BREAKWATER OVERTOPPING AND TRANSMISSION CHARACTERISTICS ASSOCIATED WITH LIVING SHORELINE FUNCTIONAL ATTRIBUTES

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A series of physical model tests were performed to explore what, if any, functional benefits in wave protection and damping are associated with various structural augmentations to a traditional breakwater intended to also serve as habitat creating or enhancing. The augmentations are in structural and geometric form and are intended to make large-scale alterations to wave behavior and transmission, and as such, do not involve secondary small-scale measures such as fronting seagrass meadows of vegetated edges. Those would be considered "opportunities" to further increase the ecological value but were felt to have limited functional impact or likely value given the scale of wave aggression. The model test results revealed significant performance deviations from traditional overtopping transmission formulas and experience. Raising the interior breakwater core allowed for significant lowering of the required breakwater crest height for the same incident wave conditions. Flattening of front face slope, combined with a reduction in armor size to better achieve bio compatibility, gave improved results but reached a limiting beneficial level. The biggest impact on reduction of wave overtopping and transmission was found with the introduction of quasi-two-dimensional protruding fronting reef ridges. Similar beneficial results were noted for lee side habitat ponds where perched pools of water intended as juvenile fish nurseries co-serve as stilling basins in severe wave events before transmitting onward to shore. Incorporating these new design elements into the design of a breakwater offers opportunities to improve visual aesthetics by lowering breakwater crest heights and creating breakwater geometries which better emulate natural landforms. Such solutions are more conducive to recreating habitat while still retaining the needed wave mitigating properties of the breakwater.

Keywords: living shoreline, wave transmission, fish alleys

INTRODUCTION

At Illinois Beach State Park, the Illinois Department of Natural Resources sought to find a way to mitigate, in as natural and least intrusive means possible, rapid erosion losses to the last vestiges of a rare, irreplaceable, and highly eco-valued shoreline. Given the natural setting, an ideal solution would be a form of mitigation that would be unseen by park visitors. The hope and vision was that a perfect solution would incorporate the limited use of major offshore structures, not touch the beach, but embody significant habitat character. To achieve a litany of ecological as well as physical performance goals such as wave transmission reduction, quantitative measures of exactly how atypically shaped and configured "eco-structures" can influence the incident wave field as compared to traditional breakwater designs were needed.

Immediately recognized was that an appreciation that attempts to rely on purely biologically based erosion mitigation measures is not resilient against large wave forces, and dampening the effects of the waves sufficiently would require massive areal extent due to the slow attenuation rate properties of such systems. The question remained as to whether the proposed habitat enhancements or alternations to breakwaters might degrade their performance, which would detract from the overall project intent. Conversely, these biological additions might improve performance, resulting in a win-win scenario. The study therefore explored the performance of breakwaters whose geometry diverges from traditional forms due to the introduction of large-scale integrated habitat elements.

APPROACH

Hypothetical breakwater cross sections, each embodying possible habitat enhancement features, were tested for overtopping wave transmission. In the tests, variants of a traditional trapezoidal layered armor breakwater cross section were examined subject to a range of wave conditions and structure freeboard combinations. The tests were conducted in a 2D wave flume at the HR Wallingford laboratories at a scale of 1:30. Tests were conducted using monochromatic waves to make the measurement more deterministic and repeatable between test series.

Various geometric parameters were initially considered that could be logically extended or evolved into habitat enhancing features. First among the options was an increase in breakwater crest width. Breakwaters with wide crests could hold the potential to be transformed into more aesthetically pleasing nearshore features by intentionally or incidentally encouraging vegetative growth on the crest and/or by being able to lower the crest height so that the view from shore was of a less visually impaired horizon. Second, was an exploration of how the porosity of the crest armor layer influenced wave overtopping

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and transmission. Devising breakwater cross sections such that the large armor crest layer became largely impervious might again allow for the structure to be lowered, for cost and aesthetic benefit, but also might be configured structurally to create avian habitat nesting areas.

The holy grail of nearshore breakwater design is one that is completely invisible from the shoreline, i.e. completely submerged. Not only is it unseen, but the submerged structure might be made to intentionally break incoming waves or be used to redirect the wave energy away from an area of concern. Its texture could also be made of various composition for both aquatic habitat value and reduced erodibility or sediment transport potential. Finally, two geometric structure options were examined that are specifically design targeted as highly desirable habitat features: a “stilling” pool on the lee side of the breakwater, and a set of fish ridges or “fingers” extending normal to the breakwater on the stoss side of the structure. The latter has been evolved from juvenile fish behavior where confined areas between the fingers are more protective from predators, and the sinuosity of the added fingers dramatically increased the length of available habitat “edges” which are the most ecologically productive areas.

