.00	1.96	9.70	2.58	2.71
37	1.5	11.33	3.00	2.00	1.99	14.84	3.95	.00
38	1.5	11.33	3.00	2.00	2.08	25.06	6.67	.00
39	1.5	11.33	3.00	2.00	2.38	49.14	13.07	53.92
40	1.5	5.67	1.50	1.00	1.99	9.71	2.58	35.73
41	1.5	5.67	1.50	1.00	2.77	14.83	3.94	35.85
42	1.5	5.67	1.50	1.00	3.78	25.04	6.66	32.49
43	1.5	5.67	1.50	1.00	4.34	34.75	9.24	45.80
44	1.5	2.83	.75	.50	1.79	9.71	2.58	39.68
45	1.5	2.83	.75	.50	2.85	14.82	3.94	43.58
46	1.5	8.33	.00	3.00	4.02	49.14	13.07	8.82
47	1.5	4.17	.00	1.50	1.08	14.83	3.94	.00
48	1.5	4.17	.00	1.50	2.13	25.04	6.66	5.40
49	1.5	9.83	1.50	3.00	1.99	9.70	2.58	.34
50	1.5	9.83	1.50	3.00	2.78	14.84	3.95	.68
51	1.5	9.83	1.50	3.00	3.78	25.06	6.67	4.75
52	1.5	9.83	1.50	3.00	4.68	49.14	13.07	18.99
53	1.5	4.92	.75	1.50	1.79	9.71	2.58	5.04
54	1.5	4.92	.75	1.50	2.85	14.83	3.94	19.90
55	1.5	4.92	.75	1.50	4.33	25.04	6.66	13.19
56	1.5	2.46	.38	.75	1.02	9.71	2.58	3.31
57	1.5	11.33	3.00	3.00	2.38	49.14	13.07	10.51
58	1.5	5.67	1.50	1.50	1.99	9.71	2.58	18.95
59	1.5	5.67	1.50	1.50	2.77	14.83	3.94	18.59
60	1.5	5.67	1.50	1.50	4.34	34.75	9.24	17.51
61	1.5	2.83	.75	.75	1.79	9.71	2.58	29.63
62	1.5	8.33	.00	4.00	4.02	49.14	13.07	1.02
63	1.5	4.17	.00	2.00	2.13	25.04	6.66	1.32
64	1.5	9.83	1.50	4.00	1.99	9.70	2.58	.00
65	1.5	9.83	1.50	4.00	2.78	14.84	3.95	.00
66	1.5	9.83	1.50	4.00	3.78	25.06	6.67	.00
67	1.5	9.83	1.50	4.00	4.68	49.14	13.07	3.05
68	1.5	4.92	.75	2.00	1.79	9.71	2.58	2.40
69	1.5	4.92	.75	2.00	2.85	14.83	3.94	11.75
70	1.5	4.92	.75	2.00	4.33	25.04	6.66	8.15
71	1.5	2.46	.38	1.00	1.02	9.71	2.58	1.02
72	1.5	11.33	3.00	4.00	2.38	49.14	13.07	.00
73	1.5	5.67	1.50	2.00	1.99	9.71	2.58	5.52
74	1.5	5.67	1.50	2.00	2.77	14.83	3.94	5.40
75	1.5	5.67	1.50	2.00	3.78	25.04	6.66	7.67
76	1.5	5.67	1.50	2.00	4.34	34.75	9.24	4.32
77	1.5	2.83	.75	1.00	1.79	9.71	2.58	20.01
78	1.5	2.83	.75	1.00	2.85	14.82	3.94	28.32
79	1.5	9.83	1.50	5.00	4.68	49.14	13.07	.00
80	1.5	4.92	.75	2.50	1.79	9.71	2.58	.72

