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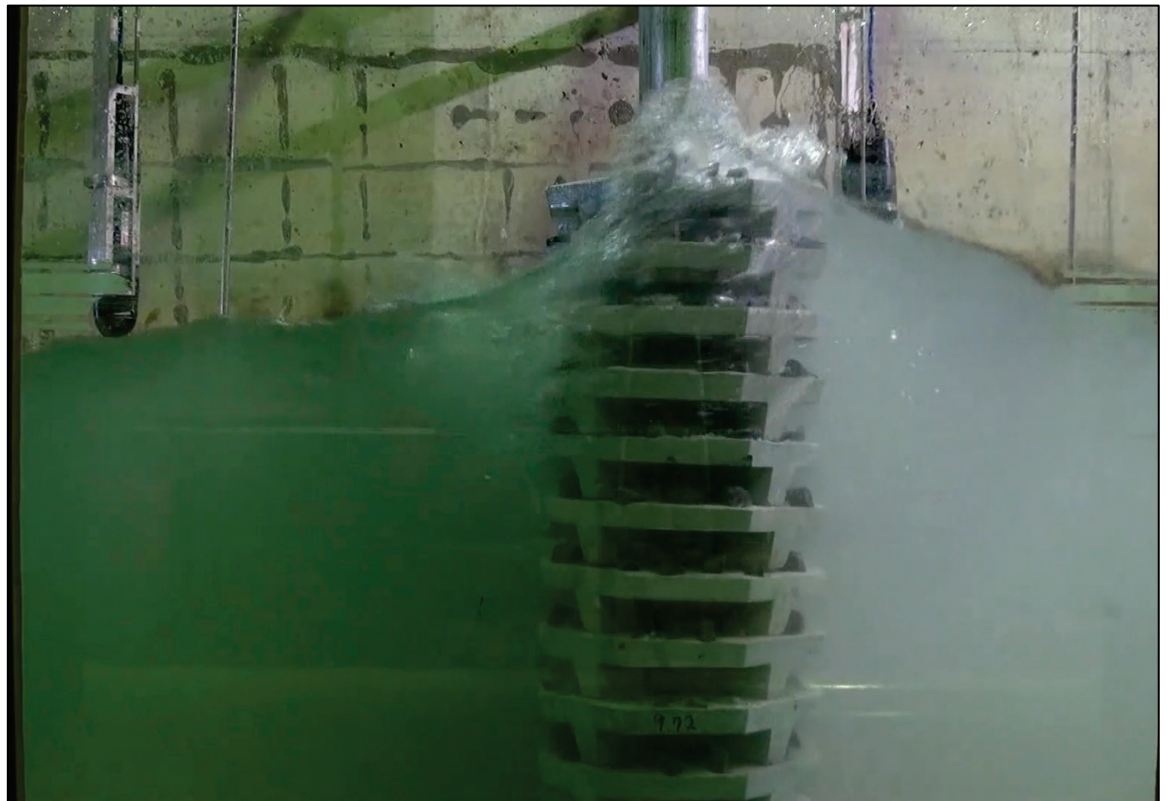


Walter Marine and Atlantic Reefmaker Wave Attenuator

Wave Transmission Testing Results

Duncan B. Bryant and Leigh A. Provost

February 2022



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Wave Transmission Testing Results

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Abstract

As part of a testing service agreement with Walter Marine and Atlantic Reefmaker, a 1:5.2 physical model of the Reefmaker Wave Attenuator was constructed and tested by the US Army Engineer Research and Development Center to evaluate its influence on wave attenuation. The tested prototype wave periods ranged from 2.5 to 8 sec with prototype wave heights between 1 ft and 6.5 ft. The Reefmaker Wave Attenuator included orthogonal and square designs and was tested under a variety of configurations including a suspended configuration, a bed-mounted configuration, and a rotated configuration. Testing demonstrated that depending on configurations and wavelength, the wave transmission coefficients ranged from 0.29 to 0.70. The most improvement, however, was demonstrated when testing the square unit designs with transmission coefficients, k_t , below 0.51. The smallest k_t of 0.29 occurred during square unit testing, which consisted of eight bed-mounted, square Ecosystem disks plus a base unit (24.05 in. freeboard) and with a wave period of 3.0 sec and height of 0.84 ft. Of all 134 tests performed, including the suspended case, the average transmission through the structure was 58%.

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Preface

This study was conducted for Walter Marine and Atlantic Reefmaker under a testing service agreement; MIPR TSA-2020-CHL-3681.

The work was performed by the Coastal Processes Branch of the Flood and Storm Protection Division, US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL). At the time of publication of this report, Mr. Victor Gonzales Nieves was chief, Coastal Processes Branch; Dr. Cary A. Talbot was chief, Flood and Coastal Protection Division; and Dr. Julie D. Rosati, was the technical director for Flood Risk Management. The deputy director of ERDC-CHL was Mr. Keith Flowers, and the director was Dr. Ty V. Wamsley.

COL Teresa A. Schlosser was the commander of ERDC, and the director was Dr. David W. Pittman.

1 Introduction

Walter Marine and Atlantic Reefmaker entered into a testing service agreement with the US Army Engineer Research and Development Center (ERDC) to perform wave transmission experimental testing on a novel wave attenuator product. This testing was meant to evaluate the reduction in wave height provided by the Reefmaker Ecosystems Wave Attenuator structure using a physical model.

1.1 Background

Walter Marine and Atlantic Reefmaker have developed a novel, pile-driven-based wave attenuation product for estuarine and off-shore environments. Conventional wave breakers and marsh sills are typically rubble mound structures that create a barrier to flushing, affecting sediment transport and water quality. With this novel system, piles are driven into the sediment to a specified depth and spacing; then, concrete units, cast with a 4,500 psi* composite strength marine mix, are placed onto the piles and supported by a composite clamp on or above the substrate material. This design eliminates the need for excessive fill material typical of rubble mound structures as well as eliminates the need to source material locally. Figure 1 is a photograph of an open water installation in North Carolina. Figure 2 is a photograph of a coastal marsh and wetland application as a sill construction replacement.

1.2 Objective

The objective of the study was to measure and document the performance of the Ecosystem Wave Attenuator to reduce wave energy in estuarine environments. This was accomplished using scale-model testing at the ERDC Coastal and Hydraulics Laboratory (CHL).

* For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248-52, <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

Figure 1. Section of Ecosystem Wave Attenuator installed on sound side of the Outer Banks.



1.3 Approach

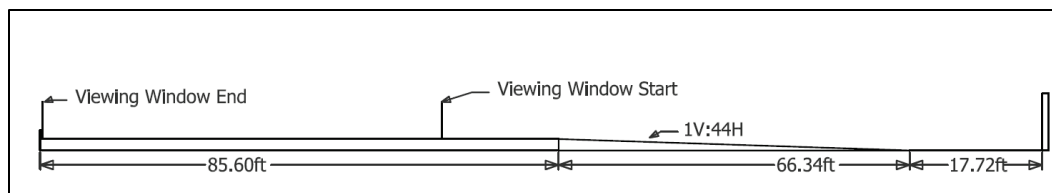
A scaled physical model flume study was conducted to measure the wave reflection and wave transmission of the Ecosystem Wave Attenuator in estuarine conditions. Estuarine conditions for this study were characterized by wave heights between 1 and 6.5 ft and wave periods of 2.5 to 8 sec. This range covers the reasonable wave conditions in most estuaries. Given the approximate size of the units, the capabilities of the ERDC-CHL wave machines in the 5 ft flume, and model constructability, a scale of 1 to 5.2 was used. This resulted in model concrete unit widths of approximately 11.24 in., with an average weight of 9.1 lb, model wave periods between 1.1 and 3.5 sec, and model wave heights between 0.16 and 0.93 ft. The allowable height of the structure design is dependent on the design wave condition, which provides a resulting load on the pile structure.

2 Description of Experiments

2.1 Testing facility

Testing was performed at the ERDC-CHL 5 ft flume facility. The flume is approximately 207 ft long, 5 ft deep, and 5 ft wide and is equipped with a computer-controlled, electro-hydraulic, piston wave generator. This flume can produce both monochromatic and spectral wave conditions with periods between 0.75 to 10 sec and a maximum wave height of 1.5 ft. The flume is also equipped with glass-paned viewing windows to allow for testing observation. Figure 3 represents a two-dimensional section view diagram of the 5 ft flume, not drawn to scale.

Figure 3. A 5 ft flume diagram (not to scale).



The Ecosystem Wave Attenuator has two main design components, the base disk and the Ecosystem disk. The base disk is placed first on a driven pile and sits on the sediment bed. The required number of Ecosystem disks stack on top of the base disk. The number of Ecosystem disks subsequently stacked is dependent on the water depth at the location and the application of wave attenuator. The freeboard, or height above the still water level, is also an important parameter. This desired freeboard is a function of the tidal range, regulations on structure heights, and as documented in this report, the desired wave attenuation. The Ecosystem disks are then held in place by a clamping system. For the purpose of this study, two Ecosystem disk designs were tested: octagonal units and square units at a 1:5.2 scale.

The prototype dimensions of the octagonal Ecosystem disk are provided in Figure 4 and Figure 5. The octagonal Ecosystem disk is 58 in. by 58 in. with a circular hole in the middle allowing it to fit over a 12.25 in. diameter pile. The disk has a maximum height of 12.50 in. The disks are designed to allow water to pass between units. Each unit has a solid top section that is 5.0 in. supported by legs or *paddles* that are 7.5 in. (Figure 5). The paddles

are tapered from 16.5 in. at the top to 11.75 in. at the bottom over the 7.5 in. height. Though not shown, the disk can be made with or without aggregate placed on the top disk. For this study, simulated sorted rip rap with a size between 3.9 and 5.2 in. was used to replicate the specified 4 to 6 in. aggregate this is typically incorporated into the units when manufactured. Other geometric details that can be seen in the drawings provided by the sponsors. The octagonal Ecosystem disk will be referred to as the *octagonal disk* moving forward.

The square Ecosystem disks have the same height as the octagonal design and are 57.5 in. \times 57.5 in. square. The paddles are extended and set along the diagonal. This allows for a greater blockage area. The square Ecosystem disks are also designed with a top disk with four paddles. The top disk is square in shape with a height of 5 in. Centered on the top deck is a 12.25 in. cylindrical hole for units to slide over the pre-installed pile. Below the top deck are the four paddles that are tapered in length from 20.375 in. at the top to 18.5 in. at the bottom over the 7.5 in. height. The square Ecosystem disk will be referred to as the *square disk* moving forward. Last, the base disk has the same octagonal geometry as the octagonal disk, but instead of paddles, the unit is solid over the height of 12.5 in.

Figure 4. Prototype octagonal Ecosystem disk drawing in inches – plan view.

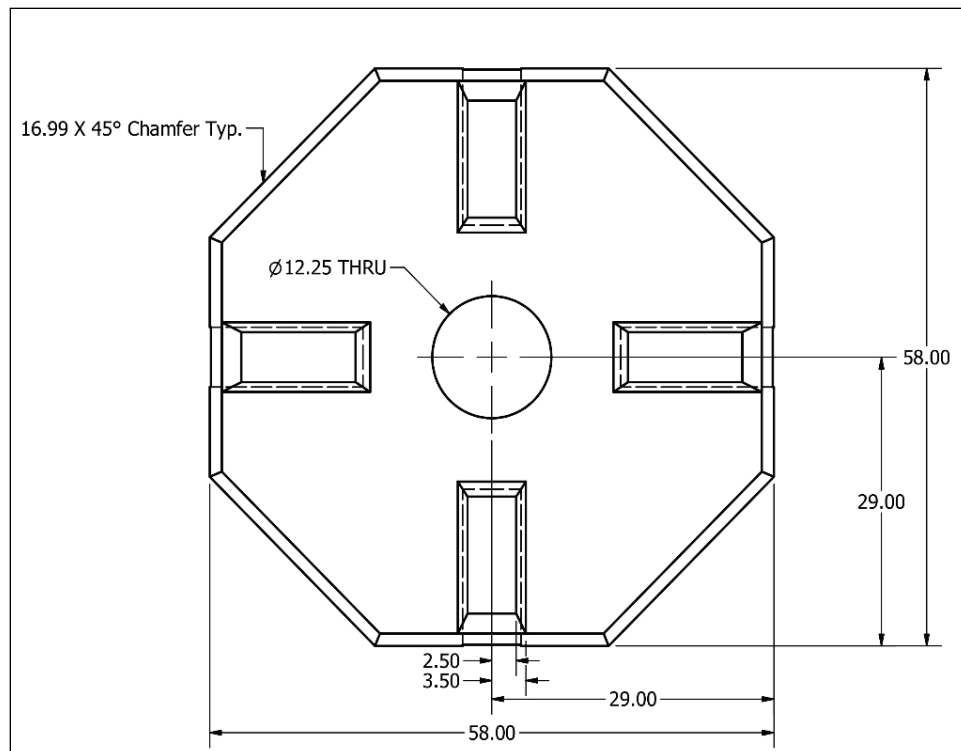
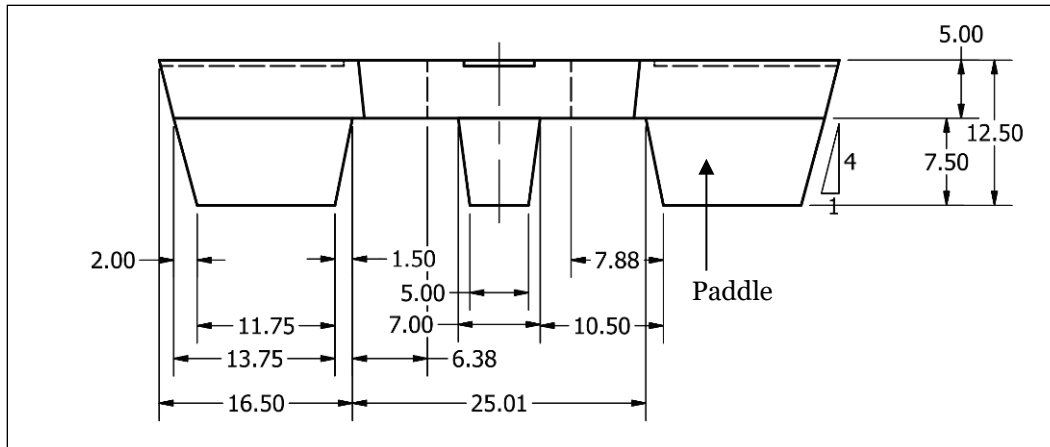


Figure 5. Prototype octagonal Ecosystem disk drawing in inches – section view.



