Design of an Experimental Traveling Wave Tank

Auguste Brown
Oct 30, 2023

Project Overview

As an effort to expand wave capabilities in the Ocean Lab, an 8 foot long traveling wave tank was designed, built, and tested. Traveling waves are waves whose peaks traverse across the water, and are being investigated as an alternative to standing waves. This project was intended as an initial step into the space, and provides a proof of concept for traveling wave generation.

Motivation & Background

Running Tide uses wave tanks to stress test samples as part of the larger efforts to design a viable macroalgae substrate and verify offshore intervention float times. Up to this point, all wave tanks in the Ocean Lab have generated standing waves, where waves are allowed to reflect off the walls of the tank and constructively interfere with subsequent waves. Standing wave generation requires less tank space than other options, making them a good choice for testing many samples in parallel in a space-limited facility.

However, standing waves also limit the breadth and accuracy of substrate tests. Standing waves are constrained to resonant frequencies based on the tank geometry, and limit wave size due to their tendency to grow uncontrollably at larger paddle stroke lengths. Additionally, water particle motion in standing waves is not accurate to real ocean conditions, complicating offshore substrate float time and macroalgae attachment & growth predictions. The limitations of standing waves have not been a significant constraint historically, but we expect to need larger and more realistic waves in the future for testing and verification of formed substrates and macroalgae growth. This expanded wave capability is expected to accompany standing waves as a test option, rather than replace them, due to their space efficiency.

Waves in the ocean, whose peaks traverse across the water (rather than remaining stationary as in standing waves), are called traveling waves. Objects floating in traveling wave environments drift over time due to forces imparted by passing waves—a phenomenon called Stokes Drift. This presents a major problem for typical substrate testing, where substrates are unconstrained in the tank and would quickly drift into a wall, corrupting data. Recently, however, the substrate lab has moved towards constraining substrates on vertical sliders to limit drift, enabling traveling waves as an option.

This initial investigation into traveling waves is intended as a proof of concept for an alternative to standing waves and a first step towards better wave control and quantification. This project set out to demonstrate continuous frequency wave generation at a wider amplitude range than our current wave tank capability, and identify unforeseen challenges in traveling wave generation. When paired with position controlled paddle drive, traveling wave capability will eventually enable generation of highly quantifiable and realistic waves in the Ocean Lab—including generation of multi-tone sea states.

Design

To generate traveling waves, a tank must be outfitted with a wave absorber at one end. This allows waves to traverse the length of the tank without being disrupted by reflected waves. Many different wave absorption methods have been implemented in academic and commercial labs, including porous wedges and active absorption with controlled paddles. The most common method is beaches, which use a sloped surface to make waves break and dissipate energy. A beach absorber was chosen for this project because they have been widely tested, are relatively cost effective, and could help us gain experience with crashing waves. Ultimately, the design was broken into four main components: tank, wave absorber, paddle, and paddle drive.

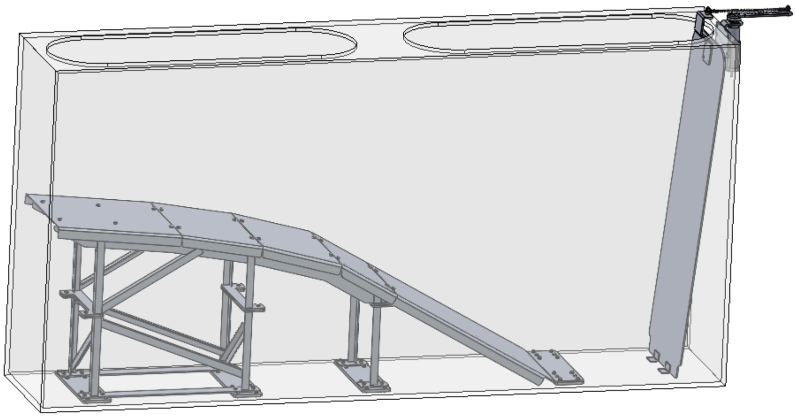
Tank

This project made use of a previously unused 8’ x 4’ x 1.5’ acrylic tank that had been designed and fabricated in Q3 of 2022. The tank is made of ½” thick acrylic sheet, allowing the paddle and wave absorber to be mechanically mounted inside.

Wave Absorber

The optimal shape of beach absorbers is fairly well-established, enabling reflection of as little as 10% or less of wave energy. Edinburgh Designs, a leading wave basin contractor, recommends not exceeding an incline of 30 degrees, with a 6 degree incline at the water line. Based on these parameters, a 24” maximum water height was chosen, making for a roughly 6 foot long beach, with 2 feet of tank space left for the paddle and substrate sample. This also leaves 2 feet of vertical headroom for wave swells and splashing.

As maximum wave size is based on water height (see Paddle section below), the beach was designed to withstand a fully cyclical load associated with the largest expected wave. From wave momentum calculations, this load was found to be approximately 50 lbf.



After some early concepting, a design was settled upon which uses two aluminum weldments. One weldment, mounted to the bottom surface of the tank, acts as a spacer for a second weldment which provides the gradual slope shape of the beach. Four panels are bolted on top, providing a modular surface for the waves to interact with, and allowing ease of access to the bottom frames during installation. The spacer weldment can be swapped for a shorter spacer in the event of a water height change, without requiring redesign of any other components.