TEST NO.	$\cot\theta_s'$	d_h	d_s	H_c	R	σ	ξ	Q_{TEST} $.10^3$
81	1.5	4.92	.75	3.00	1.79	9.71	2.58	.00
82	1.5	4.92	.75	2.50	2.85	14.83	3.94	5.52
83	1.5	4.92	.75	3.00	2.85	14.83	3.94	1.32
84	1.5	4.92	.75	3.50	2.85	14.83	3.94	.24
85	1.5	4.92	.75	2.50	4.33	25.04	6.66	3.12
86	1.5	4.92	.75	3.00	4.33	25.04	6.66	1.08
87	1.5	4.92	.75	3.50	4.33	25.04	6.66	.00
88	1.5	2.46	.38	1.25	2.30	17.86	4.75	.17
89	1.5	2.46	.38	1.50	2.30	17.86	4.75	.00
90	1.5	5.67	1.50	2.50	1.99	9.71	2.58	1.08
91	1.5	5.67	1.50	3.00	1.99	9.71	2.58	.00
92	1.5	5.67	1.50	2.50	2.77	14.83	3.94	1.08
93	1.5	5.67	1.50	2.50	2.77	14.83	3.94	.00
94	1.5	5.67	1.50	2.50	3.78	25.04	6.66	4.20
95	1.5	5.67	1.50	3.00	3.78	25.04	6.66	.84
96	1.5	5.67	1.50	3.50	3.78	25.04	6.66	.00
97	1.5	5.67	1.50	2.50	4.34	34.75	9.24	1.32
98	1.5	2.83	.75	1.25	1.79	9.71	2.58	15.77
99	1.5	2.83	.75	1.50	1.79	9.71	2.58	10.09
100	1.5	2.83	.75	1.75	1.79	9.71	2.58	5.89
101	1.5	2.83	.75	2.00	1.79	9.71	2.58	3.98
102	1.5	2.83	.75	2.50	1.79	9.71	2.58	1.48
103	1.5	2.83	.75	2.75	1.79	9.71	2.58	.51
104	1.5	2.83	.75	3.00	1.79	9.71	2.58	.00
105	1.5	2.83	.75	1.25	2.85	14.82	3.94	21.11
106	1.5	2.83	.75	1.50	2.85	14.82	3.94	15.94
107	1.5	2.83	.75	1.75	2.85	14.82	3.94	9.24
108	1.5	2.83	.75	2.00	2.85	14.82	3.94	6.95
109	1.5	2.83	.75	2.25	2.85	14.82	3.94	5.43
110	1.5	2.83	.75	2.75	2.85	14.82	3.94	1.57
111	3.0	9.83	1.50	1.00	1.19	9.70	1.29	3.05
112	3.0	9.83	1.50	1.00	2.05	14.84	1.97	25.44
113	3.0	9.83	1.50	1.00	3.35	25.06	3.33	49.85
114	3.0	9.83	1.50	1.00	4.05	34.40	4.57	21.37
115	3.0	9.83	1.50	1.00	4.82	49.14	6.54	126.84
116	3.0	6.56	1.00	.67	*)	7.92	1.05	5.72
117	3.0	6.56	1.00	.67	1.56	12.12	1.61	26.77
118	3.0	6.56	1.00	.67	2.81	20.46	2.72	81.23
119	3.0	6.56	1.00	.67	3.71	28.09	3.74	72.74
120	3.0	6.56	1.00	.67	4.67	40.12	5.34	91.20
121	3.0	4.92	.75	.50	1.13	9.71	1.29	33.21
122	3.0	4.92	.75	.50	1.92	14.83	1.97	66.43
123	3.0	4.92	.75	.50	3.30	25.04	3.33	59.71
124	3.0	2.46	.38	.25	.85	9.71	1.29	43.45
125	3.0	11.33	3.00	1.00	1.29	9.70	1.29	4.07
126	3.0	11.33	3.00	1.00	1.89	14.84	1.97	31.88
127	3.0	11.33	3.00	1.00	2.50	25.06	3.33	34.93
128	3.0	11.33	3.00	1.00	2.84	34.40	4.57	40.02
129	3.0	11.33	3.00	1.00	3.17	49.14	6.54	190.60
130	3.0	7.56	2.00	.67	*)	7.92	1.05	5.72
131	3.0	7.56	2.00	.67	1.63	12.12	1.61	35.08
132	3.0	7.56	2.00	.67	2.77	20.46	2.72	90.27
133	3.0	7.56	2.00	.67	3.51	28.09	3.74	67.94
134	3.0	7.56	2.00	.67	4.17	40.12	5.34	129.78
135	3.0	5.67	1.50	.50	1.19	9.71	1.29	45.44
136	3.0	5.67	1.50	.50	2.05	14.83	1.97	64.27
137	3.0	5.67	1.50	.50	3.35	25.04	3.33	93.89
138	3.0	5.67	1.50	.50	4.08	34.75	4.62	112.11
139	3.0	2.83	.75	.25	1.14	9.71	1.29	57.19
140	3.0	9.83	1.50	2.00	1.19	9.70	1.29	.00
141	3.0	9.83	1.50	2.00	2.05	14.84	1.97	.00
142	3.0	9.83	1.50	2.00	3.35	25.06	3.33	5.09
143	3.0	9.83	1.50	2.00	4.05	34.40	4.57	9.50
144	3.0	9.83	1.50	2.00	4.82	49.14	6.54	45.79
145	3.0	6.56	1.00	1.33	*)	7.92	1.05	.00
146	3.0	6.56	1.00	1.33	1.56	12.12	1.61	.00
147	3.0	4.92	.75	1.00	1.13	9.71	1.29	5.52
148	3.0	4.92	.75	1.00	1.92	14.83	1.97	41.37
149	3.0	4.92	.75	1.00	3.30	25.04	3.33	16.55
150	3.0	2.46	.38	.50	.85	9.71	1.29	29.97
151	3.0	11.33	3.00	2.00	1.29	9.70	1.29	.00
152	3.0	11.33	3.00	2.00	1.89	14.84	1.97	.00
153	3.0	11.33	3.00	2.00	2.50	25.06	3.33	3.73
154	3.0	11.33	3.00	2.00	2.84	34.40	4.57	21.03
155	3.0	11.33	3.00	2.00	3.17	49.14	6.54	73.93
156	3.0	7.56	2.00	1.33	*)	7.92	1.05	1.48
157	3.0	7.56	2.00	1.33	3.51	28.09	3.74	24.92
158	3.0	7.56	2.00	1.33	4.17	40.12	5.34	76.61
159	3.0	5.67	1.50	1.00	1.19	9.71	1.29	5.76
160	3.0	5.67	1.50	1.00	2.05	14.83	1.97	36.33

