ARMOR POROSITY AND HYDRAULIC STABILITY OF MOUND BREAKWATERS

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INTRODUCTION

Hydraulic stability significantly decreases if armor porosity (p%) is significantly higher than the recommended values. Literature regarding mound breakwaters protected with a variety of concrete armor units (CAUs) shows that hydraulic stability decreases if p% increases; however, p% or packing density (Φ=n[1-p%]) is not included in most commonly-used hydraulic stability formulas (i.e. Hudson's formula). This paper aims to explain the quantitative impact of p% on the hydraulic stability of massive CAUs (cubes, Antifer cubes, Cubipods, etc).

In any given design storm, armor layer thickness depends on hydraulic stability; if structural integrity is guaranteed (massive CAUs), higher hydraulic stability means lower concrete consumption. The hydraulic stability of the armor layer of large mound breakwaters depends on armor porosity (p%) as well as the specific weight, CAU geometry, number of layers (n=1 or n=2), placement arrangement (random, oriented, etc.), core permeability and other factors. Nevertheless, very few hydraulic stability formulas described in the literature explicitly include p% or Φ as an explicative variable. Engineering manuals and designers usually refer to recommended values for Φ or nominal porosity and layer coefficient; however, for randomly-placed CAUs, a specific Φ is not so easy to obtain in small-scale models, and it is generally difficult to achieve at prototype scale. Therefore, p% may be a relevant source of uncertainty (model effects) which should be taken into account during the breakwater design process.

Over the last three decades, Level I (partial coefficients) and Level II and Level III probabilistic approaches have been proposed for use in the design of large breakwaters. Nevertheless, most projects and practitioners still refer to the stability coefficient (K_D) of the generalized Hudson formula ($H=H_s$) where p% or Φ is not included but assumed to be fixed at the recommended values. K_D was originally proposed by Hudson (1959) to characterize the hydraulic performance of conventional double-layer armors. Half a century later, it is still widely used to characterize a wide variety of CAUs placed on both single- and double-layer armors with much different hydraulic performance. Medina et al. (2012) developed a methodology to calculate design K_Ds and then analyzed the implicit and explicit global safety factors associated with the recommended K_Ds found in the literature. This research highlighted the need to measure p% and explicitly indicate the packing densities at small-scale as well as prototype-scale, to effectively assess the impact of Φ on hydraulic stability and safety factors associated with the K_Ds used during the design process.

LITERATURE REVIEW

Experimental results given by different authors, corresponding to small-scale models protected by double-layer cube armors, refer to 25%<p%<40%. Cube armors with p%=30% were found to be more stable than those with p%=40%; however, at prototype scale p% is usually much higher (SPM recommended p%=42% for modified cube armors). Using small-scale models and crawler cranes, Medina et al. (2010) reported that p%<35% is not realistic when crawler cranes are used for placement and underwater viewing conditions are poor. The random placement by hand in perfect conditions observed in laboratory tends to reduce p% below the recommended values. On the contrary, wind, waves and poor viewing, tend to increase p% during construction above recommended values; furthermore, a higher p% reduces the costs and concrete consumption but also reduces the hydraulic stability. Therefore, a scenario of small-scale models with lower-than-recommended p% and real breakwaters built with higher p% values is likely appear, with a model effect that clearly reduces the target safety factors.

A similar trend was observed for randomly-placed Antifer cube armors (39%<p%<55%). The stability number was higher for lower p%; the observed increment of $N_s=H_s/[\Delta D_n]$ was much higher than that of Φ=n[1-p%]. Small-scale experiments with other CAUs, such as Tetrapod, Dolos and Xbloc

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also revealed this general trend both in single- and double-layer armors. The goal of this paper is to quantify the effect of p% on hydraulic stability and thus to better assess breakwater safety.

HYDRAULIC STABILITY TESTS

Project CLIOMAR (2009-2011) involved overtopping and hydraulic stability testing of the double-layer 150-tonne cube armored Punta Langosteira breakwater (see Maciñeira et al., 2009). The experiments were carried out at the UPV wind and wave test facility (see Medina et al., 2010). Fig. 1 shows three cube armor models with armor porosities p%=37%, 41% and 46% (Φ=1.26, 1.18 and 1.08), which are below, near and above the recommended value (p%=42%, Φ=1.16) given by the SPM (1984). Fig. 2 compares the observed failure functions corresponding to models having Φ=1.18 (p%=41%) and Φ=1.08 (p%=46%); as observed elsewhere, the higher the packing density (lower p%), the higher hydraulic stability (higher N_s for the same damage level).

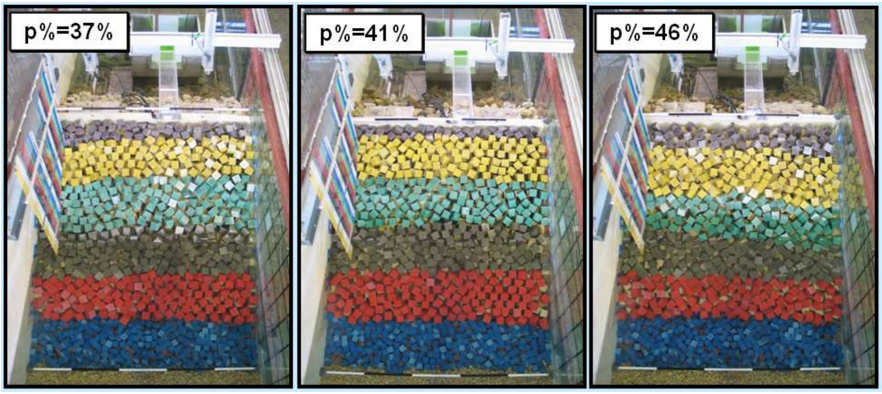

Figure 1. Double-layer cube armored breakwater models with different packing densities.

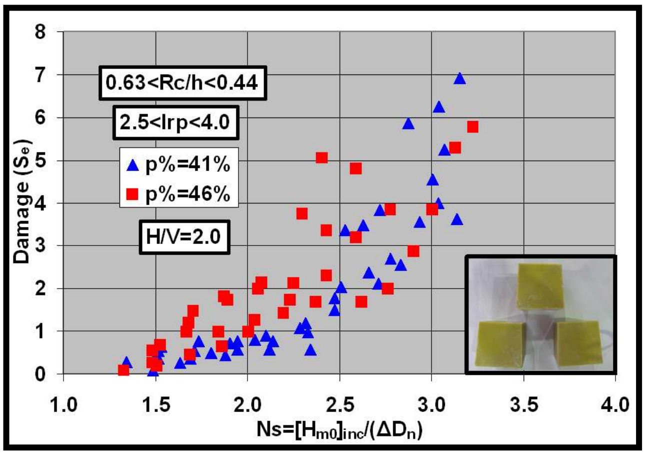

Figure 2. Observed failure functions corresponding to breakwater models with Φ=1.18 and Φ=1.08.

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