

Shore Protection Design Utilizing Wave Rotation

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ABSTRACT

This study examines the potential for a new type of shoreline stabilization structure. The design would modify incoming wave angles such that the longshore transport rate would be reduced or reversed in its lee. This is accomplished by refracting wave fronts so that they become more shore parallel or from the opposite side of shore-normal. This structure can also be designed to have a beneficial effect on the surfability of the waves, thereby providing a recreational amenity. Physical modeling was performed to determine the optimum configuration of the design structure. Wave basin tests were accomplished using a variety of wave conditions. These tests demonstrated the ability of the proposed structure to rotate waves past shore-normal. Wave ray tracing was used to validate the physical modeling results. The optimized design would significantly alter the coastal processes of the area, causing a salient to form in its lee. The proposed design was applied to an area on the coast of Brevard County, Florida. Predictive empirical formulas on salient and tombolo formations indicate that a salient would form with an apex of 270 feet offshore from the original shoreline. The accretion resulting from the shoal would extend approximately 2160 feet in the longshore. This could become an integral part of a more cost effective beach preservation plan.

ADDITIONAL INDEX WORDS: *wave rotation, refraction, artificial surfing reef, littoral drift.*

INTRODUCTION

History has demonstrated a tendency for coastal projects to protect land without considering the degradation of the beach. This is a holdover from a time when coastal processes were not well understood. The use of hard structures such as groynes, jetties, bulkheads, seawalls, and breakwaters is declining. These structures detract from the natural beauty of the beach and are being phased out in favor of submerged or soft structures, such as beach renourishment or soft easily removable geotextile tubes (BLACK, 2001b).

These more environmentally sensitive solutions to coastal protection have been promoted by a variety of interests. Artificial surfing reefs have been built with the purpose of packaging improved surfing, diving, fishing, and coastal protection into one design. This allows for

multiple sources to be utilized for funding. Multi-interest projects can remove obstacles that would have impeded earlier plans, in addition more potential users provides greater justification for these projects. The design location is Indialantic Beach, in Brevard County, Florida. This stretch of Florida's coastline is in a state of erosion. The U.S. Army Corps of Engineers is planning on renourishing the stretch of coastline that includes Indialantic with 601,000 cubic yards of sand every 6 years, over the next 50 years (USACE, 1996).

The purpose of this project was to determine the feasibility of a new type of offshore structure that would provide both coastal protection and recreational amenities, such as surfing, diving and fishing. The majority of shoreline stability projects using offshore breakwaters aim to reduce the wave energy that reaches the beach through wave breaking. The proposed design is intended to stabilize and protect the beach by wave turning. It accomplishes this by rotating wave fronts from their original orientation, such that the incident angle would be reduced or potentially inverted. By changing the wave angles it would slow and possibly reverse the longshore transport rate in the lee of this structure. The rotation of wave crests can create an area with improved surfability, especially when other nearby spots are "closed out", unsurfable, therefore increasing surfing amenity. This innovative type of coastal structure design has not been extensively studied.

METHODS

Wave ray tracing and physical modeling were performed for this study. A wave basin was constructed for refraction/diffraction analyses. The wave basin was given a slope of 0.01, which is approximately the slope off Indialantic Beach past the depth of closure (\approx 30ft) (KRIEBEL, 2002). The basin had the dimensions of 12 feet by 10 feet and was outfitted with a sinusoidal flap type wave generator.

The basins original slope was altered by the placement of a variety of materials, such as, cement forms, sand filled bags, small rock, and sand, various wave climates were produced over the different topographies. The optimum experimental shoal material was found to be coarse sand piled on the basins hard bottom. This allowed for quick alterations of the experimental shoal. An optimal design shape was eventually established and further tested. The wave period was the primary design factor in this study, due to the fact that refraction is dependent on water depth and wave period. The natural conditions of the study site were modeled using Froude scaling along with geometric similitude with a scale factor of 1/90 (DEAN *et al.*, 1991).



Figure 1. Wave basin utilized in study.

The most common periods at the Brevard County coast are from 4 to 13 seconds (HARRIS, 2003). However, shorter period waves contribute less to the sediment transport rate in comparison to longer period swells of the same height. Therefore, waves periods of 7 to 13 seconds were selected as the design wave criteria because they are the most important to the designs performance and optimization. The coastline in this region has a relatively wide flat shelf with a nearshore slope of 1/100. This gentle slope has a significant impact on the wave conditions through refraction. Employing the design wave periods the largest wave angle possible at the 13 foot depth contour was calculated to be 32.7 degrees, using Snell's Law, given the offshore topography.