RESULTS

The performance of each of the explored options is compared to the measured performance of a traditional rock armored breakwater with a 1V:1.5H trapezoidal layer armor cross section. The base performance is plotted for reference in each of the cases, including the equivalent submerged reef scenario. Consistent with previous research by van der Meer (CIRIA/CUR, 1991) and Briganti et, al. (2004), the action of wave transmission over any of the structures follows a linear trend with declining transmission directly relatable to freeboard. In general, the rate of wave height decay is found to be expressed as:

$$\Delta K_t \approx -0.3\ \Delta F \qquad (1)$$

where Kt is the transmission coefficient and F is the relative freeboard (Rc/H) with Rc equal to the true freeboard and H is the incident wave height. Only the true magnitude of the change associated with the design modifications changes between cases.

Influence of Crest Widening

The model test results are shown in Figure 1. The base crest width is taken to be three stone diameters across and the stone diameter, as can be surmised from Hudson’s armor sizing formula (CERC, 1984), is approximately one-third of the wave height.

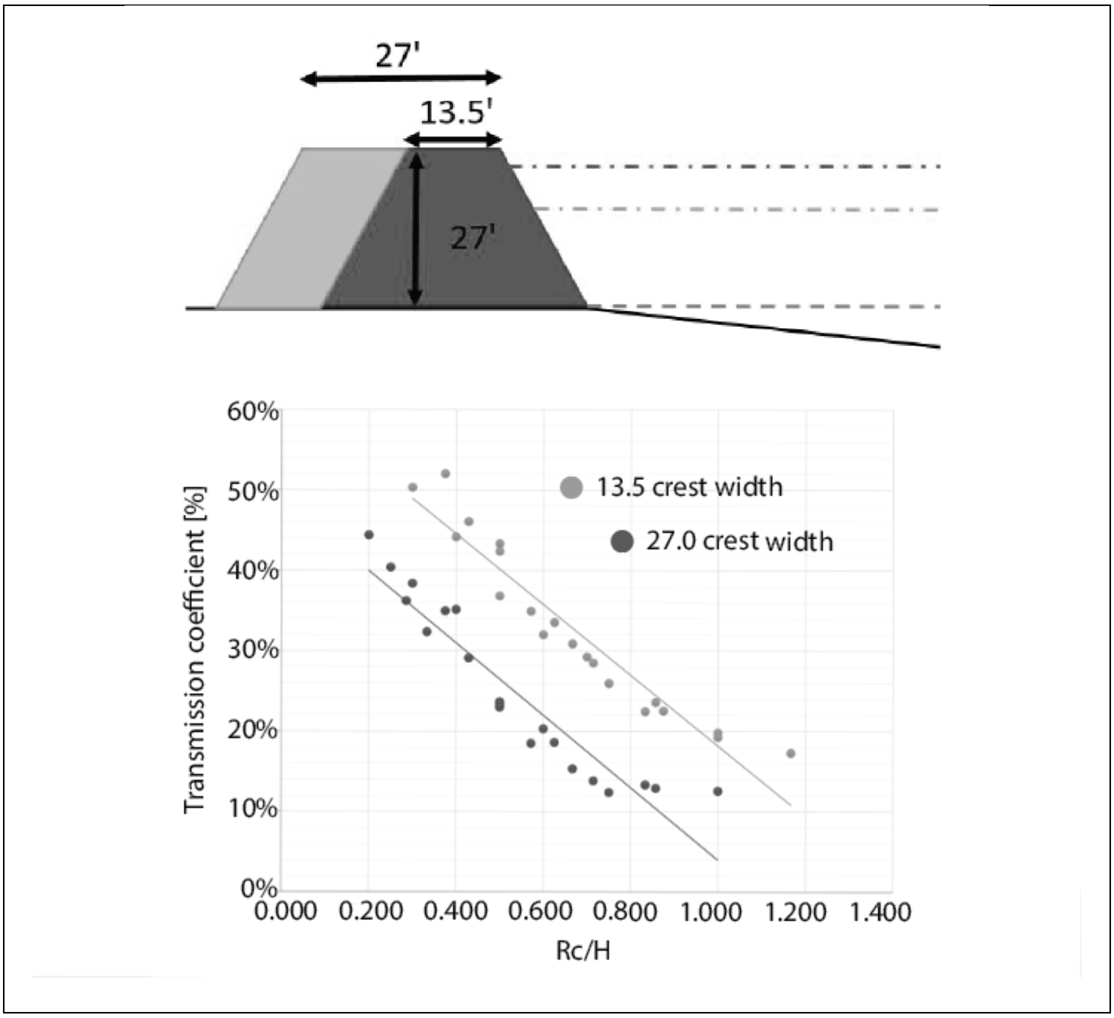

Figure 1. Impact of crest widening

Using 30% transmission as a realistic transmission target goal, the results indicate that the crest height could be lowered nearly 50% while achieving the same performance. Given the 1V:1.5H breakwater slope this represents less total volume required but with improved aesthetics as less of the horizon is blocked with the lower profile.

Influence of Crest Armor Porosity

In the ideal breakwater, the transmissivity of the breakwater is constant and solid to its full height. However, in larger wave climates the required armor sizing calls for very large rock placed atop the core, leaving large voids between even the individual stones through which waves can penetrate. The higher the core of a breakwater, the more efficient it is. For transmission reduction, it is not necessary for the entire crest to become solid provided that no transmission through the armor layer can occur. To introduce avian habitat on a breakwater, the crest area would involve creating solid structural nesting pods for birds. Making the crest structurally solid and impervious accommodates both the ecological goal of adding pods and a lowered transmission. Figure 2 presents the lowered transmission benefits of an impervious crest.

