STRENGTHENING THE CASE FOR NATURE BASED SOLUTIONS IN THE CARIBBEAN

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INTRODUCTION

Uncertain climate changes, rapid environmental degradation, and threats from natural disasters are among some present pressures facing global communities (Reguero et al. 2022). Addressing these intractable issues requires adaptability and innovation to meet project objectives while ensuring sustainability and climate resilience. Climate adaptation measures cannot only focus on finding engineering solutions to address issues such as coastal erosion or flooding but must also consider the level of the receiving community's acceptance to or involvement in a proposed solution which can shape not only the implementation phase of an engineered design, but guide on mechanisms for maintenance and monitoring (Anderson et al. 2021). Therefore, local knowledge is critical to the success of proposed solutions and understanding potential opportunities and challenges within a region is key.

In addition to a changing climate, many global coastal cities and islands, such as those in the Caribbean, are subjected to extreme weather events along with other concerns that increase coastal risk (Griggs and Reguero 2021). Therefore, in order to achieve sustainability goals, traditional hard engineering structures alone cannot be the optimal solution for a given site, and ecosystems can be integrated into solutions (Eggermont et al. 2015; Moosavi 2017; Gracia et al. 2018; Schoonees et al. 2019; Reguero et al. 2022). Where any component of a coastal solution incorporates a natural system or ecosystem over any period of the design life, these can be referred to as nature-based solutions (NbSs). Recently, there has been an increased focus on the design of the ecological aspect of NbSs to ensure that engineers can adequately ascribe levels of protection to designs. NbSs are attractive options to Small Island Developing States (SIDS), such as those islands in the Caribbean region, who require protection from the various natural drivers but must maintain aesthetic appeal to ensure the sustainability of tourism-driven coastal infrastructure. One main concern in the design of a NbS is the limited data on engineering performance which is linked to the inadequate research on components to be included, where to locate these components and how to best construct ecological components (Sutton-Grier et al. 2015; Moosavi 2017; Schoonees et al. 2019; Reguero et al. 2022).

The Caribbean is an ecologically diverse region (Miloslavich et al. 2010) and there are ecological systems such as mangroves, upper beach vegetation, sea grass or coral reefs which can provide ecosystem services such as flooding and erosion mitigation. Integrating these ecosystems into NbSs requires augmenting the knowledge that can link the ecosystems' attributes, the environmental conditions and the engineering design output. The characteristics of a given ecosystem and the environmental conditions will vary spatially and temporally, and engineering designs must account for these changes over the design life.

In an attempt to address some of these data limitations regionally, a series of physical and numerical experiments were conducted to investigate the impacts of the characteristics of coral reefs on wave energy dissipation and sediment patterns. Coral reefs have been demonstrated to provide coastal protection and other valuable ecosystem services to benefit communities (Storlazzi et al. 2019; Roelvink et al. 2021). The investigation specifically aimed to assess the impact of water depth, reef rugosity, reef width and the wave characteristics on the ability of the reef to attenuate incident wave energy and quantify the impact to above-reef currents which can support sediment transport studies. This study builds on the work of previous researchers but also highlights how Caribbean SIDS researchers have overcome practical limitations to reinforce support for the adoption of NbSs regionally.

METHODOLOGY

This investigation comprised of approximately three hundred and thirty (330) physical modelling experiments that were executed in a 1m x 0.6m wide x 10m long wave flume at the Department of Civil Engineering, UWI, Trinidad and Tobago. A series of twenty (20) linear and two (2) random wave conditions were tested for five (5) reef widths and three (3) different water depths. Only one (1) reef rugosity was investigated as part of the physical experiments, but this aspect was further explored using numerical modelling. For the physical experiments, linear wave amplitudes ranged from 0.01 to 0.04m and wave frequencies from 0.70 to 1.10 Hz. The two random waves based on the Jonswap spectrum had the same peak frequency of 1.0 Hz, but significant wave heights were 0.04m and 0.1m. Six wave gauges were placed at static locations along the wave flume, with three gauges located before the reef and three after the reef. An Acoustic Doppler Velocimeter (ADV) was placed at a static location in the flume but remained centered about the artificial reef for all experiments and was used to capture current velocities over the reef. The numerical modelling used Siemen's StarCCM+ to create a CFD model of the wave flume experiments and aimed to capture and reduce some of the limitations experienced with the laboratory experiment.

The numerical model was built using three distinct geometry parts which consisted of the flume, beach, and coral reef. The automated mesh feature was used at the region level, where the surface remesher was applied to improve overall quality of the existing surface and optimize it for the volume mesh. The Trimmed Cell Mesher provided a high-quality grid for the core volume mesher. To improve computational efficiency, the adaptive mesh was implemented which allowed for free surface mesh refinement. For the physics models, using an implicit unsteady time step allowed monitors and scenes to be updated at every timestep, and an adaptive time step was implemented to control the free surface CFL conditions, allowing for a sharp interface and improved run time. A multiphase material model aimed to account for both the air and water fluid regions and the Volume of Fluid (VOF) method was used to track the free surface. For accurate representation of the dynamic evolution of turbulent fields, the Shear Stress Transport k-ω turbulence model was adopted. The k-ω wall treatment was set to all y+ wall treatment which offered a blended wall function. To account for the Porous Inertial and Viscous resistances associated with the flow through the porous coral reef and beach, the (Ergun 1952) formula was used. This porous media model was coupled with the Reynolds Average Navier Stokes equation to model the flow. The waves were simulated using the VOF Waves and various wave theories were assessed to determine which wave conditions best described the experimental waves. The first and fifth order waves, based on the Stokes Wave theory, were used for comparison in these cases along with Superposition waves (based on first order waves).

This paper will focus on the numerical modelling component of this investigation and will demonstrate the various mechanisms explored to produce a validated numerical model which was then used to explore the effects of reef rugosity on the wave attenuation and currents.

RESULTS AND DISCUSSION

Analyzing the trends from the physical experiments revealed that the coral reefs did attenuate the wave energy. General trends in the reduction of wave height were observed with increasing coral reef width or decreasing water depth. The incident wave height was the most important factor affecting the wave height after the reef, with larger incident waves experiencing greater wave attenuation. While these general trends were observed, the magnitude of the wave attenuation was less than what was expected from existing literature. Another unexpected result was an increase in velocity in the direction of wave propagation as the reef length increased. One reason for these discrepancies is the reflection present in the flume which increased as the reef length and wave period increased. This interference from the reflected wave appeared to augment the wave height after the reef.

From the numerical simulation, the first order wave provided the best results before the reef, followed by the superposition wave with a phase lag of 1.571 radians, then a superposition wave with no phase lag, and finally the 5th order wave. After the reef, the superposition wave with zero phase lag performed the best, followed by the first order wave being just marginally better than the superposition wave with a phase lag of 1.571 radians and the 5th order wave. While the first and fifth order waves showed fair results at each wave gauge, the superposition waves appeared to be better suited to describe the waves in the experimental flume. The use of the superposition wave makes it possible to remove the effects of the reflected waves observed in the physical experiments and obtain results without this interference.

CONCLUSION

The preliminary results obtained support previous research. However, the study also seeks to contribute in terms of other aspects, such as mechanisms to address wave reflection in experiments conducted in short flumes available regionally. The experimental work will be augmented with the aim of better quantifying the impact of reef features on wave energy dissipation, current magnitude and morphological response. This work can support engineers to better incorporate effects of regional coral reefs into designed solutions as it can provide guidance on levels of protection offered due to changing reef conditions.

Figure 1 – The numerical wave tank used for these investigations

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