2.3 Model design

Prototype designs as well as hydrodynamic conditions were scaled to a 1:5.2 scale based on Froude scaling parameters. The Froude number is the ratio of fluid inertia to the gravitational field and the dominant parameter to accurately represent the interaction of surface gravity waves with coastal structures (Hughes 1993). Table 1 displays the Froude scaling relationships of standard properties. Another key parameter is the Reynolds number. Models with a low Reynolds number could have dramatic scale effects as the model is laminar and the prototype is fully turbulent. For rubble mound structures the Reynolds number, Re_D , is often defined as

$$Re_D = \frac{\sqrt{gH_s}D_n}{\nu} \quad (1)$$

where g is the gravitational acceleration, H_s , is the significant wave height, D_n , is the diameter of the armor units and ν is the kinematic viscosity of water. Substituting the diameter of the model disk for D_n , and the smallest model significant wave height, the Re is greater than 30,000, a targeted minimum for this type of testing (Wolters et al. 2007). Finally, the surface tension forces, characterized with the Weber number, are negligible due to the model depth and wave periods.

Table 1. Froude scaling parameters.

Properties	Scaling
Length	λ
Mass	λ^3
Velocity	$\lambda^{1/2}$
Time	$\lambda^{1/2}$

The intent of this model was not to replicate the stability or function of the design to resist damage or movement from waves but only to measure and document the performance of the design to reduce wave energy in an estuarine environment. Given this, the actual method of driving piles was not replicated. Instead, the piles were designed out of standard steel hardware. Five mounting plates with a threaded female coupler were machined and mounted across the flume to the base of the bed. A 2 in. galvanized steel pipe, which has an outer diameter of 2.375 in., was then threaded into the coupler for use as the piles. The piles were centered 138 ft from the wave machine. These mounting plates and model piles are shown in Figure 6.

Figure 6. Mounting plates and pipe installation in flume.



2.3.1 Model disk

Scaled concrete disks were cast from custom three-dimensional (3D)-printed molds, printed with ABS* material. Type S mortar mix with construction sand was used to cast the molds along with reinforcement wire. Gravel stones between 0.75 in. and 1 in. were placed in the concrete units to mimic the rip-rap material that is typically included in the prototype design for the octagonal and square disk.

Base disks were constructed of concrete and wood. When the base disk was set on the flume bottom, the wood-constructed units were used. This allowed for special consideration for the pile mounting hardware to be accounted for. The base disks fit over the couplers and anchor bolts, hiding them entirely and sitting flush on the concrete floor. A custom snug fit for each base disk was ensured such that the base disk would not float up.

* Acrylonitrile butadiene styrene: a common thermoplastic polymer.

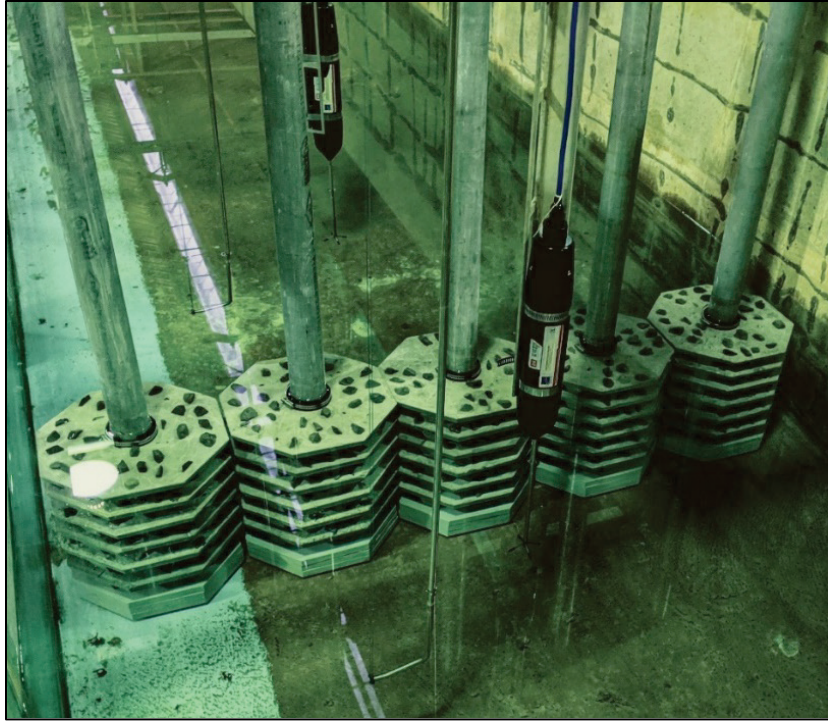
when submerged. The base disk was placed on the piles first, followed by varying numbers of the orthogonal or square disks.

The model octagonal disks were scaled using the chosen scale of 5.2. This scaling resulted in a unit with a solid top deck 11.15 in. \times 11.15 in. and a total height of 2.4 in. An image of the mold itself is shown in Figure 7, and the installed model orthogonal disk units can be seen in Figure 8. Model disks were clamped in place using a rubber seal and hose clamp. Images demonstrating this arrangement in the flume are shown in the following sections.

Figure 7. Model scale (1:5.2) octagonal disk mold.



Figure 8. Model (1:5.2) wave attenuator in flume.



The square units were created utilizing an altered version of the original 3D-printed molds. Figure 9 shows an image of the mold utilized to create the model square units. The units were 11.15 in. \times 11.15 in. and had a total height of 2.4 in. The paddles of the model unit extend to the center pile with 0.5 in. of clearance between. A comparison between the two designs, square and octagonal, shows that they are very similar. The primary difference is the top disk shape, which allows for a larger paddle size on the square disk.

Figure 9. Model square disk mold.



A top view of a square disk model is provided in Figure 10, which shows the aggregate that was placed to match the prototype. Last, Figure 11 shows a picture of the installed model square disk.

Figure 10. Square disk model top view.



Figure 11. Square disks installed in flume.



The suspended wave attenuator test used the same clamping method under the base disks used for the other test on top to keep the units approximately 7 in. above the flume bed. At the prototype scale, this is 3 ft above the seabed. Figure 12 shows the suspended testing arrangement with a base unit and four octagonal disks.

Figure 12. Model wave attenuator in flume with suspended units.



2.3.2 Model attributes

The octagonal disks weighed an average of 9.12 lb. The weight of the disk was not relevant for this study because the structural stability was not being tested. Each octagonal disk had a volume of approximately 114 in³. With the octagonal disks in the typical configuration with the support legs, paddles, being turned at a 45° to the wave propagation direction as shown in Figures 8 and 9, the model projected area was 20 in². Testing was also conducted with the octagonal disk turned with the support legs 90° or orthogonal to the wave propagation direction. This resulted in a model projected area of 18.5 in². The concrete model base disk weighed an average of 16.94 lb, with a model volume of 223 in³. and a model projected area of 25.74 in².

The square disk, which is only configured with the paddles being turned at 45° to the wave propagation direction, had a model volume of 143 in³.

25% greater than the octagonal disk. The square disk had a model projected area of approximately 21.8 in².

Porosity of the structure is a critical consideration for breakwater performance. The flume is 5 ft wide with a constant model still water depth of 1.5 ft, and the models are 0.94 ft in length. Given these dimensions, the control volume is 7.05 ft³. The octagonal disk configured with a base disk and six octagonal disks, which results in a structure height equivalent to the water surface, has a porosity of 59%. Additional units above the still water unit or turning the units does not change the porosity. An equivalent square disk configuration, a base disk and six square disks, has a porosity of 52%. The suspended octagonal disk configuration has a porosity of 73%.

Finally, the blockage area percentage can be calculated for each configuration. All bed-mounted tests had a structure elevation equivalent to the still water level (SWL), which consisted of six octagonal or square units and a base unit. The octagonal disk with the piles had a 77% area blockage. Turning the units 45° resulted in a reduced blockage area percentage of 68%. The square units including the piles blocked 82% of the projected area, and the suspended octagonal disk configuration blocked 52% of the area.

2.4 Hydrodynamic conditions

Wave conditions for the purpose of this study were designed to target estuarine conditions. For these experiments, both spectral and monochromatic conditions were run. Monochromatic waves, or regular waves, are defined as having one singular frequency whereas irregular conditions contain a variety of frequencies, phases, and amplitudes that better represent real-world sea surface conditions (Dean and Dalrymple 1991). A Texel, Marsen, and Arsløe (Hughes 1984) spectra was used for generation of the spectral conditions given that locally generated wind waves are typical of estuarine environments. Table 2 lists the spectral conditions at both the prototype and model scale while Table 3 lists the monochromatic conditions. Both tables are representative of the target wave height (H) and period (T). Each irregular and regular wave condition was run at a model depth of 1.5 ft and for a duration of 20 min to ensure a total number of waves greater than 300. Irregular conditions ranged from a model period of 1.1 sec to 1.8 sec with wave heights of 0.2 ft (2.4 in.) and 0.6 ft (7.2 in). The same conditions were run as regular waves, with

additional wave periods up to 3.5 seconds and wave heights up to 0.8 ft (9.6 in.). Both the irregular and monochromatic wave conditions had a variation in wave period and wave height. This selection of testing cases was intended to allow for the determination of variables that had the greatest impact on the wave transmission. The greatest prototype wave height possible for the water depth was tested using a monochromatic wave height of 4.8 ft at prototype wave period of 5 and 5.9 sec.

Table 2. Target irregular wave conditions.

Prototype Scale			Model Scale		
Wave Period (sec)	Wave Height (ft)	Water Depth (ft)	Wave Period (sec)	Wave Height (ft)	Water Depth (ft)
2.5	0.98	7.74	1.1	0.2	1.50
3	0.98	7.74	1.3	0.2	1.50
3	1.64	7.74	1.3	0.3	1.50
4	1.64	7.74	1.8	0.3	1.50
4	2.30	7.74	1.8	0.4	1.50
4	3.28	7.74	1.8	0.6	1.50

Table 3. Target monochromatic wave conditions.

Prototype Scale			Model Scale		
Wave Period (sec)	Wave Height (ft)	Water Depth (ft)	Wave Period (sec)	Wave Height (ft)	Water Depth (ft)
2.5	1.1	7.74	1.1	0.22	1.50
3	0.95	7.74	1.3	0.18	1.50
3	1.6	7.74	1.3	0.30	1.50
4	2.1	7.74	1.8	0.40	1.50
4	3.0	7.74	1.8	0.58	1.50
4	4.4	7.74	1.8	0.84	1.50
5	4.6	7.74	2.2	0.90	1.50
5	4.7	7.74	2.2	0.91	1.50
5	4.8	7.74	2.2	0.93	1.50
5.9	4.8	7.74	2.6	0.93	1.50
7.9	4.7	7.74	3.5	0.91	1.50

2.5 Instrumentation

A total of 10, single-wire, 1 m, Akamina AWP-24-3* capacitance wave gauges were used to measure wave height. The capacitance wave gauges provide a varying voltage depending on the instantaneous water level due to changes in the capacitance. These measurements were translated to wave heights using calibration data. Calibration results are found in Appendix A. During the calibration, voltage measurements were taken at five locations along each gauge. Recorded voltage data and depth are then fit to a line of best fit. The calibration was performed so that the coefficient of determination, R^2 , value for each gauge was 1. A coefficient of determination of 1 means the linear fit perfectly fits the data. The voltage was converted from analog to digital using an NI 9202 module and transmitted to a computer for recording by an NI 9184 compact data acquisition chassis. A custom LabVIEW program recorded the voltages.