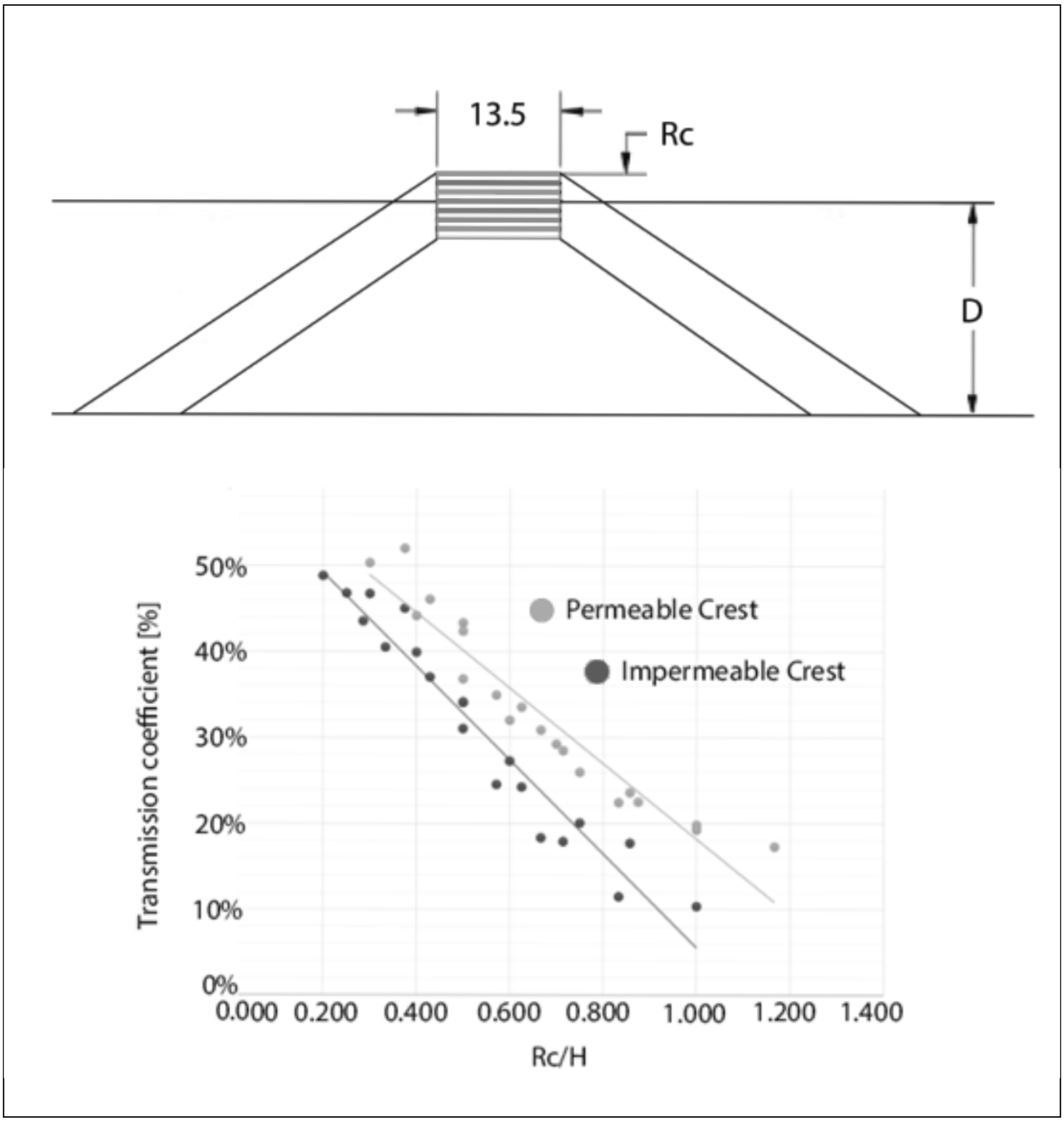

Figure 2. Impact of crest armor porosity

To achieve the same 30% overtopping transmission, the transmission can be reduced by the addition on an internal crest transmission barrier which lowers the required equivalent relative freeboard by 26%.

Benefits of a Fronting Artificial Reef

Figure 3 suggests the benefits of introducing a fronting reef structure waterward from a main breakwater or simply a beach. When the relative freeboard is submerged by no more than roughly 10% of the wave height, transmission can be reduced to roughly 40%. The data suggests that adding a flatter front slope to the reef does improve its effectiveness, however, the majority of the benefit is largely achieved with up to a 1V:6H slope, and flatter slopes only incrementally decrease transmission further.

