APPENDIX B

ASSESSMENT OF HYDRAULIC PERFORMANCE

CONTENTS

APPENDIX B ASSESSMENT OF HYDRAULIC PERFORMANCE

B.1 General

This appendix discusses some methods of assessing run-up, overtopping, reflection and transmission due to waves on a structure. These methods are empirical based on simplified configurations and should not be regarded as exhaustive. The results of calculations should only be treated as quick estimate of the order of magnitude of the hydraulic parameters. Further details of these methods can be found in Besley (1999), CIRIA (1991) and Goda (2000). Where complicated situations are encountered, or if more accurate results are required, physical model tests should be carried out to determine the hydraulic performance of the structure.

B.2 Wave Run-up

For simple armoured rubble slopes, Van der Meer (1988) has given prediction formulae for rock slopes with an impermeable core having permeability factor P = 0.1 and porous mounds of relatively high permeability given by P = 0.5 and 0.6. The prediction formulae are :

$$R_{ui} / H_{1/3} = a\xi_m \qquad \text{for } \xi_m < 1.5$$

$$R_{ui} / H_{1/3} = b\xi_m{}^c \qquad \text{for } \xi_m > 1.5$$

The run-up for permeable structures ($P > 0.4$) is limited to a maximum :

$$R_{ui} / H_{1/3} = d$$

where R_{ui} = Run-up at i % exceedance level (m).
$H_{1/3}$ = Significant wave height (m).
ξ_m = Surf similarity parameter based on mean wave period = $\tan\alpha / \sqrt{s_m}$.
α = Average slope angle (degree).
s_m = Offshore wave steepness based on mean wave period = $2\pi H_{1/3} / gT_m{}^2$.
T_m = Mean wave period (s).

Values of the coefficients a , b, c and d for exceedance levels of i equal to 1%, 2%, 5%, 10%

and significant run-up levels are given in Table B1.

When subject to oblique waves, the wave run-up behaviour will be different for short-crest waves and long-crested waves (CIRIA, 1991). For short-crested waves, the run-up is maximum for normal incidence and the reduction of run-up for large wave angles is not more than a factor of 0.8 compared with normal incidence. For long-crested waves, the increase in run-up is only present when the incident wave angle is about 10 to 30 degrees.

B.3 Wave Overtopping

B.3.1 Armoured Rubble Slope

Owen (1980) has derived the following formulae to estimate the mean overtopping discharge for rough impermeable and rough permeable structures :

$$R_* = R_c/(T_m(gH_{1/3})^{0.5}) \qquad (0.05 < R_* < 0.30)$$
$$Q_* = A\exp(-BR_*/r)$$
$$Q = Q_* T_m g H_{1/3}$$

where R_c = Freeboard between still water level and crest of structure (m).
$H_{1/3}$ = Significant wave height at the toe of the structure (m).
T_m = Mean wave period at the toe of the structure (s).
r = Roughness coefficient given in Table B2.
g = Acceleration due to gravity (m/s^2).
A,B = Empirical coefficients dependent on cross-section (see Table B3).
Q = Mean overtopping discharge rate per metre run of seawall (m^3/s/m).
Q_* = Dimensionless mean overtopping discharge.
R_* = Dimensionless freeboard.

For a permeable crest, a reduction factor C_r may be applied to the overtopping discharge as calculated above (Besley, 1999) :

$$C_r = 3.06\exp(-1.5C_w/H_{1/3})$$

where C_w = Crest width of the structure (m).

If $C_w/H_{1/3}$ is less than 0.75, C_r may be assumed as 1.

If the incident waves are not normal to the structures, the overtopping rate may further be multiplied by a reduction factor O_r (Besley, 1999) :

$$O_r = 1 - 0.000152\,\beta^2$$

where β = Angle of wave attack to the normal, in degrees.

The formula is valid for $0^o < \beta \le 60^o$. For angles of approach greater than 60°, it is suggested that the result for $\beta = 60^o$ be applied.

