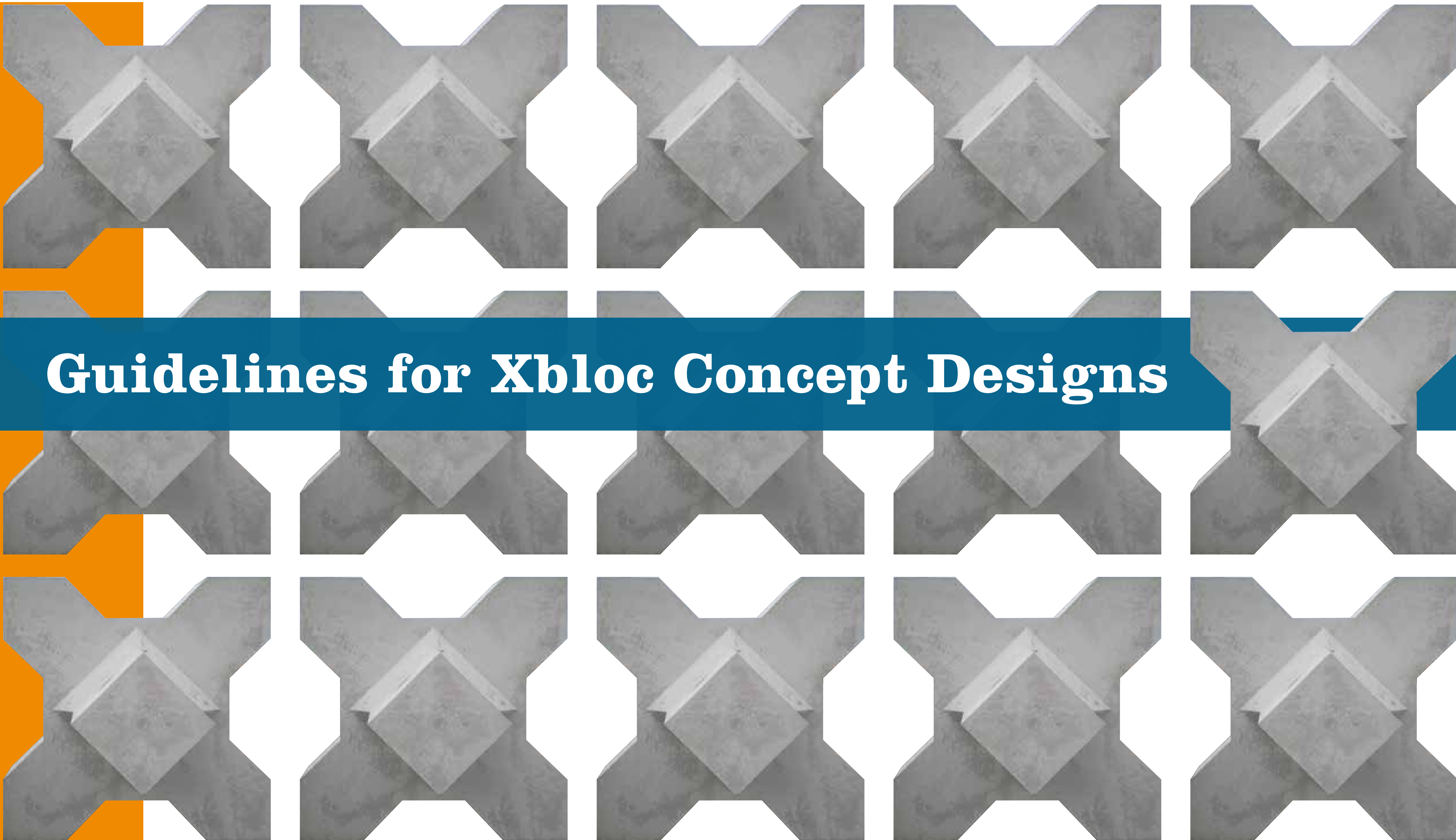
Guidelines for Xbloc Concept Designs



Guidelines for Xbloc Concept Designs

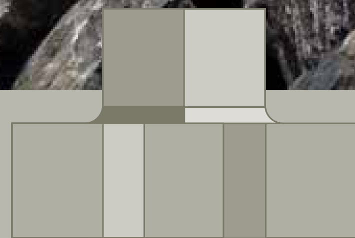
xbloc®

Edition March 2014

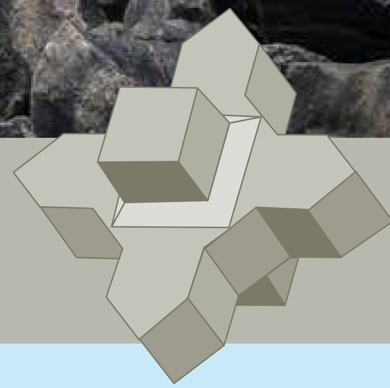
Guidelines for Xbloc Concept Designs

Edition March 2014

Contents



Xbase



Xbloc

1 Introduction

Over the last decades, Delta Marine Consultants (DMC) has gained a vast experience in the design of breakwaters and shore protections. Following the development of Xbloc which started in 2001 and its market introduction in 2003, DMC has been involved in design, physical model testing and construction of many Xbloc projects around the world.

The objective of this document is to share this experience with design consultants who are working on concept designs with Xbloc armour units. Although the required Xbloc unit size is determined mainly by the design wave conditions, a number of phenomena is presented in this document which may require the application of a larger unit size than purely based on the design wave height. Furthermore typical details are presented such as the toe, crest and head of a breakwater and transitions.

This document is not a design manual and it is not a complete description of all factors that affect a design. The objective of this document is to provide general information to be used for concept designs with Xbloc armour units. The design remains the responsibility of the designer who shall take into account the various factors that affect the design. Physical model tests are always recommended by DMC to verify the stability of the design. The conditions which apply to the use of this document are described in Section 10.

