

DEVELOPMENT OF THE XBLOC BREAKWATER ARMOUR UNIT

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INTRODUCTION

Since 2001, Delta Marine Consultants [DMC] have been active with the development of a new innovative interlocking armour unit. This development is based on review of existing armour unit concepts, desk studies, physical model tests, prototype tests and discussions with designers and contractors.

The result of this process is the Xbloc[®] breakwater armour unit. The Xbloc[®] is an interlocking concrete armour unit which is placed in a single layer. The Xbloc[®] has a large hydraulic and structural stability. It is easy to fabricate, easy to place and has a low concrete demand. Application of the Xbloc[®] can therefore result in significant costs savings compared to conventional single layer armour units.

In this paper the reasons why the Xbloc[®] is developed will be discussed. Results from various tests will be presented. A comparison will be made with other single layer interlocking armour units. Finally guidelines for the application of Xbloc[®] armour units will be given.

XBLOC DEVELOPMENT ROUTE

The development of the Xbloc started with the analysis of the strength and weaknesses of existing armour units (Muttray et al., 2003). Armour units for application on rubble mound breakwaters can be distinguished into two categories:

1. Uniformly placed armour units
2. Randomly placed armour units

Examples of uniformly placed armour units are: Seabee, Hollow cube, Diahitis, Cob and Shed. These units depend mainly on friction to provide hydraulic stability. Presently the uniformly placed armour is mainly applied in situations with relatively mild wave attack and in situations where the armour units do not have to be placed below water. The latter aspect follows from the fact that these blocks need to be placed securely.

Randomly placed breakwater armour units can be divided in blocks which have hydraulic stability by their own weight, and blocks which rely on interlocking to provide hydraulic stability. The first category consists of cubes, Antifer cubes, and parallelepiped blocks. As the use of these blocks in the conventional double layer application is not very cost effective due to the large concrete demand, recent application is very limited. Studies are being done on single layer cube armour (d'Angremond, 2002, van Gent, 2002). The interlocking blocks which can be considered are: Tetrapod, Dolos, Tribar, Stabit, Accropode, A-Jacks[®] and Core-loc[®] (Core-loc[®] is a registered trademark of the US Government). From publications of breakwaters constructed over the past 20 years it can be observed that a significant part has been constructed with Accropode armour. In the past five years Core-loc[®] armour has started to be used instead of Accropode armour. This type of armour is also used for breakwaters in deep water, and exposed to high wave loading.

The development of a new breakwater armour unit by DMC is aimed at an improvement over the present state of the art in armour units. It was thus decided to develop a single layer interlocking armour unit as this has the widest range of application. Desirable properties of the new breakwater armour block are:

- Stability coefficient K_d same as for Accropode and Core-loc[®]
- Reduced concrete demand compared to Accropode
- Increased structural strength compared to Core-loc[®]
- Easier placement than Accropode and Core-loc[®]

Various concepts were discussed in brain storm sessions within the coastal engineering team of DMC. Scale models were made of promising concepts. The best concept was tested using regular waves in a simple wave flume set up. From these tests it was concluded that the tested block showed a hydraulic

stability comparable to that of the Accropode and Core-loc[®]. Simple placement tests on a

Figure 1 also shows that the unit has a bulky robust shape without slender members. This shape has been developed to minimise tensile

slope were done to determine ease of placement and packing density. These tests showed that the Xbloc[®] armour has a significantly lower concrete demand than the Accropode, and is easy to place. Preliminary Finite Element calculations indicated that structural performance is better than that of the Core-loc[®]. After these preliminary tests and calculations it was decided to start a research program consisting of 2D and 3D model test series, casting of prototype units, Finite Element studies, placement studies and drop tests.

