

# STRUCTURAL AND HYDRODYNAMIC ANALYSIS OF THE BREAKAGE OF BRANCHING AND PLATE CORALS

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## INTRODUCTION

Climate change is amplifying the frequency and intensity of severe weather events, with coastal regions such as the Great Barrier Reef (GBR) facing heightened vulnerability to cyclonic wave forces. Structural models have been developed for coral colonies to enhance comprehension and prediction of the effects of hydrodynamic disturbances on coral reefs. However, the methodology for quantifying complicated and variable coral morphologies remains inadequate, and the corresponding data remains considerably limited, thereby impeding structural analysis and hindering the broader-scale forecasting of coral breakage. This study focuses on two of the most prevalent coral morphologies within the GBR, namely branching and plate corals. Both laboratory and field measurements have been executed to assess coral morphologies and material characteristics. Based on the collected data, 3D structural models of branching and plate coral colonies have been developed, demonstrating the capability to generate multiple coral colonies with varying morphological patterns from different forereef zones. These models are combined with hydrodynamic modelling to predict the probability of failure under different wave climates. As part of the GBR Reef Restoration and Adaption Program, the results are used to create risk maps of coral failure and rubble generation at reef and GBR scales.

## METHODS AND LITERATURE REVIEW

For branching corals, the method of Carrillo-Mendoza (Carrillo-Mendoza et al., 2010) is adopted as the ordering system to quantify the branching patterns and evaluate the complexity of coral colony. This system starts from the stem part and assigns all the branches with an order value based on their hierarchical position (Figure 1(a)). Detailed in situ measurements at the relatively shallow (5-7m) and deep (9-11m) forereef areas were conducted, comprising branch length, diameter, location of bifurcation, angle, and the number of higher order branches. From these, distributions of the different parameters were obtained for parametric modelling. For the plate corals, the measured morphological parameters include the span and height of the colony, the diameter and height of the stem part, and the thickness and angle of the plate part (Figure 1(b)).

Madin (2005) and Baldock et al. (2014) summarized data of coral skeleton strength, which was supplemented by further in-situ (field) and laboratory stress testing. Bending tests for 66 samples of branching corals and 14 samples of plate corals were performed to determine the tensile strength  $\sigma$  of branching corals and plate corals, respectively.

$$\sigma = \frac{MD}{2I} \quad (1)$$

where  $M$  is the bending moment,  $D$  is the diameter,  $I$  is the second moment of area at the failure section. The degree of bioerosion was quantified at the failure section.



Figure 1. Method of quantifying the branching and plate coral morphology.

For sinusoidal waves, the maximum total force on a unit length of coral is given by Dean and Dalrymple (1992):

$$F_T = F_D + \frac{F_I^2}{4F_D} \quad (2)$$

where  $F_D$  represents the maximum drag force and  $F_I$  stands for the maximum inertia force. The relative importance of the drag and inertia force component is related to  $u_m T/D$ , also known as the Keulegan-Carpenter (KC) parameter. The relatively small diameters of branching coral result in a high KC number, which implies that inertia forces are negligible on branching coral in comparison to the drag force (Baldock et al., 2014). Consequently, the maximum force can be calculated using the drag force equation:

$$F_D = 0.5C_D\rho A_f u_m^2 \quad (3)$$

where the projected area  $A_f$  of each component in the structural model can be simplified as the mean branch diameter multiplied by the length.  $C_D$  values were taken from Dean and Dalrymple (1992) for relevant KC numbers. For each coral morphology, the maximum loads and bending moments at each structural component are calculated and summed. If the maximum bending stress exceeds its tensile strength, the model will indicate the type of failure; pruning of branches or dislodgement by breakage of the stem. The morphological parameters used in the model follow the distribution of observed field data, each generated coral is unique and slightly different from another (Figure 2). Using 1000 iterations of coral structure generation and subsequent analysis, the probability of coral failure against the peak bottom flow velocity is then estimated.

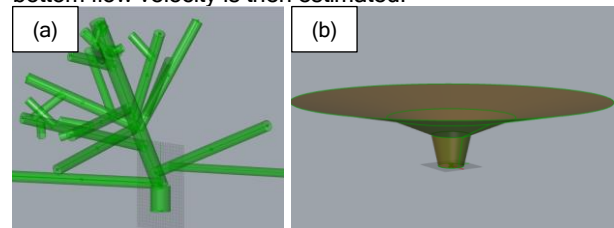


Figure 2. Example realisation of 3D structural models of branching and plate corals using field morphology distributions.