*) Value not found in runup charts

TEST NO.	$\cot\theta_s'$	d_h	d_s	H_c	R	σ	ξ	Q_{TEST} $.10^3$
161	3.0	5.67	1.50	1.00	3.35	25.04	3.33	40.41
162	3.0	5.67	1.50	1.00	4.08	34.75	4.62	69.79
163	3.0	2.83	.75	.50	1.14	9.71	1.29	40.44
164	3.0	2.83	.75	.50	1.92	14.82	1.97	69.86
165	3.0	9.83	1.50	3.00	3.35	25.06	3.33	.00
166	3.0	9.83	1.50	3.00	4.05	34.40	4.57	.00
167	3.0	9.83	1.50	3.00	4.82	49.14	6.54	13.23
168	3.0	6.56	1.00	2.00	3.71	28.09	3.74	8.86
169	3.0	6.56	1.00	2.00	4.67	40.12	5.34	19.01
170	3.0	4.92	.75	1.50	1.13	9.71	1.29	.00
171	3.0	4.92	.75	1.50	1.92	14.83	1.97	19.19
172	3.0	4.92	.75	1.50	3.30	25.04	3.33	4.20
173	3.0	2.46	.38	.75	.85	9.71	1.29	19.63
174	3.0	11.33	3.00	3.00	2.50	25.06	3.33	.00
175	3.0	11.33	3.00	3.00	2.84	34.40	4.57	.00
176	3.0	11.33	3.00	3.00	3.17	49.14	6.54	21.03
177	3.0	7.56	2.00	2.00	*)	7.92	1.05	.00
178	3.0	7.56	2.00	2.00	1.63	12.12	1.61	.00
179	3.0	7.56	2.00	2.00	2.77	20.46	2.72	9.23
180	3.0	7.56	2.00	2.00	3.51	28.09	3.74	5.54
181	3.0	7.56	2.00	2.00	4.17	40.12	5.34	25.48
182	3.0	5.67	1.50	1.50	1.19	9.71	1.29	1.68
183	3.0	5.67	1.50	1.50	2.05	14.83	1.97	8.15
184	3.0	5.67	1.50	1.50	3.35	25.04	3.33	7.91
185	3.0	5.67	1.50	1.50	4.08	34.75	4.62	26.86
186	3.0	2.83	.75	.75	1.14	9.71	1.29	25.61
187	3.0	2.83	.75	.75	1.92	14.82	1.97	51.55
188	3.0	9.83	1.50	4.00	4.82	49.14	6.54	.00
189	3.0	6.56	1.00	2.67	2.81	20.46	2.72	.37
190	3.0	6.56	1.00	2.67	3.71	28.09	3.74	.00
191	3.0	6.56	1.00	2.67	4.67	40.12	5.34	.37
192	3.0	4.92	.75	2.00	1.92	14.83	1.97	.72
193	3.0	4.92	.75	2.00	3.30	25.04	3.33	.00
194	3.0	2.46	.38	1.00	.85	9.71	1.29	9.62
195	3.0	11.33	3.00	4.00	3.17	49.14	6.54	.00
196	3.0	7.56	2.00	2.67	2.77	20.46	2.72	.00
197	3.0	7.56	2.00	2.67	3.51	28.09	3.74	.00
198	3.0	7.56	2.00	2.67	4.17	40.12	5.34	11.45
199	3.0	5.67	1.50	2.00	1.19	9.71	1.29	.00
200	3.0	5.67	1.50	2.00	2.05	14.83	1.97	.00
201	3.0	5.67	1.50	2.00	3.35	25.04	3.33	.00
202	3.0	5.67	1.50	2.00	4.08	34.75	4.62	9.47
203	3.0	2.83	.75	1.00	1.14	9.71	1.29	13.69
204	3.0	2.83	.75	1.00	1.92	14.82	1.97	40.91
205	3.0	6.56	1.00	3.33	2.81	20.46	2.72	.00
206	3.0	6.56	1.00	3.33	4.67	40.12	5.34	.00
207	3.0	4.92	.75	2.50	1.92	14.83	1.97	.00
208	3.0	2.46	.38	1.25	1.68	17.86	2.37	.64
209	3.0	2.46	.38	1.50	1.68	17.86	2.37	.59
210	3.0	2.46	.38	1.75	1.68	17.86	2.37	.00
211	3.0	7.56	2.00	3.33	4.17	40.12	5.34	.00
212	3.0	5.67	1.50	2.50	4.08	34.75	4.62	.00
213	3.0	2.83	.75	1.25	1.14	9.71	1.29	4.88
214	3.0	2.83	.75	1.50	1.14	9.71	1.29	.81
215	3.0	2.83	.75	1.75	1.14	9.71	1.29	.00
216	3.0	2.83	.75	1.25	1.92	14.82	1.97	29.72
217	3.0	2.83	.75	1.50	1.92	14.82	1.97	20.43
218	3.0	2.83	.75	1.75	1.92	14.82	1.97	9.33
219	3.0	2.83	.75	2.00	1.92	14.82	1.97	4.45
220	3.0	2.83	.75	2.25	1.92	14.82	1.97	2.29
221	3.0	2.83	.75	2.50	1.92	14.82	1.97	.42
222	3.0	5.81	2.32	.37	1.65	12.31	1.64	51.32
223	3.0	5.71	2.28	.45	2.04	14.91	1.98	50.35
224	3.0	3.87	1.55	.35	1.24	10.05	1.34	45.12
225	3.0	3.80	1.52	.46	1.61	12.17	1.62	47.91
226	3.0	2.87	1.15	.34	1.17	9.61	1.28	40.63
227	3.0	2.86	1.14	.41	1.47	11.52	1.53	45.02
228	3.0	2.28	.91	.27	1.13	9.43	1.25	35.05
229	3.0	2.31	.92	.34	1.41	11.20	1.49	43.85
230	3.0	1.91	.76	.23	1.09	9.40	1.25	41.22
231	3.0	1.94	.78	.30	1.36	11.08	1.47	41.27
232	3.0	5.81	2.32	.73	1.65	12.31	1.64	31.58
233	3.0	5.71	2.28	.90	2.04	14.91	1.98	22.10
234	3.0	3.87	1.55	.70	1.24	10.05	1.34	19.34
235	3.0	3.80	1.52	.91	1.61	12.17	1.62	18.83
236	3.0	2.87	1.15	.68	1.17	9.61	1.28	17.24
237	3.0	2.86	1.14	.82	1.47	11.52	1.53	23.54
238	3.0	2.28	.91	.53	1.13	9.43	1.25	21.49
239	3.0	2.31	.92	.67	1.41	11.20	1.49	24.69
240	3.0	1.91	.76	.47	1.09	9.40	1.25	20.05

