HYDRAULIC STABILITY AND OVERTOPPING PERFORMANCE OF A NEW TYPE OF REGULAR PLACED ARMOR UNIT

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INTRODUCTION

Single layer, randomly placed, interlocking concrete units are widely used for the protection of exposed breakwaters. Based on 15 years of experience with Xbloc projects around the world, DMC started the development of an armour unit called Xbloc^{Plus}. Xbloc^{Plus} is a single layer concrete unit which is placed in a regular pattern. An essential part of this development were hydraulic model tests in 2D and in 3D to determine the hydraulic stability under wave loading and the overtopping volumes for the new units. These studies and the results regarding the stability, failure mechanisms and roughness coefficient are described in this paper.

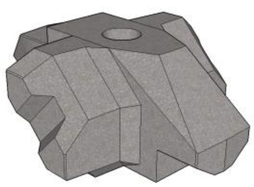

Figure 1 – Xbloc^{Plus} armour unit isometric view

SHAPE DEVELOPMENT

For the shape development of the new Xbloc^{Plus} unit, the original Xbloc unit was used as a reference. In a cyclic design process, the Xbloc unit was first modified for regular placement and then optimized for concrete use and water pressure build-up. Main improvements of the shape during the design process include the introduction of a central opening which prevents water overpressure under the units during wave run-down and the adjustment of different chamfered edges which increases interlocking stability and allows for greater placement tolerances. Like the Xbloc, Xbloc^{Plus} units are made of unreinforced concrete.

ARMORING CONCEPT

One main objective of the invention of the Xbloc^{Plus} units was to design a unit which can easily be placed by crane operators. Therefore, a regular placement pattern was chosen. The Xbloc^{Plus} units are all placed in the same orientation which is expected to increase the speed of installation. Moreover, the Xbloc^{Plus} units have been designed such that neighbouring units will easily slide into a position where contact points match.

Regular placement of existing single layer units like Xbloc, Coreloc® and Accropode™ is not desirable as it increases packing density resulting in higher concrete use and possibly increased wave overtopping. The Xbloc^{Plus} units have been designed for regular placement whilst keeping the porosity high and the overtopping low. The new armour unit has a central opening to increase armour layer porosity and to prevent build-up of excess pore pressure under the units. The efficiency of these measures was investigated in numerical and physical model tests.

MODEL TESTS

2D model tests have been performed to investigate the hydraulic stability and the amount of overtopping discharge for a breakwater slope protected with Xbloc^{Plus}. During these tests the following configurations were tested:

- Breakwater slope α = 1:2, α = 3:4 and α = 2:3
- Foreshore of 1:30 and horizontal
- JONSWAP wave spectra with wave steepness between $s_0 = 0{,}01$ and $s_0 = 0{,}06$
- Relative freeboard $f/H_{m,0} = 0{,}5$ to 3

In addition, the influence of the placement accuracy, accuracy of the underlayer and the influence of an extracted unit on the stability of the armor layer have been investigated.

Figure 2 – Test configuration for the 2D model tests

3D model tests have been performed to determine the hydraulic stability of the Xbloc^{Plus} armour layer under oblique wave attack. In addition, overtopping volumes were analysed during these tests. The 3D tests were performed with the following configurations:

- Breakwater slope α = 3:4
- Horizontal foreshore
- JONSWAP wave spectra with wave steepness of $s_0 = 0{,}02$, $s_0 = 0{,}04$ and $s_0 = 0{,}06$
- Wave directions of 0°, 30° and 60°

Figure 3 – Wave attack during 3D tests

RESULTS

The stability number for design is chosen as $H_s/(\Delta D_n)$ = 2,5, with H_s being the design significant wave height, Δ being the relative density of the armour units and D_n being the nominal diameter of the unit. Both the 2D and 3D tests showed that this formula gives a very robust design since overload tests with up to 200%H_s did not lead to damage. Figure 4 shows the stability number with respect to the wave steepness for all tests conducted with a 3:4 slope. Figure 5 shows these results for the tests performed with a 1:2 slope.

