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ARMOR UNIT PLACEMENT, RANDOMNESS AND POROSITY OF CUBE AND CUBIPOD ARMOR LAYERS

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1. Introduction

In the 1800s, cube and parallelepiped concrete armor units (CAUs) began to replace heavy quarry stones to construct rubble mound breakwaters in deep waters and severe wave climates. As described by Dupray and Roberts (2009), since 1950, numerous precast CAUs have been designed to reduce construction costs. After the Dolosse armored breakwater collapsed at the Port of Sines (Portugal) in 1978, new CAU designs (see bottom row in Fig. 1) aimed to balance concrete consumption, hydraulic performance and structural strength.

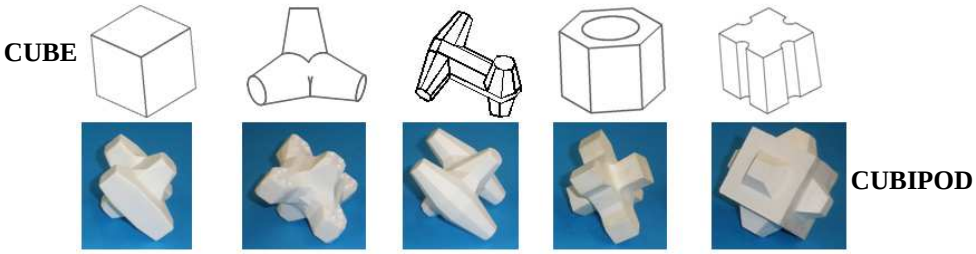

Figure 1. Examples of concrete armor units (CAUs) described by Dupray and Roberts (2009)

This paper focuses on random placement of cube and Cubipod units, two examples of massive CAUs with high structural strength (see Medina et al., 2011). Many CAUs are specially designed for uniform, oriented or patterned armor unit placement, but CAUs are most often randomly placed on the armor layer of mound breakwaters. When CAUs are not randomly placed, special attention is given to the placement technique, construction monitoring and the differences between small scale models and prototypes. By contrast, when CAUs are randomly placed, little attention is paid to CAU randomness in small scale models and prototypes. A significant model effect is likely when armor unit randomness is not considered in small scale models and is not monitored at prototype scale. This paper describes a new methodology to measure armor unit randomness in small scale models which may be applicable to prototype scale.

The hydraulic stability of armor layers depends on a range of structural and wave climate variables. When CAUs are randomly placed, armor layer porosity influences hydraulic stability, wave reflection, overtopping, self-packing and other breakwater performance characteristics. However, most formulae and hydraulic stability tests reported in the literature do not take armor porosity into account. In this paper, placement methods and armor porosity of cube and Cubipod CAUs are analyzed with conventional laboratory manual placement as well as blind underwater placement with waves and scaled crawler cranes. Medina et al. (2010) reported a 10% reduction in the stability numbers at the start of damage and at the initiation of destruction when cube armor porosity increased from p%=36% (small scale) to p%=42% (prototype).

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2. 3D Placement Tests with Small-Scale Crawler Cranes

Realistic 3D placement tests of cube and Cubipod CAUs were conducted using small-scale crawler cranes and pressure clamps as shown in Fig. 2a. Cube and Cubipod units were placed on a H/V=2/1 slope and subjected to different construction grids (blind underwater placement) and wave action (low and moderate waves). With the appropriate placement grid, cube armor porosity can drop as low as p%=40%, but it is not possible to obtain randomly placed cube armors with p%<38%, which are typical of 2D hydraulic stability tests with manual placement. On the contrary, Cubipod units tend to p%=41% either with small-scale crawler cranes or manual placement.

3. Armor Unit Randomness Measurement using Laser Scanners

It is known that cube CAUs randomly placed on a slope tend to face parallel to the slope and fit face-to-face with other cubes. In order to measure armor unit randomness, cube and Cubipod CAUs were characterized by the position of the center of gravity and three orthogonal vectors for 3D orientation. The laser scanner (0.1 mm precision), shown in Fig. 2b, was used to scan armor layers with D_{n50}[mm]=40 CAUs. The Armor Randomness Index (ARI) was defined as the average of three percentile ratios (10%, 50% and 90%) of the cumulative distribution of the minimum 3D angle between neighboring CAUs when compared to true random 3D orientation. Measured ARIs were much higher for Cubipods than conventional cubes (ARI[Cubipod]≈90%>ARI[cube]≈60%) when placed with scaled crawler cranes as shown in Fig. 2a.

Figure 2. 3D placement tests: (a) small scale crawler crane and (b) laser scanning of CAUs

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