*) Value not found in runup charts

TEST NO.	$\cot\theta_s'$	d_h	d_s	H_c	R	σ	ξ	$Q_{TEST} .10^3$
241	3.0	1.94	.78	.59	1.36	11.08	1.47	24.57
242	3.0	5.81	2.32	1.10	1.65	12.31	1.64	3.95
243	3.0	5.71	2.28	1.35	2.04	14.91	1.98	3.07
244	3.0	3.87	1.55	1.06	1.24	10.05	1.34	4.30
245	3.0	3.80	1.52	1.37	1.61	12.17	1.62	3.45
246	3.0	2.87	1.15	1.02	1.17	9.61	1.28	7.39
247	3.0	2.86	1.14	1.23	1.47	11.52	1.53	9.21
248	3.0	2.28	.91	.80	1.13	9.43	1.25	6.37
249	3.0	2.31	.92	1.01	1.41	11.20	1.49	7.56
250	3.0	1.91	.76	.70	1.09	9.40	1.25	7.24
251	3.0	1.94	.78	.89	1.36	11.08	1.47	8.86
252	3.0	5.81	2.32	1.46	1.65	12.31	1.64	.00
253	3.0	5.71	2.28	1.80	2.04	14.91	1.98	.00
254	3.0	3.87	1.55	1.41	1.24	10.05	1.34	.00
255	3.0	3.80	1.52	1.83	1.61	12.17	1.62	.00
256	3.0	2.87	1.15	1.36	1.17	9.61	1.28	1.23
257	3.0	2.86	1.14	1.64	1.47	11.52	1.53	3.07
258	3.0	2.28	.91	1.07	1.13	9.43	1.25	3.16
259	3.0	2.31	.92	1.35	1.41	11.20	1.49	.69
260	3.0	1.91	.76	.93	1.09	9.40	1.25	3.34
261	3.0	1.94	.78	1.18	1.36	11.08	1.47	1.95
262	6.0	5.81	2.32	.20	.85	12.31	.82	35.53
263	6.0	5.71	2.28	.22	1.04	14.91	.99	40.93
264	6.0	3.87	1.55	.16	.62	10.05	.67	23.64
265	6.0	3.80	1.52	.23	.80	12.17	.81	44.46
266	6.0	2.87	1.15	.13	.57	9.61	.64	32.01
267	6.0	2.86	1.14	.19	.72	11.52	.77	39.91
268	6.0	2.28	.91	.12	.54	9.43	.63	32.62
269	6.0	2.31	.92	.16	.68	11.20	.74	35.56
270	6.0	1.91	.76	.11	.53	9.40	.63	30.08
271	6.0	1.94	.78	.14	.66	11.08	.74	40.85
272	6.0	5.81	2.32	.41	.85	12.31	.82	15.79
273	6.0	5.71	2.28	.45	1.04	14.91	.99	18.83
274	6.0	3.87	1.55	.33	.62	10.05	.67	15.04
275	6.0	3.80	1.52	.46	.80	12.17	.81	17.16
276	6.0	2.87	1.15	.26	.57	9.61	.64	14.77
277	6.0	2.86	1.14	.39	.72	11.52	.77	15.35
278	6.0	2.28	.91	.23	.54	9.43	.63	19.88
279	6.0	2.31	.92	.32	.68	11.20	.74	15.06
280	6.0	1.91	.76	.23	.53	9.40	.63	14.48
281	6.0	1.94	.78	.28	.66	11.08	.74	20.14
282	6.0	5.81	2.32	.61	.85	12.31	.82	3.95
283	6.0	5.71	2.28	.67	1.04	14.91	.99	3.07
284	6.0	3.87	1.55	.49	.62	10.05	.67	4.30
285	6.0	3.80	1.52	.68	.80	12.17	.81	1.67
286	6.0	2.87	1.15	.40	.57	9.61	.64	4.92
287	6.0	2.86	1.14	.58	.72	11.52	.77	2.05
288	6.0	2.28	.91	.35	.54	9.43	.63	7.15
289	6.0	2.31	.92	.48	.68	11.20	.74	4.10
290	6.0	1.91	.76	.34	.53	9.40	.63	5.57
291	6.0	1.94	.78	.43	.66	11.08	.74	5.88
292	6.0	5.81	2.32	.81	.85	12.31	.82	.00
293	6.0	5.71	2.28	.89	1.04	14.91	.99	.00
294	6.0	3.87	1.55	.65	.62	10.05	.67	.00
295	6.0	3.80	1.52	.91	.80	12.17	.81	.00
296	6.0	2.87	1.15	.53	.57	9.61	.64	.00
297	6.0	2.86	1.14	.78	.72	11.52	.77	.00
298	6.0	2.28	.91	.47	.54	9.43	.63	2.38
299	6.0	2.31	.92	.65	.68	11.20	.74	1.38
300	6.0	1.91	.76	.46	.53	9.40	.63	2.23
301	6.0	1.94	.78	.57	.66	11.08	.74	1.95