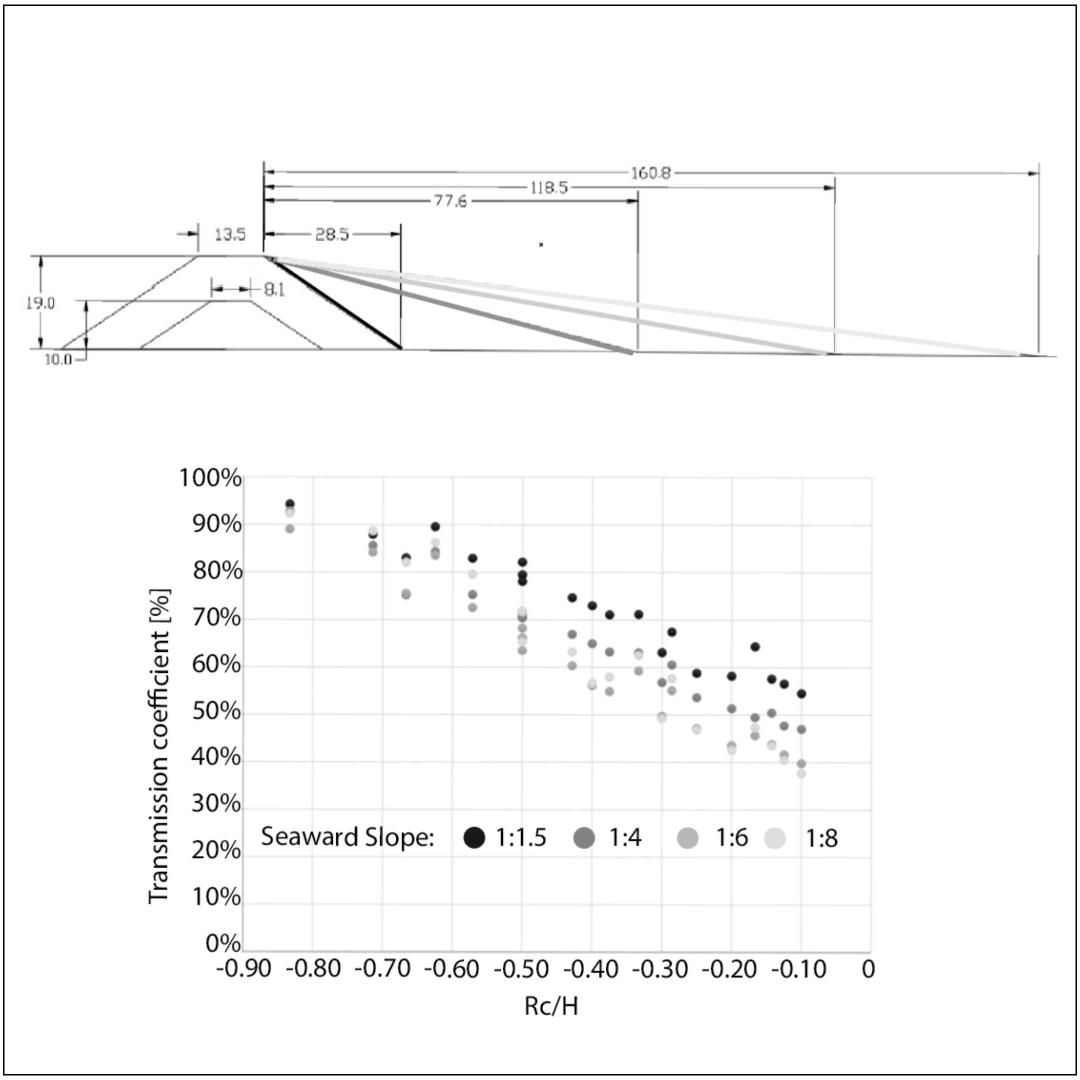

Figure 3. Artificial reef stoss slope impact

Given the significant increase in volume of the reef as the slope flattens, and concerns over bottom impact associated with forming the artificial reef, a fronting slope not exceeding 1V:4H is likely the practical limit for functional consideration.

Influence of a Lee Side Stilling Basin

Especially in high energy coastlines, scarce and significant habitat in the form of vegetative aquatic zones is hard to sustain. The lee of a breakwater structure may offer calm waters, however, provided its length is sufficient to reduce end wave diffraction back into the shadow zone. The lee agitation is therefore only dictated by overtopping and the magnitude of transmitted waved towards the shore. Figure 4 explores the benefits of intentionally introducing a stilling basin on the lee side of a breakwater in terms of the ultimate transmitted wave behavior. In this case the stilling basin was specified to be of a suitable substrate to serve as a habitat scale aggregate with a “fish mix” of material ranging in size from ½ inch to up to 6 inches. The pool of aggregate was submerged 9 feet below design water level (presuming a super elevated water level concurrent with a storm condition) and was 6 feet thick. The results are presented in Figure 4 and show that, again using 30% transmission as a realistic target, that the fronting main breakwater relative freeboard can be reduced in height by as much as 70% with the addition of the lee side pool.

