HYDRAULIC PERFORMANCE OF HOMOGENEOUS LOW-CRESTED STRUCTURES FOR BEACH PROTECTION IN CORAL REEF AREAS

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INTRODUCTION

Across the globe, coastal ecosystems are confronting the far-reaching impacts of climate change and human activities. Among these ecosystems, coral reefs, renowned for being one of the most biodiverse ecosystems in the world, have been undergoing a progressive retreat at an annual rate of 1% to 2% over recent decades (Rinkevich, 2014). In addition to their rich biodiversity, coral reefs have extraordinary economic and social value and also act as natural physical barriers protecting adjacent beaches (Silva et al., 2016). Thus, the degradation of coral reefs affects the stability of nearby beaches protected by these reefs (Ferrario et al., 2014).

In the short term, coral reefs protect adjacent beaches by reducing the wave energy that reaches the coastline and reducing the risk of flooding during severe storms. In the long term, coral reefs become reliable generators of biogenic sand, nourishing beaches and generating favorable conditions for the establishment of other ecosystems, such as seagrass fields.

Conventional Low-Crested Structures (LCS) are used worldwide to protect beaches from erosion. Artificial reefs, made of rocks and concrete elements that favor coralline colonization, can be used to actively regenerate retreating coral reefs (Blakeway et al., 2013). To protect sandy beaches in coral reef areas, Homogeneous Low-Crested Structures (HLCS) made of large rocks or pre-cast concrete elements has emerged as an option (Odériz et al., 2018).

HLCS may be considered multi-purpose ecologically enhanced hard infrastructure (Silva et al., 2017). As a detached breakwater, HLCS replicate the protective function of conventional LCS while introducing several advantages. LCS have low core permeability and adequate quarries are required to provide the large rocks for the armor layer.

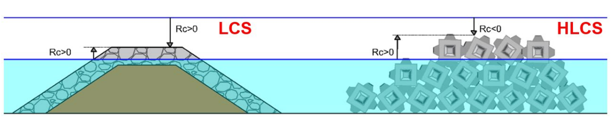

Figure 1 – Cross sections of detached breakwaters: (a) Conventional LCS, and (b) Cubipod HLCS

HLCS are functionally similar to conventional LCS but present some key advantages: concrete units can be used if large rocks are not available, easy to dismantle with re-use of units, highly porous structure with different light exposures, adequate for coralline colonization and regeneration, or attraction and hosting different fish species (Medina et al., 2020). An HLCS mimics the wave energy control provided by a coral reef and may restore habitats and enhance ecosystem services.

Previous research on Cubipod HLCS was primarily focused on: (1) checking its constructive feasibility for different placement grids through numerical and physical placement tests and (2) analyzing hydraulic stability and wave energy transmission in trunk sections for one triangular placement grid. On-going HOLOBRACE project is focused on: (1) the hydraulic performance of trunk and roundhead Cubipod HLCS's and (2) analysis of squared and triangular placement grids.

HOLOBRACE PROJECT

In order to mimic some of the hydrodynamic functions of coral reefs and allow the establishment of habitats, it is critical to characterize transmission, reflection and dissipation coefficients, as well as the porosity and hydraulic stability for both the trunk and the roundhead of the structure. It is also crucial to define the placement grid that combines the best characteristics in terms of ease of construction and hydraulic response. These are the main objectives that the project HOLOBRACE aims to address.

To achieve this, 2D physical model tests for trunk and roundhead cross-sections are currently being conducted in the wave flume of the Laboratory of Ports and Coasts at the Universitat Politècnica de València. In these tests, the wave transmission, reflection, and energy dissipation, as well as the hydraulic stability of the structure, are being analyzed.

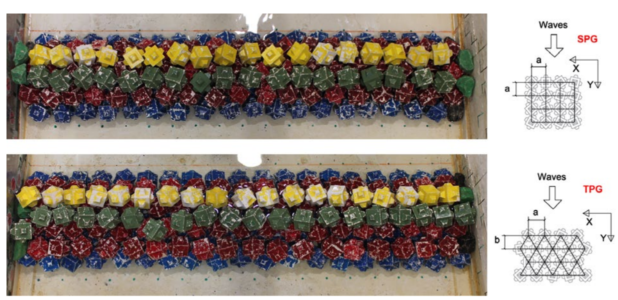

Figure 2 – HLCS's placement grid tested in wave flume

Different placement grids – squared placement grid, (SPG) and triangular placement grids (TPG) – with porosities of 52% and 50% respectively, are being tested for both trunk and roundhead cross-sections, in depth-limited wave breaking conditions.