XBLOC CHARACTERISTICS

The main dimensions of the Xbloc[®] armour unit are shown in Figure 1. The block consists of a flat base with four indentations. On both sides of the base two cubic noses are located. The block has just two faces and is characterised by its main dimension D, which is both its height and width. The volume of the block is equal to 1/3 of a corresponding cube volume. [$V=1/3 D^3$]. The thickness of all members is $D/3$

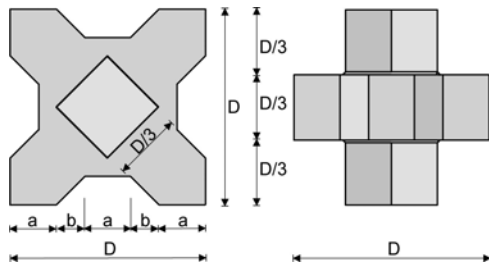


Figure 1: Geometry of the Xbloc[®]

From Figure 1 one of the main advantages of the Xbloc[®] over the Accropode and Core-loc[®] can be observed. The Xbloc[®] has more interlocking sides because it has only two faces. The block therefore easily interlocks with adjacent blocks on a slope (automatic interlocking). This feature improves hydraulic stability and facilitates placement. Placement of the blocks does not have to follow strict guidelines and will thus be faster. The blocks are placed randomly in a single layer to a certain packing density, without any specification on the orientation of the individual blocks.

stresses during handling, and due to wave loading. As known from breakwater history, The breakage of armour units can be a starting point for a breakwater failure.

RESULTS OF STUDIES

After preliminary model tests at DMC in a small wave flume, 2-D and 3-D tests have been carried out at WL Delft (Delft Hydraulics). In the 2-D experiments hydraulic stability, wave overtopping and the influence of placement patterns have been tested. The 3-D experiments focussed on hydraulic stability under oblique wave attack. An image of the Xbloc[®] slope in the 2-D and 3-D tests is given in Figure 2 and 3 respectively.



Figure 2: Xbloc[®] slope in wave flume



Figure 3: Xbloc[®] slope in wave basin

The main conclusions from the hydraulic model tests are the following:

• The Xbloc[®] is highly stable in randomly as well as in regularly placed armour layers. For preliminary design a design stability

With the confirmation from the 2-D model tests that the Xbloc[®] armour had a hydraulic stability in the same order as Accropode and Core-loc[®] (van der Meer, 1998, Melby et al.

coefficient K_D of 16 is recommended (for gentle foreshore slopes) in order to have a safety margin of 20 – 40 % on the design wave height for the start of damage (see Figure 4).

- Xbloc[®] armour layers remain stable after the start of damage. After initial displacement of armour units the damage is only slowly progressing with increasing wave height and the functionality of the armour layer is completely maintained.
- Xbloc[®] units can easily find a stable position on the slope (automatic interlocking). Therefore the Xbloc[®] units are easy to place and consequently the placing rates are higher than for other single layer armour units like Accropode and Core-loc[®].
- The average packing density is slightly lower for Xbloc[®] than for other single layer armour units.
- A density specification is sufficient for the placement of Xbloc[®], a prescriptive orientation of individual units is unnecessary.

1997), structural integrity tests were started. For this purpose, four 4 m³ Xbloc[®] armour units were cast. Casting was done with one of the cubic noses pointing upwards. As only four blocks were made, casting was done with a wooden mould consisting of four sides and a cube on top as shown in Figure 5. The whole mould is open at the top, facilitating access for pouring and vibrating of concrete. For a normal casting situation where large numbers of units are produced with steel moulds, various mould concepts have been developed consisting of 2, or 3 mould parts



Figure 5: Vibrating of concrete in the mould

A completed 4 m³ Xbloc[®] armour unit is shown in Figure 6. All four blocks have been cast using the standard Dutch b35 concrete quality.