Eight of the ten gauges were fixed in two Goda arrays (Goda and Suzuki 1976), one array incident to the wave attenuator and one behind the wave attenuator incident to the flume beach. The seaward (towards the wave generator) Goda array had gauges positioned 29.58, 28.60, 26.63, and 22.69 ft from the center of the model piles. The landward (towards the beach) Goda array had gauges positioned 17.33, 18.32, 20.29, and 24.22 ft from the center of the model piles. One gauge was placed 21.5 in. incident to the structure and a second gauge was placed the same distance behind. Wave gauge data were collected at 60 Hz for 1,300 sec for each test to ensure the final wave for each condition was propagated down the length of the flume and was recorded.

* Details on Akamina wave gauge calibration can be found in the Akamina AWP-24-3 User Manual (Akamina 2018).

3 Experimental Procedure and Analysis

Seven different configurations of the wave attenuator were tested for the octagonal disk designs. Five bed-mounted configurations were used that consisted of six to ten disk units and one base unit per pile. The suspended configuration used four octagonal disks and one base unit per pile. A seventh configuration was tested in which the octagonal disks were rotated 45°, which resulted in the paddles being 90° to the wave propagation direction. For the square disk design, a configuration of eight square units plus a base was tested, with the support legs being set at the standard 45° to the wave propagation direction (Figure 11) and compared to its respective configuration utilizing the octagonal design. This resulted in a total of 134 tests. Testing was conducted from June 2020 until January 2021.

Each wave condition was run on the structure for 20 min with data recording starting at the start of wave propagation and lasting 21 min. Video of the structure was recorded during each permutation. Following each test, the basin was stilled before running the next wave condition. The water depth was maintained at 1.5 ft.

3.1 Wave height analysis

Data analysis was performed on the time-series wave data. For each wave condition, a Fast Fourier Transform (FFT) was performed on the signal. The FFT converts a signal into a frequency domain to produce the wave spectral energy density ($S(f)$). The zero-moment wave height was calculated based on the following relationship:

$$H = 4 \sqrt{\sum_{j=1}^n S(f)_j \Delta f} \quad (2)$$

where

n = number of frequency components
 Δf = frequency resolution (hertz).

3.2 Reflection analysis

A reflection analysis was conducted to accurately determine the wave height used for the transmission analysis. It was expected that reflection off the flume beach and the structure would lead to larger total wave heights since

waves moving toward the structure and those moving away are interacting. The reflection coefficient, k_r , is the ratio of the reflected wave height to the incident wave height and was calculated using the Goda array incidental to the wave attenuator. This reflection analysis was performed following methods outlined by Goda and Suzuki (1976).

3.3 Transmission analysis

Wave transmission is used to determine the effectiveness of the wave attenuator; wave transmission was calculated based on the transmitted wave height and the incidental wave height. The transmission coefficient (k_t) defines the ratio of the incidental wave height to the transmitted height through the structure. If $k_t = 1$, then 100% of the incident wave height was transmitted through the structure. This relationship is shown below in Equation 3 (Dean and Dalrymple 1991):

$$k_t = \frac{H_t}{H_i} \quad (3)$$

where

- k_t = transmission coefficient
- H_t = transmitted wave height
- H_i = incidental wave height.

Additional analysis was required to develop an equation that accurately represents the wave transmission, to account for the flume hydrodynamics. The incidental wave is transmitted through the structure, and there is some reflection off the flume's dissipative beach (k_{rb}). Some of that energy can be reflected off the leeside of the structure (k_{rs}) and back toward the beach. This wave interaction between the beach and structure continues throughout testing. Thus, the measured wave (H_{meas}) propagating from the structure to the beach can be represented as a power series as

$$H_{meas} = \sum_{n=0}^{\infty} H_t k_{rcomb}^n = H_t + H_t k_{rcomb} + H_t k_{rcomb}^2 + H_t k_{rcomb}^3 + \dots (3)$$

where

- H_t = wave height transmitted through the structure
- k_{rs} = reflection coefficient of structure
- k_{rb} = reflection coefficient of beach
- $k_{rcomb} = k_{rb} * k_{rs}$.

Integrating this power series and solving for the wave transmitted through the structure yields the equation

$$H_{t_corrected} = \frac{H_{meas}}{\left(\frac{1}{1-k_{rcomb}}\right)} \quad (4)$$

Therefore, Equation 3 can be re-written as

$$k_t = \frac{H_{t_corrected}}{H_i} \quad (5)$$

This transmission coefficient was calculated for each of the testing cases, bed-mounted, suspended, rotated, and square.

Due to oscillatory effects caused by significant wave reflection during short period events, the 2.5 sec (1.1 sec model scale) condition was processed via an alternative method. The transmission coefficient would be equal to 1 minus the reflection coefficient of the structure, or $k_t = 1 - k_{rs}$. This leads to an overestimation of the transmission coefficient as it assumes no friction loss through the breakwater.

4 Results/Discussion

The following sections provide testing results from both the spectral and monochromatic conditions. These results are reported based on the structure configuration during testing. Measured wave conditions from testing and transmission coefficients are presented. Raw k_t results from each test can be found in Appendix B.

4.1 Irregular conditions

Table 4 lists the measured wave heights from the experiment at model and prototype scale for the spectral conditions without any structure installed. These measurements have been corrected for the reflection off the dissipative beach and are the expected wave conditions that occur during testing of the structure.

Table 4. Measured spectral wave conditions.

Prototype Scale			Model Scale		
Peak Wave Period (sec)	Wave Height (ft)	Water Depth (ft)	Peak Wave Period (sec)	Wave Height (ft)	Water Depth (ft)
2.5	1.00	7.74	1.1	0.19	1.50
3.0	0.98	7.74	1.3	0.19	1.50
3.0	1.57	7.74	1.3	0.31	1.50
4.1	1.64	7.74	1.8	0.32	1.50
4.1	2.22	7.74	1.8	0.43	1.50
4.1	2.86	7.74	1.8	0.55	1.50

4.1.1 Bed-mounted case

Figures 13–15 represent the transmission coefficients calculated for the bed-mounted case. The colored dots represent each of the freeboard of each configuration, referenced to inches above the SWL. All results are presented at prototype scale. Figure 13 displays k_t results plotted against the peak wave period (a) and wavelength divided by the structure width (b).

Figure 13 (a) shows that most transmission through the structure occurs during longer wave periods while more attenuation is provided during shorter wave periods. A max k_t of roughly 0.58 is found for the peak period of 3.0 sec and 0.65 at 4.1 sec. The most attenuation was seen during the irregular waves with a peak period 2.5 sec and a wave height of 1.0 ft at

prototype scale. During this condition, the nine ecosystem unit configuration, 36.07 in. above the SWL, saw the most attenuation with a k_t of 0.43, or 43% of the wave height having been transmitted. These results demonstrate that the structure becomes less effective at attenuating or reflecting wave energy as the wave period increases. Subplot (b) provides the transmission coefficient given the ratio of the wavelength to the structure width. These results imply that a wider structure, such as multiple rows of disk, would further reduce the wave transmission.

The significant wave height is another variable that could impact the effectiveness to attenuate or reflect waves. Figure 14 and Figure 15 display the irregular wave results for the 3.0 sec conditions and 4.1 sec conditions respectively, compared to their respective wave heights. The results show that larger waves had a similar transmission values as the smaller waves. This suggests that the wave period or corresponding wavelength is the more important parameter.

Figure 13. k_t of all irregular wave conditions for bed-mounted case (prototype).

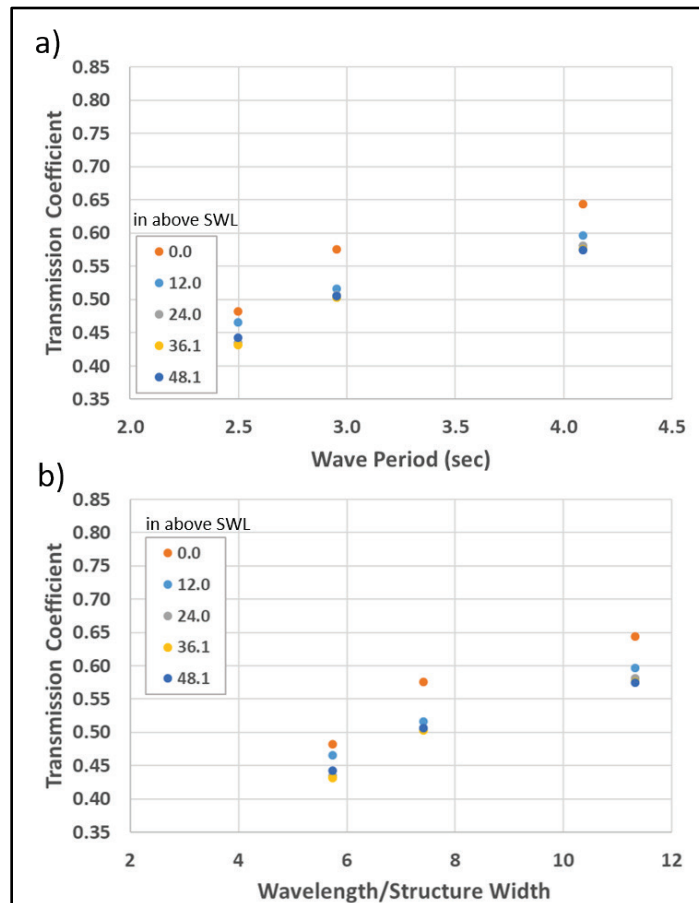


Figure 14. k_t of $T_p=3.0$ sec irregular wave conditions for bed mounted case (prototype).

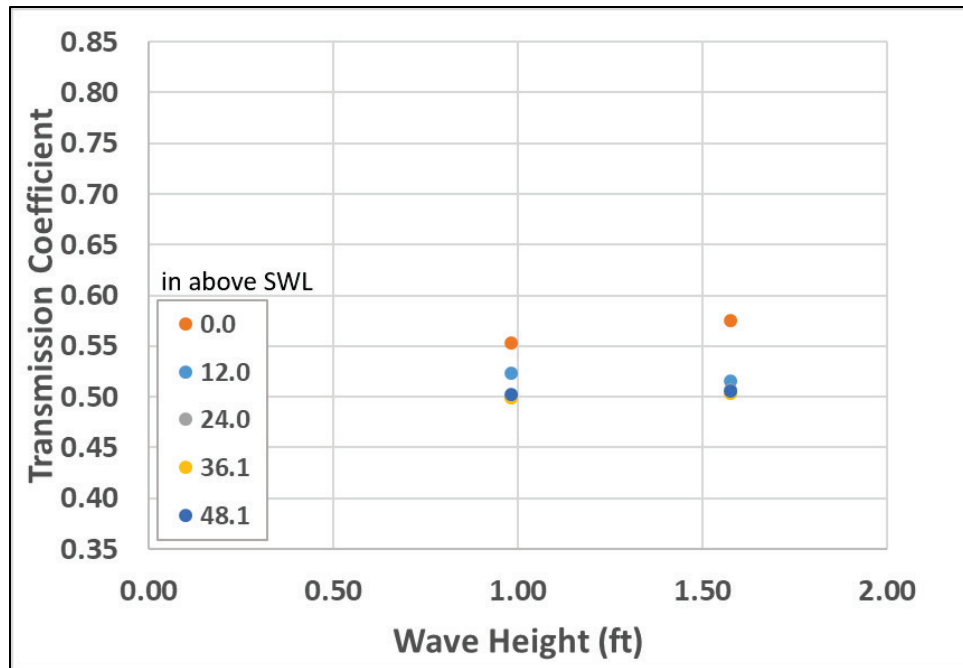
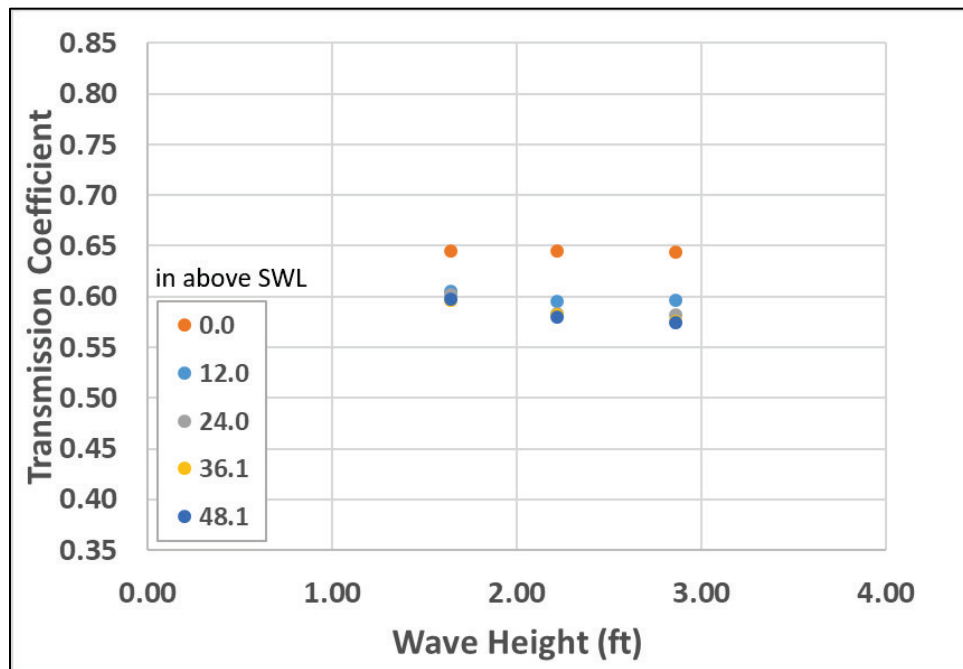


Figure 15. k_t of $T_p=4.1$ sec irregular wave conditions for bed mounted case (prototype).