In case of questions about a concept design or about the use of Xbloc, please feel free to contact DMC at:

- xbloc@xbloc.com;
- dmc@dmc.nl;
- +31 182 590 610

2 Symbols and Definitions

The following symbols are used in this document:

Symbol	Description	Unit
D	Xbloc unit height	m
D_{n50}	Median nominal diameter of rock	m
Δ	Relative concrete density	-
D_x	Horizontal c.t.c. distance between Xblocs along alignment	m
D_y	Upslope c.t.c. distance between Xblocs	m
H_s	Significant wave height based on time domain analysis	m
H_{mo}	Significant wave height calculated from wave spectrum	m
h_t	Water depth above rock toe	m
h	Water depth	m
N	Packing density of Xblocs on slope	Units/m²
N_{od}	Damage value; number of displaced rocks	-
ρ_w	Mass density of seawater	kg/m³
ρ_c	Mass density of concrete	kg/m³
T_p	Peak wave period	s
V	Xbloc unit volume	m³
W	Xbloc unit mass	t

The following definitions are used in this document:
(the numbers shown refer to Figure 2-1)

Armour layer	(1)	Outer layer of structure
Core	(4)	Inner part of breakwater
Crest height	(5)	Top level of structure
Crown wall	(6)	Concrete structure placed on breakwater crest
Filter	(8)	Filter layer between sea bed and breakwater toe
Freeboard	(7)	The crest height above design high water level
Relative Freeboard		The freeboard divided by the design wave height
Under layer	(2)	Rock layer between core and armour layer
Toe	(3)	Rock protection; foundation of armour layer

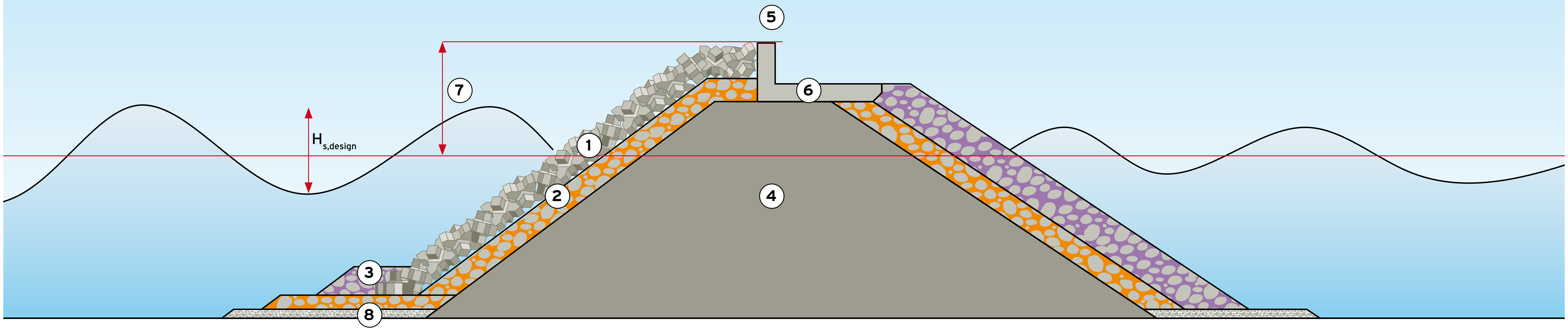


Figure 2-1: Typical outline symbols and definitions

3 Starting Points and Boundary Conditions

The most important starting points for the design of a breakwater / shore protection are:

- The required lifetime of the structure;
- The return period of the design conditions;
- Allowable overtopping;
- Allowable wave disturbance behind a breakwater;
- Construction aspects (e.g. crest width and height).

The most important boundary conditions for the design of a breakwater / shore protection are:

- The design wave height and period;
- The design water level (high water and low water);
- The bathymetry;
- The soil conditions;
- Seismic conditions.

The geotechnical design of breakwaters and shore protections is determined by local soil conditions, surcharge loads, hydraulic loads and seismic conditions. These aspects should be carefully considered by the design consultant and are not a part of this document.

4 Front Armour Design

The required armour size is typically determined by the design wave height as described in Section 4.1. Depending on the local conditions, there are however phenomena that may require the application of a larger unit than based on the equation in Section 4.1. These phenomena are described in Section 4.2.

4.1 Required Xbloc size

For the design of typical cross sections of breakwaters and shore protections, the required Xbloc size depends on the design wave height and can be determined with the following formula:

$$V = \left[\frac{H_s}{2.77 \times \Delta}\right]^3$$

Where:

V	Xbloc volume	[m³]
H_s	Design significant wave height [1) 2)]	[m]
Δ	Relative concrete density $(\rho_c - \rho_w) / \rho_w$	[-]
ρ_w	Mass density of seawater	[kg/m³]
ρ_c	Mass density of concrete [3)]	[kg/m³]

1) DMC does not recommend a reduction for oblique waves without physical model tests.

2) If H_{mo} is higher than H_s, H_{mo} shall be applied.

3) DMC does not recommend the use of concrete densities outside the range of 2350-2500kg/m³.

This formula in fact gives the same results as the Hudson Formula for an armour slope steepness of 3V:4H and a K_d factor of 16. Please note that for Xbloc on a milder slope, the required unit weight is not reduced.

Xblocs are typically applied on an armour slope steepness between 3V:4H and 2V:3H.

The above formula results in the following Xbloc Design Table which is based on
$\rho_{concrete}$ = 2400 kg/m^3 and $\rho_{seawater}$ = 1030 kg/m^3

Unit volume V [m³]	Design wave height H_s [m]	Unit height D [m]	Unit weight W [t]	Thickness of armour layer h [m]	Packing density N [1/100m²]	Concrete volume [m³/m²]	Placement distance horizontal D_x [m]	Placement distance up-slope D_y [m]	Porosity of armour layer [%]	Rock grading for under layer [t]	Thickness under layer f [m]
0.75	3.35	1.31	1.8	1.3	70.03	0.53	1.73	0.83	58.7	0.06-0.3	0.8
1	3.69	1.44	2.4	1.4	57.81	0.58	1.90	0.91	58.7	0.06-0.3	0.8
1.5	4.22	1.65	3.6	1.6	44.12	0.66	2.18	1.04	58.7	0.3-1.0	1.3
2	4.65	1.82	4.8	1.8	36.42	0.73	2.40	1.14	58.7	0.3-1.0	1.3
2.5	5.01	1.96	6.0	1.9	31.38	0.78	2.58	1.23	58.7	0.3-1.0	1.3
3	5.32	2.08	7.2	2.0	27.79	0.83	2.75	1.31	58.7	0.3-1.0	1.3
4	5.86	2.29	9.6	2.2	22.94	0.92	3.02	1.44	58.7	0.3-1.0	1.3
5	6.31	2.47	12.0	2.4	19.77	0.99	3.26	1.55	58.7	1.0-3.0	1.8
6	6.70	2.62	14.4	2.5	17.51	1.05	3.46	1.65	58.7	1.0-3.0	1.8
7	7.06	2.76	16.8	2.7	15.80	1.11	3.64	1.74	58.7	1.0-3.0	1.8
8	7.38	2.88	19.2	2.8	14.45	1.16	3.81	1.82	58.7	1.0-3.0	1.8
9	7.67	3.00	21.6	2.9	13.36	1.20	3.96	1.89	58.7	1.0-3.0	1.8
10	7.95	3.11	24.0	3.0	12.45	1.25	4.10	1.96	58.7	1.0-3.0	1.8
12	8.44	3.30	28.8	3.2	11.03	1.32	4.36	2.08	58.7	1.0-3.0	1.8
14	8.89	3.48	33.6	3.4	9.95	1.39	4.59	2.19	58.7	3.0-6.0	2.4
16	9.29	3.63	38.4	3.5	9.10	1.46	4.80	2.29	58.7	3.0-6.0	2.4
18	9.67	3.78	43.2	3.7	8.42	1.52	4.99	2.38	58.7	3.0-6.0	2.4
20	10.01	3.91	48.0	3.8	7.85	1.57	5.17	2.47	58.7	3.0-6.0	2.4