Figure 6: Xbloc[®] of 4 m³

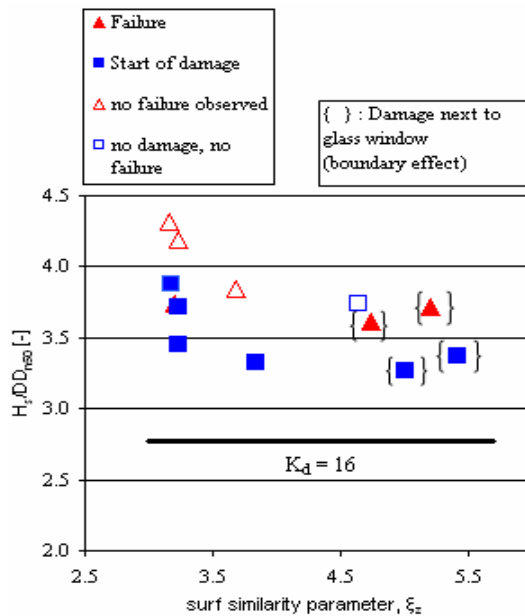


Figure 4: Stability of Xbloc[®] armour in 2-D tests at WL Delft.

Various drop tests have been carried out with the four blocks, tip drop tests on nose and star, hammer drop tests and free fall drop tests in various positions. The tip drop tests, and hammer drop test have been carried out to study the effect of rocking armour units on the

integrity of the blocks. The tip drop tests consist of repeatedly tipping a block over (up to 50 times), in such a way that it falls on one of its protrusions. All tests were done on a 0.5m thick reinforced concrete floor, embedded in the sandy subsoil, and covered with a 30 mm thick steel plate. Figure 7 shows a 4 m³ Xbloc[®] during the hammer drop test.



Figure 7: Hammer drop test

The tip drop tests did not result in any significant damage, even after dropping from the maximum geometrical height. The hammer drop test resulted in the breaking off of the tip on which the bloc was dropped at a drop height of 0.45 m. The block still retained ca. 90% of its original mass. On completion of the tests which simulated rocking armour units, all blocks were subjected to free fall tests. These blocks simulate the accidental dropping of a block during construction of a breakwater. In reality blocks will not be dropped onto a rigid concrete floor. Therefore the test set up can be considered as being conservative. The blocks were dropped onto the concrete floor starting with 0.5 m drop height to 4 m drop height. The blocks were dropped in various positions. One block ready to be dropped is shown in Figure 8.



Figure 8: Free fall drop test.

The following can be concluded from the drop tests:

- Xbloc[®] units can cope with settlements and repeated rocking on a breakwater slope during extreme conditions.
- The most critical test is the hammer drop test (as found in Core-loc[®] drop tests), as no energy can be absorbed by the crushing of edges.
- The Xbloc[®] outperforms the Core-loc[®] with a large margin with respect to structural strength. Failure of the Core-loc already occurred for drop heights as low as 0.3 m. The Accropode has only been tested for one drop position, which is regarded not critical for its integrity.

Apart from the drop tests, also detailed numerical calculations have been carried out using the Finite Element program ANSYS 6.1. Seven different load cases have been studied for 4 m³ Xbloc[®] units, including torsion, flexure, and combined torsion and flexure. Numerical calculations have been done for Xbloc[®], Accropode and Core-loc[®] units using 10 noded tetrahedron elements. Figure 8 shows tensile stress contours of an Xbloc[®] unit exposed to a 9 tons load on the tip of one of the protrusions.

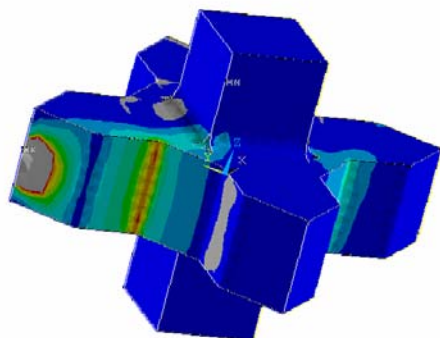


Figure 8: ANSYS stress contours

The calculated maximum tensile stresses at critical locations in the units are shown in Figure 9 for three load cases.