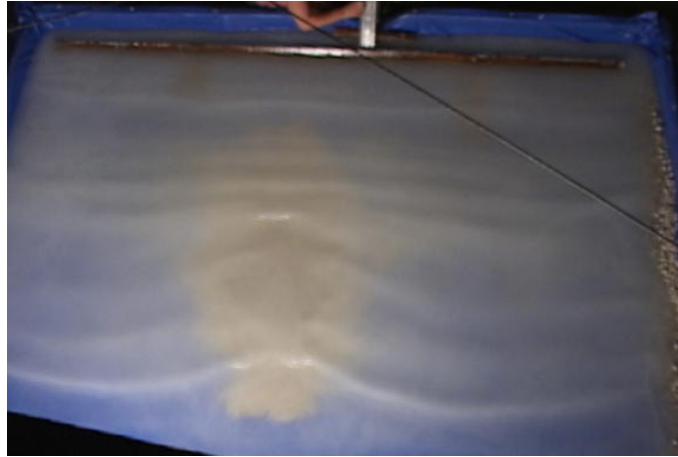


Figure 2. Wave basin with optimized shoal.

The optimized shoal's bathymetry was measured by placing a grid of 0.33 feet squares over the shoal and measuring the sand depth at each corner. The shoal was then plotted in three dimensions using Matlab.

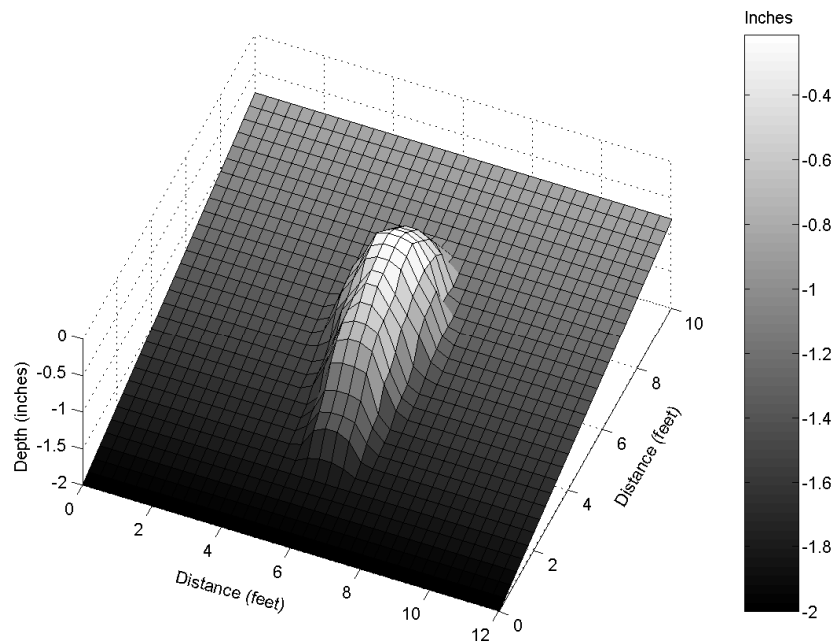


Figure 3. Optimized shoal's bathymetry.

Using the scale factor of 1/90 the shoal dimensions would become approximately 300 feet in the longshore, 560 feet in the cross-shore, the shoal would be a distance offshore of 775 feet, and the depth at the offshore toe of the structure would be placed at the 13 foot contour.

RESULTS AND DISCUSSION

The wave basin was configured to produce waves at angles of 0, 15, 25, 35, and 45 degrees from shore-parallel. In each setup waves of various periods were generated and photographed. Three groups of periods were used for analysis purposes: (1) 0.7-0.8s, (2) 0.9-1.1s, and (3) 1.2-1.4s. A coordinate axis was defined to describe the wave rotation as shown in, Figure 4. The angles measured clockwise from shore parallel were considered negative and those measured counterclockwise were deemed positive.