B.3.2 Vertical Structures

When the toe of a vertical structure is close to the seabed level, the overtopping rate may be estimated using the diagrams in Figures B1 and B2 (Goda, 2000). These diagrams are compiled by Goda from the results of a series of random wave tests with allowance of wave deformation in the surf zone. Equivalent deepwater wave steepness of 0.012, 0.017 and 0.036, and seabed slopes of 1/10 and 1/30 are covered.

Besley (1999) also suggests method for calculating the amount of wave overtopping discharge for vertical walls, which is given in the following paragraphs.

Reflecting waves predominate when $d_* > 0.3$, in which case the following equation applies :

$$d_* = (d/H_{1/3})(2\pi d/(gT_m^2))$$

$$Q^{\#} = 0.05 \exp(-2.78\, R_c/H_{1/3}) \qquad \text{(Valid for } 0.03 < R_c/H_{1/3} < 3.2\text{)}$$

$$Q = Q^{\#}\,(gH_{1/3}^3)^{0.5}$$

where d_* = Dimensionless depth parameter.
d = Water depth at the toe of the structure (m).
$H_{1/3}$ = Significant wave height at the toe of the structure (m).
g = Acceleration due to gravity (m/s^2).
T_m = Mean wave period (s).
$Q^{\#}$ = Dimensionless discharge.
Q = Mean overtoping discharge rate per metre run of seawall (m^3/s/m).
R_c = Freeboard (height of crest of the wall above still water level) (m).

If the incident waves are at an angle to the normal of the seawall,

$$Q^{\#} = 0.05 \exp \{(-2.78/\gamma)\,(R_c/H_{1/3})\}$$

γ is the reduction factor for angle of incident waves and is given by :

$$\gamma = 1 - 0.0062\beta \qquad \text{for } 0° < \beta \leq 45°$$
$$\gamma = 0.72 \qquad \text{for } \beta > 45°$$

where β = Incident wave angle relative to the normal, in degrees.

Impact waves predominate when $d_* \leq 0.3$, in which case the following equation applies :

$$Q_h = 0.000137 R_h^{-3.24} \qquad \text{(Valid for } 0.05 < R_h < 1.00)$$

where Q_h = Dimensionless discharge = $\{Q/(gh^3)^{0.5}\}/d_*^2$
R_h = Dimensionless crest freeboard = $(R_c/H_{1/3})\, d_*$

No data is available to describe the effect of oblique wave incidence on the mean discharge when waves are in impacting mode.

B.4 Wave Reflection

There are various formulae for the coefficient of wave reflection of armoured slopes. It will be useful to compare the results of these formulae when assessing the coefficient of reflection of rubble mound structures.

For a rough permeable slope, the following formula was given by Seelig and Ahrens (CIRIA, 1991) to estimate the coefficient of reflection :

$$C_r = a\xi_p^{\,2}/(b + \xi_p^{\,2})$$

where ξ_p = Surf similarity parameter based on peak wave period.

C_r = Coefficient of reflection.
a = 0.6 and b = 6.6 for a conservative estimate of rough permeable slopes.

Postma (1989), taking into account Van der Meer (1988) data for rock slopes and Seelig and

Arhens formula, derived the following formula for C_r :

$$C_r = 0.14\xi_p^{\;0.73} \qquad \text{with standard deviation of } C_r = 0.055$$

Postma also treated the slope angle and wave steepness separately and derived another relationship :

$$C_r = 0.071P^{-0.082}(\cot\alpha)^{-0.62}s_p^{\;-0.46} \qquad \text{with standard deviation of } C_r = 0.036$$

where P = Notional permeability factor.
α = Slope of structure face.
s_p = Offshore wave steepness based on peak wave period.