The two frames use plasma cut 5052 aluminum for alignment and bolt plates, and 1”x1”x1/8” 5052 aluminum angle stock as structural members. Basic bending calculations were performed to select the angle stock. Additionally, bolt shear calculations were used to size ¼”-20 fasteners throughout the structure and ensure screws in the frame would fail at lower stress than the screws used to mount to the tank. This helps prevent failures in the tank itself, which is by far the most expensive component.

Paddle

The paddle design for the traveling wave tank builds on previous paddles in Running Tide tanks, using 3/16” 5052 aluminum sheet and angle stock for rigidity. The dimensions and placement of the paddle are driven by the expected maximum stroke length. Edinburgh Designs cautions against paddle strokes greater than 12 degrees from vertical in systems without force feedback controlled drive. Thus, the maximum stroke length at the water line is $2h \cdot tan(12)$, where h is the water height. In order to save some tank space for the test samples, paddle stroke was limited to 12 degrees forward and 6 degrees backwards from vertical.

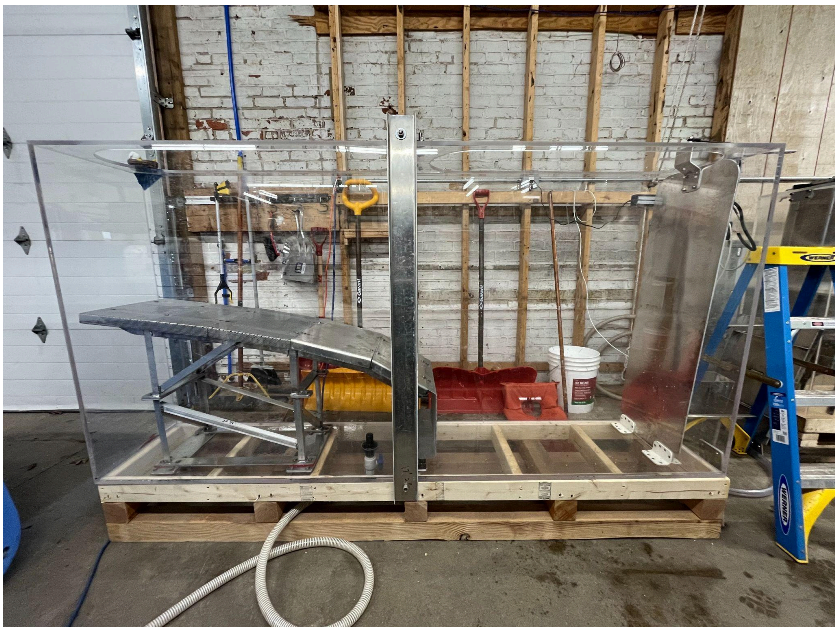
Paddle Drive

The paddle drive system used for this project was directly inherited from the 4 foot dynamic wave tanks. This includes the motor, motor controller, motor shaft hub, crank arm, and linkage. The crank arm and linkage lengths were modified to generate the angular stroke discussed above.

Capabilities

After fabrication and installation of the beach, paddle, and drive system, the tank successfully demonstrated generation of continuously variable frequency traveling waves. Maximum wave heights as of October 2023 are comparable to those in the 4 foot dynamic float tanks, with a known path towards larger waves as discussed in the Next Steps section.

In an effort to reduce the length of the beach and gain more space for substrate testing, a test was conducted comparing two different beach configurations. The baseline configuration features a 30 degree inclined panel that connects the beach to the tank floor. Testing showed that a truncated beach configuration, which uses a perforated vertical panel to connect the main beach to the tank floor, performed comparably in terms of wave absorption. This truncated version is 2 feet shorter than the baseline configuration, and is recommended as the normal operating configuration.



The beach in the truncated configuration

Limitations & Next Steps

The 8 foot traveling wave tank represents a step towards more accurate, quantifiable, and larger waves. While it provides a proof of concept, it has several limitations as a test fixture—mostly due to intentional scope constraint.

Most notably, the paddle creates significant wave turbulence at higher stroke lengths and frequencies. This was an expected result of choosing a “wet-back” paddle, where water is allowed to pass by the sides of the paddle and fill the region behind it. As the paddle moves through this water, it creates eddies which grow in size as the stroke length increases. A way to solve this problem and create better-controlled waves is to use a “dry-back” paddle, where the sides of the paddle are sealed and no water is allowed behind it. An example of this type of paddle can be seen in the OMEY Labs tank.

A side effect of this wave turbulence is that waves are less repeatable and quantifiable (e.g. wave height is hard to determine). This makes it difficult to experimentally produce a wave height to paddle stroke ratio, complicating prediction of waves based on input drive (see Water Wave Mechanics for Engineers and Scientists, Chapter 6, for more details).

As built, the tank is capable of running waves with frequencies between 25 - 110 RPM, and stroke lengths of 3 - 10 inches. The maximum wave frequency is limited by the encoder on the motor, and this range could easily be expanded by configuring the motor with a different encoder. The stroke length is limited by the crank linkage, which produces less-sinusoidal motion as the crank arm length approaches the length of the connecting linkage. To generate larger waves, the crank assembly would need to be adjusted, or replaced with a linear drive system.

A linear drive system with position feedback control would also open up the ability to make multitone waves. This would enable us to recreate actual sea states in the Ocean Lab, making for a highly representative test environment. Sea state replication is widely used in labs across the world, and will eventually be an invaluable tool for substrate and macroalgae testing and offshore correlation in the Ocean Lab.

Overall, this project demonstrated traveling wave capability in the Ocean Lab, creating an additional test option for candidate substrates. To unlock the full potential of traveling waves, a longer wave flume with a dry-back paddle and position feedback control would be necessary.