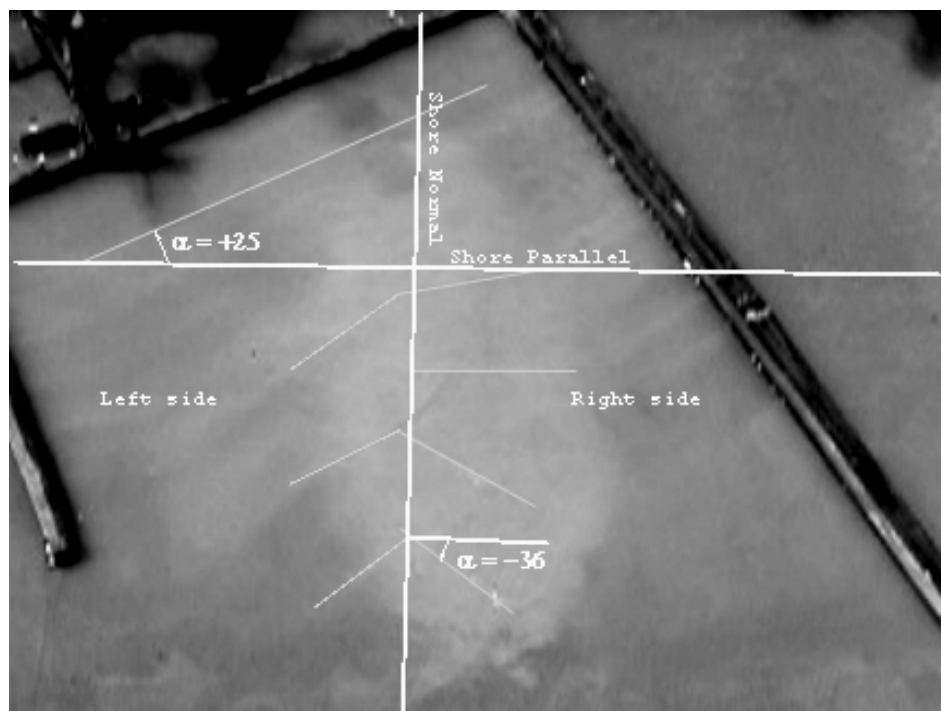
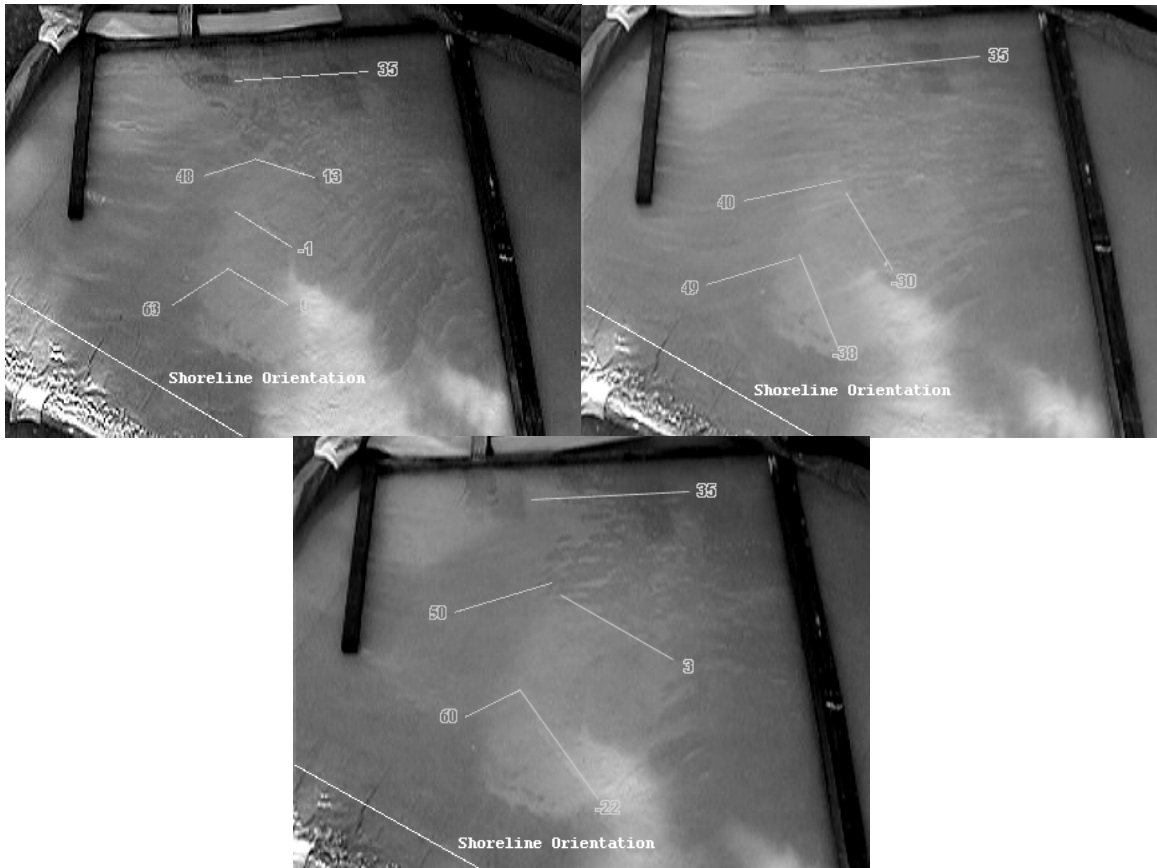