The results demonstrate that there is a decrease in the transmission as more units are added above the SWL, increasing the freeboard. The reduction in transmission is not linear with the additional units. For example, the results demonstrate for the irregular waves tested that a freeboard above 24.05 in. did not offer significant additional reduction in

transmission. This may be attributed to the local water depth, which limits the size of the waves. Deeper installations that allow for greater water depth could see improved attenuation with a greater height above the still water level.

4.1.2 Suspended case

The suspended cases were tested as they offer much greater water exchange across the structure given a much higher porosity. Figures 16–18 display k_t results of the suspended configuration. The suspended configuration results are plotted alongside the equivalent crest height bed mounted case of 12 in. At the prototype scale, the base of the suspended arrangement is 3 ft above the seabed. Similar to the bed-mounted case, Figure 16 displays k_t results plotted against wave period while Figure 17 and Figure 18 display k_t results for the 3.0 sec conditions and 4.1 sec conditions plotted against their respective wave heights.

The suspended case results in k_t trends similar to the bed-mounted case, with more attenuation being for smaller wave periods. However, the suspended structure does not attenuate energy as effectively as the bed-mounted case. On average, this difference in attenuation is approximately 7% among all spectral-suspended vs. bed-mounted tests and is most likely caused by the difference in blockage area and porosity provided by the structure.

Figure 16. k_t of irregular waves for suspended case compared to equivalent bed-mounted case (prototype).

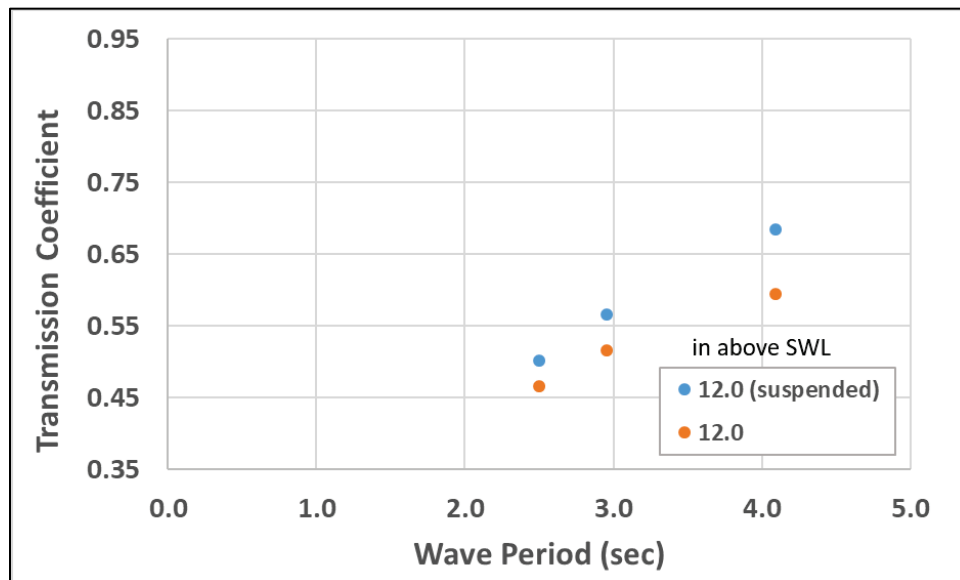


Figure 17. k_t of $T_p=3.0$ sec irregular wave conditions for suspended case compared to equivalent bed-mounted case (prototype).

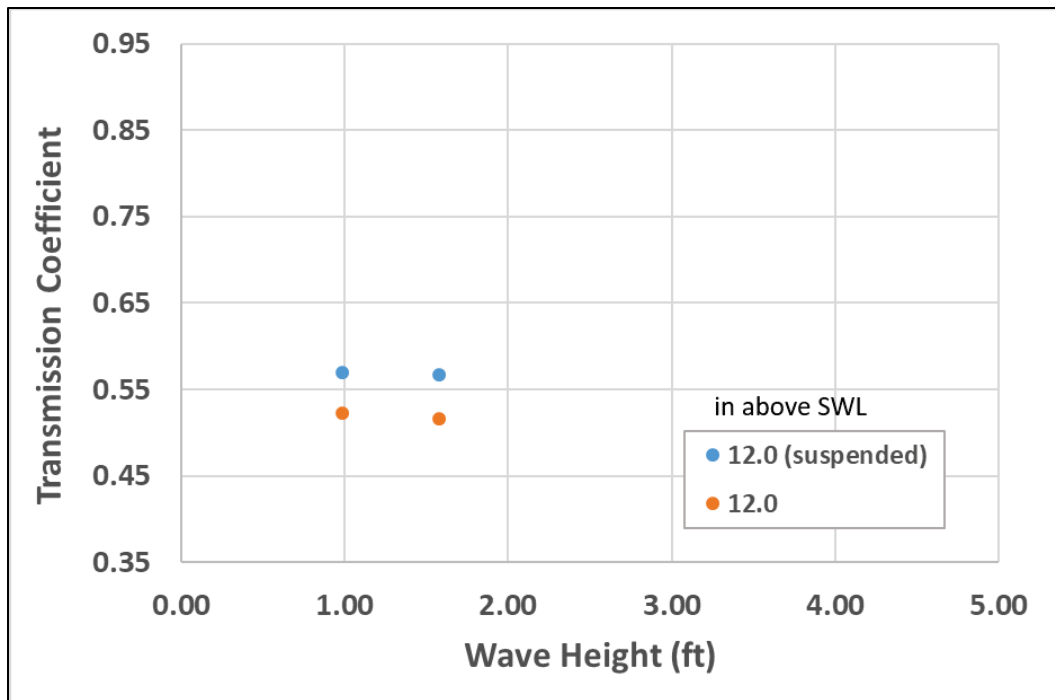
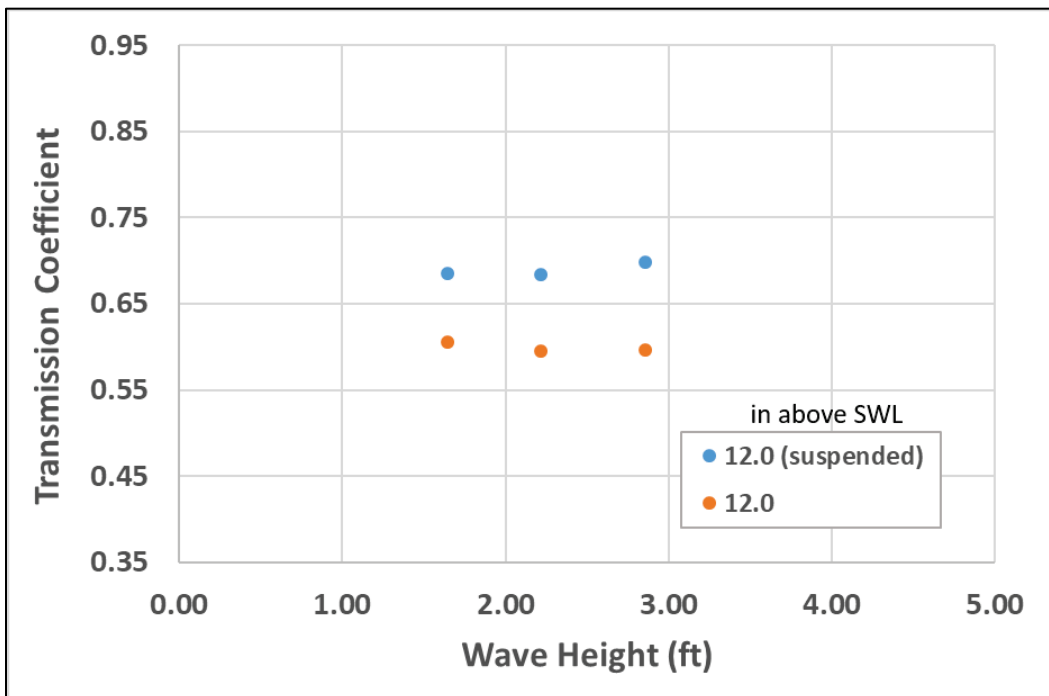


Figure 18. k_t of $T=4.1$ sec irregular wave conditions for suspended case compared to equivalent bed-mounted case (prototype).



4.1.3 Rotated case

Figures 19–21 show k_t results for the rotated case, where the units were bed mounted and rotated 45° from the previously presented bed-mounted orientation. This case was performed with the configuration of 10 Ecosystem disks since this was the maximum number of disks tested for the bed-mounted case. These results were compared to the equivalent 10-disk, bed-mounted case.

Like the case in the bed-mounted and suspended configurations, the rotated case showed an increase in k_t with wavelength. Under all but one condition, the rotated configuration shows a slight improvement in wave attenuation compared to the original orientation.

Figure 19. k_t of irregular waves for rotated case compared to equivalent bed-mounted case (prototype).

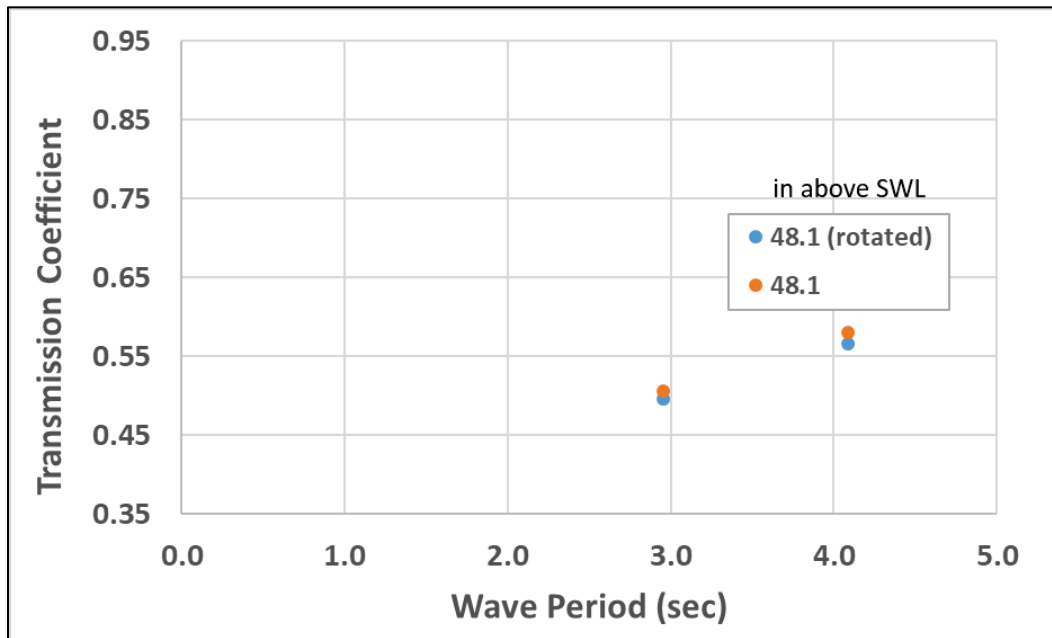


Figure 20. k_r of $T_p=3.0$ sec irregular wave conditions for rotated case compared to equivalent bed-mounted case (prototype).