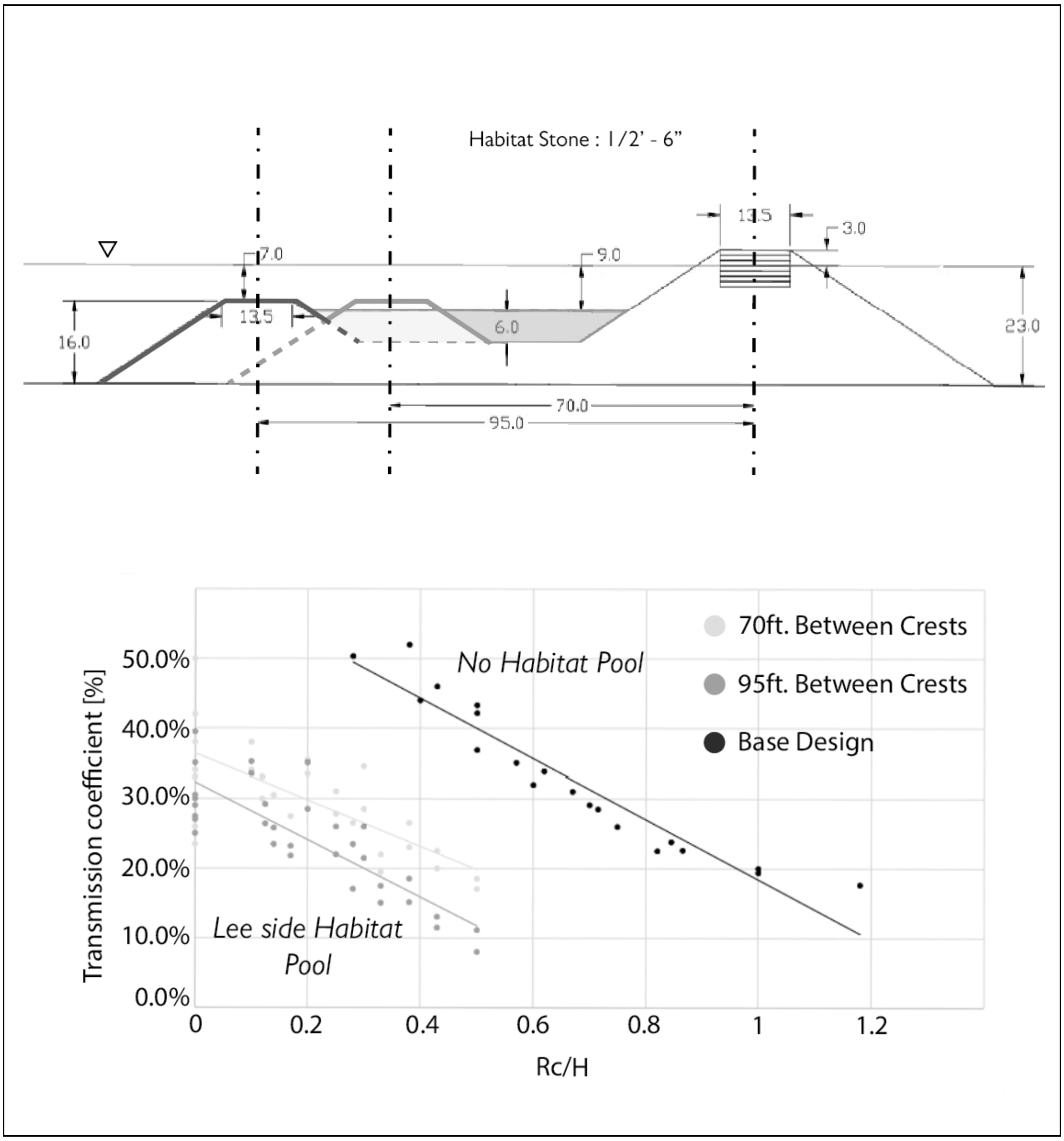

Figure 4. Impact of Lee Side Pool Addition

For the conditions tested, the modeled habitat stone in the lee side pool showed no notable displacement from the static equilibrium, suggesting the plunge jet of the overtopping wave was ineffective in dislodging the habitat material.

Stoss Face Appendages

In a significant departure from traditional thinking, a modification to a breakwater involving stoss (seaward) pointing appendages or fingers, normal to the breakwater were examined. Ecologically, these are functionally very desirable, and they significantly increase the length of the near waterline perimeter of the breakwater, which is where the greatest amount biological activity occurs along the edges. More importantly, the alleys between the fingers or ridges are constricted waters which well protect smaller and juvenile fish and other species against predators. The non-intuitive results are presented in Figure 5.