The results of random wave tests by Allsop and Channell (1989), analyzed to give values for the coefficients *a* and *b* in Seelig and Ahrens formula, but with ξ_m instead of ξ_p, are shown below. The slopes used armour rock in one or two layers with an impermeable slope covered by underlayer rock equivalent to notional permeability factor P equal to 0.1 :

Rock, 2-layer	$a = 0.64$	$b = 8.85$
Rock, 1-layer	$a = 0.64$	$b = 7.22$

The range of wave conditions for which the coefficients may be used is given by :

$$0.004 < s_m < 0.052 \qquad \text{and} \qquad 0.6 < H_{1/3}/(\Delta D_{n50}) < 1.9$$

where s_m = Offshore wave steepness based on mean wave period.
D_{n50} = Nominal rock diameter equivalent to that of a cube.
Δ = Relative mass density.
= (mass density of rock/mass density of seawater) – 1

Postma (1989) also reanalyzed the data of Allsop and Channell and modified his previous formula for coefficient of reflection as follows :

$$C_r = 0.125\xi_p^{\;0.73} \qquad \text{with standard deviation of } C_r = 0.060$$

For structures with no-porous and steep faces, approximately 100% of the wave energy incident on the structure will be reflected.

B.5 Wave Transmission

Van der Meer (1990) re-analysed the hydraulic model test results of various researchers and suggested a prediction method for wave transmission :

Range of Validity	*Equation*
$-2.00 < R_c/H_{1/3} < -1.13$	$C_t = 0.80$
$-1.13 < R_c/H_{1/3} < 1.20$	$C_t = 0.46 - 0.3R_c/H_{1/3}$
$1.20 < R_c/H_{1/3} < 2.00$	$C_t = 0.10$

These formulae give a very simplistic description of the data available but will usually be used for preliminary estimate of the performance.

For the range of low wave heights compared to rock diameter and $R_c/H_{1/3} > 1$, Ahrens (1987) gave a formula relating the coefficient with wavelength, rock size and cross-sectional area of the structure :

$$C_t = 1.0/(1.0+X^{0.592}) \qquad \text{for } R_c/H_{1/3} > 1$$

where $X = H_{1/3}A_t/(L_p D_{n50}^2)$

A_t = Cross-sectional area of structure

L_p = Local wave length

B.6 References

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Table B1 Wave Run-up Coefficients

Exceedance Levels i	*a*	*b*	*c*	*d*
1%	1.01	1.24	0.48	2.15
2%	0.96	1.17	0.46	1.97
5%	0.86	1.05	0.44	1.68
10%	0.77	0.94	0.42	1.45
Significant	0.72	0.88	0.41	1.35
Note : These are coefficients used in the Van der Meer wave run-up prediction formulae.				

Table B2 Roughness Coefficients

Type of Slope	Roughness Coefficient *r*
One layer of rock armour on impermeable base	0.80
One layer of rock armour on permeable base	0.55 - 0.60
Two layers of rock armour	0.50 - 0.55

Table B3 Wave Overtopping Coefficients

Front Face Slope of Structure	*A*	*B*
1 : 1	0.00794	20.1
1 : 1.5	0.00884	19.9
1 : 2	0.00939	21.6
1 : 2.5	0.0103	24.5
1 : 3	0.0109	28.7
1 : 3.5	0.0112	34.1
1 : 4	0.0116	41.0