APPENDIX D: OVERTOPPING RATES BASED ON EMPIRICAL FORMULA

The following parameters for each test are listed in the attached table:

$\cot\theta_s'$ = parameter related to the slope of the structure which is 1 on $\cot\theta_s'$;

(d_s'/H_0') = d_s = normalized water depth below SWL at the toe of the structure whose slope is 1 on $\cot\theta_s'$;

(H_0'/gT'^2) = σ^{-2} = parameter related to wave steepness;

α = $(0.1085/\alpha_*)$ = empirical coefficient in the empirical formula for the average overtopping rate given in SPM;

Q_0^* = empirical coefficient in the empirical formula for the average overtopping rate given in SPM;

R = (R'/H_0') = normalized wave run-up on the structure slope whose slope is 1 on $\cot\theta_s'$;

Q_{SPM} = $[Q_{SPM}'/(H_0'\sqrt{gH_0'})]$ = normalized averaged overtopping rate based on the empirical formula in SPM; and

Q_{TEST} = $[Q_{TEST}'/(H_0'\sqrt{gH_0'})]$ = normalized average overtopping rate based on the measured value Q_{TEST}' for each test.

The values α and Q_0^* for each test are obtained using the figures in SPM for given values of d_s and σ^{-2} for the smooth 1:1.5, 1:3 or 1:6 slope fronted by the 1:10 slope. The value of R for each test is found using the figures in SPM which plot R as a function of $\cot\theta_s'$, σ^{-2} and d_s for smooth impermeable slopes fronted by the 1:10 slope.

TEST NO.	$\cot\theta_s'$	$\frac{d_s'}{H_o'}$	$\frac{H_o'}{gT'^2}$	α	Q_o^*	R	Q_{SPM} $.10^3$	Q_{TEST} $.10^3$
2	1.5	.00	.00454	.057	.0021	1.08	.10	.68
3	1.5	.00	.00159	.080	.0060	2.14	19.54	6.78
4	1.5	.00	.00041	.055	.0400	4.02	73.42	84.79
6	1.5	.00	.00455	.057	.0021	1.08	6.80	9.95
7	1.5	.00	.00159	.080	.0060	2.13	40.53	39.45
8	1.5	1.50	.01063	.062	.0145	1.99	17.39	35.95
9	1.5	1.50	.00454	.066	.0140	2.78	34.23	38.32
10	1.5	1.50	.00041	.065	.0800	4.68	137.16	140.75
11	1.5	.75	.01061	.059	.0059	1.79	26.77	35.73
12	1.5	.75	.00455	.075	.0056	2.85	44.80	50.72
13	1.5	.75	.00159	.065	.0065	4.33	54.75	48.92
14	1.5	.38	.01060	.046	.0043	1.02	20.16	27.00
15	1.5	3.00	.01063	.081	.0070	1.96	18.44	24.76
18	1.5	3.00	.00041	.095	.0880	2.38	106.40	146.85
19	1.5	1.50	.01061	.062	.0145	1.99	49.04	65.35
20	1.5	1.50	.00455	.066	.0140	2.77	64.98	66.79
21	1.5	1.50	.00159	.067	.0135	3.78	75.47	53.48
22	1.5	1.50	.00083	.055	.0580	4.34	152.48	111.03
23	1.5	.75	.01060	.059	.0059	1.79	45.84	53.42
24	1.5	.75	.00455	.075	.0056	2.85	58.01	57.44
25	1.5	.00	.00159	.080	.0060	2.14	.75	.00
26	1.5	.00	.00041	.055	.0400	4.02	23.22	35.95
28	1.5	.00	.00455	.057	.0021	1.08	.09	1.08
29	1.5	.00	.00159	.080	.0060	2.13	19.51	20.38
30	1.5	1.50	.01063	.062	.0145	1.99	.00	7.12
31	1.5	1.50	.00454	.066	.0140	2.78	5.96	10.51
32	1.5	1.50	.00159	.067	.0135	3.78	17.22	20.35
33	1.5	1.50	.00041	.065	.0800	4.68	61.70	56.98
34	1.5	.75	.00455	.075	.0056	2.85	25.91	30.82
35	1.5	.38	.01060	.046	.0043	1.02	5.24	10.60
36	1.5	3.00	.01063	.081	.0070	1.96	.00	2.71
39	1.5	3.00	.00041	.095	.0880	2.38	17.95	53.92
40	1.5	1.50	.01061	.062	.0145	1.99	17.42	35.73
41	1.5	1.50	.00455	.066	.0140	2.77	34.20	35.85
42	1.5	1.50	.00159	.067	.0135	3.78	48.25	32.49
43	1.5	1.50	.00083	.055	.0580	4.34	95.34	45.80
44	1.5	.75	.01060	.059	.0059	1.79	26.79	39.68
45	1.5	.75	.00455	.075	.0056	2.85	44.79	43.58
46	1.5	.00	.00041	.055	.0400	4.02	4.46	8.82
47	1.5	.00	.00455	.057	.0021	1.08	.00	.00
48	1.5	.00	.00159	.080	.0060	2.13	7.25	5.40
49	1.5	1.50	.01063	.062	.0145	1.99	.00	.34
50	1.5	1.50	.00454	.066	.0140	2.78	.00	.68
51	1.5	1.50	.00159	.067	.0135	3.78	3.48	4.75
52	1.5	1.50	.00041	.065	.0800	4.68	22.46	18.99
53	1.5	.75	.01061	.059	.0059	1.79	.89	5.04
54	1.5	.75	.00455	.075	.0056	2.85	13.76	19.90
55	1.5	.75	.00159	.065	.0065	4.33	24.14	13.19
56	1.5	.38	.01060	.046	.0043	1.02	.78	3.31
57	1.5	3.00	.00041	.095	.0880	2.38	.00	10.51
58	1.5	1.50	.01061	.062	.0145	1.99	3.89	18.95
59	1.5	1.50	.00455	.066	.0140	2.77	16.17	18.59
60	1.5	1.50	.00083	.055	.0580	4.34	57.99	17.51
61	1.5	.75	.01060	.059	.0059	1.79	14.92	29.63
62	1.5	.00	.00041	.055	.0400	4.02	.00	1.02
63	1.5	.00	.00159	.080	.0060	2.13	.74	1.32
64	1.5	1.50	.01063	.062	.0145	1.99	.00	.00
65	1.5	1.50	.00454	.066	.0140	2.78	.00	.00
66	1.5	1.50	.00159	.067	.0135	3.78	.00	.00
67	1.5	1.50	.00041	.065	.0800	4.68	4.08	3.05
68	1.5	.75	.01061	.059	.0059	1.79	.00	2.40
69	1.5	.75	.00455	.075	.0056	2.85	6.01	11.75
70	1.5	.75	.00159	.065	.0065	4.33	15.22	8.15
71	1.5	.38	.01060	.046	.0043	1.02	.00	1.02
72	1.5	3.00	.00041	.095	.0880	2.38	.00	.00
73	1.5	1.50	.01061	.062	.0145	1.99	.00	5.52
74	1.5	1.50	.00455	.066	.0140	2.77	5.94	5.40
75	1.5	1.50	.00159	.067	.0135	3.78	17.20	7.67
76	1.5	1.50	.00083	.055	.0580	4.34	33.63	4.32
77	1.5	.75	.01060	.059	.0059	1.79	7.59	20.01
78	1.5	.75	.00455	.075	.0056	2.85	25.90	28.32
79	1.5	1.50	.00041	.065	.0800	4.68	.00	.00
80	1.5	.75	.01061	.059	.0059	1.79	.00	.72
81	1.5	.75	.01061	.059	.0059	1.79	.00	.00
82	1.5	.75	.00455	.075	.0056	2.85	1.44	5.52
83	1.5	.75	.00455	.075	.0056	2.85	.00	1.32
84	1.5	.75	.00455	.075	.0056	2.85	.00	.24
85	1.5	.75	.00159	.065	.0065	4.33	8.96	3.12
86	1.5	.75	.00159	.065	.0065	4.33	4.68	1.08
87	1.5	.75	.00159	.065	.0065	4.33	1.91	.00