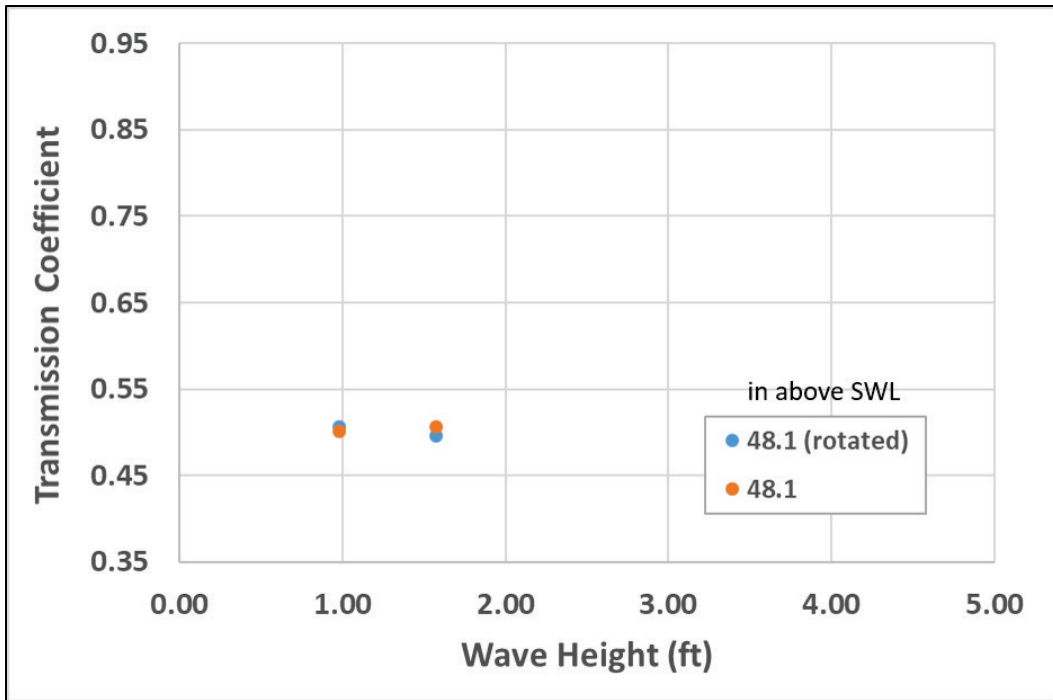
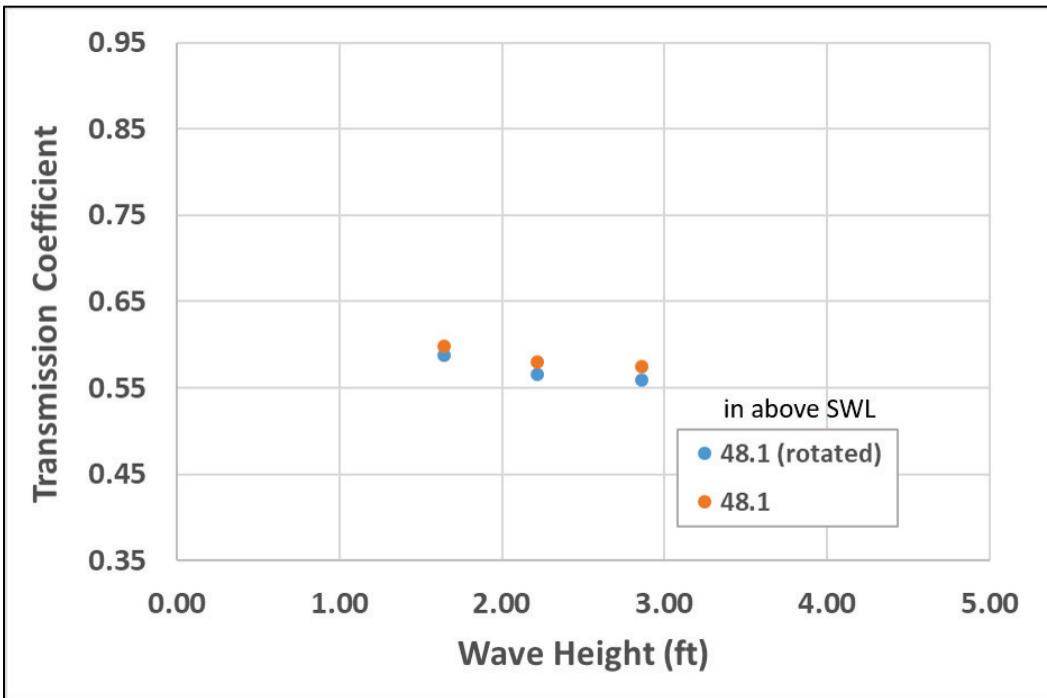


Figure 21. k_r of $T=4.1$ sec irregular wave conditions for rotated case compared to equivalent bed-mounted case (prototype).



4.1.4 Square unit case

Figures 22-24 show k_t results for the square unit comparison. For this case, a crest height 24 in. above SWL was used, which is eight square units and one base unit.

The square disks provide an increase in attenuation for all irregular wave conditions when compared to its equivalent octagonal disks. The smallest transmission coefficient seen during the spectral conditions was a k_t of approximately 0.32 (Figure 22) during the 2.5 sec period, or a 68% reduction in wave height. For all spectral conditions, the average k_t for the square units was 0.40, a reduction from an average k_t of 0.53 for the octagonal units.

Figure 22. k_t of irregular wave conditions for square disk compared to equivalent octagonal disk (prototype).

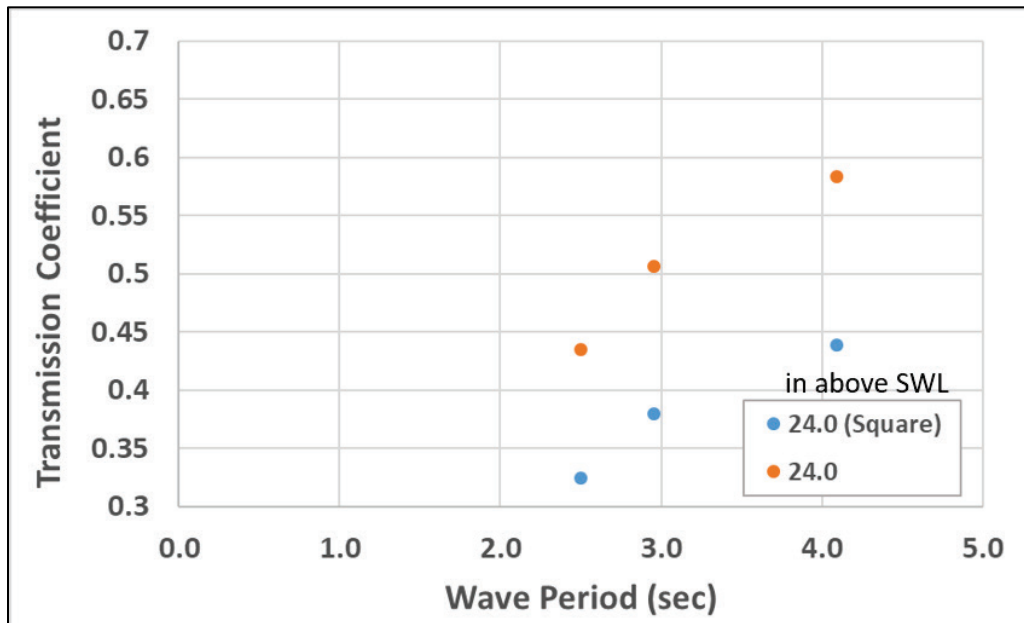


Figure 23. k_t of $T_p=3.0$ sec irregular wave conditions for square disk compared to equivalent octagonal disk case (prototype).

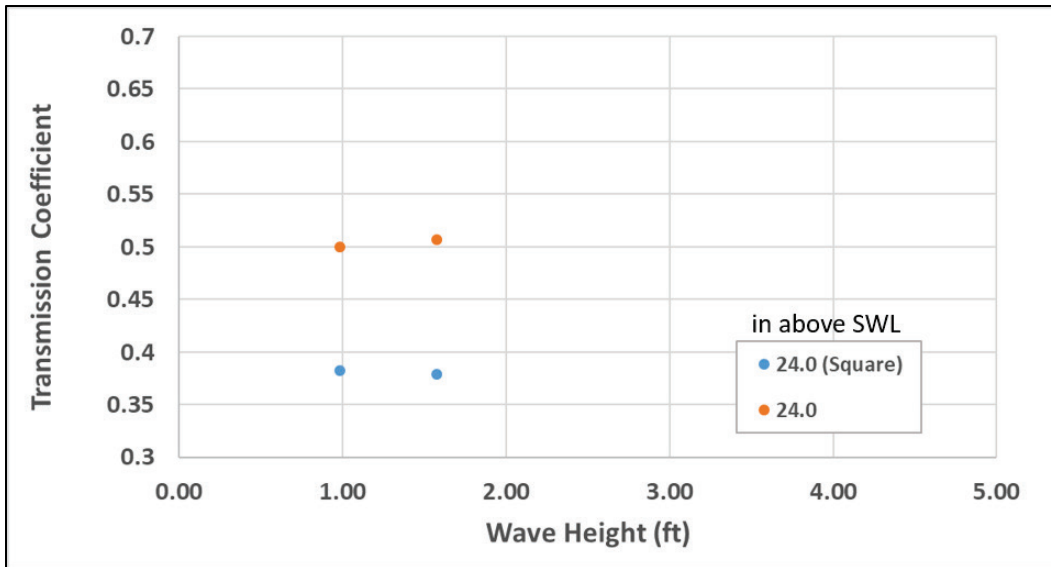
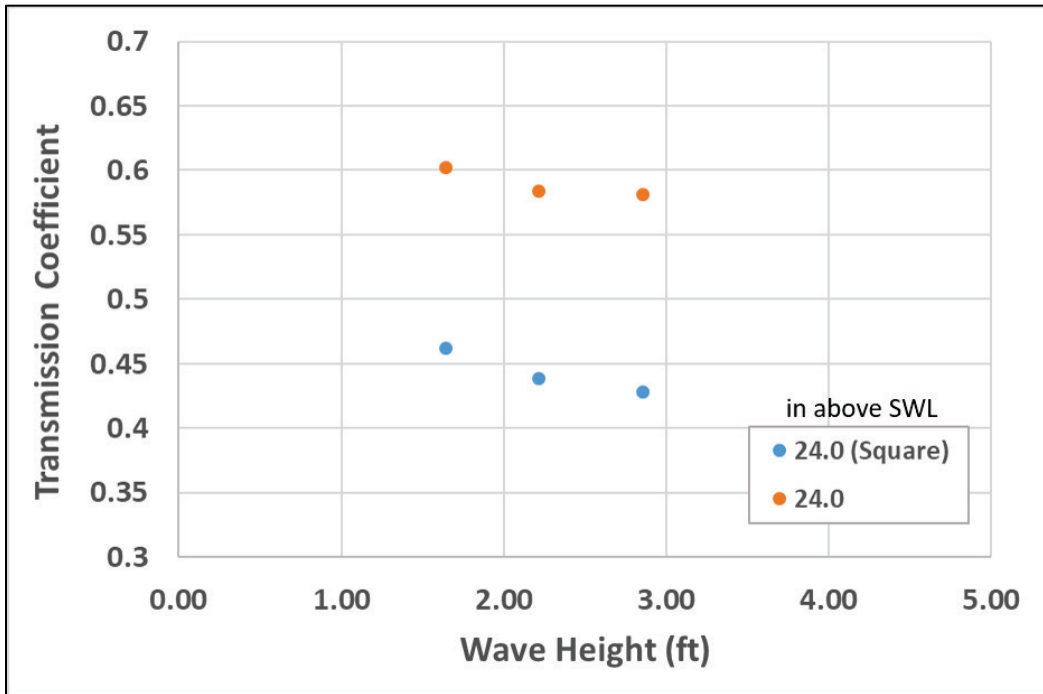


Figure 24. k_t of $T_p=4.1$ sec irregular wave conditions for square disk compared to equivalent octagonal disk case (prototype).



4.2 Monochromatic conditions

Table 5 lists the measured wave heights from the experiment at model and prototype scale for the monochromatic conditions.

Table 5. Measured monochromatic wave conditions.

Prototype Scale			Model Scale		
Wave Period (sec)	Wave Height (ft)	Water Depth (ft)	Wave Period (s)	Wave Height (ft)	Water Depth (ft)
2.5	1.20	7.74	1.1	0.23	1.50
3.0	0.84	7.74	1.3	0.16	1.50
3.0	1.40	7.74	1.3	0.27	1.50
4.1	1.64	7.74	1.8	0.32	1.50
4.1	2.30	7.74	1.8	0.45	1.50
4.1	3.43	7.74	1.8	0.67	1.50
5.0	3.23	7.74	2.2	0.63	1.50
5.0	3.89	7.74	2.2	0.75	1.50
5.0	4.06	7.74	2.2	0.79	1.50
5.9	4.93	7.74	2.6	0.96	1.50
8.0	4.30	7.74	3.5	0.83	1.50