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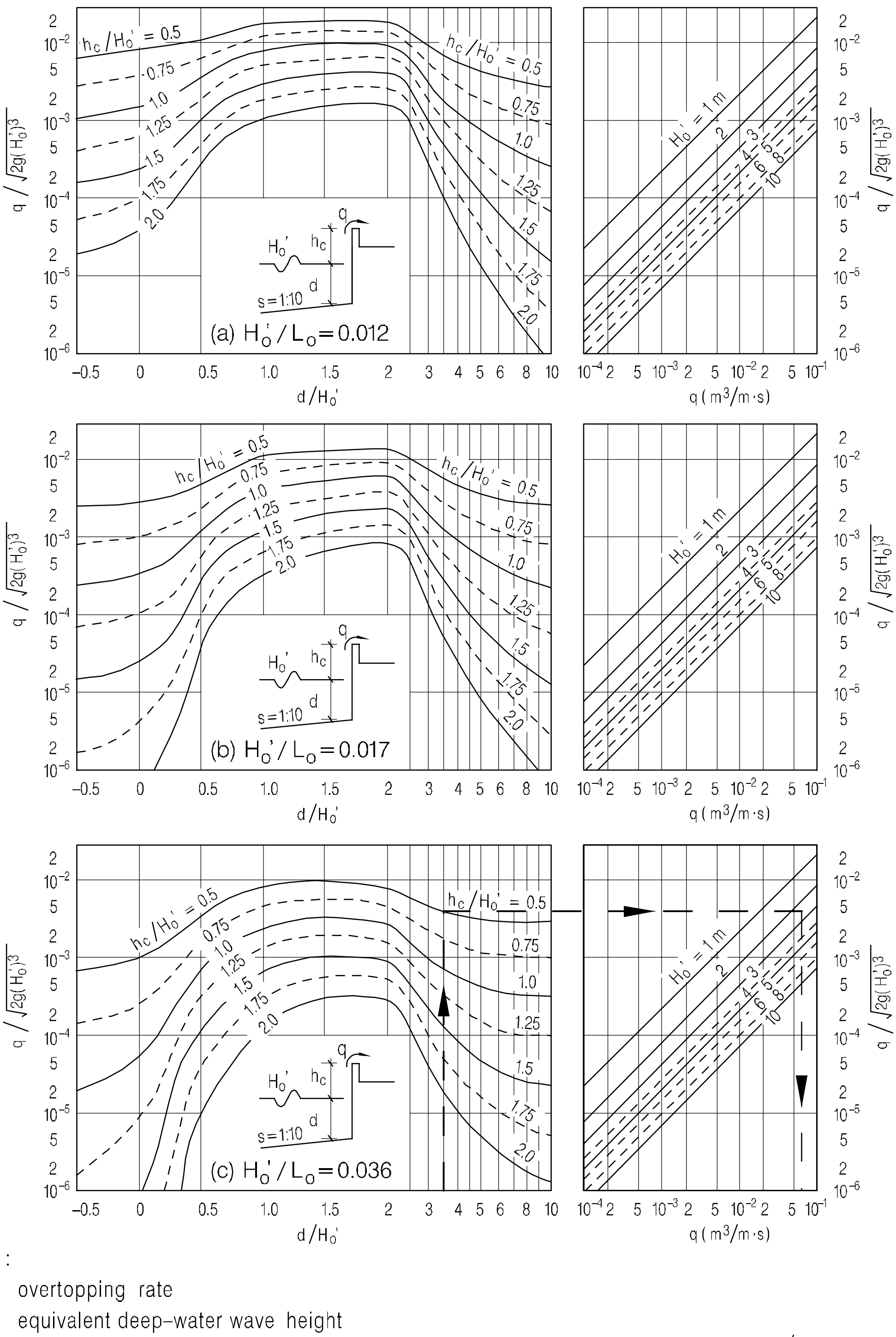


Legend :