TEST NO.	$\cot\theta'_s$	$\frac{d'_s}{H'_o}$	$\frac{H'_o}{gT'^2}$	α	Q^*_o	R	Q_{SPM} $.10^3$	Q_{TEST} $.10^3$
90	1.5	1.50	.01061	.062	.0145	1.99	.00	1.08
91	1.5	1.50	.01061	.062	.0145	1.99	.00	.00
92	1.5	1.50	.00455	.066	.0140	2.77	.91	1.08
93	1.5	1.50	.00455	.066	.0140	2.77	.91	.00
94	1.5	1.50	.00159	.067	.0135	3.78	8.80	4.20
95	1.5	1.50	.00159	.067	.0135	3.78	3.47	.84
96	1.5	1.50	.00159	.067	.0135	3.78	.58	.00
97	1.5	1.50	.00083	.055	.0580	4.34	18.00	1.32
98	1.5	.75	.01060	.059	.0059	1.79	3.23	15.77
99	1.5	.75	.01060	.059	.0059	1.79	.90	10.09
100	1.5	.75	.01060	.059	.0059	1.79	.02	5.89
101	1.5	.75	.01060	.059	.0059	1.79	.00	3.98
102	1.5	.75	.01060	.059	.0059	1.79	.00	1.48
103	1.5	.75	.01060	.059	.0059	1.79	.00	.51
104	1.5	.75	.01060	.059	.0059	1.79	.00	.00
105	1.5	.75	.00455	.075	.0056	2.85	19.16	21.11
106	1.5	.75	.00455	.075	.0056	2.85	13.75	15.94
107	1.5	.75	.00455	.075	.0056	2.85	9.43	9.24
108	1.5	.75	.00455	.075	.0056	2.85	6.01	6.95
109	1.5	.75	.00455	.075	.0056	2.85	3.37	5.43
110	1.5	.75	.00455	.075	.0056	2.85	.22	1.57
111	3.0	1.50	.01063	.080	.0110	1.19	3.81	3.05
112	3.0	1.50	.00454	.090	.0190	2.05	38.13	25.44
113	3.0	1.50	.00159	.077	.0360	3.35	79.63	49.85
114	3.0	1.50	.00085	.090	.0380	4.05	106.13	21.37
115	3.0	1.50	.00041	.080	.0760	4.82	155.81	126.84
118	3.0	1.00	.00239	.080	.0230	2.81	78.65	81.23
119	3.0	1.00	.00127	.080	.0240	3.71	94.63	72.74
120	3.0	1.00	.00062	.090	.0270	4.67	116.19	91.20
121	3.0	.75	.01061	.075	.0110	1.13	26.67	33.21
122	3.0	.75	.00455	.090	.0110	1.92	55.11	66.43
123	3.0	.75	.00159	.090	.0160	3.30	87.49	59.71
124	3.0	.38	.01060	.090	.0040	.85	30.51	43.45
127	3.0	3.00	.00159	.080	.0150	2.50	38.89	34.93
128	3.0	3.00	.00085	.350	.0030	2.84	43.62	40.02
129	3.0	3.00	.00041	.085	.1500	3.17	168.41	190.60
131	3.0	2.00	.00681	.074	.0150	1.63	34.17	35.08
132	3.0	2.00	.00239	.090	.0330	2.77	100.44	90.27
133	3.0	2.00	.00127	.090	.0190	3.51	86.68	67.94
134	3.0	2.00	.00062	.120	.0400	4.17	149.40	129.78