Figure 4. Coordinate axis of wave basin.

The various testing conditions were videotaped and from this the wave period was accurately measured and verified. The videos were taken from roughly 20 feet directly above the nearshore section of the basin. There were many attempts to improve the resolution of the waves. Spherical hollow glass “micro-ballons” were added to the water to increase reflectivity. These hollow glass spheres are approximately 1 micron in diameter, and greatly improved the visibility of the waters surface when using photography. The pictures obtained from the videos were used to make wave angle measurements. The wave fronts were highlighted in each photograph and their angles relative to shore-normal were measured. The pictures were left un-rectified, because the lens and angle distortion was insufficient to alter the wave angle measurements. This was a result of the height at which the pictures were taken and the relatively vertical view as well as the fact that the angles were measured near the center of the pictures.



Figures 5-7. The initial wave angle was 35 degrees and the wave period in the three pictures increases from 0.7s, 1.0s to 1.4s from top to bottom.

In this series of pictures Figures 5-7 it is easily recognizable that the wavelength increases with period. This is what is expected from linear wave theory. However, there are no other easily discernable relationships. Using the data collected from photographs such as these, the maximum rotation from the initial wave angle (α) was measured for each of the various conditions and on both sides of the shoal. The results of this are shown in Table 1.

Table 1. Maximum wave rotation (both sides of the shoal)

	Wave Period						
	0.7 s		0.9-1.1 s		1.2-1.4 s		
	left	right	left	right	left	right	
Wave Angle α	0 Degrees	42	-38	17	-21	16	-15
	15 Degrees	35	-14	29	-1	27	-5
	25 Degrees	39	-36	33	-24	43	-27
	35 Degrees	63	0	49	-38	60	-22
	45 Degrees	54	11	54	28	80	31

Wave crests rotated by both sides of the shoal will influence the energy flux and thus the longshore transport rate. It is apparent that significant refraction occurs on both sides of the shoal regardless of initial wave angle. This is qualitative proof that the design shoal did

function as a “rotator reef”. Several relationships have been found between wave period, rotation, initial and final wave angle.

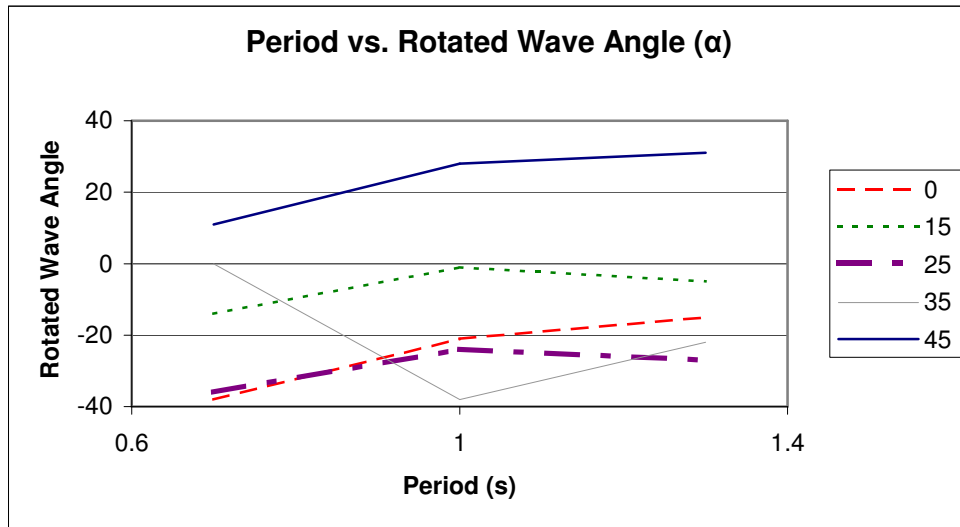


Figure 8. Wave period vs. Rotated Wave Angle (right side)