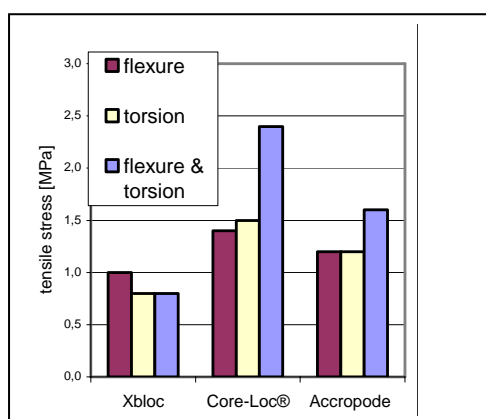


Figure 9: Tensile stresses from numerical model

From the figure it can be seen that for the three load cases the Xbloc[®] has significantly lower stresses than the Core-loc[®]. The Accropode also performs better than the Core-loc[®]. It can be concluded that an Xbloc[®] can cope with all loads that can be expected for the complete cycle from manufacturing to operation. The structural strength of Xblocs[®] is comparable to Accropodes and significantly larger than for Core-loc[®].

COMPARISON OF ARMOUR UNITS

The costs of an Xbloc[®] armour layer have been compared with the costs of Accropode and Core-loc[®] armour layers. For this comparison packing densities have been used from literature on Accropode and Core-loc[®] armour, and as determined for Xbloc[®] during the model

tests at WL Delft (Delft Hydraulics). K_D values of 16 have been used for Xbloc[®] and Core-loc[®] and 15 for Accropode armour. The results are shown in Figure 10.

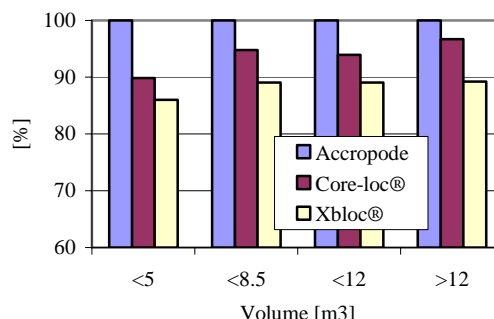


Figure 10: Concrete demand armour units as function of block size, Accropode = 100%

The concrete demand for Xbloc[®] armour is significantly lower than for Accropode and even lower than for Core-loc[®] armour. This is mainly due to lower packing densities. The cost benefit of Xbloc[®] will be further increased for larger armour blocks if the increased concrete quality, which is recommended for Core-loc[®], is taken into consideration. Apart from the general comparison of the costs of the armour layer, also three practical breakwater cases have been considered:

- Hazira, India, 2.1 km with Accropode armour
- Coega, South Africa, 2.4 km with Dolos armour
- Maasvlakte 2, Netherlands, 5 km with cube armour

Table 1 shows the anticipated cost benefits with Xbloc[®] armour. It can be concluded that application of Xbloc[®] armour can yield significant savings.

Hazira	US\$ 6.9 mln	8% of the total costs
Coega	US\$ 14.6 mln	6% of the total costs
Maasvlakte 2	US\$ 189.1 mln	42% of the total costs

Table 1: Cost benefits for alternative Xbloc[®] design (as compared to original design)

XBLOC

Xbloc[®] armour units are applied in a random pattern in a single armour layer. There is only a requirement on packing density, and no specifications on the orientation of individual units. As the block has only two faces, it easily interlocks with neighbouring units. This was confirmed during hydraulic model testing at WL Delft. The armour can be placed on slopes as steep as 3V:4H or 1V:1.5H.

In Table 2 the preliminary design wave height is given for various unit sizes. The table is based on a slope of 3V:4H, a concrete density of 2400 kg/m³ and a seawater density of 1025 kg/m³. The preliminary design Hudson stability factor K_d value is 16 for foreshore seabed slopes of 1:30 or less.