4.2 Local phenomena that affect the required unit size

The design formula and design table presented in the previous section are applicable for typical cross sections of breakwaters and shore protections. There is however a number of phenomena which require to increase the Xbloc size. The phenomena and the proposed correction factor on the unit weight are described below.

Phenomenon	Effect on Armour Stability	Correction factor on unit weight
Frequent occurrence of near-design wave height during the lifetime of the structure	Rocking of units, which can occur for a small percentage of the armour units during the design event of a breakwater, can occur frequently during the lifetime of the structure. Therefore rocking should be carefully assessed during the physical model tests.	1.25
The foreshore in front of the structure is steep	A steep foreshore can lead to adverse wave impact against the armour layer.	1.1 for a steepness between 1:30 and 1:20 1.25 for a steepness between 1:20 and 1:15 1.5 for a steepness between 1:15 and 1:10 2 for a steepness greater than 1:10
The structure is low crested	Armour units placed on the horizontal crest and high on the slope are less stable than units placed lower on the slope, where interlocking is increased by gravity and the above-lying units. In case of a low breakwater, the crest area sustains significant wave impacts and as a consequence a larger unit size is applied.	2 for a relative freeboard < 0.5 1.5 for a relative freeboard < 1
The water depth is large	For typical nearshore breakwater cross sections, the ratio between the highest wave heights in the spectrum and the significant wave height is in the order of 1.2 – 1.4. For breakwaters in deep water, this ratio can be up to 1.8 – 2. As the largest waves in the spectrum cause the largest loads on the armour layer, the stability of the armour layer is reduced compared to breakwaters in lower water depths. Furthermore a breakwater cross section in deep water typically contains a high rock toe which can affect the wave impacts on the armour slope. Therefore rocking should be carefully assessed during the physical model tests.	1.5 for a water depth > 2.5 x H_s 2 for a water depth > 3.5 x H_s
The core permeability is low	A low core permeability can lead to large pressures in the armour layer and reduce the stability of the armour layer. The permeability of the core depends on the materials used and the distance at the water line between the armour layer and the impermeable layer.	1.5 for a low core permeability 2 for an impermeable core
The armour slope is mild (<1:1.5)	On a mild slope, the interlocking of armour units is less effective and as a consequence the stability is reduced.	1.25 for a slope milder than 1V: 1.5H 1.5 for a slope milder than 1V:2H

For the concept design of structures where one or more of these phenomena apply, the following design formula is recommended:

$$V = \left[\frac{H_s}{2.77 \times \Delta}\right]^3 \times \text{correction factor}$$

If more than one of the above-mentioned phenomena is applicable to a design, it is advised to apply the largest correction factor as a starting point for the physical model tests.

On a breakwater head or on a curved breakwater section, placement of the units is complicated by the breakwater geometry. Furthermore the wave action can be affected by the geometry and as a consequence the stability of the units is reduced. Therefore the weight of the Xblocs on a breakwater head or curved section is increased by 25% compared to the unit mass on a straight section.

These correction factors are presented with the objective to make designers aware of the effect of these phenomena and to give a first estimate of the required Xbloc size in a project. It should be noted that the factors presented should be used with care as these are based more on project specific model test experience rather than on vast research programs. For the detailed design, physical model tests are always recommended.

Although this document focuses on the design of Xbloc breakwaters and shore protections, DMC expects that the phenomena described above apply to all armour units which derive their stability from interlocking.

4.3 Maximum allowable number of rows

Another phenomenon which may require to apply a larger armour unit than purely based on the design formula presented in section 4.1 is a long breakwater slope.
To limit possible settlements the maximum number of rows on the slope is 20. This results in a maximum slope length of 19 x D_y + 0.5 x D where D_y is the upslope distance between the Xblocs and D is the characteristic height of the Xbloc.
If the slope length requires more than 20 rows, there are 2 possible solutions:

- Increase the unit size and/or;
- Raise the toe level by applying a rock berm.

It should be noted that applying a berm may affect the wave impacts on the armour slope. Therefore this solution may still lead to applying a larger armour unit.

