Proceedings of the 9th International Conference on Physical Modelling in Coastal Engineering (Coastlab24)

Delft, Netherlands, May 13-16, 2024

Extended Abstract, DOI: 10.59490/coastlab.2024.765

2D MODEL FOR ADDU CITY PROJECT - WAVE TRANSFORMATION OVER REEF FLAT

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KEYWORDS: Reef flat, udha, nearshore wave transformation effects, water level set-up, low-frequency waves

1 INTRODUCTION

Van Oord DMC was awarded the Contract for the Reclamation by Dredging and Shore Protection works for land in Addu City by The Ministry of National Planning, Housing and Infrastructure of the Maldives. The Scope of Works consists of the Design and Construction of (among others) Reclamation and Shore Protection Works on various locations in the Addu City atoll. The project execution started in 2022 and has been finalized at the end of 2023.

The design of the Shore Protection Works has been verified in 2022 by means of 2D physical model testing in the wave flume of DHI in Denmark. Cross-sections of shore protection works for three different reclamation areas have been tested, where this abstract will focus on 2 locations at the outside of the atoll: Maradhoo and Four Lane Link Road (4LLR). All dimensions given in this abstract are prototype values, unless otherwise specified.

The length scale of the both models was selected at 1:30. The foreshore of the 2 tested cross-sections is very typical for atolls, consisting of a relatively shallow reef flat followed by a very steep slope to deep water. The modelled foreshores are presented in **Figure 1** (left). This figure also shows the locations of the wave gauges, which were placed both offshore (near the wave generator) and on top of the reef flat (in front of the structure). The tested seabed levels directly at the toe of the 4LLR and Maradhoo structures were MSL-0.70m and MSL-0.40m respectively. The target wave conditions were defined in deep water (in front of the wave generator), with design wave heights (H_{m0}) between 3.8m and 4.4m and 120% overload conditions. The tested peak wave periods (T_p) varied between 11.9s and 19.7s.

1.1 Nearshore wave breaking effects

The steep foreshore and shallow reef flat caused extensive shoaling and wave breaking in the flume, resulting in wave energy being transferred to lower frequencies during wave transformation over the reef. The peak in the energy density spectrum of the nearshore measurements was at lower frequencies than the frequency corresponding with the offshore target peak period T_p. This shift was clearly visible in the flume near the structure, where limited wave energy with the offshore target T_p was present and very long waves (relatively high T_p) created large water level fluctuations.

Another result of the extensive wave breaking was the water level set-up (increase in water level) on top of the reef flat. The set-up is a result of long period waves, the so-called surf-beat, that are initiated and released due to the wave breaking and transformation over the steep foreshore and shallow reef flat. The measured differences between the water levels at the toe of the structures and offshore (in front of wave generator) could be in the order of magnitude of 0.50m during design conditions and 0.60m during overload conditions.

1.2 Wave overtopping

The above described water level set-up and low-frequency waves on top of the reef flat were dominant for the measured wave overtopping discharges. In absence of short wave energy, almost no overtopping was caused by waves breaking on the slope and resulting wave run-up. Most of the overtopping was a caused by a water level increase near the structure due to the combined water level set-up and low-frequency waves. At certain moments during the test, the water level even exceeded the crest level, resulting in a flooding rather than overtopping (see **Figure 1** right). These severe storm and resulting flooding events are well-known in the Maldives and locally referred to as "Udha".

The measured overtopping volumes could not have been predicted or reproduced by any calculation method. No formula or method accounts for these complex nearshore wave breaking effects. The EurOtop Manual (EurOtop, 2018) states that, in general, there is no requirement to add on an additional water level increase for wave set-up when calculating overtopping discharges using the methods in the Manual, mainly because wave set-up is implicitly included in the empirical overtopping equations. Obviously this is not valid in current specific case with a very shallow reef flat as foreshore. It can be concluded that only physical model testing is suitable to determine the overtopping discharges for these specific situations.