TEST NO.	$\cot\theta'_s$	$\frac{d'_s}{H'_o}$	$\frac{H'_o}{gT'^2}$	α	Q^*_o	R	Q_{SPM} $.10^3$	Q_{TEST} $.10^3$
135	3.0	1.50	.01061	.080	.0110	1.19	31.17	45.44
136	3.0	1.50	.00455	.090	.0190	2.05	75.59	64.27
137	3.0	1.50	.00159	.077	.0360	3.35	124.13	93.89
138	3.0	1.50	.00083	.090	.0380	4.08	144.82	112.11
139	3.0	.75	.01060	.075	.0110	1.14	54.88	57.19
140	3.0	1.50	.01063	.080	.0110	1.19	.00	.00
141	3.0	1.50	.00454	.090	.0190	2.05	.70	.00
142	3.0	1.50	.00159	.077	.0360	3.35	27.22	5.09
143	3.0	1.50	.00085	.090	.0380	4.05	52.86	9.50
144	3.0	1.50	.00041	.080	.0760	4.82	83.30	45.79
147	3.0	.75	.01061	.075	.0110	1.13	1.92	5.52
148	3.0	.75	.00455	.090	.0110	1.92	26.01	41.37
149	3.0	.75	.00159	.090	.0160	3.30	59.43	16.55
150	3.0	.38	.01060	.090	.0040	.85	12.49	29.97
153	3.0	3.00	.00159	.080	.0150	2.50	6.27	3.73
154	3.0	3.00	.00085	.350	.0030	2.84	31.87	21.03
155	3.0	3.00	.00041	.085	.1500	3.17	58.29	73.93
157	3.0	2.00	.00127	.090	.0190	3.51	52.52	24.92
158	3.0	2.00	.00062	.120	.0400	4.17	109.82	76.61
159	3.0	1.50	.01061	.080	.0110	1.19	3.84	5.76
160	3.0	1.50	.00455	.090	.0190	2.05	38.05	36.33
161	3.0	1.50	.00159	.077	.0360	3.35	79.59	40.41
162	3.0	1.50	.00083	.090	.0380	4.08	106.59	69.79
163	3.0	.75	.01060	.075	.0110	1.14	26.71	40.44
164	3.0	.75	.00455	.090	.0110	1.92	55.10	69.86
165	3.0	1.50	.00159	.077	.0360	3.35	3.17	.00
166	3.0	1.50	.00085	.090	.0380	4.05	19.61	.00
167	3.0	1.50	.00041	.080	.0760	4.82	38.24	13.23
168	3.0	1.00	.00127	.080	.0240	3.71	30.17	8.86
169	3.0	1.00	.00062	.090	.0270	4.67	54.50	19.01
170	3.0	.75	.01061	.075	.0110	1.13	.00	.00
171	3.0	.75	.00455	.090	.0110	1.92	8.32	19.19
172	3.0	.75	.00159	.090	.0160	3.30	38.70	4.20
173	3.0	.38	.01060	.090	.0040	.85	2.29	19.63
174	3.0	3.00	.00159	.080	.0150	2.50	.00	.00
175	3.0	3.00	.00085	.350	.0030	2.84	.00	.00
176	3.0	3.00	.00041	.085	.1500	3.17	4.06	21.03
178	3.0	2.00	.00681	.074	.0150	1.63	.00	.00
179	3.0	2.00	.00239	.090	.0330	2.77	20.08	9.23
180	3.0	2.00	.00127	.090	.0190	3.51	28.91	5.54