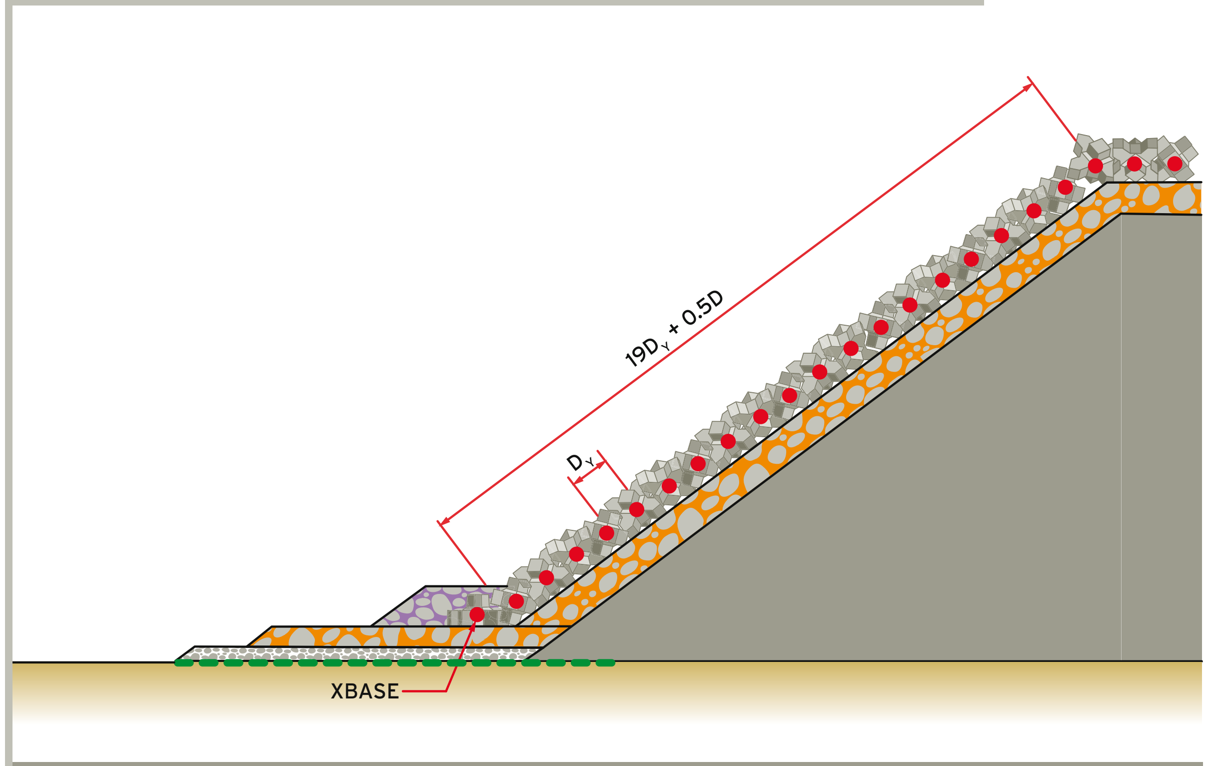


Figure 4-1: Maximum slope length

5 Toe Design

For the design of the toe, the combination of wave heights and water level shall be carefully considered. In a depth limited situation the toe design shall be checked for various water levels with corresponding wave height combinations. If the design wave conditions can occur during design low water level, this combination will be governing.

5.1 Depth variation along alignment

If the water depth varies along the breakwater alignment, the number of Xblocs on the slope will vary along the alignment. DMC generally recommends to design the breakwater toe in such a way that it follows the seabed (hence not to design sudden steps along the alignment). The maximum gradient for which this is recommended is 1V:10H. For steeper gradients, the toe should be levelled either by filling with rock material or by dredging.

5.2 Sandy seabed

For a sandy seabed DMC recommends the following toe geometry:

- A rock filter layer or a geotextile with a protective small rock layer on top;
- Foundation layer underneath the Xbase units. Typically the rock size applied in this layer has a W_{50} of the Xbloc weight divided by 30;
- A row of Xbase units (for easy placement of the first row of armour units);
- A rock toe in front of the Xbase units.

The minimum dimensions of the rock toe are indicated in Figure 5-1. In section 5.4 the required mass of the rock is described.

In very shallow water depths, it may be impossible to design a toe as shown in Figure 5-1 as the required rock size becomes too large. In such situations, it can be considered to dig a trench below the planned breakwater toe and fill this trench with rock layers (see Figure 5-2). This geometry is also suitable in situations with a risk of scour.

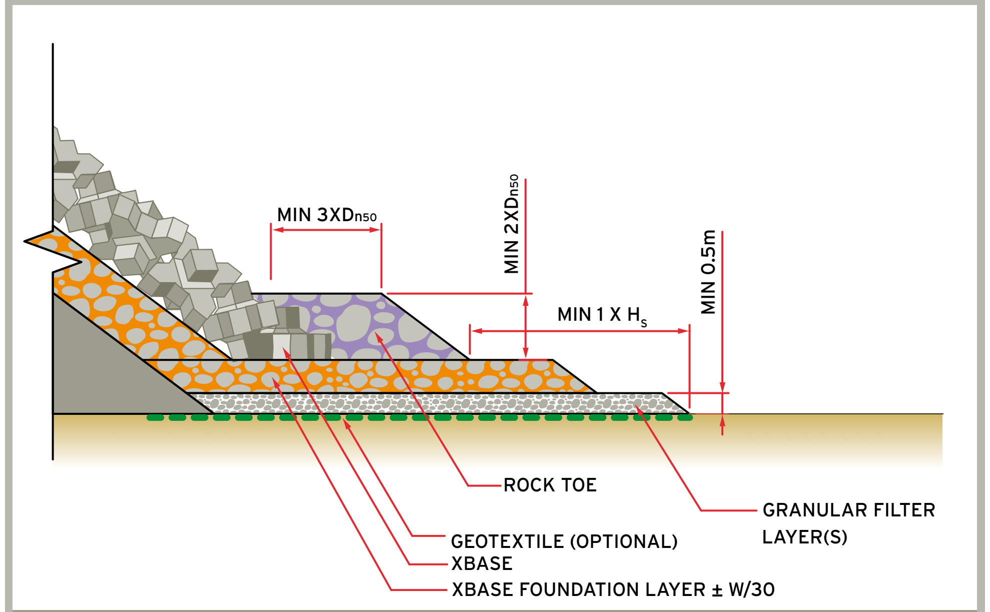


Figure 5-1: Typical toe layout on sandy seabed (if required a geotextile shall be applied between seabed and core layer)

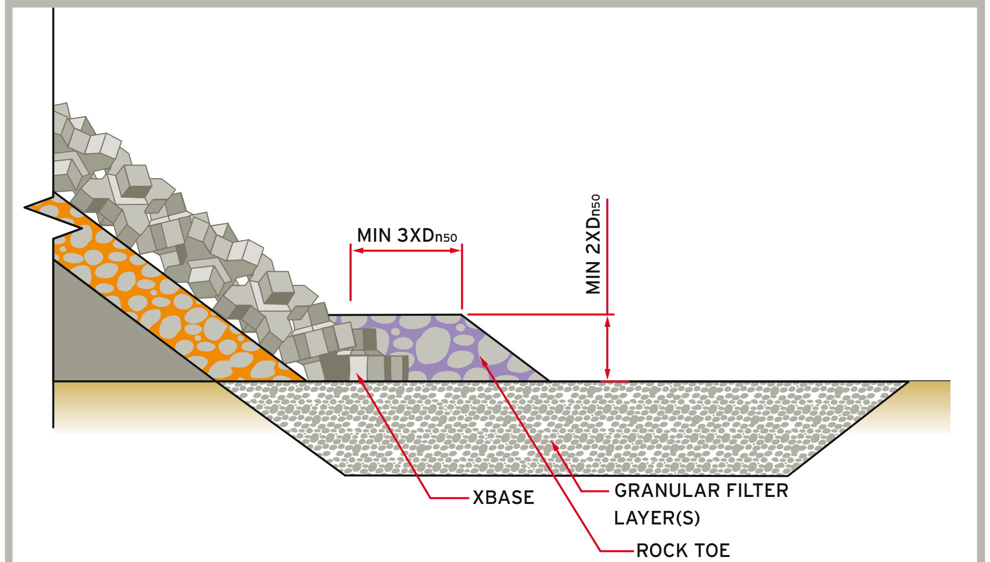


Figure 5-2: Toe layout on sandy seabed in very shallow water depths

5.3 Rocky Seabed

For a rocky seabed, the toe geometry is slightly different as there is no need for filter layers. In this case the toe consists of:

