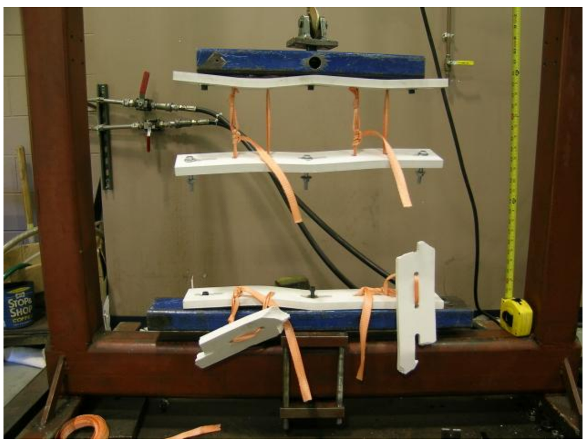
How BioHaven® Testing and Analysis Data Can Support Future Projects

Alden has provided extensive hydraulic testing services to Floating Island International to support the use of BioHavens® for various purposes including open water beautification and shoreline stabilization applications. This document summarizes the testing that was performed and how that testing can be used in order to support future proposed projects.

Module Linkage Tensile Strength



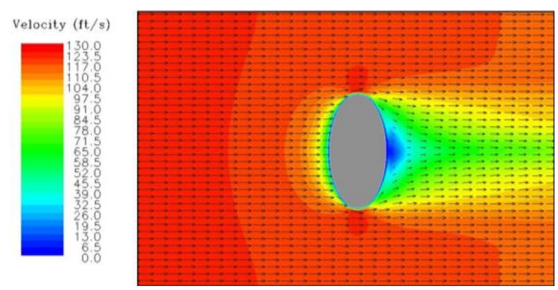
Linkage tensile strength testing

At the request of Floating Island International and under Alden's supervision, Massachusetts Materials Research, Inc. performed tensile strength testing on the end-plate and webbing type BioHaven® linkages. Individual end plate combinations as well entire island modules were tested. Results for all cases were similar, showing failure at a force of between 2,480 and 2,800 lbs per end plate, indicative of the failure strength of a single plate tether attachment. Failure strength in an island interior can be estimated by multiplying this force by the number of end plates in an island cross-section.

Computational Modeling of BioHaven® Wave and Drag Forces

When an island is deployed, one aspect of the design is establishing the system which will be used to restrain the island and prevent its movement within the water body. Forces on the island which can cause it to move are water currents, wind, and wave action. Alden used Computational Fluid Dynamics (CFD) methods to compute these forces under extreme conditions expected for a planned tern nesting island.

Computing the wind drag and current drag on an island are similar to applications for which CFD has been extensively validated. However, the methods used to simulate wave effects were new. The method was validated with physical testing, showing the CFD approach to be conservative, but not overly so. Given that conservatism, the computational method was used to calculate loads on the tern nesting island.



Wind velocity field computed for tern nesting island

In this case, the relatively small waves yielded the dominant load on the tether relative to wind and current forces. Loads on the tether can be significant, particularly for larger islands, and it is desirable to consider using multiple tethers in some applications. Projects with significant safety or cost consequences of tether failure should

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always employ some redundancy in the tether system.

Below are results showing average wave-induced tether forces on both a small BioHaven® module (the one used for validation) and the much larger tern nesting island. While every shape of island will have different average forces for different wave heights and periods, these results can be used by BioHaven® installers to give an order-of-magnitude preliminary estimate of the force per square foot that can be expected. The cost of a more detailed study can be weighed against the costs of large safety factors and/or the cost of anchor failure on a case-by-case basis.

BioHaven® Area (ft^2)	Wave Height (in)	Wave Period (s)	Force (lbf)
30	5	1.42	65
21,780	12	3.14	285,000

Table 1: Average wave-induced force calculated for BioHavens®

BioHaven® module in current testing flume

As with the wave forces, current drag force computation was validated by direct experimental measurement of forces on a small island module. The computational method was then used to calculate loads for a large scale installation. Wind and current drag forces on the island are complicated by the possible presence of roots and vegetation, which increase the forces. For scaling, drag is often expressed in terms of the drag coefficient, $C_d = D/½\ \rho V^2 A$, where D is the drag force, ρ is the fluid density (of air or water), V is the air or water velocity, and A is the cross-sectional area of the object facing the wind or current. In these studies, A includes the mean cross-sectional area of the roots below the island and/or the vegetation above the island, which can make the associated drag coefficient appear artificially low. While the drag associated with any particular island installation will vary significantly by island shape and vegetation density, it is possible to make a preliminary estimate of the order of magnitude of these forces by knowing the range of drag coefficients and multiplying by ½ $\rho V^2 A$. Drag coefficients are generally dependent upon a dimensionless number (the Reynolds number), as well as object shape. The Reynolds number is defined as $Re=\rho VW/\mu$, where W is the width of the island and μ is the air or water dynamic viscosity. Results from all drag studies are shown in Table 2.

