Scaled Surfing Waves

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Problem Statement

The USNA Hydromechanics Lab is limited in ability to create and simulate plunging breaking waves. This project aimed to develop a design capable of generating these waves while utilizing existing Hydromechanics Lab facilities.

Kelly Slater Surf Ranch

Real world plunging wave at "Pipeline" in Hawaii

Design Alternatives

After extensive literature review, the team identified 3 design alternatives capable of producing plunging waves in the Hydromechanics Lab facilities

1. Wave Generator with Bathymetry: This alternative creates waves by using a wave flap generator to displacing water in the tank and pass it along bathymetry to give the waves their shape as they shoal along the shallower part of the tank
2. Towed Hydrofoil: This alternative generates waves by towing a fixed object along the length of the tank. Can be done successfully with or without bathymetry
3. Piston Water Displacement with Bathymetry: This alternative involved a heavy object that is dropped into the water using a piston and gravity to displace large amounts of water and create waves

Decision Matrix

Criteria	Weight	Towed Hydrofoil	Wave Generator with Bathymetry	Piston Water Displacement with Bathymetry
Versatility	0.30	3	2	1
Deployability	0.05	3	2	1
Reusable	0.10	2	3	1
Accuracy	0.30	2	3	1
Durability	0.10	2	3	1
Compatibility	0.10	3	2	1
Storability	0.05	3	2	1
Weighted Total	1.00	2.63	2.23	1.13

Based on results from the Towed Hydrofoil, we determined that the tow tank facility is too limited in it's ability to produce plunging waves using bathymetry. The Ramp design was considered as it solves the bathymetry problem.

Lab Testing Outcomes

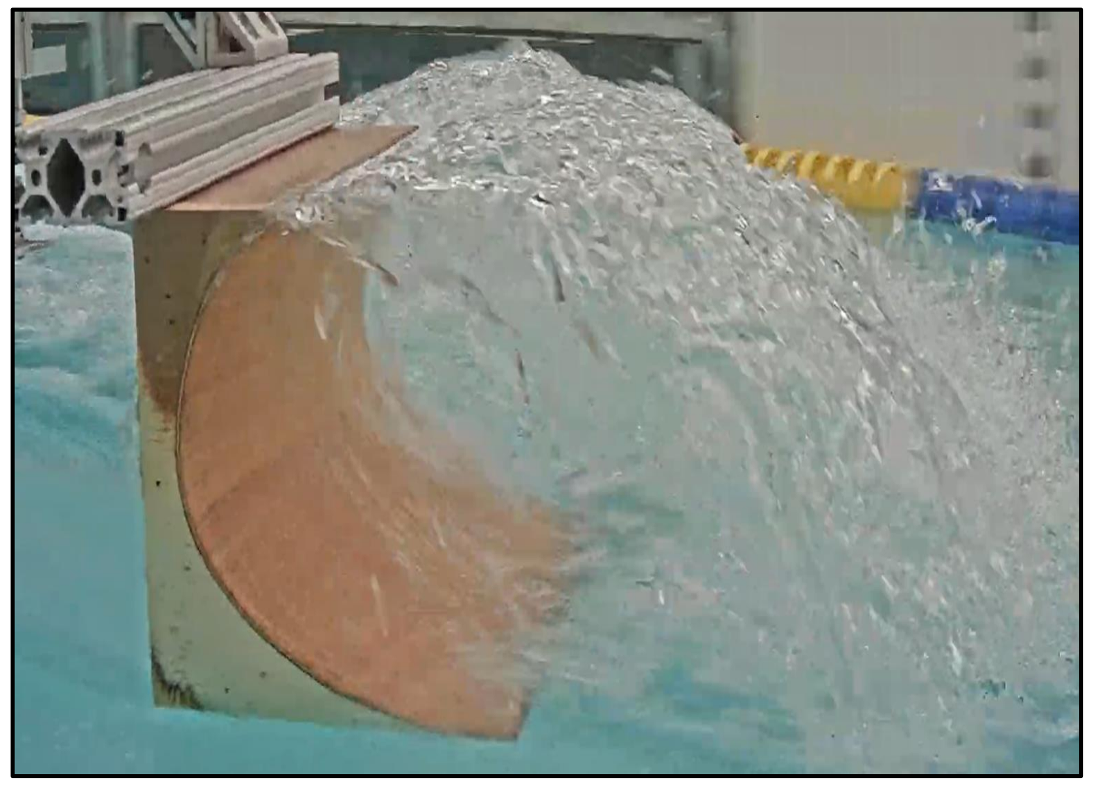
Hydrofoil: The design was severely limited by depth, width of tank, and adequate space to develop bathemetry

Lessons Learned: Acceleration was a key variable that determined whether the created wave would sufficiently develop before reaching the bathymetry contours

Ramp: The design concept limits use for surf parks but offers a method for studying breaking wave shape and has potential to be a design foundation for breaking wave research

Lessons Learned: This design concept accomplished producing scaled breaking waves. Limiting variables to testing are speed and depth of the plow while the plow design shape dictates the shape of the wave.

Hydrofoil testing with Bathymetry



Wave Ramp Testing in 120 ft Tank

Background Theory

The Physics of the Surf
When deep-water waves reach the shore, the decreasing depth triggers wave shoaling. As the ocean floor rises, the wave is compressed, forcing its energy upward until it can no longer support itself.

The Shoaling Process
- Celerity (Speed) Decreases: Friction with the seafloor slows the wave down.
- Wavelength Shortens: Waves "bunch up" as the front slows and the back catches up.
- Height Increases: To conserve energy, the wave grows taller and steeper.
- Plunging waves are characterized by a steep slope; the crest curls and traps a pocket of air.

Froude Number: $Fr = \frac{V}{\sqrt{gy}}$

- Wave Ramp: V=9.25ft/s, y=0.5in, Fr=7.9
- In fluid hydrodynamics, the geometry of the ramp is only half the battle; the real magic happens when you master the flow dynamics. To achieve a crisp, plunging wave shape, reaching a supercritical Froude number is essential.
- By precisely increasing the flow velocity, we transitioned the water into a high-energy state where inertial forces dominate gravity. This supercritical state provides the necessary momentum for the water to hit the ramp and "trip" into a perfect barrel, rather than simply churning into a turbulent mess.

Eccentricity: $e = \sqrt{1 - \frac{b^2}{a^2}}$

- Eccentricity is a number that represents variance from a perfect circle. Therefore, an eccentiricy of "0" would be a perfect circle. Commonly, surfing waves typically have an eccentricity ranging from 0.5-0.8
- Pipeline: h=16ft, w=25ft, a=8ft, b=12.5ft, e=0.6 (This shows Pipelines natural "hallow" and tube like shape)
- Wave Ramp: h=9in, w=8in, a=4.5in, b=4in, e=0.458 (This shows that our wave ramp produced an eplisoid type shape, similar to the shape of an almond

*Pipeline calculations were made by best estimates based on actual wave heights

Conclusions

- Bathymetry based designs are difficult to scale in tow tanks for research purposes
- Towing the wave ramp gave us a relatively clear picture of what a breaking wave would look like in a lab setting
- Future work includes investigating Bathymetry designs for tow tank style facilities and investigate if those designs can support surf park infrastructure

Acknowledgements

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References

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