- A row of Xbase units placed on the seabed;
- A rock toe in front of the Xbase units.

The minimum dimensions of the toe on a rocky seabed are indicated in Figure 5-3. In section 5.4 the required mass of the rock is described.

For the detail as shown in Figure 5-3, the smoothness and gradient of the seabed should be considered. If the roughness of the seabed is larger than D/4 or if the gradient of the seabed is larger than 1V:10H, the toe design as per Figure 5-1 is recommended.

5.4 Size of rock toe in front of Xbase unit

The required rock size depends on the water depth and the wave height. A prediction of required rock mass can be derived by generic approach developed by Van der Meer et al (1995). The formula derived by Van der Meer is given below:

$$D_{n50} = \frac{H_s}{\left(2 + 6.2\left(\frac{h_t}{h}\right)^{2.7}\right) \times N_{od}^{0.15}\Delta}$$

Where

D_{n50}	Median nominal diameter of rock	[m]
H_s	Design significant wave height	[m]
h_t	Depth above toe	[m]
h	Water depth in front of toe	[m]
N_{od}	Damage value Number of displaced units	[-]
Δ	Relative concrete density $(\rho_c - \rho_w)/\rho_w$	[-]
ρ_w	Mass density of seawater	[kg/m³]
ρ_c	Mass density of concrete	[kg/m³]

It is recommended to design the required toe size with a N_{od} value of 0.5 (start of damage), a higher value is not recommended as it may lead to settlement of the Xbloc armour layer.

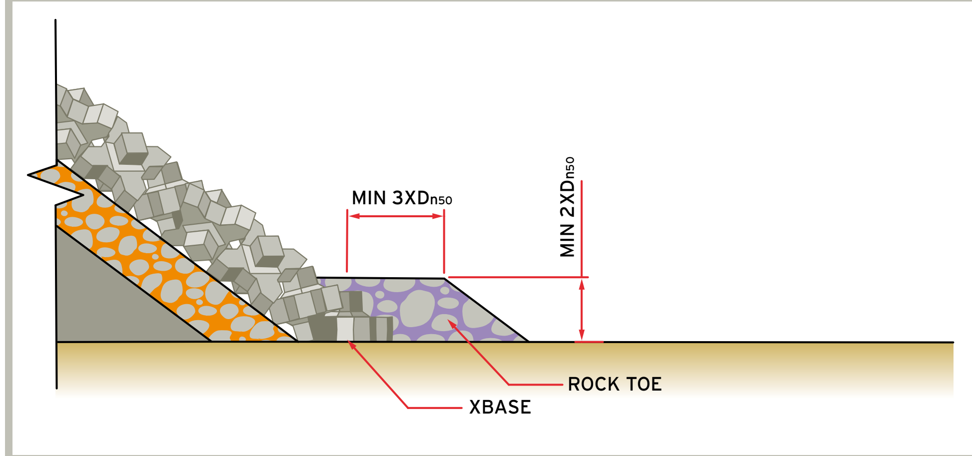


Figure 5-3: Typical toe layout on rocky seabed

6 Crest Design

The design of the breakwater crest depends on:

- The required crest level;
- Whether or not road access is required on the breakwater and by whom it will be used (access road or service road only);
- The allowable overtopping;
- The crest width at a certain level required for construction purposes.

Figures 6-1 and 6-2 give an overview of typical crest designs depending on the relative freeboard and whether or not access to the breakwater is required (with a crown element or not). The crown elements given in Figure 6-2 are indicative only. The hydraulic stability of the crown elements can be critical and shall be assessed in a concept design.

It should be noted that these are typical sketches and that physical model tests are recommended for the crest design, especially if the freeboard is low.

If the breakwater has a relative freeboard of 0.8 – 1.2, it is recommended to place at least 2 armour units in front of the crown wall. This corresponds to a width of 1.64D where D is the characteristic unit height. Without a crown wall it is recommended to apply at least 3 armour units on the crest, which corresponds to a minimum crest width of 2.28D.

In case the crest height of the breakwater has a relative freeboard of 1.2 – 1.5 the recommended minimum crest width in front of a crown wall is 1D, which corresponds to placing 1 unit on the crest.

