APPENDIX D

WORKED EXAMPLES

CONTENTS

D.1 WAVE OVERTOPPING OF RUBBLE MOUND SEAWALL

Reference Section 5.3 and Appendix B.3.

Given

A rubble mound seawall with two layers of rock armour.
Crest level = +4.5 mPD
Slope of seawall (front face) = 1 : 2
Sea level = +3.2 mPD
Significant wave height at seawall = 2.0 m
Mean wave period = 4.4 s
Angle of incident wave to the normal of the seawall = 30 degrees

Find

Mean overtopping rate of the rubble mound seawall.

Solution

Take g = 9.81m/s^2 and use Owen's formulae in Appendix B.3.1

Dimensionless crest freeboard R_*

$$= R_c/(T_m(gH_{1/3})^{0.5})$$

$$= \frac{(4.5-3.2)}{4.4\times\sqrt{9.81\times 2.0}}$$

$$= 0.067$$

Dimensionless mean discharge Q_*

$$= A \exp(-BR_*/r)$$

From Table B3, for slope of seawall (front face) = 1:2, take empirical coefficients A and B to be 0.00939 and 21.6 respectively.

From Table B2, for two layers of rock armour, take roughness coefficient r to be 0.5.

$$Q_* = 0.00939 \exp(-21.6\times 0.067/0.5)$$
$$= 5.2\times 10^{-4}$$

$$Q = Q_* T_m g H_{1/3}$$

= $5.2\times10^{-4}\times4.4\times9.81\times2.0$

= 0.045 m^3/s per meter run of the seawall

Reduction factor for incident waves not normal to the structures O_r

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

= $1-0.000152\ (30)^2$

= 0.86

Therefore, mean overtopping discharge

= $Q \times O_r$

= 0.045×0.86

= 0.039 m^3/s per meter run of the seawall

This overtopping rate is nearly equal to the suggested limit of the damage to unpaved surface, $5\text{x}10^{-2}$ m^3/m/s listed in Section 5.3.2 of this part of the Manual.

D.2 WAVE OVERTOPPING OF SOLID FACE VERTICAL SEAWALL

Reference Section 5.3 and Appendix B.3.

Given

A solid face vertical seawall with toe level close to the seabed level.
Crest level = +4.5 mPD
Sea level = +3.2 mPD
Seabed level = –6.0 mPD
Significant wave height at seawall = 2.0 m
Mean wave period = 4.4 s
Incident wave angle : normal to seawall
Seabed slope = 1:30

Find

Mean rate of wave overtopping of the vertical seawall.

Solution 1

Based on the method mentioned by Besley (1999) in Appendix B.3.2 :

Water depth d = 3.2 – (–6.0) = 9.2 m
Height of top of wall above still water level R_c
= 4.5 – 3.2 m
= 1.3 m

Dimensional parameter d_*
$= (d/H_{1/3})(2\pi d/(gT_m^2))$
$= (9.2/2.0)(2\pi\, 9.2/(9.81 \times 4.4^2))$
= 1.4

As $d_* > 0.3$, reflecting waves predominate, and $R_c/H_{1/3} = 1.3/2.0 = 0.65$. The following equations should apply.

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

where $Q^\#$ is the dimensionless discharge, given by $Q/(gH_{1/3}^3)^{0.5}$

$Q^\# = 0.05 \exp(-2.78 \times 1.3 / 2.0) = 8.2 \times 10^{-3}$

Mean overtopping discharge
$= Q^{\#} (gH_{1/3}{}^3)^{0.5}$
$= 8.2 \times 10^{-3} \times (9.81 \times 2.0^3)^{0.5}$
$= 0.073$ m^3/s per meter run of seawall

<u>Solution 2</u>
Based on the diagram by Goda (2000) in Appendix B.3.2 :

Equivalent deepwater wave height $H_0' \approx H_{1/3} = 2.0$ m
Significant wave period $T_{1/3} \approx 1.2\ T_m = (1.2)(4.4) = 5.3$ s
Wave steepness $= H_0'/((g/2\pi) \times T_{1/3}{}^2) \approx 2.0/((9.81/2/3.1459) \times 5.3^2) = 0.046$
Dimensionless depth parameter $d/H_0' \approx d/H_{1/3} = 9.2/2.0 = 4.6$
Dimensionless crest parameter $h_c/H_0' \approx R_c/H_{1/3} = 1.3/2.0 = 0.65$

By using Figure B2 (c) for the wave steepness $H_0'/L_0 = 0.036$ as having the steepness nearest to the design condition, and reading off the diagram, the dimensionless overtopping rate is obtained as :

$Q/[2g(H_0')^3]^{1/2} \approx 2\times10^{-3}$

Mean overtopping rate
$= 2 \times 10^{-3} \times (2\times9.81\times2.0^3)^{1/2}$
$= 0.025$ m^3/s per meter run of seawall

Even though the above estimate differs from the previous estimate of Solution 1 by a factor of 3, such diversity should be expected because the phenomenon of wave overtopping involves a large spread of data.