Preliminary data analysis shows that beach protection offered by HLCS is related to energy dissipation and wave transmission. This is highly dependent on the crest freeboard; the higher the dimensionless crest freeboard, (R_c/H_{si}), the lower the transmission coefficient.

Furthermore, preliminary results also appear to indicate that the rectangular placement grid (RPG) shows greater ease of construction and less structural damage, although the tests are still ongoing.

Figure 3 – HLCS tests currently being conducted at LPC-UPV

Simultaneously, the project includes realistic construction simulations for the different placement grids tested in the physical model. For this purpose, software that simulates real-world physics is being used (Molines et al., 2021). This type of software with physics engines are commonly used in virtual simulation and video game industry.

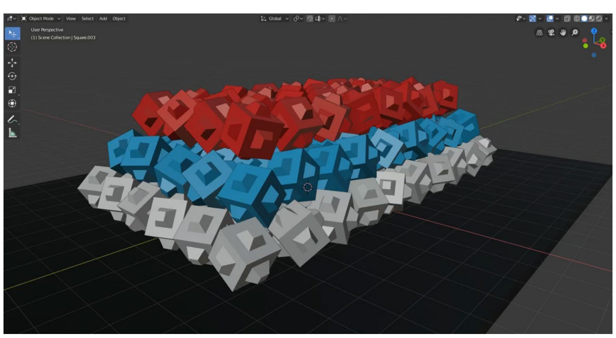

Figure 4 – Realistic construction simulation with real-world physics engine

Finally, statistical techniques and artificial intelligence methods are being explored to identify and develop predictive empirical formulas for evaluating the hydraulic response of Cubipod HLCS. The ultimate goal is to establish recommendations and design criteria for HLCS structures for beach protection in coral reefs areas.

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REFERENCES

Blakeway, Byers, Stoddart, & Rossendell (2013): Coral colonisation of an artificial reef in a turbid nearshore environment, Dampier Harbour, Western Australia. PLoS ONE, 8 (9), e75281. doi:10.1371/journal.pone.0075281.

Ferrario, Beck, Storlazzi, Micheli, Shepard & Airoldi (2014): The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. Nature Communications, 5 (3794), 98-101.

Medina, Gómez-Martín, Mares-Nasarre, Escudero, Odériz, Mendoza & Silva (2020): Homogeneous Low-Crested Structures for Beach Protection in Coral Reef Areas. Proc. 36th International Conference on Coastal Engineering, ICCE No 36v (2020), ASCE, Papers.59.

Molines, Centi, Di Risio & Medina (2021): Estimation of layer coefficients of Cubipod homogeneous low-crested structures using physical and numerical model placement tests. Coastal Engineering, 168, 103901.

Odériz, Mendoza, Silva & Medina (2018): Hydraulic performance of a homogeneous Cubipod low-crested mound breakwater. Proc. of the 7th International Conference on the Application of Physical Modelling in Coastal and Port Engineering and Science (Coastalab18), (in press).

Rinkevich (2014): Rebuilding coral reefs: does active reef restoration lead to sustainable reefs? Current Opinion in Environmental Sustainability, 7 (2014), 28-36.

Silva, Lithgow, Esteves, Martínez, Moreno-Casasola, Martell, Pereira, Mendoza, Campos-Cascaredo, Grez, Osorio, Osorio-Cano & Rivillas (2017): Coastal risk mitigation by green infrastructure in Latin America. Proc. of the Institution of Civil Engineers-Maritime Engineering, 170 (2), 39-54.

Silva, Mendoza, Mariño-Tapia, Martínez & Escalante (2016): An artificial reef improves coastal protection and provides a base for coral recovery. Journal of Coastal Research, 75, 467-471.