Relative Freeboard

Without Crown Wall

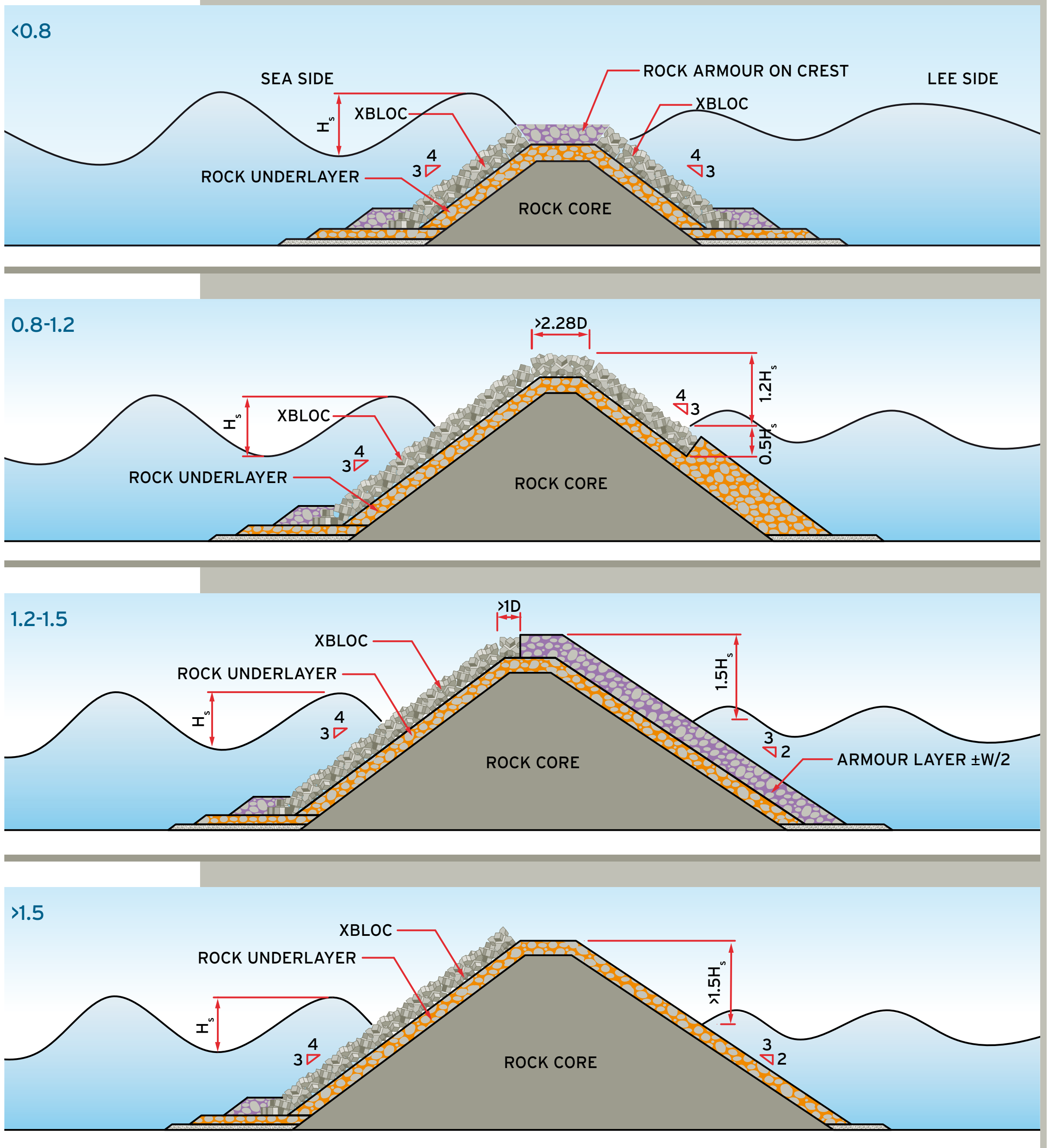


Figure 6-1: Typical crest and rear armour design without crest structure (depending on relative freeboard)

With Crown Element

Relative Freeboard

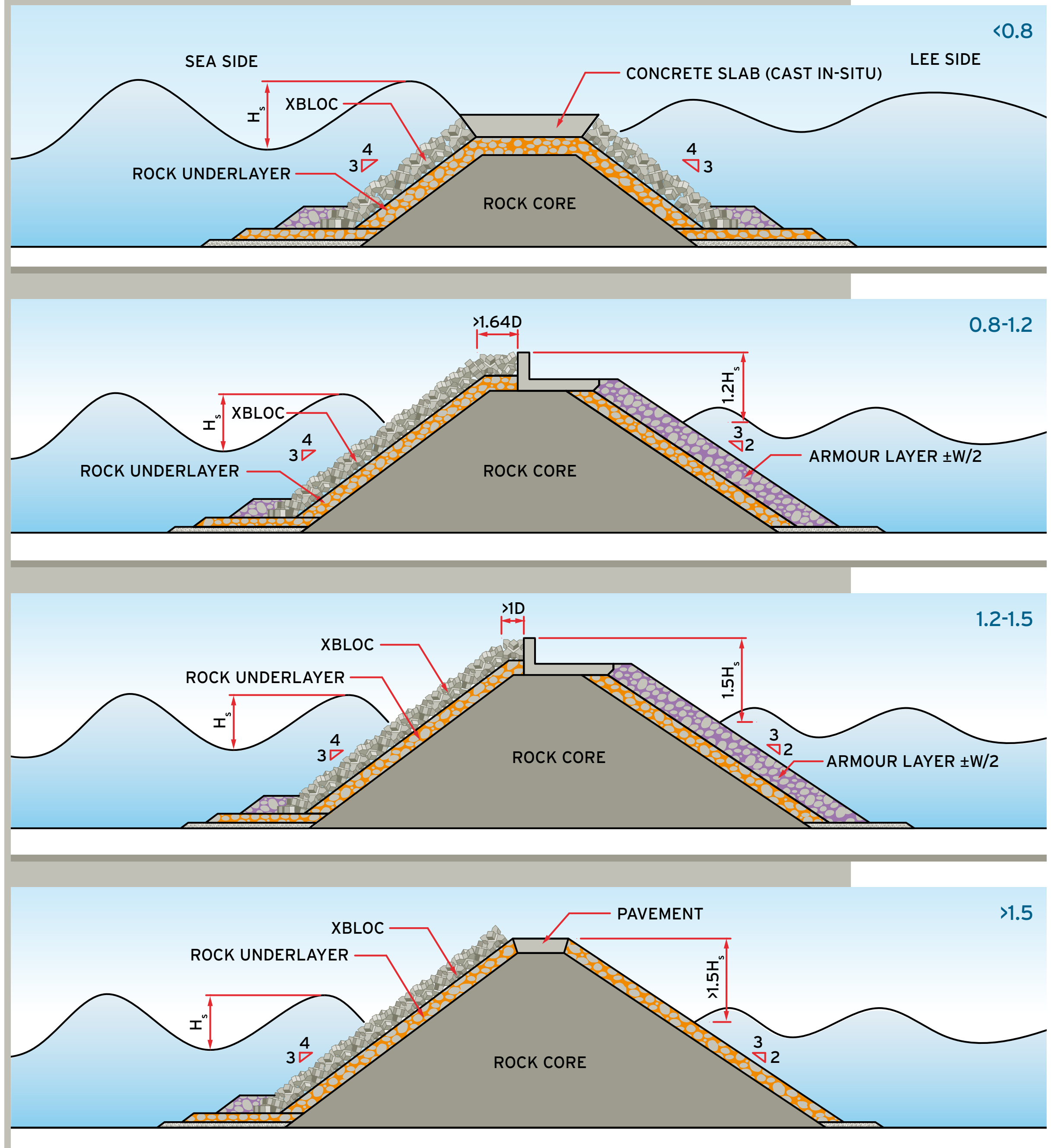


Figure 6-2: Typical crest and rear armour design with crest structure (depending on relative freeboard)

7 Rear Armour Design

The design of the rear armour is determined by:

- The overtopping waves;
- The waves at the rear side of the breakwater (mostly as a result of wave penetration).