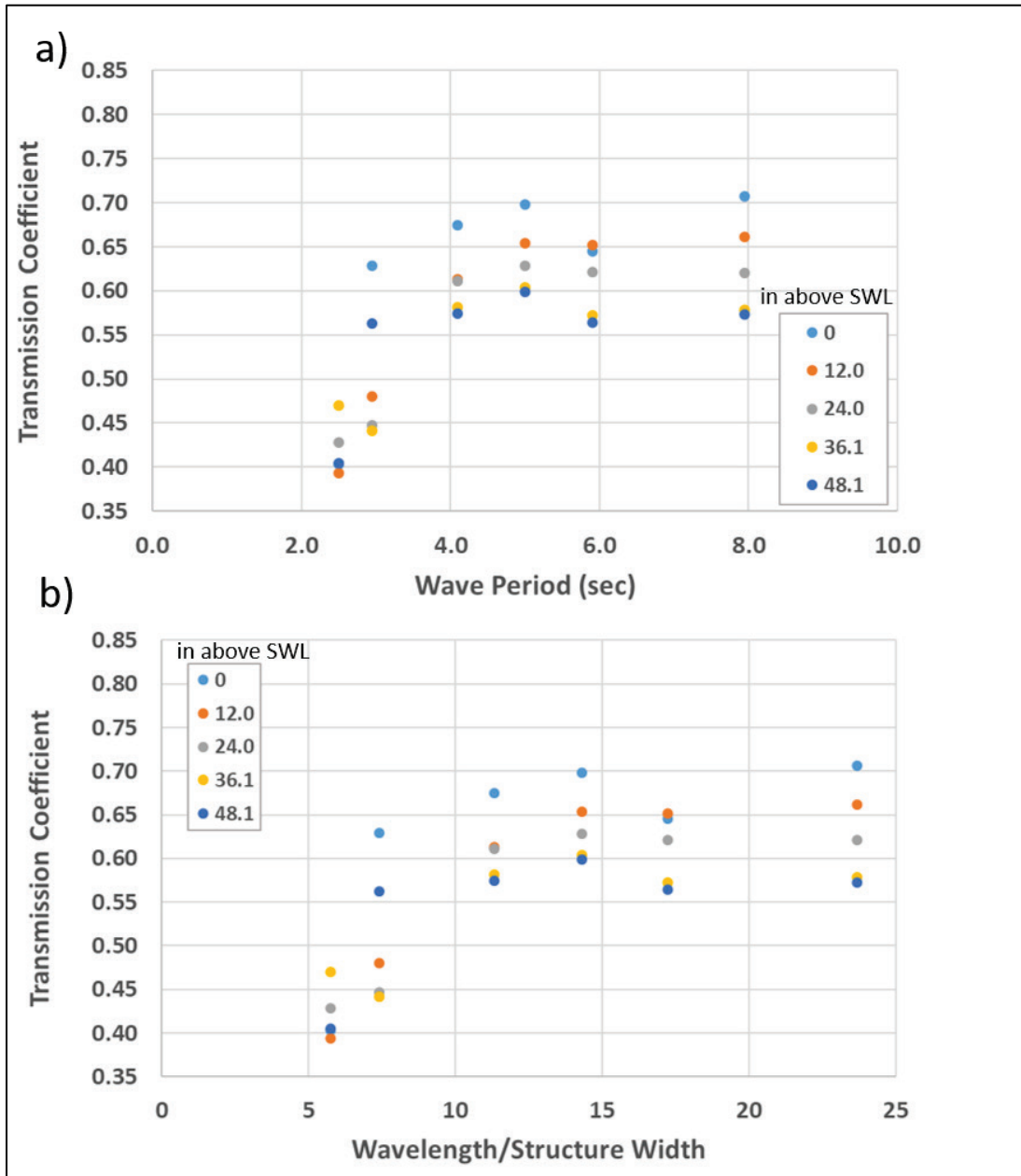
4.2.1 Bed-mounted case

Figures 25–27 show the transmission coefficients calculated for the bed-mounted case. The colored dots represent each of the structure height configurations, referenced to inches above the SWL. All results are presented at prototype scale. Figure 25 displays k_t results plotted against the peak wave period (a) and wavelength divided by the structure width (b). Figure 26 and Figure 27 display all results for the 4.1 sec conditions and 5.0 sec conditions, respectively, compared to their respective wave heights.

The most attenuation was provided during the 2.5 sec monochromatic wave, with a wave height of 1.20 ft. During this condition, a structure height or freeboard of 12.02 in. above the SWL performed best with a k_t of 0.39. This translates to 39% of the wave being transmitted through the structure. The results show some scatter in the response of the structure at smaller period or shorter wavelengths. However, at wave periods above 4 sec, the results are much more consistent. The lower structure consistently attenuates less wave energy, with increased attenuation with

greater height. Like the irregular wave testing, this response is not linear, with the 36 and 48 in. structure height performing very similarly. Below 4.0 sec, the results are more difficult to interpret.

Figure 25. k_t of all monochromatic wave conditions for bed-mounted case (prototype) for peak wave period (a) and wavelength divided by structure width (b).



The structure performance increased with larger waves as shown Figure 26 and Figure 27. This trend was not as clear for irregular wave testing. These results can possibly be attributed to greater turbulence generation and energy dissipation.

Figure 26. k_t for T=4.1 sec monochromatic wave conditions for bed-mounted case (prototype).

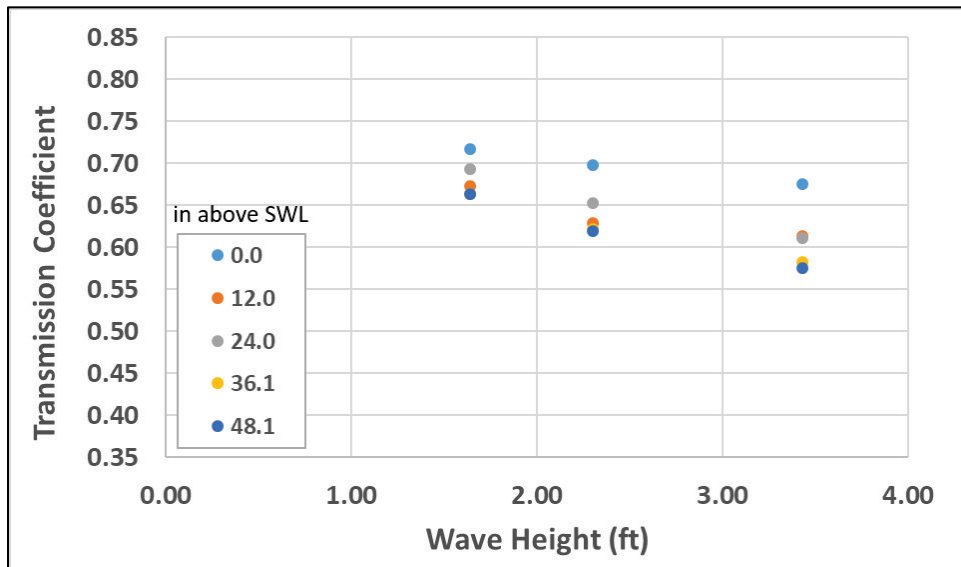
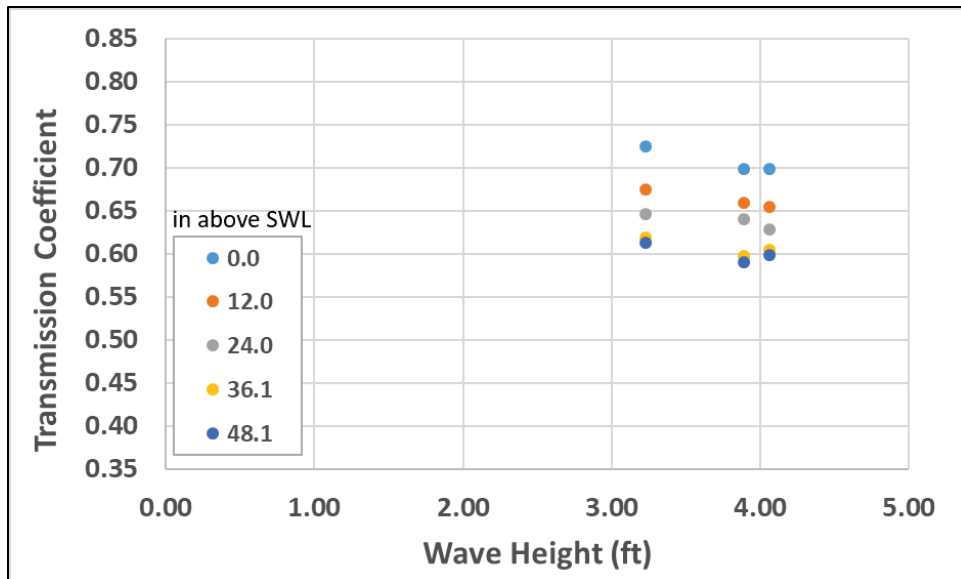


Figure 27. k_t of T=5.0 sec monochromatic wave conditions for bed mounted case (prototype).



4.2.2 Suspended case

Figures 28–30 display results of the suspended condition compared with the equivalent bed-mounted case with the same crest height above the SWL. There is a significant improvement in the attenuation when bed

mounted as opposed to suspended. This would be expected, given that the total projected area provided by the bed-mounted case is larger than the suspended whereas the suspended case allows for more energy to pass below the structure.

Figure 28. k_t of All monochromatic wave conditions for suspended case compared to equivalent bed-mounted case (prototype).

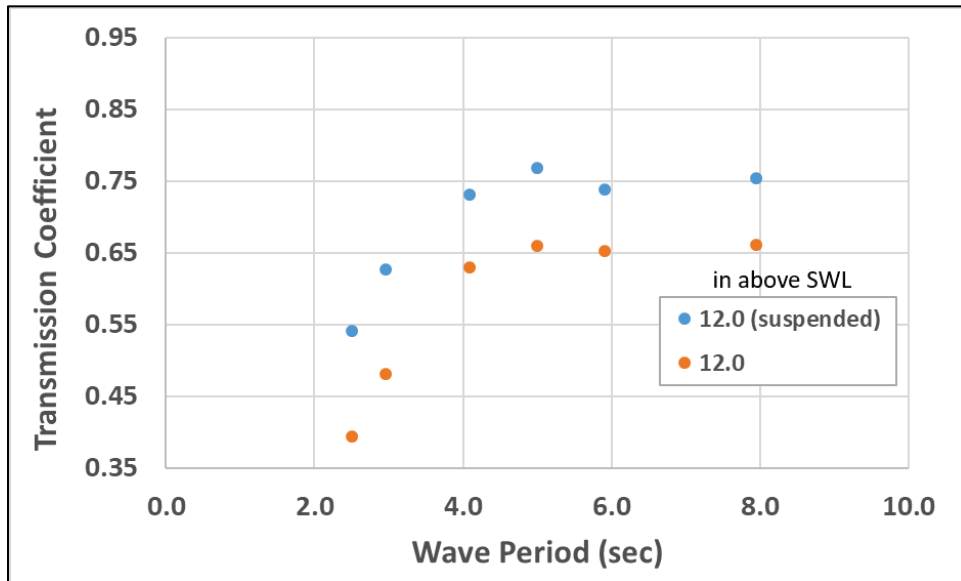


Figure 29. k_t for T=4.1 sec monochromatic wave conditions for suspended case compared to equivalent bed-mounted case (prototype).

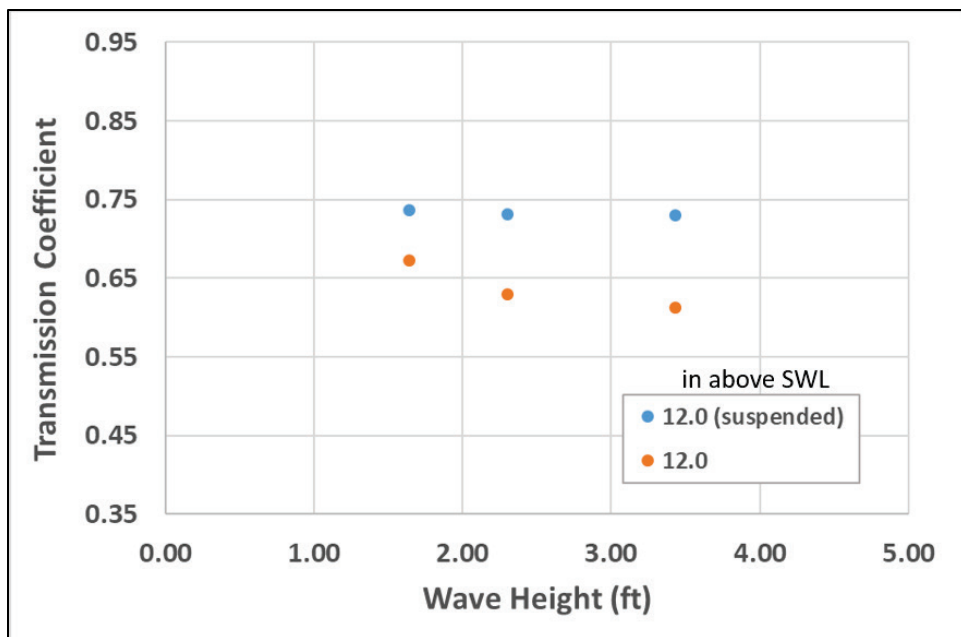
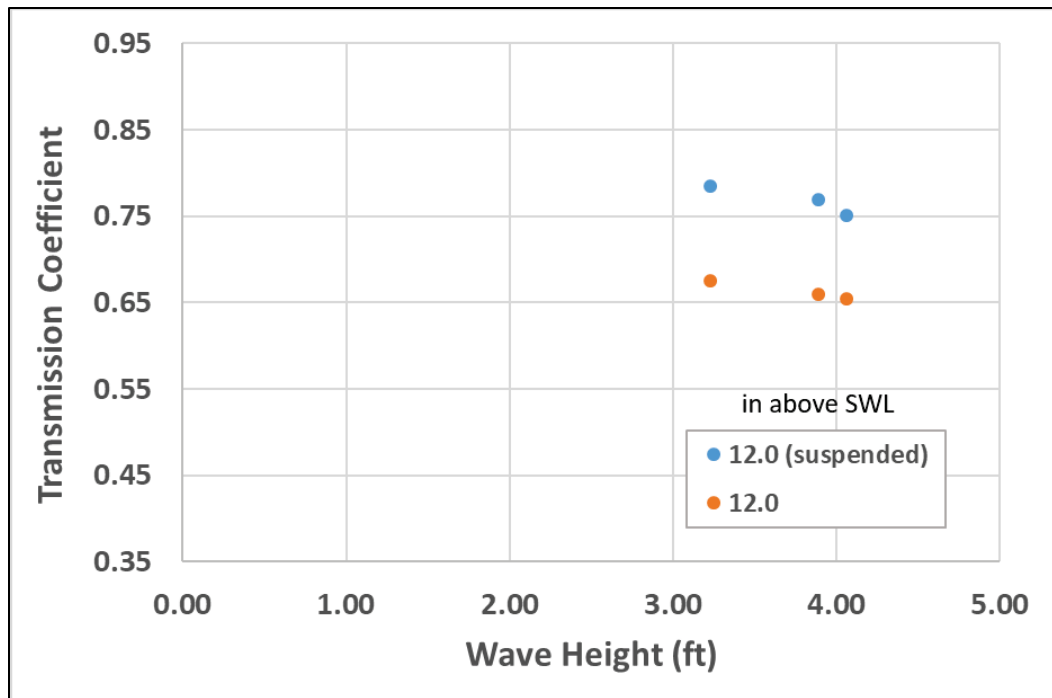


Figure 30. k_t for $T=5.0$ sec monochromatic wave conditions for suspended case compared to equivalent bed-mounted case (prototype).