Case Description	Re	C_d
Average from physical current experiments, no roots	$8.5X10^5$	1.26
Simulated laboratory current experiments, no roots	$8.5X10^5$	1.1
Simulated oval island, wind aligned with long axis, no roots	$9.5X10^7$	0.75
Simulated oval island, current aligned with long axis, no roots	$1.9X10^7$	0.91
Simulated oval island, wind aligned with short axis, with roots	$1.9X10^8$	0.58
Simulated oval island, current aligned with short axis, with roots	$3.8X10^7$	0.71

Table 2: Drag coefficients for various laboratory tests and simulations

Wave Attenuation Properties

In addition to tests of forces on the BioHavens®, wave attenuation properties were studied in anticipation of their usage for bank stabilization and for beach erosion prevention. Several module arrangements were simulated, including deep water attenuation (individual modules and two in series), and attenuation adjacent to a simulated beach slope (various configurations as shown in figure to the right). For deep water waves, attenuation was observed to be 80% ± 4% for 7 to 10 inch wave heights. For the shoreline studies, wave run-up reduction ranged from about 58% (for a single module—Test 1) to approximately 93% (Test 4).

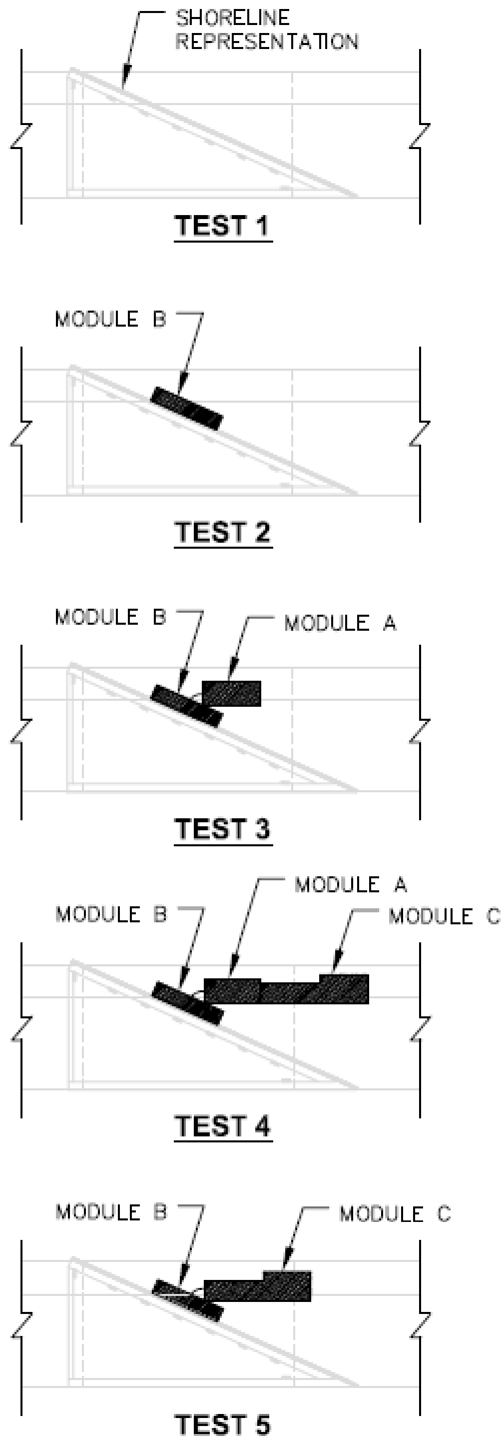
Shoreline wave testing, test configuration 2, side view

As with the drag force experiments and computations, exact attenuation properties will be site dependent, and will depend on wave height and shape, as well as water depth and shoreline angle.

Summary

In order to assist BioHaven® licensees and users in estimating anchor forces and wave attenuation applicability, Alden and Floating Island International have worked together to develop preliminary test and simulation data. For site-specific application, particularly where a high level of risk is perceived, further analysis will be required. The results shown in this document, however, should act as a preliminary guide to help users in the planning process.

Detailed report data can be requested from Floating Island International.



Module configurations for wave attenuation testing on a simulated beach slop