The Effect of Submerged Engineered Reef Structures on Wave Overturn Shape

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Wave breaking occurs when the horizontal particle velocity at the crest exceeds the wave's phase speed, causing the crest to steepen, overturn, and form a jet that impacts the free surface. The overturn shape governs turbulence generation, bubble formation, sediment transport, and the loads applied to coastal infrastructure. Breaker types such as spilling, plunging, surging, and collapsing, have been traditionally classified using the Iribarren number: a function of the planar beach slope and wave steepness. This classification system, however, is based on planar beach slopes without additional bathymetric features such as sand bars or reefs, and it provides only a qualitative description of wave breaking, without capturing the geometry of the wave overturn. Although some laboratory and numerical studies have examined overturn geometry on simple planar slopes, the effect of submerged engineered reef structures on wave overturn shape remains unexplored.

To address this gap, we use the open source computational fluid dynamics (CFD) software, OpenFOAM, to simulate 2-D wave breaking over an idealized bathymetric profile representative of a San Diego, CA, USA beach, with and without an engineered reef superimposed on the natural slope. The reef structure is modeled as a functional perturbation to the slope, defined by reef amplitude (A_r), cross-shore length (L_r), and position (X_r). A larger A_r indicates a more elevated reef crest relative to the surrounding bathymetry, while a larger L_r represents a longer reef in the cross-shore direction. A larger X_r corresponds to a reef located farther onshore. We perform simulations over a range of reef parameters, incident random wave parameters (e.g., significant wave height H_s, peak period f_p), and tide parameters. We investigate how these parameters modify overturn characteristics, including overturn area, jet area, aspect ratio, and overturn angle. Understanding these changes is important for predicting wave energy dissipation and informing the design of multi-benefit coastal resilience structures that can reduce beach erosion, foster marine habitat growth, and enhance surfing conditions. Our results show the differences between wave breaking on natural and engineered profiles, which can inform coastal infrastructure design.

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