TEST NO.	$\cot\theta_s'$	$\frac{d_s'}{H_o'}$	$\frac{H_o'}{gT'^2}$	α	Q_o^*	R	Q_{SPM} $.10^3$	Q_{TEST} $.10^3$
181	3.0	2.00	.00062	.120	.0400	4.17	77.71	25.48
182	3.0	1.50	.01061	.080	.0110	1.19	.00	1.68
183	3.0	1.50	.00455	.090	.0190	2.05	14.50	8.15
184	3.0	1.50	.00159	.077	.0360	3.35	48.70	7.91
185	3.0	1.50	.00083	.090	.0380	4.08	76.86	26.86
186	3.0	.75	.01060	.075	.0110	1.14	10.55	25.61
187	3.0	.75	.00455	.090	.0110	1.92	38.73	51.55
188	3.0	1.50	.00041	.080	.0760	4.82	11.05	.00
189	3.0	1.00	.00239	.080	.0230	2.81	1.06	.37
190	3.0	1.00	.00127	.080	.0240	3.71	13.28	.00
191	3.0	1.00	.00062	.090	.0270	4.67	34.36	.37
192	3.0	.75	.00455	.090	.0110	1.92	.00	.72
193	3.0	.75	.00159	.090	.0160	3.30	23.17	.00
194	3.0	.38	.01060	.090	.0040	.85	.00	9.62
195	3.0	3.00	.00041	.085	.1500	3.17	.00	.00
196	3.0	2.00	.00239	.090	.0330	2.77	1.48	.00
197	3.0	2.00	.00127	.090	.0190	3.51	12.46	.00
198	3.0	2.00	.00062	.120	.0400	4.17	50.81	11.45
199	3.0	1.50	.01061	.080	.0110	1.19	.00	.00
200	3.0	1.50	.00455	.090	.0190	2.05	.65	.00
201	3.0	1.50	.00159	.077	.0360	3.35	27.17	.00
202	3.0	1.50	.00083	.090	.0380	4.08	53.43	9.47
203	3.0	.75	.01060	.075	.0110	1.14	1.94	13.69
204	3.0	.75	.00455	.090	.0110	1.92	26.00	40.91
205	3.0	1.00	.00239	.080	.0230	2.81	.00	.00
206	3.0	1.00	.00062	.090	.0270	4.67	19.00	.00
207	3.0	.75	.00455	.090	.0110	1.92	.00	.00
211	3.0	2.00	.00062	.120	.0400	4.17	27.47	.00
212	3.0	1.50	.00083	.090	.0380	4.08	34.85	.00
213	3.0	.75	.01060	.075	.0110	1.14	.00	4.88
214	3.0	.75	.01060	.075	.0110	1.14	.00	.81
215	3.0	.75	.01060	.075	.0110	1.14	.00	.00
216	3.0	.75	.00455	.090	.0110	1.92	16.04	29.72
217	3.0	.75	.00455	.090	.0110	1.92	8.31	20.43
218	3.0	.75	.00455	.090	.0110	1.92	2.54	9.33
219	3.0	.75	.00455	.090	.0110	1.92	.00	4.45
220	3.0	.75	.00455	.090	.0110	1.92	.00	2.29
221	3.0	.75	.00455	.090	.0110	1.92	.00	.42
224	3.0	1.55	.00990	.080	.0110	1.24	47.47	45.12
226	3.0	1.15	.01084	.055	.0140	1.17	36.05	40.63
228	3.0	.91	.01124	.070	.0085	1.13	43.61	35.05
230	3.0	.76	.01131	.075	.0110	1.09	56.05	41.22
231	3.0	.78	.00815	.040	.0410	1.36	61.38	41.27
234	3.0	1.55	.00990	.080	.0110	1.24	18.23	19.34
236	3.0	1.15	.01084	.055	.0140	1.17	8.42	17.24
238	3.0	.91	.01124	.070	.0085	1.13	18.68	21.49
240	3.0	.76	.01131	.075	.0110	1.09	28.07	20.05
241	3.0	.78	.00815	.040	.0410	1.36	16.37	24.57
244	3.0	1.55	.00990	.080	.0110	1.24	3.39	4.30
246	3.0	1.15	.01084	.055	.0140	1.17	.54	7.39
248	3.0	.91	.01124	.070	.0085	1.13	5.87	6.37
250	3.0	.76	.01131	.075	.0110	1.09	11.72	7.24
251	3.0	.78	.00815	.040	.0410	1.36	3.03	8.86
254	3.0	1.55	.00990	.080	.0110	1.24	.00	.00
256	3.0	1.15	.01084	.055	.0140	1.17	.00	1.23
258	3.0	.91	.01124	.070	.0085	1.13	.34	3.16
260	3.0	.76	.01131	.075	.0110	1.09	2.69	3.34
261	3.0	.78	.00815	.040	.0410	1.36	.16	1.95
266	6.0	1.15	.01084	.095	.0052	.57	42.13	32.01
268	6.0	.91	.01124	.082	.0045	.54	37.74	32.62
270	6.0	.76	.01131	.082	.0045	.53	37.54	30.08
271	6.0	.78	.00815	.095	.0045	.66	40.65	40.85
276	6.0	1.15	.01084	.095	.0052	.57	23.02	14.77
278	6.0	.91	.01124	.082	.0045	.54	19.99	19.88
280	6.0	.76	.01131	.082	.0045	.53	19.74	14.48
281	6.0	.78	.00815	.095	.0045	.66	23.36	20.14
286	6.0	1.15	.01084	.095	.0052	.57	10.26	4.92
288	6.0	.91	.01124	.082	.0045	.54	8.94	7.15
290	6.0	.76	.01131	.082	.0045	.53	8.71	5.57
291	6.0	.78	.00815	.095	.0045	.66	11.53	5.88
296	6.0	1.15	.01084	.095	.0052	.57	1.80	.00
298	6.0	.91	.01124	.082	.0045	.54	2.27	2.38
300	6.0	.76	.01131	.082	.0045	.53	2.11	2.23
301	6.0	.78	.00815	.095	.0045	.66	3.40	1.95