D.3 REFLECTION COEFFICIENT OF RUBBLE MOUND SEAWALL

Reference Section 5.4 and Appendix B.4.

Given

A rubble mound seawall with two layers of rock armour.
Slope of seawall = 1 : 2
Significant wave height = 2.0 m
Mean wave period = 4.4 s

Find

Reflection coefficient of the rubble mound seawall.

Solution

Assume notional permeability factor $P = 0.3$

Peak wave period $T_p = 1.1\times T_{1/3} = 1.1\times 1.2\times T_m = 1.1\times 1.2\times 4.4 = 5.8$ s
(See Section 2.5.3 of Part 1 of this Manual)

Offshore wave steepness based on peak wave period s_p

$= 2\pi H_{1/3}/(gT_p^2)$

$= 2\pi\times 2.0/(9.81\times 5.8^2)$

$= 0.038$

Surf similarity parameter based on peak wave period ξ_p

$$= \frac{\tan\alpha}{\sqrt{s_p}}$$

$$= \frac{1/2}{\sqrt{0.038}}$$

$= 2.56$

(a) Seelig and Ahrens formula

Coefficient of reflection $C_r = a\xi_p^2/(b+\xi_p^2)$

$= 0.6\times 2.56^2/(6.6+2.56^2)$

$= 0.30$

(a=0.6 and b=6.6 as given by the formula)

(b) Postma formula

Coefficient of reflection C_r $= 0.14\xi_p^{\,0.73}$

$= 0.14 \times 2.56^{0.73}$

$= 0.28$

(c) Postma formula with slope angle and wave steepness treated separately

Coefficient of reflection C_r $= 0.071P^{\,-0.082}\,(\cot\alpha)^{-0.62}\,s_p^{\,-0.46}$

$= 0.071(0.3)^{-0.082}(2)^{-0.62}(0.038)^{-0.46}$

$= 0.23$

(d) Postma formula modified with Allsop and Channel data

Coefficient of reflection C_r $= 0.125\xi_p^{\,0.73}$

$= 0.125 \times 2.56^{0.73}$

$= 0.25$

D.4 ROCK ARMOUR OF RUBBLE MOUND BREAKWATER

Reference Section 6.2 and Appendix C.

Given

A conventional rubber mound breakwater in deepwater with two-diameter thick armour layer.
Slope of breakwater = 1 : 2
Significant wave height = 2.0 m
Mean wave period = 5.0 s
Damage level : Only start of damage is allowed

Find

Size of rock armour.

Solution

Mass density of rock armour ρ_r = 2600 kg/m^3
Mass density of seawater ρ_w = 1025 kg/m^3
Acceleration due to gravity g = 9.81 m/s^2

(a) Hudson's formula

Relative mass density of armour Δ
$=(\rho_r / \rho_w) - 1$
= (2600/1025) – 1
= 1.54

Assume non-breaking wave condition as the breakwater is in deepwater. For non-breaking waves, design wave height at structure is taken as $H_{1/10}$.

$$H_{1/10} = 1.27 H_{1/3} = 1.27 \times 2.0 = 2.54 \, \text{m}$$

From Table 7 of BS6349:Part 7:1991, for trunk of structures with two layers of rough angular rock under non-breaking wave condition, dimensionless stability coefficient K_D = 4.0 .

Therefore, weight of armour unit

$$W = \frac{\rho_r g H^3}{K_D \Delta^3 \cot\alpha} = \frac{(2600)(9.81)(2.54)^3}{(4.0)(1.54)^3(2)} = 14305\text{N} = 14.3 \text{ kN}$$

(b) Van der Meer formula

The breakwater is not in shallow water.
Take design wave height as significant wave height $H_{1/3}$ = 2.0 m.
Relative mass density of armour Δ
$=(\rho_r / \rho_w)-1$ = 1.54

Offshore wave steepness based on mean period s_m

$$= \frac{2\pi H_{1/3}}{gT_m{}^2} = \frac{2\times\pi\times2.0}{9.81\times5.0^2} = 0.051$$

Surf similarity parameter for mean wave period ξ_m

$$= \frac{\tan\alpha}{\sqrt{s_m}} = \frac{1/2}{\sqrt{0.051}} = 2.21$$

Only start of damage is allowed and slope of breakwater = 1 : 2.
Therefore, from Table C1, damage level S = 2.

Assume number of waves N = 4000 and notional permeability factor P = 0.3.