Figure 8 shows that the amount of wave rotation on the right side of the shoal is reduced with increasing period, only the initial wave angle of 35 degrees did not follow this trend. It is also easily seen that the only case where the wave crest does not rotate past shorenormal is when the initial wave angle is 45 degrees. This means that the design shoal will alter the longshore transport rate by reversing the incident angle for each of the design waves. In order to determine the total amount of wave turning, the initial wave angle has to be added to the values on the right side and subtracted from the values in the left side to obtain the total wave angle change. The total wave turning ($\Delta\alpha$) that occurs on the right side of the shoal is shown in Figure 9.

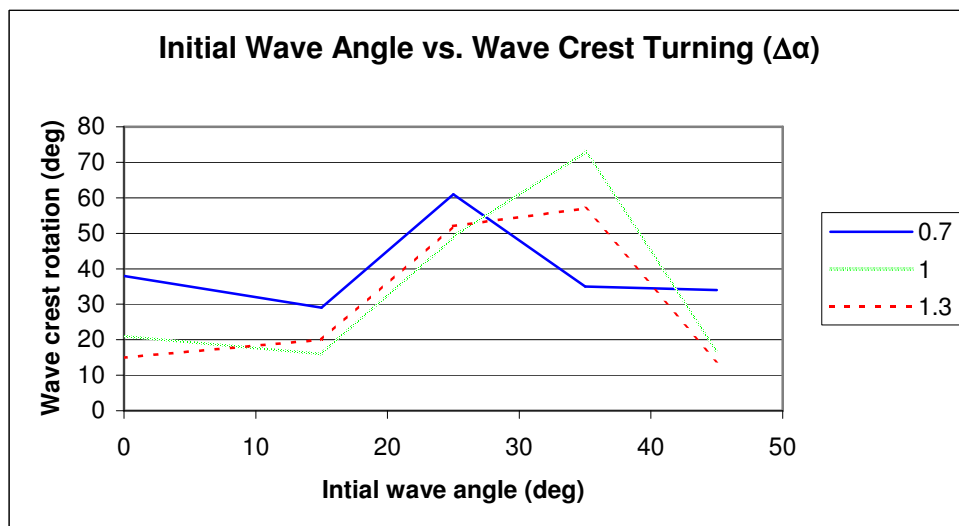


Figure 9. Initial wave angle vs. Total wave crest turning (right side)

From Figure 9 it is apparent that the shoal had the most wave turning for waves with the initial angles of 25 and 35 degrees. There was a lesser but similar amount of total wave

turning for the 0, 15, 45 degree cases. The refracted wave angle measurements for the left side of the shoal are displayed in Figure 10.

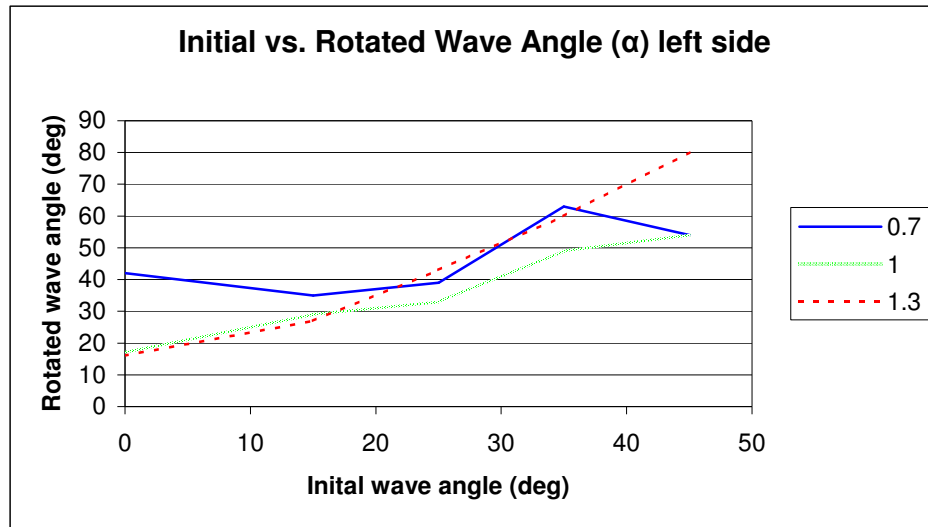


Figure 10. Initial wave angle vs. Rotated wave angle (left side)

Figure 10 shows that that the refracted wave angles increase quite linearly with the initial wave angle. This is expected because as the initial wave angle increases the total rotation should similarly increase, due to the fact the values are additional. The wave ray tracing method corroborated the physical modeling by obtaining similar refraction patterns for each of the cases.