In this section it is assumed that the wave climate at the rear side of the breakwater is calm (hence no significant wave penetration, ship induced waves etc.).

There is no generic design formula for rear armour as the geometry of the breakwater has a large impact on the overtopping volume and on the wave impacts on the rear armour. Figure 6-1 and Figure 6-2 give an overview of the rear armour at typical breakwater cross sections depending on the relative freeboard and whether or not access to the breakwater is required.

Please note that these are typical sketches and that physical model tests are required for detailed rear armour design.

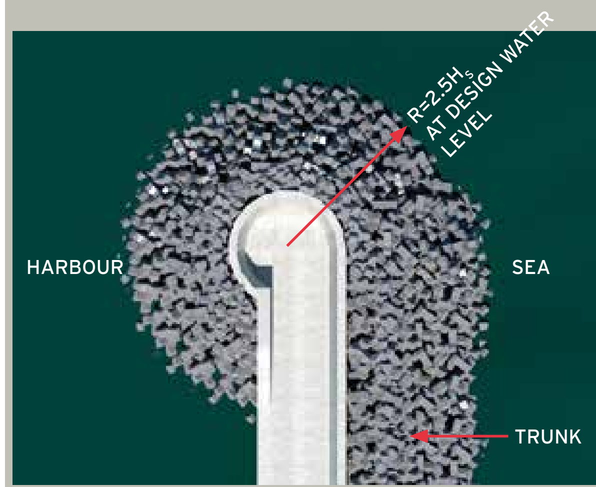
8 Breakwater Head and Curved Sections

In general the breakwater head is the most exposed part of the breakwater. The armour at this section is designed with a correction factor of 1.25 as described in Section 4-2. This means that the weight of the Xbloc armour units at the head section is 25% heavier than the units at the trunk section.

The exposed bends of the breakwater shall also be designed with Xbloc armouring which is 25% heavier than what would be required for a straight trunk section.

The minimum radius of a breakwater head section with Xbloc armour is 2.5 times the design H_s taken at design high water level (DHWL). If a larger armour unit is applied than based on a correction factor of 1.25, the minimum radius is 5.9 times the characteristic height (D) of the Xbloc size.

A typical design of a breakwater head is shown in Figure 8-1.



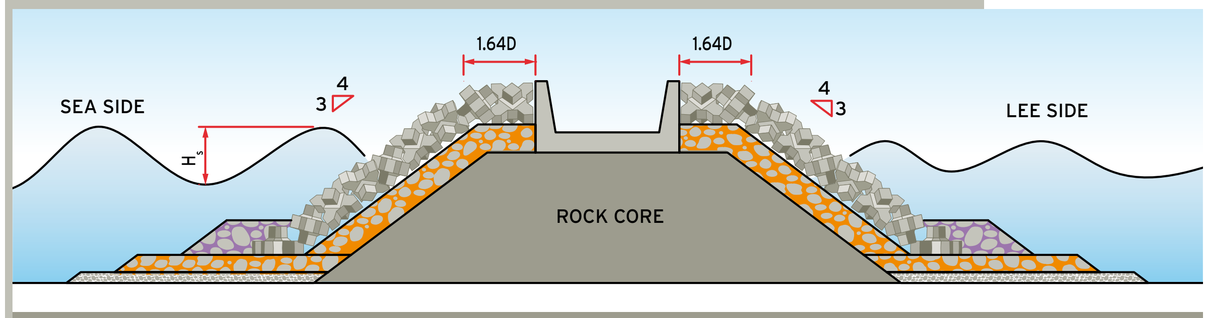


Figure 8-1: Typical design breakwater head

9 Transitions

9.1 Transitions between Xbloc sizes

Transitions between Xbloc sizes are required if multiple unit sizes are applied along a breakwater / shore protection.
The maximum recommended step is a doubling of the unit size (e.g. from $2m^3$ to $4m^3$ units).
The entire transition shall be located in the area where the smallest unit size is stable.

9.2 Transitions between Xbloc sections and rock sections

At the transition from Xbloc armour to rock armour, the Xbloc armour will be ended in a triangle shape as shown in Figure 9-1. This triangle shall be covered by suitable rock.

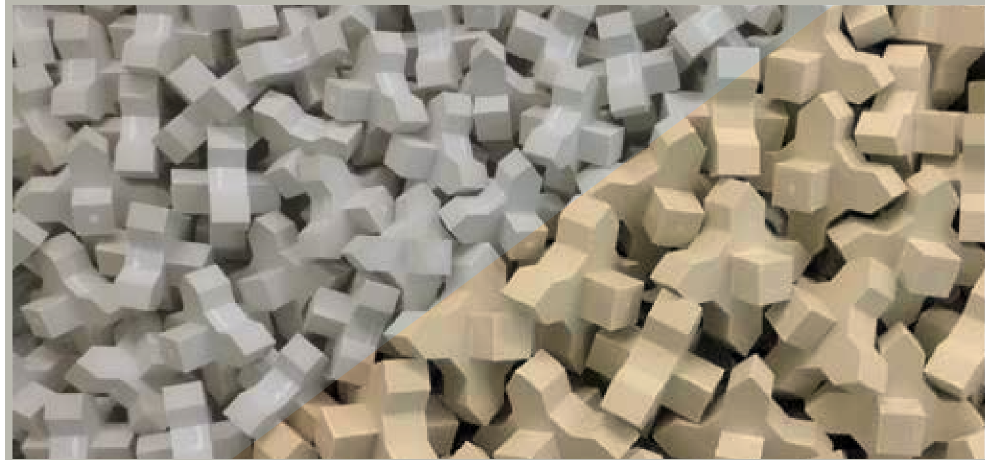


Figure 9-1: Typical transition rock-Xbloc and Xbloc-Xbloc

10 Conditions of use

Delta Marine Consultants [DMC] is a trademark of BAM Infraconsult B.V., a private company with limited liability, with registered office at H.J. Nederhorststraat 1, Gouda, The Netherlands.