Unit volume V [m ³]	Preliminary design wave height H _s [m]	Unit height D [m]	Density number of blocks per 100 m ²
1.0	3.69	1.44	57.78
2.0	4.65	1.82	36.40
3.0	5.32	2.08	27.78
4.0	5.86	2.29	22.93
5.0	6.31	2.47	19.76
6.0	6.70	2.62	16.71
7.0	7.06	2.76	15.08
8.0	7.38	2.88	13.80
9.0	7.67	3.00	12.75
10.0	7.95	3.11	11.89
12.0	8.44	3.30	10.53
14.0	8.89	3.48	9.08
16.0	9.29	3.63	8.31
18.0	9.67	3.78	7.68
20.0	10.01	3.91	7.16
24.0	10.64	4.16	6.34
28.0	11.20	4.38	5.72

Table 2: preliminary design table

The required dimensions of the under layer of the armour layer is given in Table 3.

Unit volume V [m ³]	Layer thickness armour [m]	Weight of filter layer rock [ton-ton]	Thickness of filter layer [m]
1.0	1.4	0.06 - 0.3	0.8
2.0	1.8	0.3 - 1.0	1.3
3.0	2.0	0.3 - 1.0	1.3
4.0	2.2	0.3 - 1.0	1.3
5.0	2.4	1.0 - 3.0	1.8
6.0	2.5	1.0 - 3.0	1.8
7.0	2.7	1.0 - 3.0	1.8
8.0	2.8	1.0 - 3.0	1.8
9.0	2.9	1.0 - 3.0	1.8
10.0	3.0	1.0 - 3.0	1.8
12.0	3.2	1.0 - 3.0	1.8
14.0	3.4	3.0 - 6.0	2.4
16.0	3.5	3.0 - 6.0	2.4
18.0	3.7	3.0 - 6.0	2.4
20.0	3.8	3.0 - 6.0	2.4
24.0	4.0	3.0 - 6.0	2.4
28.0	4.2	3.0 - 6.0	2.4

Table 3: Dimensions of filter layer

The units are cast using a steel mould. Due to the simple shape of the unit, mould construction is not complicated. The shape also facilitates handling on site. Two different methods of lifting the block with a fork are shown in Figure 11 and 12. the unit shown in the figures is 4 m³



Figure 11: Handling of Xbloc[®] armour unit

Placing the blocks on the breakwater slope is done with a sling. The sling can be placed around the whole Xbloc[®] unit, or around one of the legs, as is shown in Figure 13.



Figure 12: Handling of Xbloc[®] armour unit



Figure 13: Lifting the Xbloc[®] with a sling.

The shape of the block allows for a tight packing on the casting yard, thus limiting the required storage area. Xbloc[®] units can be stored in multiple layers as shown in Figure 14.

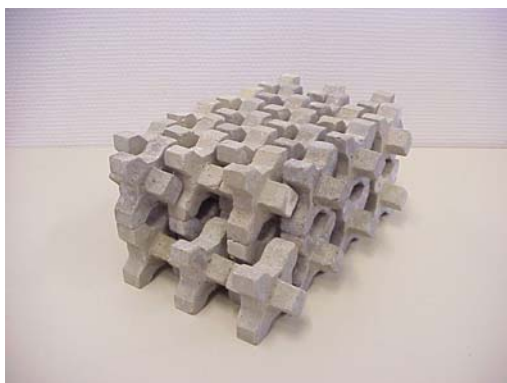


Figure 14: Double-layer storage

Due to the “automatic interlocking”, application on a round head is simple. A round

head model is shown in Figure 15



Figure 15: Roundhead with Xbloc[®] armour units

Xbloc[®] armour is patent pending.
For application of Xbloc[®] armour units the authors can be contacted.

CONCLUSIONS

The Xbloc[®] is a promising alternative for conventional single layer armour units as Accropode and Core-loc[®] with respect to processing armour units (fabrication, handling and storage) and to their function on the breakwater slope (structural integrity and hydraulic stability). Significant cost savings can be achieved due to:

- easier fabrication; Xbloccs[®] have a relatively simple and mostly rectangular shape
- faster placement; Xbloccs[®] are designed for ‘automatic interlocking’ and thus can easily find and maintain a stable position on the slope
- lower concrete volume; Xbloccs[®] provide large hydraulic stability and require relatively low packing densities
- limited requirements for concrete quality; Xbloccs[®] have a large structural stability



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