4.2.3 Rotated case

Figures 31–33 show k_t results for the rotated case, where the units were bed mounted but rotated 45° from their initial orientation. The rotated case was performed with a structure height of 48 in. above SWL (10 octagonal disks plus a base disk) and was compared to the equivalent bed mounted case.

Like the irregular wave conditions, the attenuation is increased by rotating the units. The largest change in attenuation was a reduction of k_t of 0.10 condition observed for a wave period of 3.0 sec (Figure 31) and a wave height of 1.4 ft. This suggests the rotated units were more efficient at reflecting wave energy for shorter wave periods.

Figure 31. k_t of all monochromatic wave conditions for rotated case compared to equivalent bed-mounted case (prototype).

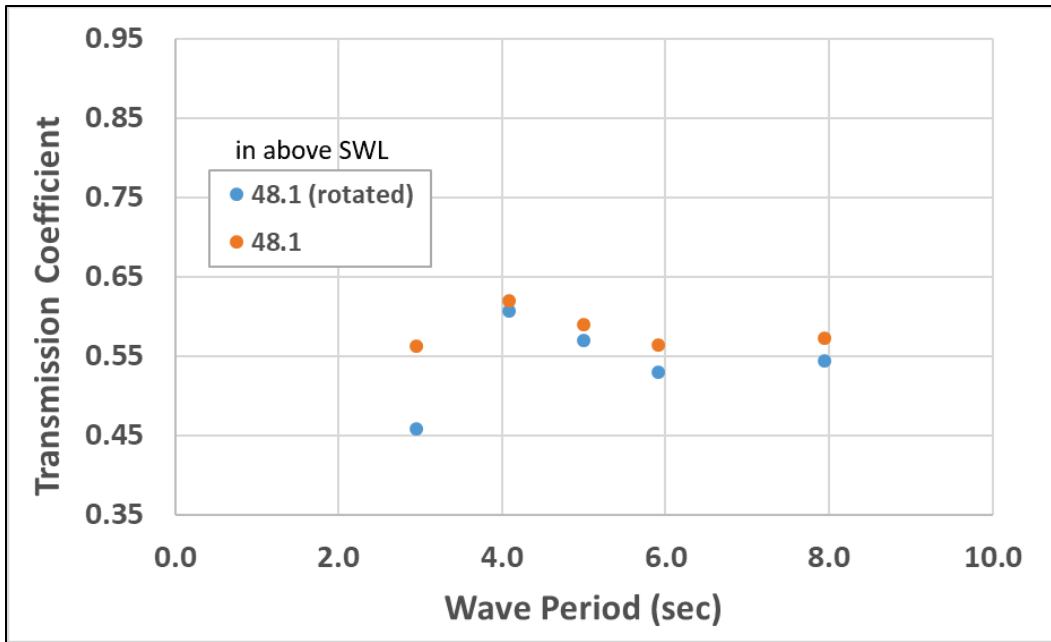


Figure 32. k_t for T=4.1 sec monochromatic wave conditions for rotated case compared to equivalent bed-mounted case (prototype).

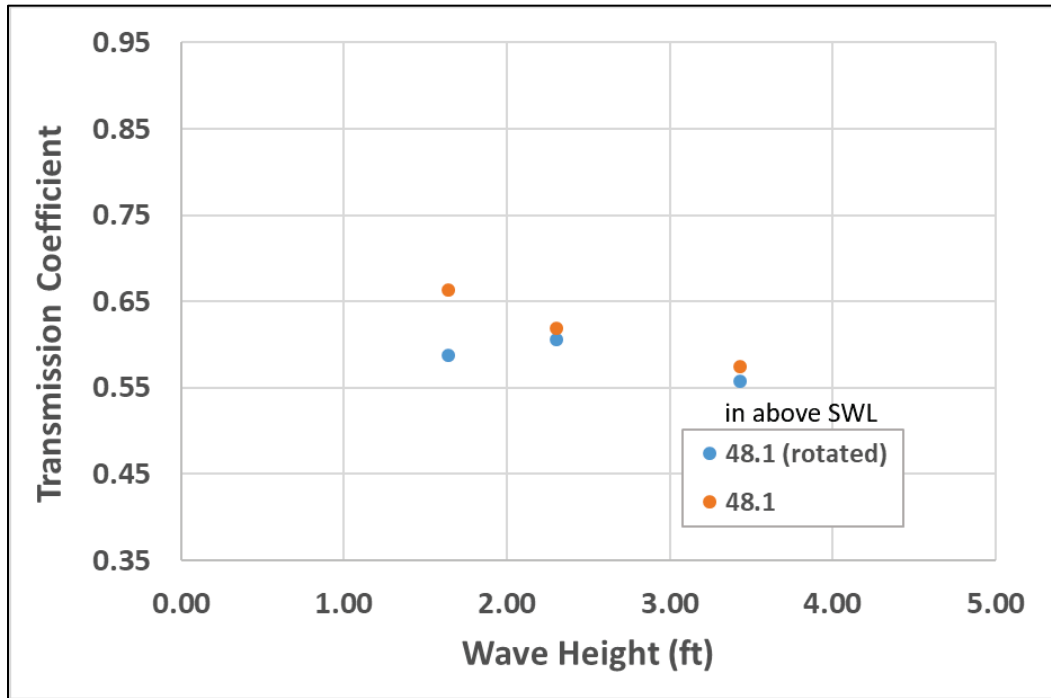
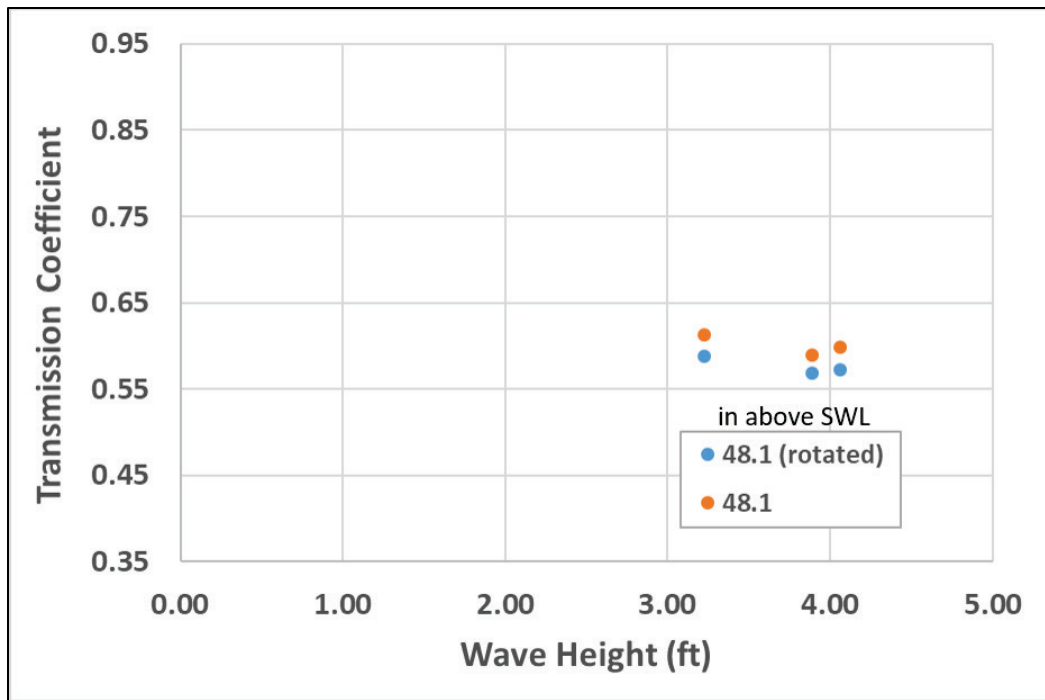


Figure 33. k_t for T=5.0 sec monochromatic wave conditions for rotated case compared to equivalent bed-mounted case (prototype).



4.2.4 Square disk case

Figures 34–36 show k_t results for the square unit testing, where the units were bed mounted with a structure height of 24 in. above SWL. Similar to the irregular wave testing, monochromatic wave attenuation improved when utilizing the square units. The lowest transmission coefficient, 0.29, occurred during the 2.5 sec wave period condition (Figure 34). The average k_t for the square disk was 0.44, a reduction from 0.58 with the octagonal disk.

Figure 34. k_t of monochromatic wave conditions for square units compared to equivalent octagonal unit case (prototype).

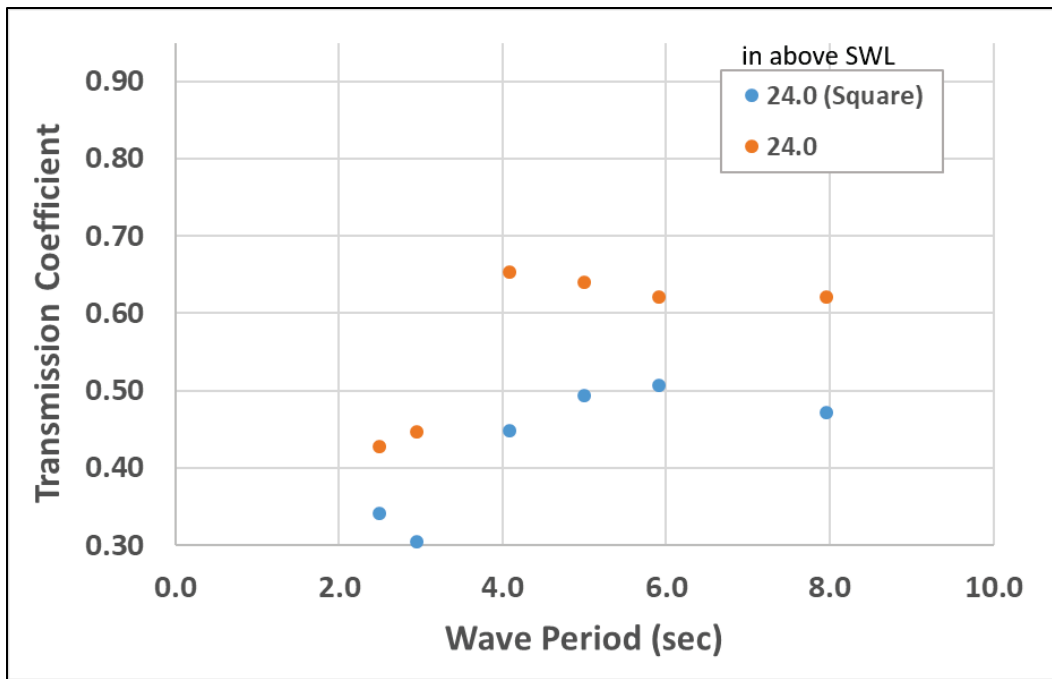


Figure 35. k_t for T=4.1 sec monochromatic wave conditions for square units compared to equivalent octagonal unit case (prototype).

