APPENDIX C

DETERMINATION OF SIZE OF ARMOUR

CONTENTS

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C.1 General

This appendix discusses the Hudson Formula and the Van der Meer Formulae for calculating the size of rock armour of rubble mound structures.

C.2 Hudson Formula

The Hudson formula was derived from a series of regular wave tests using breakwater models. The formula is given by :

$$W = \frac{\rho_r g H^3}{K_D \Delta^3 \cot\alpha}$$

where W = Weight of an armour unit (N).
H = Design wave height at the structure (m).
K_D = Dimensionless stability coefficient.
α = Slope angle of structure.
ρ_r = Mass density of armour (kg/m^3).
g = Acceleration due to gravity (m/s^2).
Δ = Relative mass density of armour = (ρ_r / ρ_w) – 1
ρ_w = Mass density of seawater (kg/m^3).

ρ_r and ρ_w may be taken as 2600 kg/m^3 for rock and 1025 kg/m^3 for seawater respectively for design purposes.

For non-breaking wave conditions, the design wave height may be taken as $H_{1/10}$ at the site of the structure. For conditions where $H_{1/10}$ will break before reaching the structure, the wave height used in design should be the breaking wave height or the significant wave height, whichever has the more severe effect (BSI, 1991).

Suggested values of K_D for rock armour at the trunk and head of structures under non-breaking and breaking wave conditions can be found in BS6349:Part 7:1991 (BSI, 1991). These quoted values do not take account of the differences in factors such as wave period and spectrum, shape of armour rock, placement method, interlocking, angle of wave incidence, size of underlayer and porosity which will have influence on the stability. They should not be used without careful reviews of the factors involved.

C.3 Van der Meer Formulae

Van der Meer derived two formulae for plunging and surging waves. These formulae take account of the influence of wave period, storm duration, armour grading, spectrum shape, groupiness of waves, core permeability and damage level on rock armour, and therefore they are described as practical design formulae for rock armour. The formulae are (BSI, 1991) :

For plunging waves,

$$\frac{H}{\Delta D_{n50}}\sqrt{\xi_m} = 6.2P^{0.18}(\frac{S}{\sqrt{N}})^{0.2}$$

For surging waves,

$$\frac{H}{\Delta D_{n50}} = 1.0P^{-0.13}(\frac{S}{\sqrt{N}})^{0.2}(\sqrt{\cot\alpha})\quad \xi_m{}^{P}$$

where H = Design wave height, taken as the significant wave height (m).
D_{n50} = Nominal rock diameter equivalent to that of a cube (m).
Δ = Relative mass density of armour = $(\rho_r / \rho_w) - 1$
P = Notional permeability factor (see Figure 13).
α = Slope angle of structure.
N = Number of waves.
S = Damaged level = $A / D_{n50}{}^2$
A = Erosion area in a cross-section (m^2).
ξ_m = Surf similarity parameter for mean wave period = $(\tan\alpha)/\sqrt{s_m}$
s_m = Offshore wave steepness based on mean period = $2\pi H / gT_m{}^2$
T_m = Mean wave period (s).
g = Acceleration due to gravity (m/s^2).

The transition from plunging to surging waves is calculated using a critical value of ξ_c (CIRIA, 1991) :

$$\xi_c = (6.2P^{0.31}\sqrt{\tan\alpha})^{1/(P+0.5)}$$

Depending on the slope angle and permeability, this transition lies between ξ_c = 2.5 to 3.5. When the value of surf similarity parameter is greater than ξ_c, the formula for surging waves should be used. For $\cot\alpha \geq 4$, the transition from plunging to surging does not exist and for these slopes, only formula for plunging waves should be used.

The notional permeability factor P should lie between 0.1 for a relatively impermeable core to 0.6 for a virtually homogeneous rock structure. The choice of P depends on designer's judgement. Where data are not available for a detailed assessment, P may be taken as 0.3 for rock armoured breakwater, unless an open core is to be provided. If in doubt, it is recommended that the permeability be underestimated rather than over-estimated.

The damage level S is the number of cubic stones with a side of D_{n50} being eroded around the water level with a width of one D_{n50}. The limits of S depend mainly on the slope of the structure. For a two-diameter thick armour layer, the lower and upper damage levels have been assumed to be the values shown in Table C1. The start of damage of S = 2 to 3 is the same as that used by Hudson, which is roughly equivalent to 5% damage. Failure is defined as exposure of the filter layer.

The formulae can be used when the number of waves N, or storm duration, is in the range of 1000 to 7000. For N greater than 7000, the damage tends to be overestimated. Unless data are available for more detailed assessment, values of N from 3000 to 5000 may be used for preliminary design purpose (BSI, 1991).

The slope of the armour structure, $\cot\alpha$, should lie between 1.5 and 6. The wave steepness s_m should be within the range of 0.005 and 0.06. Waves become unstable when the steepness is greater than 0.06.

For shallow water conditions, the parameter ($H_{2\%}$ /1.4) should be used in the above Van der Meer formulae instead of significant wave height $H_{1/3}$. This is based on the analysis of some test results of breaking waves on the foreshore of a structure. These results indicated that if the structure is located in relatively shallow water and that if the wave height distribution is truncated, the 2% value of the wave height exceedance curve gives the best agreement with results showing a Rayleigh distribution (Van der Meer, 1990).

Some further remarks on the use of the formulae are also given here. A deterministic design procedure is followed if various design parameters are input in the formulae to determine the size of rock armour and if a sensitivity analysis is carried out on the various parameters. Another design procedure is the probabilistic approach in which the formulae are rewritten to so-called reliability functions and all the parameters can be assumed to be stochastic with an assumed distribution. For details of the latter approach, reference can be made to CIRIA (1991).

C.4 References

BSI (1991). Maritime Structures – Part 7 : Guide to the Design and Construction of Breakwaters (BS 6349:Part 7 : 1991). British Standards Institution, London, 88p.

CIRIA (1991). Manual on the Use of Rock in Coastal and Shoreline Engineering. Construction Industry Research and Information Association, United Kingdom, 907p.

Van der Meer, J.W. (1990). Rubble Mounds – Recent Modifications, Handbook of Coastal and Ocean Engineering, Volume 1, edited by J.B. Herbich, Gulf Publishing Company, Houston, pp. 883-894.

LIST OF TABLES

Table C1 Damage Levels for Two-Diameter Thick Rock Slopes

Slope of Structure A	Damage Level *S* at Start of Damage	Damage Level *S* at Failure
1:1.5	2	8
1:2.0	2	8
1:3.0	2	12
1:4.0	3	17
1:6.0	3	17

Note : 1. Damage Level $S = A/D_{n50}^2$, where A is the eroded area of the cross-section of the structure and is the hatched area as shown in the figure below.

2. Source : CIRIA (1991).