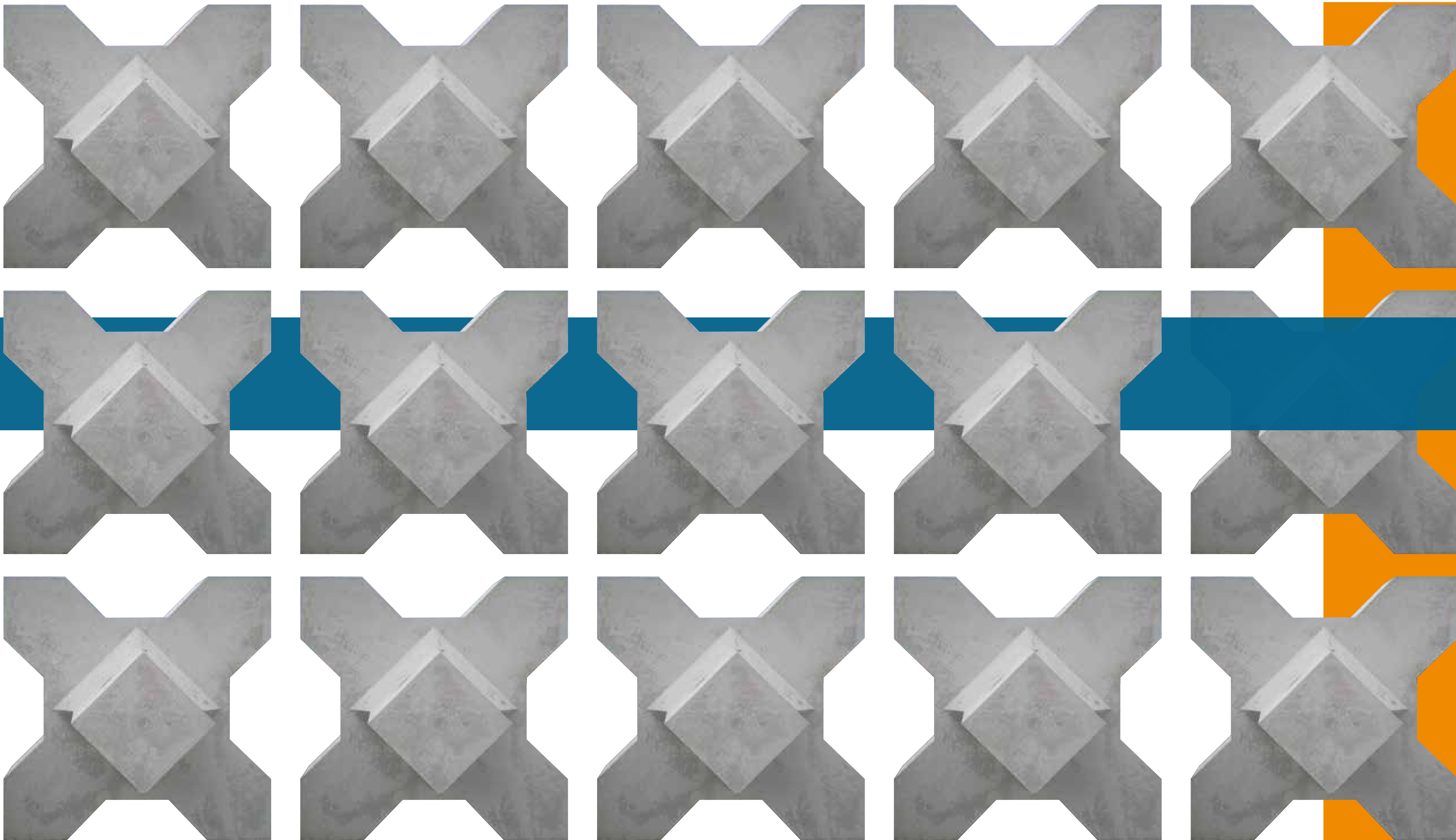
DMC is holder of several patents, patent applications and trademarks in relation to the Xbloc unit and Xbase unit. The Xbloc unit and the Xbase unit are known and legally protected by the trademarks Xbloc and Xbase.

For the use of Xbloc, a signed Xbloc License Agreement is required between Client and DMC.

In this document DMC provides some considerations for designers who intend to incorporate Xbloc armour units in a design (further referred as Designer).

The following conditions apply to the guidelines presented by DMC in this document.

- This document is based on DMC's current professional insights. Changes in these insights may lead to changes in the contents of this document. Before using this document, Designer is requested to check if this document is the latest revision.
- This document does not contain a complete description of all factors that affect a design.
- Designer shall be responsible for designs made by using the contents of this document and shall take into account the various factors that affect the design.
- DMC shall not be liable for any direct and/or indirect or consequential damages or losses such as loss of revenue, loss of profit, loss of anticipated profit, loss of use, production, product, productivity, facility downtime and business opportunity resulting from the contents of this document.
- The guidelines provided by DMC regarding the design with Xbloc armour units are subject to confirmative physical model tests.
- All information provided by DMC concerning (the application of) Xbloc is proprietary information of DMC. It shall not be disclosed by designer to any third parties.
- The relationship between Designer and DMC shall be governed by the law of The Netherlands and any disputes arising out of or in connection with the work carried out by DMC shall finally be settled by the competent courts in The Hague.



Guidelines for Xbloc Concept Designs

xbloc®

Delta Marine Consultants
H. J. Nederhorststraat 1
P.O. Box 268
2800 AG Gouda
The Netherlands
T +31 182 590 610
E xbloc@xbloc.com, dmc@dmc.nl

Delta Marine Consultants Pte. Ltd
(Singapore Branch)
51 Changi Business Park Central 2 #07 - 12
The Signature
Singapore 486066
T +65 62 943 033
E xbloc@xbloc.com, dmc@dmc.nl

Delta Marine Consultants
(Jakarta Branch)
Menera Jamsostek, North Tower 20th Floor
Jl. Jend Gatot Subroto No. 38
Jakarta 12710 – Indonesia
T +62 212 526 777
E xbloc@xbloc.com, dmc@dmc.nl

Delta Marine Consultants
(Dubai Branch)
Sidra Tower Dubai UAE
P.O. Box 25685 Dubai
United Arab Emirates
T +971 43 950 444
E xbloc@xbloc.com, dmc@dmc.nl

Delta Marine Consultants
(Perth Branch)
Australia
T +31 611 739 033
E xbloc@xbloc.com, dmc@dmc.nl

Delta Marine Consultants