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# WAVE BASIN EXPERIMENTS OF WAVE-DRIVEN HYDRODYNAMICS OVER ARTIFICIAL REEFS

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## 1 INTRODUCTION

Submerged coastal structures, such as submerged breakwaters and artificial reefs, modify incident wave fields and alter a wide range of nearshore hydrodynamic processes. Submerged breakwaters are usually designed for a singular function of wave attenuation; whereas nature-based artificial reef structures aim to both attenuate wave energy while enhancing ecosystem services, including the creation of habitat for marine organisms and the promotion of biodiversity. However, to date the application of artificial reefs has remained more limited due to the poorer understanding of how reefs influence key nearshore processes that determine their effectiveness.

Existing research on submerged breakwaters has mostly focused on quantifying the wave transmission, which is ratio between the incident wave energy onshore and offshore of the reefs (e.g., van Gent 2023). The wave transmission coefficient has conventionally served as a primary design criterion related to the effectiveness of reefs in offering coastal protection. However, a meta-analysis of the shoreline response to constructed submerged breakwaters found that in the majority of cases erosion occurred in their lee (Ranasinghe and Turner., 2006), which demonstrates our limited knowledge on how reefs modify coastal processes.

Wave-reef interactions can lead to the generation of mean (wave-averaged) currents and water levels (setup). Numerical modelling studies have found that two and four-cell mean circulation patterns can develop in response to changes to the wave field caused by submerged structures (Ranasinghe et al., 2006, da Silva et al., 2022). A two-cell circulation is characterized by diverging currents behind the reefs and at the shoreline, which could lead to an erosive shoreline. In contrast, a four-cell circulation is characterized by diverging currents in the immediate lee but converging currents at the shoreline, which would result in beach accretion. While these modelling studies advanced the understanding of how reefs influence shoreline hydrodynamics, the absence of comprehensive experimental observations replicating submerged coastal structures has hindered their rigorous validation.

Here we present the findings of an extensive set of 3D wave basin experiments that were designed to investigate the detailed wave-driven hydrodynamics around submerged coastal structures subject to a range of wave conditions, water levels and reef layouts.

## 2 EXPERIMENTAL SETUP

### 1.1 Wave basin experiments

The experiments were conducted in the wave basin in the Queensland Government Hydraulic Laboratory (Australia). The wave basin is 42-m long and 20-m wide. The experiments represented an undistorted Froude model with typical reef and beach dimensions with a length scale of 1/20. We reproduced an idealized beach with an alongshore-uniform bathymetry. The cross-shore profile consists of a 12-m long flat region followed by a 24-m 1/40 slope, which results in vertical bed elevations varying between *z* = 0 (wave maker) and 0.60 m (onshore edge of the basin). We tested both cases without and with the presence of several reef layouts positioned at the centre of the basin. The wave maker has four 5-m long paddles that were used to generate long-crested unidirectional shore-normal waves without active absorption. Irregular waves with a JONSWAP spectrum with gamma parameter of 3.3 were imposed at the wave maker. A set of wave conditions was modelled, with the significant wave heights being varied from 2.5 to 10 cm and the peak wave periods from 1.57 to 3.35 s (lab scale).

To accommodate various reef configurations, concrete reef units were built, collectively forming a reef. The reefs had a generalized trapezoidal shape with a 0.5-m long crest, a front slope of 1/2, and a vertical side slope. The range of reef unit lengths, spanning from 0.6 to 1 m, resulted in the formation of reefs measuring 3 to 5 m in length. Four reefs with varying crest heights from 5 and 18 cm were built. Each reef was positioned in a fixed cross-shore (and vertical) location, which due to the sloping nature of the bed resulted in a similar reef crest vertical position (at z = 0.425 m). By changing the still water levels, the reef free board varied from 0 to 75 cm. The distance from the reef center to the still water shoreline varied from 2 to 10 m, whereas the still water depth underneath the reef centre ranged from 5 to 25 cm. To investigate the influence of the macro-scale porosity on the hydrodynamics, we tested several layouts with 50 cm gaps between reef units, which resulted in porosities of up to 40%. We also studied the effect of the intra-reef porosity by testing perforated reefs. These reefs had a row of circle-shaped holes with diameter of 5 cm and distance between centres of 10 cm, which were located at mid-depth. Finally, we tested several reef layouts arranged in rows to evaluate the effect of arrays of reefs on the hydrodynamics.

### 1.2 Data collection and analysis

Time series of water levels were recorded with 16 wave gauges. The wave gauges were calibrated at least every morning. Time series of velocities were obtained with seven Acoustic Doppler Velocimeters (ADVs). The water level and currents data were sampled at 10 Hz by all sensors. The locations of wave gauges and ADVs varied across tests and were distributed throughout the wave basin, with a higher density from the reefs to the shoreline. Most of the measurement stations were situated in one half of the basin due to the symmetrical in the alongshore-uniform bathymetry and reef shape. Every test was repeated twice to expand the coverage of measured sites, leading to a minimum of 27 wave gauges and 14 ADV locations per test.

Three cameras with sampling frequency of 60 fps were used to capture the waterline variations along the entire basin. To enhance the contrast, the beaches were painted in white and blue dyed was added to the water. With timestack images over several transects, we characterised the swash and runup statistics with a combination of automatized and manual digitization of swash.

## 3 RESULTS AND DISCUSSION

The results were used to evaluate the influence of artificial reefs on the nearshore hydrodynamics for a wide range of wave conditions, water levels, and reef geometries. First, we calculated the wave transmission, reflection, and dissipation caused by the reefs. Next, we characterised the mean circulation patterns in the lee of reefs and clustered then into two- and four-cell circulation patterns. We also assessed the influence of wave heights and periods, water levels, and reef configurations on the strength of nearshore alongshore currents. Finally, we evaluated the influence of the presence of the reefs on the runup patterns by comparing cases with and without reefs. Overall, this study advances understanding of far-field scale hydrodynamic processes resulting from waves interacting with artificial reefs. The novel laboratory dataset developed by this research provides a foundation for developing improved predictive models and guidelines to design artificial reefs for coastal protection.

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## REFERENCES

Gent, M. R. A. Van, Buis, L., Bos, J. P. Van Den, & Wüthrich, D. (2023). Wave transmission at submerged coastal structures and artificial reefs. *Coastal Engineering*, 184(March), 104344.

Ranasinghe, R, Turner, I. L., & Symonds, G. (2006). Shoreline response to multi-functional artificial surfing reefs: A numerical and physical modelling study. *Coastal Engineering*, 53(7), 589–611.

Ranasinghe, R., & Turner, I. L. (2006). Shoreline response to submerged structures: A review. *Coastal Engineering*, 53(1), 65–79.

da Silva, R. F., Hansen, J. E., Rijnsdorp, D. P., Lowe, R. J., & Buckley, M. L. (2022). The influence of submerged coastal structures on nearshore flows and wave runup. *Coastal Engineering*, 177, 104194.