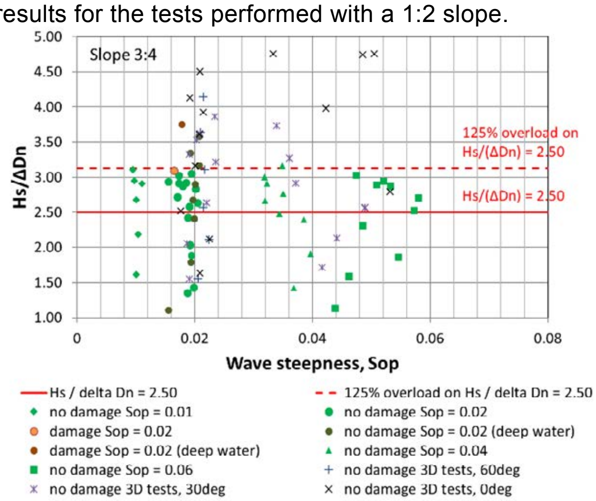

Figure 4 – Stability number over wave steepness for the tests with a 3:4 slope

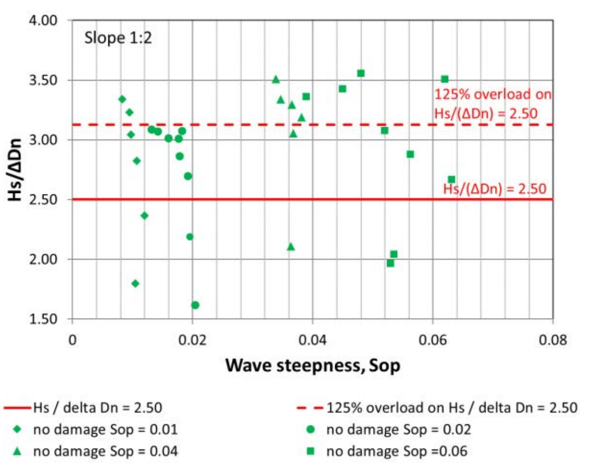

Figure 5 - Stability number over wave steepness for the tests with a 1:2 slope

It is important to note that no rocking was observed on the slope except for the tests to determine the influence of inaccuracies in the underlayer. Since rocking is considered to be the most critical damage mechanism for unreinforced concrete armour units, this is an important observation.

Even though the new armour units can adjust to distortions in the underlayer, tests in 2D showed that inaccuracies in the underlayer in some cases have an influence on the stability of the armour. Tests performed with under layer tolerances which fall within the specifications for Xbloc and Xbloc^{Plus} all showed stability of the armour layer up to 160% of the design wave height. Far developed S-profiles were concluded to have a negative effect on the armorer stability. In the worst cases tested, damage to the armour layer occurred at the design wave condition. Bad profiling and general irregularities in the underlayer, however, did not lead to a reduction in stability.

Overtopping volumes were analysed for several test set-ups and led to large deviations. To determine the roughness coefficient only the results from the tests with a set-up equal to the CLASH tests were used. These lead to a roughness coefficient of 0,45 for the new armour units when following the procedure as used in the EurOtop Manual (2016).

Furthermore, the stability of the armour units in the top crest row have been analysed and the effect of the breakwater slope, wave steepness, wave direction and water depth on the armour layer stability have been investigated.

APPLICATION

The new armour units are applicable on straight or mildly curved breakwater sections. Breakwater roundheads and sharp bends with small radiuses cannot be protected with Xbloc^{Plus} and will be armoured with Xbloc.
Xbloc^{Plus} units are suitable for horizontal and mildly sloping seabeds. On steep, uneven rocky seabeds, measures shall be taken to smoothen out the breakwater alignment. The new armour units can be used on the front and rear slope as well as on the crest.

The final paper will illustrate the main findings of the 2D and 3D model tests including the failure mechanisms and damage progression, the advantages and draw backs of the new unit as well as the characteristics concerning overtopping. Furthermore, a short overview of the shape development relating to the main aspects influencing the hydraulic stability of the new block will be included.