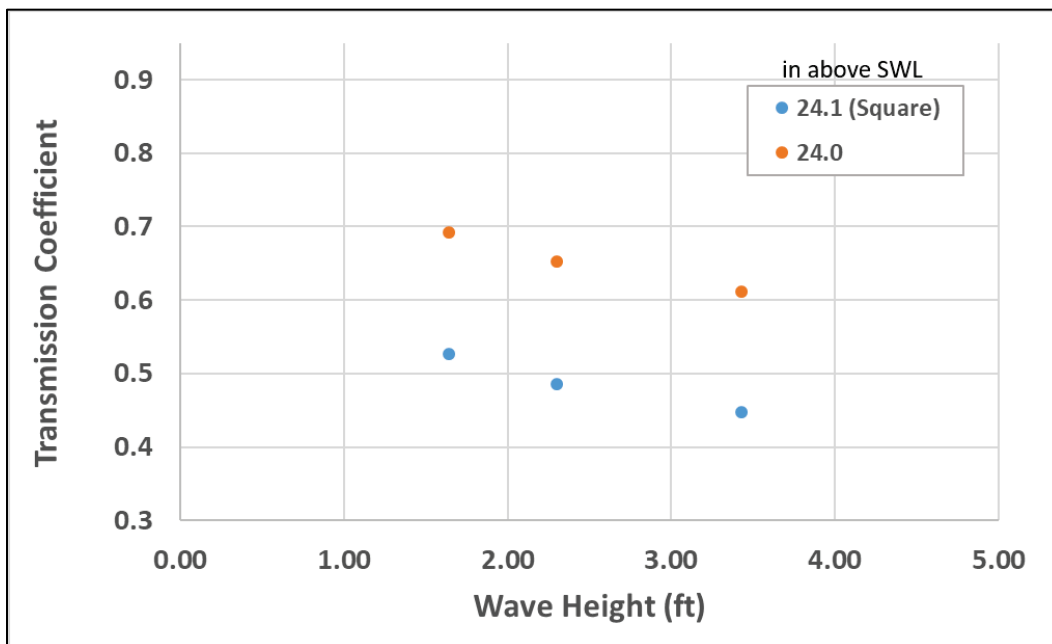
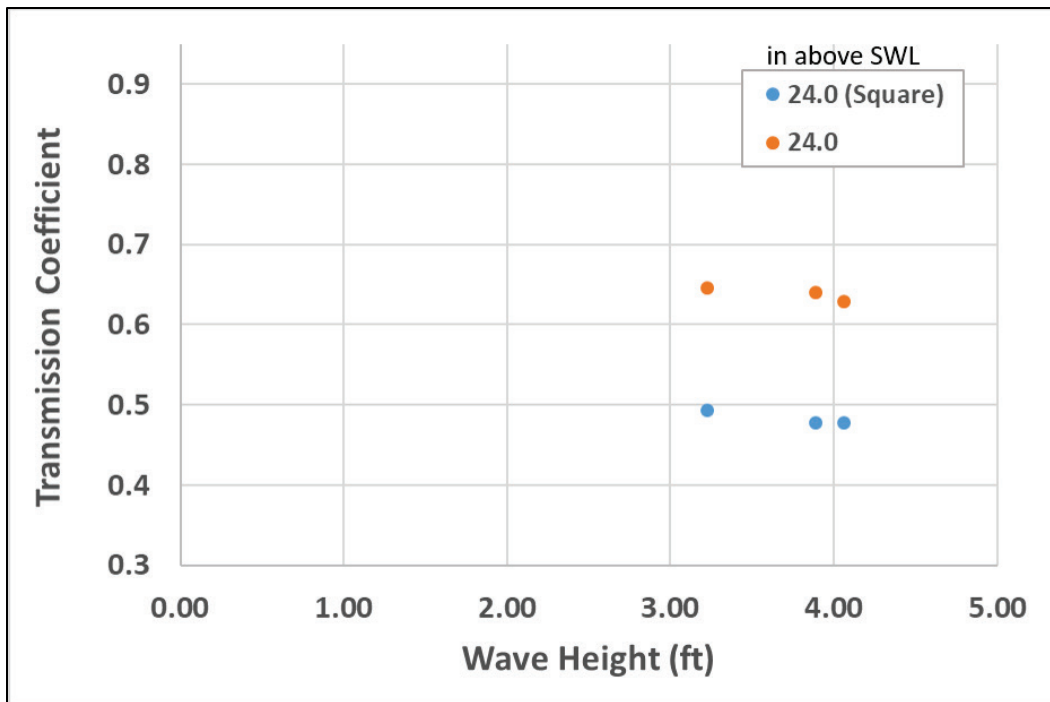


Figure 36. k_t for T=5.0 sec monochromatic wave conditions for square units compared to equivalent octagonal unit case (prototype).



5 Conclusions

The Reefmaker Ecosystem Wave Attenuator was tested under a variety of wave conditions and configurations. The configurations included a suspended configuration, a bed-mounted configuration, and a rotated configuration. An additional square design was tested for comparison to the octagonal design. The bed-mounted configuration included varying structure heights ranging between 0 in. and 48.09 in. above the SWL at prototype scale in a water depth of 7.8 ft. The suspended case, with the base disk 3.0 ft from the bed, was tested at 12.02 in. above the SWL at prototype scale, and the rotated case was tested while bed mounted at 48.09 in. above the SWL at prototype. These configurations were tested under wave conditions with periods ranging from 2.5 to 8 sec and heights from approximately 1 to 5 ft at prototype scale.

Data showed that the attenuation provided by the structure was improved when porosity and/or percent blockage area was reduced. The structure performance was best for smaller wave periods. A bed-mounted configuration with the square disk resulted in smallest wave heights behind the structure. The smallest k_t of 0.29 occurred during square unit testing, which consisted of eight bed-mounted, square disks plus a base unit (24.05 in. above SWL) and a wave period of 3.0 sec and height of 0.84 ft. The largest wave transmission value of 0.79 occurred during the suspended configuration, with a period of 5.0 sec and height of 3.23 ft. Of the 134 tests performed, including the suspended case, the average transmission through the structure was 58%.

The Reefmaker Wave Attenuator is a highly configurable system that could be used to reduce wave height while targeting a desirable porosity for water quality and sediment transport. Although not tested, it is expected a further reduction in wave transmission could be achieved by placing units into two or more rows. As testing demonstrated, a greater structure width in comparison to the wavelength resulted in a smaller wave transmission.

References

- Akamina Technologies Inc. 2018. *AWP-24-3 Wave Height Gauge User's Guide*.
http://www.akamina.com/Documents/AWP-24-3_Users_Guide.pdf
- Dean, R., and R. Dalrymple. 1991. "Water Wave Mechanics for Engineers and Scientists." *Advanced Series on Ocean Engineering*. Vol. 2. Singapore: World Scientific Publishing.
- Goda, Y., and Y. Suzuki. 1976. "Estimation of Incident and Reflected Waves in Random Wave Experiments." *Coastal Engineering Proceedings* 1 (15): 47.
<https://doi.org/10.9753/icce.v15.47>
- Hughes, S. A. 1984. *The TMA Shallow-Water Spectrum Description and Applications*. Technical Report CERC-84-7. Vicksburg, MS: Coastal Engineering Research Center.
- Hughes S. A. 1993. "Physical Models and Laboratory Techniques in Coastal Engineering." *Advanced Series on Ocean Engineering*. Vol. 7. Singapore: World Scientific Publishing.
- Wolters, G., M. R. A. van Gent, W. Allsop, L. Hamm, and D. Muhlestein. 2007. *HYDRALAB III: Guidelines for Physical Model Testing of Breakwaters: Rubble Mound Breakwaters*. Deliverable NA3.1. European Commission, Contract No. 022441. <https://www.icevirtuallibrary.com/doi/pdf/10.1680/cmsb.41318.0062>

Appendix A: Wave Gauge Calibration

Table A-1 presents wave gauge calibration.

Table A-1. Wave gauge calibration.

1		2		3		4		5	
Position (cm)	Voltage	Position (cm)	Voltage	Position (cm)	Voltage	Position (cm)	Voltage	Position (cm)	Voltage
0	-4.536	0	-4.544	0	-4.564	0	-4.567	0	-4.549
25	-2.008	25	-2.017	25	-2.024	25	-2.03	25	-2.018
50	0.533	50	0.502	50	0.508	50	0.513	50	0.521
70	2.569	70	2.519	70	2.534	70	2.537	70	2.552
90	4.547	90	4.522	90	4.543	90	4.573	90	4.566
70	2.548	70	2.52	70	2.535	70	2.546	70	2.556
50	0.527	50	0.506	50	0.509	50	0.513	50	0.522
25	-1.997	25	-2.016	25	-2.028	25	-2.027	25	-2.02
0	-4.546	0	-4.544	0	-4.56	0	-4.571	0	-4.554
Slope cm/V	9.884	Slope cm/V	9.921	Slope cm/V	9.875	Slope cm/V	9.844	Slope cm/V	9.860
Intercept	44.817	Intercept	45.04	Intercept	45.02	Intercept	44.97	Intercept	44.88
R ²	1.00	R ²	1.00	R ²	1.00	R ²	1.00	R ²	1.00
6		7		8		9		10	
Position (cm)	Voltage	Position (cm)	Voltage	Position (cm)	Voltage	Position (cm)	Voltage	Position (cm)	Voltage
0	-4.537	0	-4.553	0	-4.538	0	-4.561	0	-4.589
25	-2.012	25	-2.01	25	-2.027	25	-2.025	25	-2.046
50	0.508	50	0.529	50	0.493	50	0.494	50	0.492
70	2.528	70	2.554	70	2.515	70	2.514	70	2.532
90	4.544	90	4.566	90	4.524	90	4.54	90	4.568
70	2.529	70	2.555	70	2.517	70	2.514	70	2.539
50	0.506	50	0.534	50	0.494	50	0.497	50	0.495
25	-2.01	25	-2.005	25	-2.028	25	-2.022	25	-2.034
0	-4.536	0	-4.547	0	-4.538	0	-4.559	0	-4.587
Slope cm/V	9.911	Slope cm/V	9.864	Slope cm/V	9.925	Slope cm/V	9.896	Slope cm/V	9.831
Intercept	44.95	Intercept	44.83	Intercept	45.08	Intercept	45.09	Intercept	45.10
R ²	1.00	R ²	1.00	R ²	1.00	R ²	1.00	R ²	1.00

Appendix B: Raw Experimental Data

Tables B-1 and B-2 present raw experimental data.

Table B-1. Monochromatic wave conditions.

		Unit Configuration							
Wave Period	Incident Wave Height	Suspended	6	7	8	9	10	10 - Rotated	8 Square
Prototype (sec)	Prototype (ft)	Transmission Coefficient							
2.5	1.20	0.54	0.40	0.39	0.43	0.47	0.41		0.34
3.0	0.84	0.55	0.50	0.45	0.40	0.40	0.39	0.44	0.29
3.0	1.40	0.63	0.63	0.48	0.45	0.44	0.56	0.46	0.30
4.1	1.64	0.74	0.72	0.67	0.69	0.66	0.66	0.59	0.53
4.1	2.30	0.73	0.70	0.63	0.65	0.62	0.62	0.61	0.49
4.1	3.43	0.73	0.67	0.61	0.61	0.58	0.57	0.56	0.45
5.0	3.23	0.79	0.72	0.67	0.65	0.62	0.61	0.59	0.498
5.0	3.89	0.77	0.70	0.66	0.64	0.60	0.59	0.57	0.48
5.0	4.06	0.75	0.70	0.65	0.63	0.60	0.60	0.57	0.48
5.9	4.93	0.74	0.65	0.65	0.62	0.57	0.56	0.53	0.51
8.0	4.30	0.75	0.71	0.66	0.62	0.58	0.57	0.54	0.47

Table B-2. Spectral wave conditions.

		Unit Configuration							
Peak Wave Period	Incident Wave Height	Suspended	6	7	8	9	10	10-Rotated	8 Square
Prototype (sec)	Prototype (ft)	Transmission Coefficient							
2.5	1.00	0.50	0.48	0.47	0.43	0.43	0.44		0.32
3.0	0.98	0.57	0.55	0.52	0.50	0.50	0.50	0.51	0.38
3.0	1.57	0.57	0.58	0.52	0.51	0.50	0.51	0.50	0.38
4.1	1.64	0.69	0.65	0.61	0.60	0.60	0.60	0.59	0.46
4.1	2.22	0.68	0.65	0.60	0.58	0.58	0.58	0.57	0.44
4.1	2.86	0.70	0.64	0.60	0.58	0.58	0.57	0.56	0.43

Appendix C: Definitions of Terms

Re_D	Reynolds Number
g	Gravitational Constant
H	Wave Height
H_s	Significant Wave Height
D_n	Armor Unit Diameter
ν	Kinematic Viscosity of Water
λ	Scaling Parameter
$S(f)$	Wave Spectral Energy Density
k_r	Reflection Coefficient
k_t	Transmission Coefficient
H_t	Transmitted Wave Height (leeside)
H_i	Incidental Wave Height (seaside)
k_{rb}	Reflection Coefficient of Beach
k_{rs}	Reflection Coefficient of Structure
H_{meas}	Measured Wave Height

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
inches	0.0254	meters
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters

Acronyms and Abbreviations

3D	three-dimensional
CHL	Coastal and Hydraulics Laboratory
ERDC	US Army Engineer Research and Development Center
FFT	Fast Fourier Transform
SWL	Still water level
TSA	Testing Service Agreement

REPORT DOCUMENTATION PAGE

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14. ABSTRACT As part of a testing service agreement with Walter Marine and Atlantic Reefmaker, a 1:5.2 physical model of the Reefmaker Wave Attenuator was constructed and tested by the US Army Engineer Research and Development Center to evaluate its influence on wave attenuation. The tested prototype wave periods ranged from 2.5 to 8 sec with prototype wave heights between 1 ft and 6.5 ft. The Reefmaker Wave Attenuator included orthogonal and square designs and was tested under a variety of configurations including a suspended configuration, a bed-mounted configuration, and a rotated configuration. Testing demonstrated that depending on configurations and wavelength, the wave transmission coefficients ranged from 0.29 to 0.7. The most improvement, however, was demonstrated when testing the square unit designs with transmission coefficients, k_t , below 0.51. The smallest k_t of 0.29 occurred during square unit testing, which consisted of eight bed-mounted, square ecosystem disks plus a base unit (24.05 in. freeboard) and with a wave period of 3.0 sec and height of 0.84 ft. Of all 134 tests performed, including the suspended case, the average transmission through the structure was 58%.						
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