## CALIBRATION AND RESULTS

Laboratory tests were conducted for calibration purposes. Three samples of branching coral colonies, obtained from Heron Reef, were affixed to a digital load cell and subjected to testing within the wave flume at the UQ Hydraulics Laboratory (Figure 3(a, b)). Variations in colony orientation were examined to encompass scenarios with maximum, intermediate, and minimum frontal area exposure. The predicted total forces and bending moments are computed using the algorithm built in the model. Then, the modelled results were compared with the measured data. The outcomes reveal a good agreement between modelled and measured forces, with the differences of less than 10% in general (Figure 3(c)).

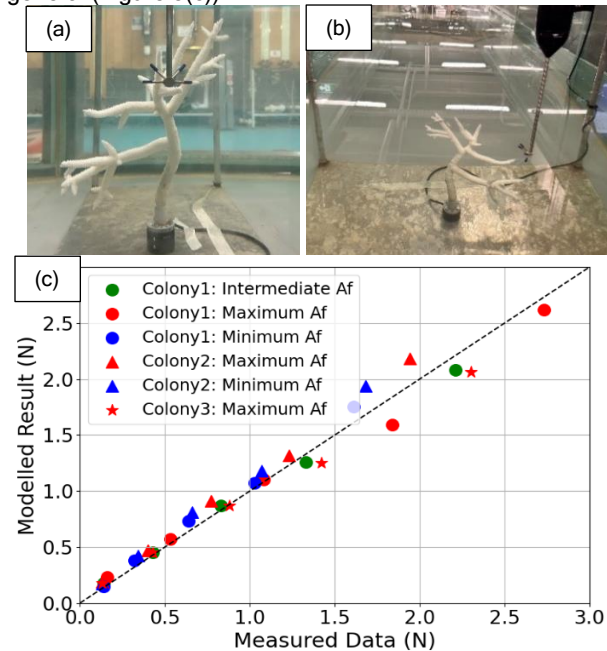


Figure 3. (a, b) Branching coral colony mounted on load cell in the wave flume. (c) Modelled results compared to the measured data using  $C_D$  values from the literature.

For the verification of the plate coral models, the predicted results are compared with previous research conducted by Vosburgh (1982), plotted in Figure 4. As the flow velocity increases, the force exerted on plate coral increases quadratically. The overall trend of the predicted force aligns closely with the findings of previous tests.

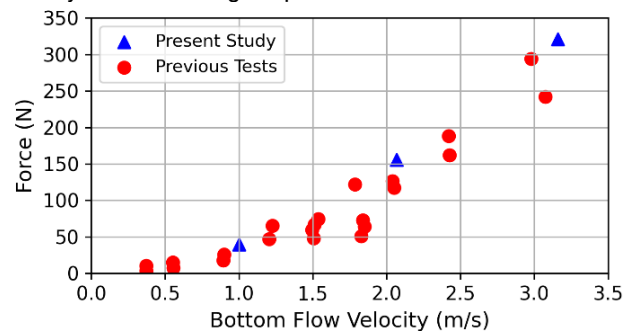


Figure 4. Modelled forces for a plate coral morphology compared to measured forces for a similar morphology in Vosburgh (1982).

After verification of the model, multiple branching coral colonies were randomly generated and the probability of failure against the peak bottom flow velocity was plotted (Figure 5). The result reveals that velocity thresholds of 2.2m/s and 5.8m/s would destroy 90% of the simulated coral structures growing in the deep and shallow parts of the forereef zone, respectively. The higher velocity breakage thresholds for corals in the shallow part are primarily attributed to their smaller coral size and fewer first order branches.

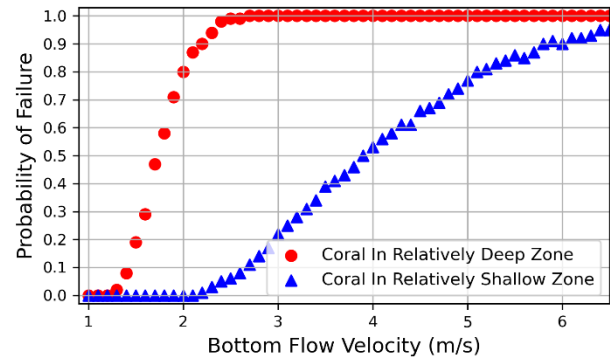


Figure 5. Comparison of the probability of failure at different flow velocities for branching coral morphology from different forereef zones.

In contrast, when a plate coral with a span of 100cm is exposed to a high bottom flow velocity of 7m/s, results show that the bending stress at the stem part ranges from 3-5MPa. This predicted stress remains significantly below the mean coral strength ( $\sigma = 12MPa$ ) obtained from the present mechanical tests. These findings suggest that the structure of plate corals is likely to remain intact even in areas with strong wave energy and they can endure extreme flow conditions.

The modelled results will be combined with benthic habitat maps and the wave models to create risk maps of coral failure and rubble generation at reef and GBR scales and consequently support decision-making on the efficacy of reef restoration.

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