q = overtopping rate

H_o' = equivalent deep-water wave height

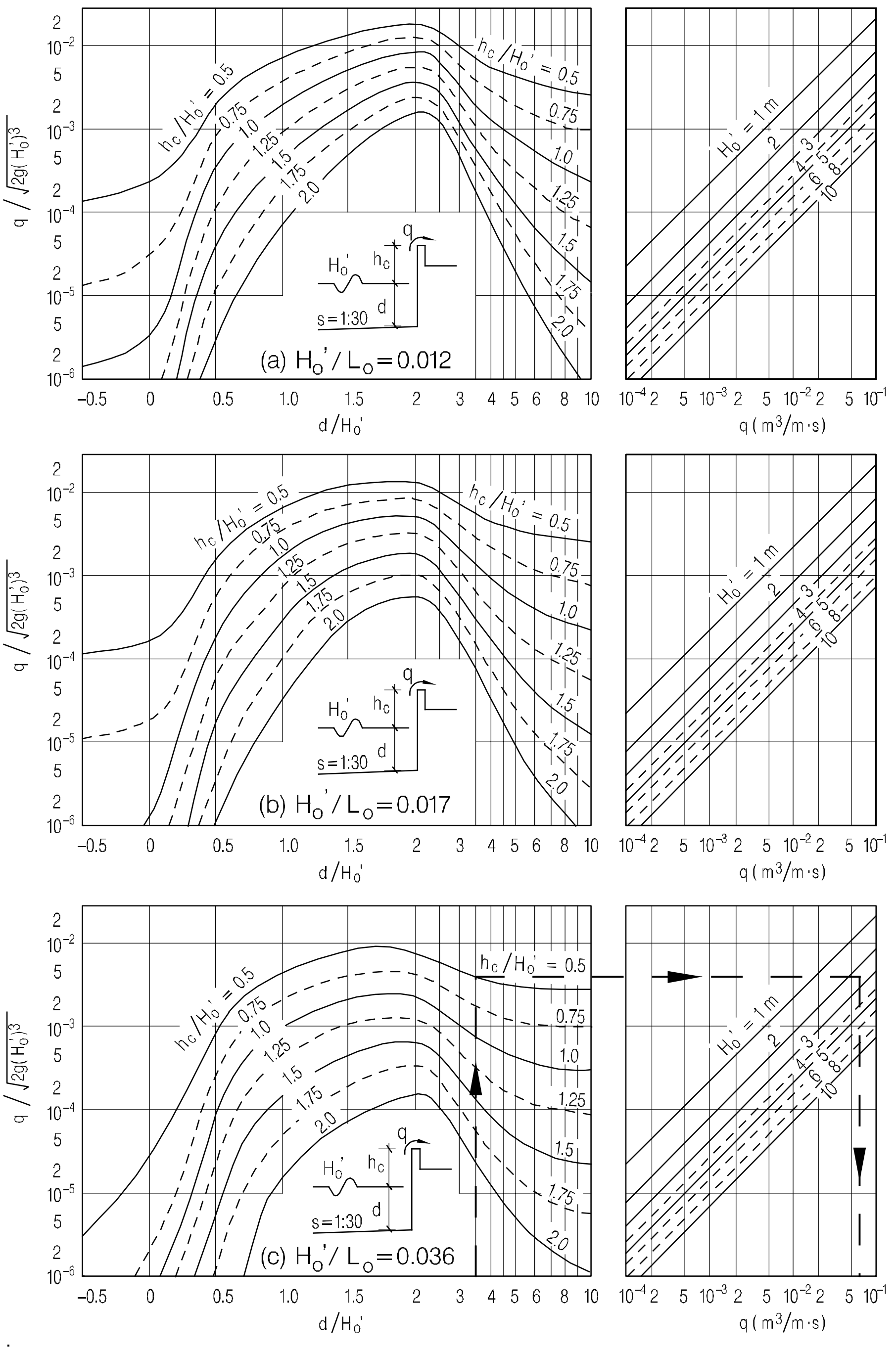
L_o = deep-water wavelength corresponding to significant wave period i.e. $L_o = gT_s^2/2\pi$

h_c = height of top of wall above still water level

s = seabed slope (tangent of angle relative to horizontal)

Source : Goda (2000)

Figure B1 – Prediction of Overtopping Rates for Vertical Structures – Seabed Slope 1 / 10



Legend :

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H_o' = equivalent deep-water wave height

L_o = deep-water wavelength corresponding to significant wave period i.e. $L_o = g T_s^2 / 2\pi$

h_c = height of top of wall above still water level

s = seabed slope (tangent of angle relative to horizontal)

Source : Goda (2000)

Figure B2 – Prediction of Overtopping Rates for Vertical Structures – Seabed Slope 1 / 30