Critical value of ξ_c

$$= (6.2P^{0.31}\sqrt{\tan\alpha})^{1/(P+0.5)} = [(6.2)(0.3)^{0.31}\sqrt{0.5}]^{1/(0.3+0.5)} = 3.98$$

Since $\xi_m < \xi_c$, the formula for plunging waves should be used.

$$\frac{H_{1/3}}{\Delta D_{n50}}\sqrt{\xi_m} = 6.2P^{0.18}\left(\frac{S}{\sqrt{N}}\right)^{0.2}$$

Thus, nominal rock diameter D_{n50}

$$= \frac{H_{1/3}\sqrt{\xi_m}}{\Delta} / \left[6.2P^{0.18}\left(\frac{S}{\sqrt{N}}\right)^{0.2}\right] = \frac{2.0\sqrt{2.21}}{1.54} / \left[(6.2)(0.3)^{0.18}\left(\frac{2}{\sqrt{4000}}\right)^{0.2}\right] = 0.77 \text{ m}$$

Nominal mass of rock armour = $(0.77)^3(2600)$ = 1187 kg

Weight of rock armour = 11.6 kN

D.5 UNDERLAYER OF RUBBLE MOUND BREAKWATER

Reference Section 6.2.4.

Given

A conventional rubber mound breakwater with two-diameter thick armour layer.
Nominal mass of rock armour = 2000 kg
D_{15} of rock armour = 0.83 m

Find

Size of underlayer rock.

Solution

Take the number of rock layers of the underlayer $n = 2$
For rock, layer thickness coefficient $k_{\Delta} = 1.15$
Mass density of rock = 2600 kg/m^3

The nominal mass of rock in the underlayer should be at least 1/10 of the nominal mass of rock armour, i.e. > 2000/10 = 200 kg.

The nominal rock size of the underlayer $D_{50} > (200/2600)^{1/3} = 0.425$ m

To prevent smaller rocks in the underlayer from being taken out through the armour layer by wave action, the following filter criteria are checked.

$$D_{15(\text{armour})} / D_{85(\text{underlayer})} \leq 4$$
$$4 \leq D_{15(\text{armour})} / D_{15(\text{underlayer})} \leq 20$$

$D_{15(\text{armour})} = 0.83$ m

Therefore, $D_{85(\text{underlayer})} \geq 0.21$ m
$0.04 \text{ m} \leq D_{15(\text{underlayer})} \leq 0.21$ m

Note :
The filter requirement of the underlayer should also be checked with the size of core material of the breakwater, although this is not shown in this worked example.

D.6 TOE PROECTION

Reference Section 6.2.8 and Figure 16.

Given

A critical vertical seawall located in an open exposed area.

Sea level = +3.2 mPD

Seabed level = –5.0 mPD

Top level of toe protection = –4.0 mPD

Slope of rubble toe protection = 1 : 2

Significant wave height at seawall = 2.0 m

Mean wave period = 4.4 s

Find

Rock size and width of toe protection.

Solution

Referring to Figure 16,

d_1 = 3.2 – (–4.0) = 7.2 m

d_s = 3.2 – (–5.0) = 8.2 m

For intermediate water depth (i.e. $\frac{1}{25} < \frac{d}{L} < \frac{1}{2}$), the wavelength associated with depth d_1 is:

$$L = \frac{gT^2}{2\pi}\tanh\left(\frac{2\pi d_1}{L}\right)$$

$$L = \frac{9.81\times 4.4^2}{2\pi}\tanh\left(\frac{2\pi\times 7.2}{L}\right)$$

By iteration, L = 27.9 m

$$\frac{d}{L} = \frac{7.2}{27.9} = 0.258$$

Therefore, the assumption of intermediate water depth is justified.

As the seawall is situated at open exposed site, the design wave height H is taken to be $H_{1/100}$ according to Figure 16.

$H = 1.67\ H_{1/3}$ = 1.67 x 2.0 = 3.3 m

The width of toe protection is given by the following:

$B \geq 0.4 d_s = 0.4 \times 8.2 = 3.3$ m

$B \geq 2H = 2 \times 3.3 = 6.6$ m

For B = 6.6 m

$$\frac{B}{L} = \frac{6.6}{27.9} = 0.24$$

$$\frac{B}{d_1} = \frac{6.6}{7.2} = 0.92$$

$$\frac{d_1}{H} = \frac{7.2}{3.3} = 2.18$$

From Figure 16, $N_s = 3.8$

The mass of rock required for toe protection is:

$$\frac{\rho_r H^3}{N_s{}^3 (s_r - 1)^3} = \frac{(2600)(3.3)^3}{(3.8)^3 (2600/1025 - 1)^3} = 469\,\text{kg}$$

The width of toe protection is checked with the following:

$B \geq$ 4 times size of rock = 4 $\times$ $(469/2600)^{1/3}$ = 2.3 m

This requirement is also satisfied. Therefore, width of toe protection = 6.6m.