The placement of the design shoal will alter the local beach processes. This in turn will change the shoreline shape and position. Several studies have found empirical relationships between offshore abnormalities and sand deposition (SHORE PROTECTION MANUAL, 1984; BLACK, *et al.*, 2001a). The offshore obstructions length (B) is divided by its distance offshore (S) this ratio is used to determine the degree of sand deposition in the lee of a submerged abnormality, tombolos form when $B/S > 0.60$, salients form when $B/S < 2.00$, and non-depositional conditions occur when $B/S \leq 0.1$ (BLACK, *et al.*, 2001a). In the case of the design shoal the ratio is:

$$B/S = 300\text{ft} / 775\text{ft} = 0.387 \quad [4.1]$$

This ratio is less than what is required for tombolo formation and more than the minimum for salient development, and it is also above the minimum for sand deposition to occur. Hence, this means that a salient would form. To determine the amount of sand deposition that would occur the following formula was empirically developed for submerged cases:

$$X_{\text{off}}/B = 0.50 (B/S)^{-1.27} \Rightarrow X_{\text{off}} = 505 \text{ ft} \quad [4.2]$$

This value determines the maximum offshore distance to which the salient would develop. The apex of the salient would be approximately $Y_{\text{off}} = 775 \text{ ft} - 505\text{ft} = 270 \text{ ft}$ offshore from the beaches current position. The length of beach that would be widened by the salient's development is determined by the following equation:

$$Y_{\text{off}}/D_{\text{tot}} = 0.125 \Rightarrow D_{\text{tot}} = 2160 \text{ ft} \quad [4.3]$$

The design shoal would have a significant impact on the local beach processes. It would increase the width of the beach, and the structure's effects would be far reaching, more than a fifth of a mile in both directions. These structures could become part of a novel and economical beach preservation plan. A series of structures similar to the design shoal can eliminate the need for maintenance renourishment along a stretch of coast. They would function similarly to a groin field but without the visual degradation of the beach. After the shoals construction an initial fill project would alleviate any immediate downdrift detrimental affects.

There have been two artificial surfing reefs built out of geotextiles and a third is in development called Oil Piers Reef in Ventura County, California. The proposed artificial design shoal has a projected volume of 16,700 cubic yards, which is comparable in size to the Oil Piers Reef of 19,600 cubic yards. Therefore, the projected expense of the Oil Piers site will be used as an estimation of the design shoal's construction and prefill costs, approximately US\$2,200,000. A structure such as the proposed shoal built out of geotextiles would have an estimated design life of 25 years (ASR, 2003). From the assumptions of a 25-year design life and US\$2,200,000 construction and prefill costs per structure, the entire length of the Brevard County coast that has ever been renourished could be protected by a series of these shoals for 50 years for a cost of US\$184,000,000. This is a considerable savings over the current 50-year renourishment plan of US\$253,000,000 (USACE, 1996).

CONCLUSIONS AND RECOMMENDATIONS

The physical model study demonstrated that a submerged shoal could effectively rotate waves. The design shoal was effective at rotating waves with scaled periods of 7 to 13 seconds, which corresponds to the periods most important to the longshore transport rate at the study site. The physical model scale of 1:90 allowed for the design wave criteria to be tested given the basins size. The design shoal has the projected dimensions of approximately 300 by 560 feet in the cross shore and longshore directions, respectively. The restriction of basin size limited the ability to produce scaled wave heights. The largest wave heights produced in the basin were on the order of 0.5 inches, which from the scale factor would be approximately a 4-foot wave. The wave height limitation did not allow for wave breaking analyses to be performed. Basin size also restricted the creation of longer periods, thus decreasing the scale factor that could be utilized. A larger basin would have more space for the dampening of wave reflections and thus produce better images with less noise. This wave attenuation was especially needed behind the paddle of the wave generator. Further research should include computer modeling of wave refraction and diffraction, along with sediment transport estimates. The effect of the shoal on sediment transport could be determined using a numerical modeling program or in a moveable bed physical model basin with cross-shore variance in littoral drift. Additional research should be conducted on potentially dangerous currents produced by the shoal.

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