1.3 Water level calibration

Due to the confined volume of the flume, the water level set-up on top of the reef flat resulted in a corresponding water level set-down near the wave maker (see **Figure 2** left). In contrary to the ocean in reality, in the flume there is no supply of water to compensate for the additional water level elevation on the reef flat. The measured water levels near the wave generator were about 0.20m lower than the target water level, also resulting in lower water levels near the structure than if the correct offshore water level was maintained, which obviously has an effect on the measured overtopping and damage values.

To overcome this issue, the water level in the flume has been calibrated and corrected. This was achieved by adding more water to the flume at the start of the test (water level above target level, see **Figure 2** center), until the correct offshore mean water level was reached during testing, and thereby also the correct water level at the structure (see **Figure 2** right).

This phenomenon of water level set-down in the flume has also been observed in the experiments of Gruwez *et al*., 2020, where a lowering of the mean water level in the offshore region was found due to the water mass that was redistributed from offshore to the surf zone during build-up of the wave set-up.

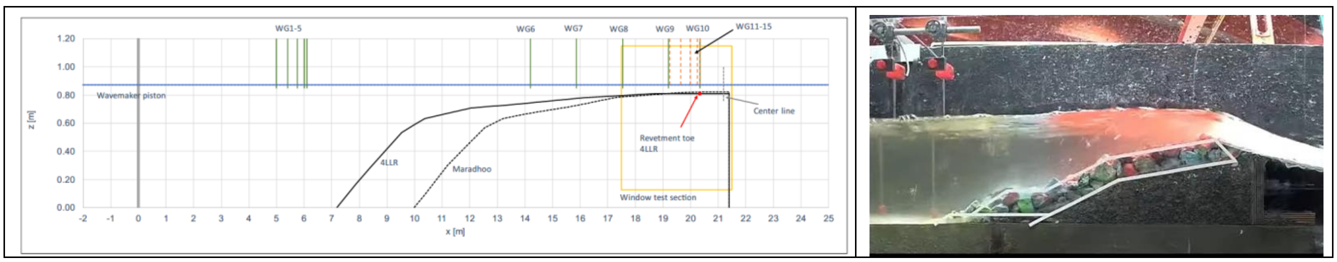

Figure 1. Modelled foreshores in model dimensions (source: DHI) (left) and flooding due to water level increase (right)

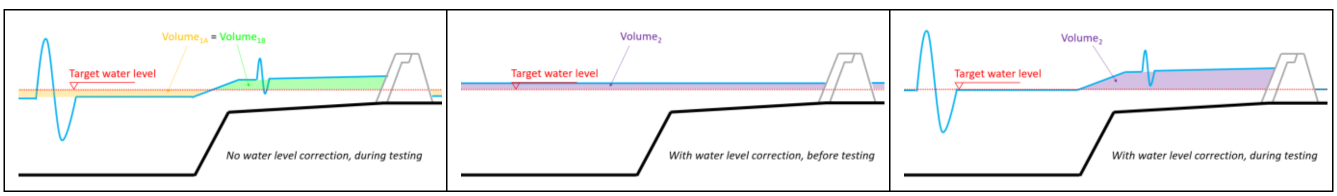

Figure 2. Water level calibration process (schematization not at scale)

2 CONCLUSIONS

1.The steep and shallow foreshore caused heavy nearshore wave breaking effects (water level set-up and low-frequency waves) on top of the reef flat, which were dominant for overtopping. No overtopping calculation method was able to predict or reproduce the measured overtopping discharges. Only physical model testing was found suitable to determine the overtopping discharges for this specific situation.

2. Due to the length of the reef, the magnitude of the water level set-up and the confined volume in the wave flume, the water level set-up on top of the reef flat caused a water level set-down near the wave generator (offshore). Therefore the measured offshore water level had to be corrected and calibrated, which was achieved by adding more water to the flume at the start of the test (offshore water level above target level) until the offshore target water level was reached during testing, and thereby also the correct water level near the structure.

ACKNOWLEDGEMENT

Acknowledged are Bjarne Jensen, Simone de Lemos and Karsten Lindegård Jensen from DHI for conducting the model testing, their expertise and the pleasant cooperation; Sebastian Iglesias, William de Lange, Ricardo van den Berg, Joffrey Cary and Stan Aarts from Van Oord DMC for their support and cooperation to make this project and the model testing happen.

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