HYDRAULIC STABILITY OF TETRAPOD ARMOUR LAYERS - PHYSICAL MODEL STUDY

J. Fabião[1], A. Trigo Teixeira[2] and M.A.V.C. Araújo[2]

Paper topic: Laboratory and field observations and techniques

1. Introduction

A breakwater is a structure built to reduce wave action in designated areas, to assist cargo handling or to protect natural shore-lines from wave action. Although breakwaters started as simple mounds of rocks, quarrying's technical and economical restraints led to the development of armour layers formed by concrete blocks. Nowadays, most breakwaters are armoured with this type of blocks, being the tetrapod one of the most used armour units worldwide. The tetrapod was introduced in 1950 and can be described as an element of non-reinforced concrete schematically formed by four tapering legs radiating from a central point.

For tetrapod layer breakwaters, different placement methods with varied packing densities can be applied, which have been used and researched throughout the years. The main objective of this research is to assess the impact of different placement methods on the hydraulic stability of tetrapod armour layers. A bidimensional model of a breakwater's trunk was built in a laboratory and two tetrapod placement methods were tested, with the same packing density.

2. Experimental Settings

The experimental research was carried out in the wave flume of the Hydraulics and Water Resources Laboratory of Instituto Superior Técnico (IST). The wave flume is 20 m long, 0.70 m wide and 1.00 m high. It is equipped with a piston-type wave-generator with a wave absorption unit that controls reflection. To measure the incident waves and enable the separation of the reflected wave, four gauges were installed at constant water depth near the model toe.

The tetrapod blocks had an average mass (M_a) of 192.5 g, an average height (h) of 6.4 cm, a mass density (ρ_c) of 2617 kg/m^3 and a nominal diameter (D_n) of 4.2 cm. The blocks were placed by hand on the section, which had a slope of 1:1.5. The core and the under layer material was chosen according to the general indications of USACE (2006) and CIRIA, CUR, CETMEF (2007). The model was tested with irregular wave series, according to the JONSWAP energy spectrum. A total of eight experiments were performed, with a wave peak period of 1.40 s and four significant wave heights (H_s) between 0.12 and 0.18 m. After every experiment, the armour layer was rebuilt. Each test was performed with a fixed cross-section, water depth, period and height. The cross-section was completely rebuilt before a new test was run. Each test was run in two stages: a first stage consisting of 1000 waves with the damage being recorded at the end, followed by a second stage consisting of 2000 waves and a cumulative damage recording.

Two placement methods were used (Figure 1). The first placement method (A) consists of a square mesh with the blocks rotated 180º in successive rows parallel to the slope, and inverted with identical modelling in the upper layer. The second placement method (B) consists of a triangular mesh with all the blocks placed in the same direction and the upper layer inverted, keeping the same modulation. Both placement methods have the same packing density.

The damage assessment was limited to the most active zone. In general, the majority of movements take place within the levels $SWL \pm H_s$ (Frens, 2007), being SWL the still water level. In this case, considering the maximum significant wave height tested, a reference area within $SWL \pm 0.18\ m$ was adopted.

---

[1] Instituto Superior Técnico, Technical University of Lisbon, Av. Rovisco Pais, 1, 1049-001 Lisbon, Portugal; joao.fabiao@ist.utl.pt

[2] CEHIDRO, Instituto Superior Técnico, Technical University of Lisbon, Av. Rovisco Pais, 1, 1049-001 Lisbon, Portugal; trigo.teixeira@civil.ist.utl.pt, amelia.araujo@ist.utl.pt

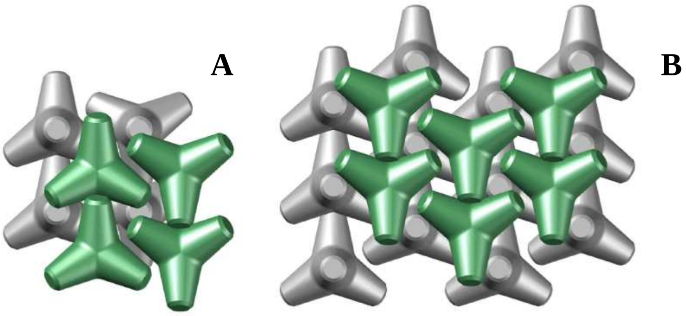

Figure 1. First (A) and second (B) placement methods.

3. Results and Conclusions

The relative damage with N_d versus the stability parameter $N_s = H_s/\Delta D_n$ for both placement methods is presented in Figure 2, for 1000 (A) and 3000 waves (B).

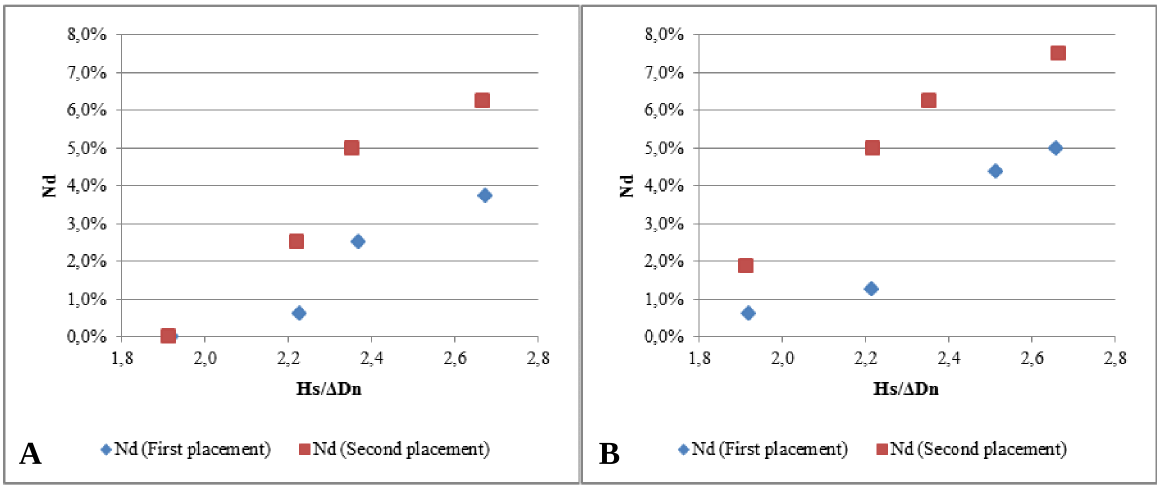

Figure 2. Damage progress for N=1000 (A) and N=3000 (B).

Despite the limited number of tests performed, the experiments showed consistently that the first placement method displayed higher stability than the second placement method. Thus, placement methods with the same geometric parameters may have substantially different reactions to wave action. Placing a certain number of blocks per area of slope may not be enough. The geometry of the tetrapod layer may influence significantly the hydraulic stability of the armour layer and, as such, the durability of the structure. In addition to the packing density, the geometry of the layer may also be a factor to consider.

Acknowledgements

The authors acknowledge the National Laboratory for Civil Engineering (LNEC) for lending 400 tetrapod blocks to build the model.

References

CIRIA, CUR, CETMEF, 2007. *The Rock Manual. The use of rock in hydraulic engineering (2nd edition)*. C683, CIRIA, London.

Frens, A.B., 2007. *The impact of placement method on Antifer-block stability*. Master of Science thesis, Delft University of Technology, Netherlands.

USACE, 2006. *Coastal Engineering Manual [CEM]* Engineer Manual 1110-2-1100, USACE, Washington D.C.