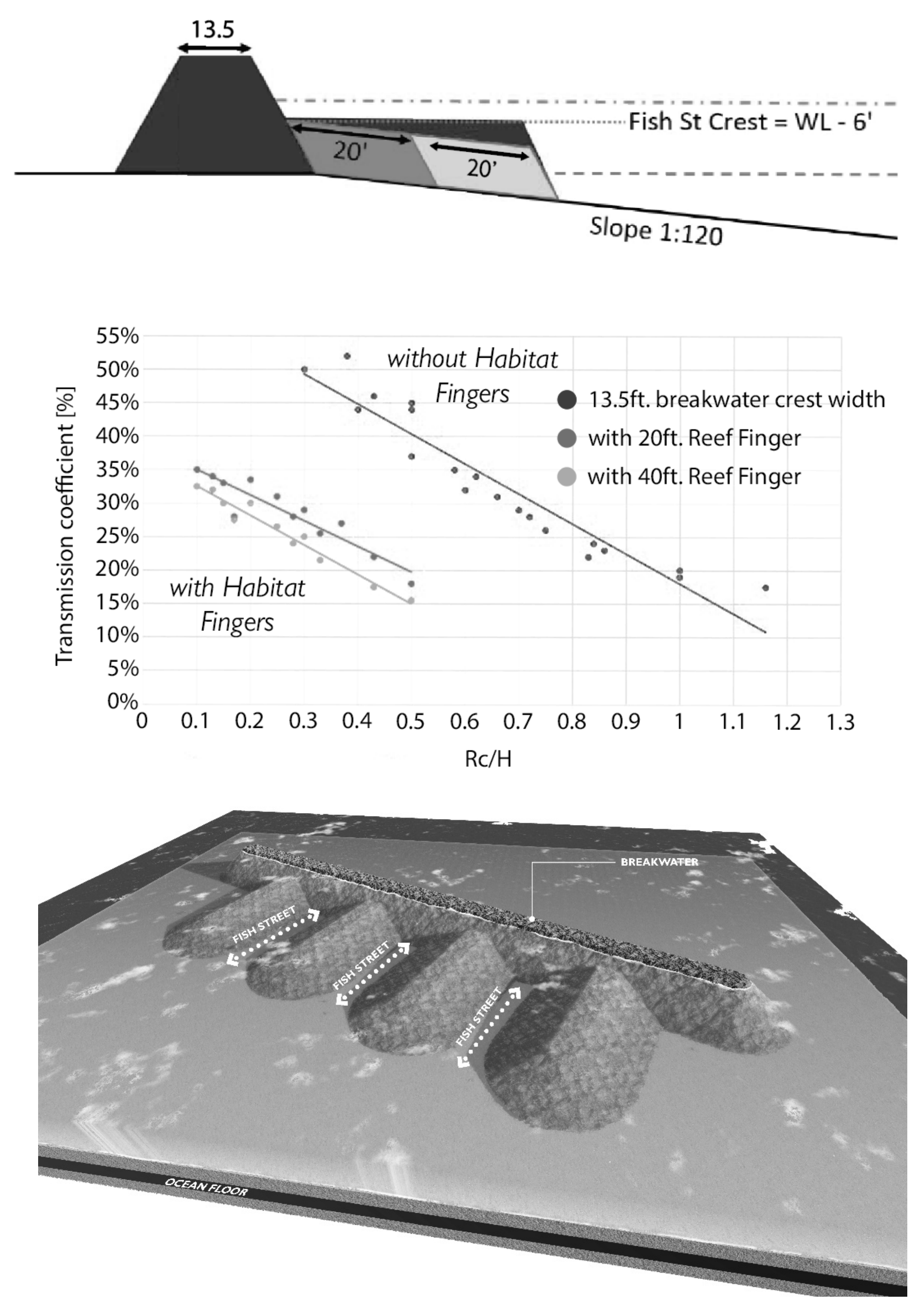

Figure 5. Stoss Face Habitat Appendages Impact

The results reveal that addition of these appendages on the stoss face can significantly reduce the overall transmission of an overtopping wave. Again, using a representative 30% transmission target, the potential relative freeboard height reduction is at least 50%. The tests also reveal that these appendages do not need to be excessively long, as the performance of a 40-foot-long finger is only slightly better than a 20-foot-long finger. Secondary benefits of the habitat appendages are that the agitation level on the stoss face is greater, so there is less tendency for siltation to occur as happens with sheltered lee side settings, and water quality remains higher. At the same time the fingers can replace toe berms so often required to inhibit scour. The section composition of the fingers is uncomplicated and comprises of single armor size material suitable for the submerged condition in the wave climate.

CONCLUSION

The twenty-first century heralded a new direction and vision for the coastal engineering community. The future is no longer to simply design solutions to resist the ravages of natural forces through brute force installation of hardened surfaces, but to instead work with nature and leverage natural processes to evolve solutions that are as effective in performing the primary role of defending the coast. The solutions studied and analyzed demonstrate that the introduction of various geometry and compositional features into a breakwater design, intended to either improve the aesthetics of the installation by lowering its visibility or more closely emulate naturally occurring morphologies, can be a functionally performing equivalent, yet also add value in the form of ecological benefit.

The findings here suggest that the long held traditional ways and assumptions toward building of breakwaters now appear to have been short-sighted in always presuming only a brute force resistance approach, relying on basic geometries and single stage performance as the solution. These new results suggest that with more two- and three-dimensional thinking it is possible to achieve equal or better performance from a structure, with added ecological and aesthetic value, at the same or even less cost. Of course, the actual degree of cost benefit may differ from site to site and is likely subject to water depth and material unit cost considerations, but the physical benefits remain. Further, the findings of these derivative designs may be most applicable to remedial repairs of existing structures, negating the need to rebuild to an original condition – replacing the mitigation with one or more of these alternative approaches and features such that the net performance is recovered or preserved while now adding the ecological benefits.

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