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Seeking Optimal Geometry of a Heaving Body for Improved Wave Power Absorption Efficiency

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Introduction

Increases in population, standard of living, and dependency on technology indicate a future increase in energy demand (Fujita, 2002). This increase in energy demand coupled with recent concern for climate change and rising oil prices has generated interest in wave energy. This project has been inspired by Salter's work to better understand wave power absorption efficiency with various shaped bodies.

The goal is to optimize the geometry of a two-dimensional, single, heaving body for maximum power absorption (η) with a regular, harmonic, linear, incident wave. The research is conducted through both wave tank experiments and numerical simulation. Numerically the optimum shape for power absorption efficiency will be found using the software AQWA, which is to be verified experimentally. In the wave tank experiments, we measured the excitation force (F_w) on several floater models of different shapes. The results on F_w are used to calculate the radiated wave amplitude (α) via:

$$F_w = \frac{2\rho A \alpha_+ g C_g i}{\omega} \tag{1}$$

The power absorption efficiency is then calculated using:

$$\eta = \frac{P_{\max}}{P_w} = \frac{\alpha_+^{\;2}}{\left|\alpha_+\right|^2 + \left|\alpha_-\right|^2} \tag{2}$$

This note presents our preliminary results from the wave tank experiments on power absorption efficiency on three floater geometries.

Experimental Set-Up

The experiments were performed in a small wave flume in the hydraulics laboratory of the civil engineering department at the University of Hawaii at Manoa. The flume is about 1.5 ft deep, 0.5 ft wide and 30 ft long. It is equipped with a computer controlled wavemaker that can generate periodic waves of different height and wavelength. Figures 1 – 3 show the experimental set-up.

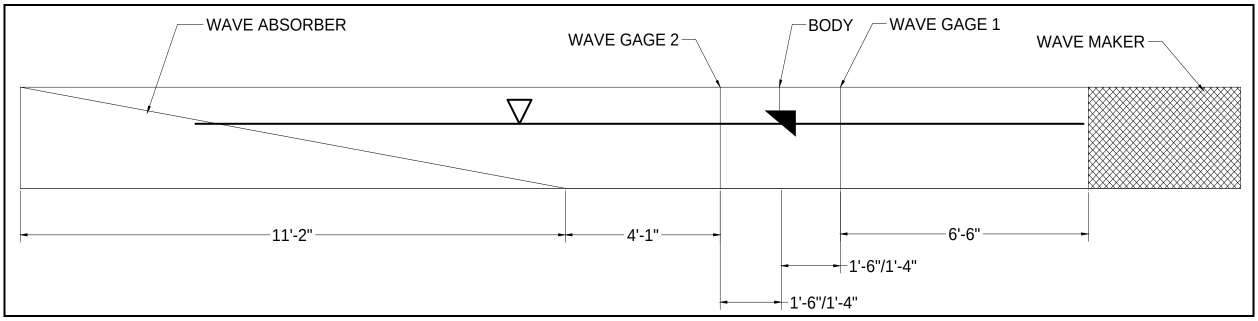


Figure 1. Sketch of experimental set-up in the wave flume

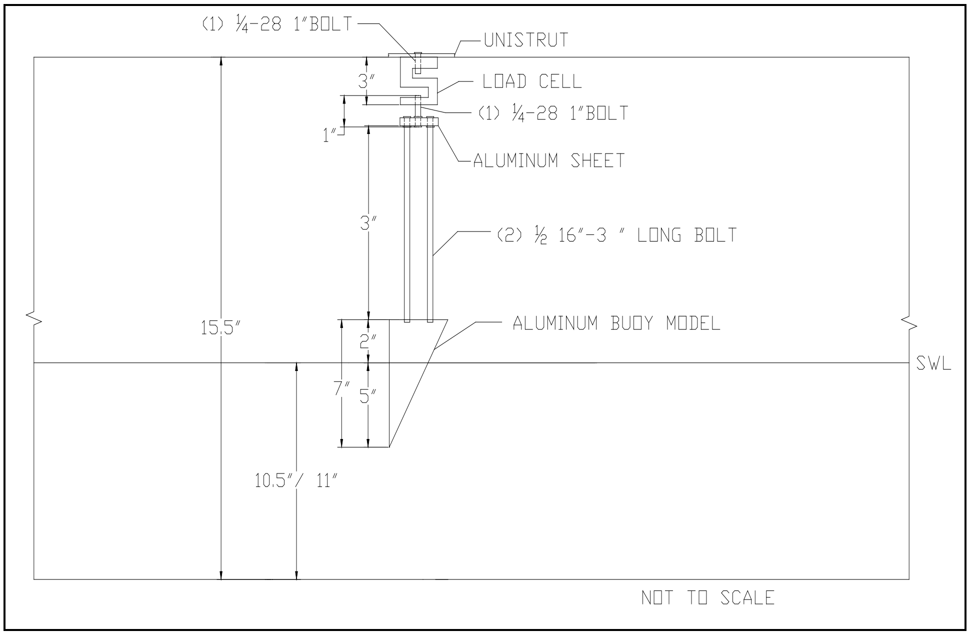


Figure 2. Sketch of instrumentation (i.e., load cell) on the buoy model

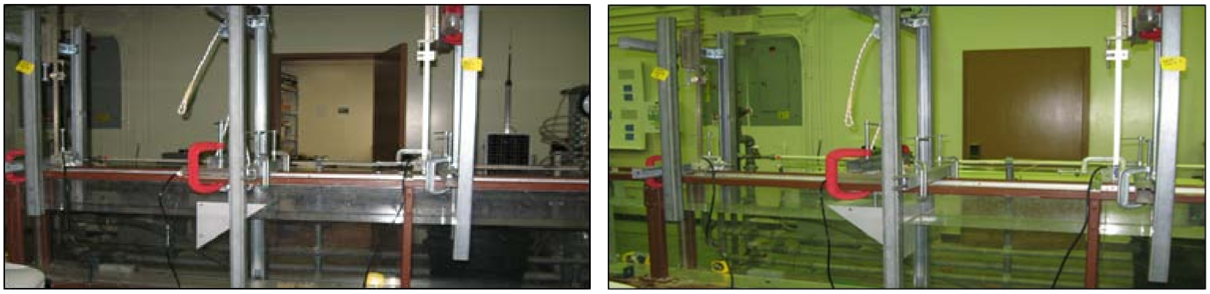


Figure 3. Buoy orientation in the experiment. Left: body facing incoming waves to measure radiated wave α_+; right: body facing incoming waves to measure radiated wave α_-.

Experimental Procedure

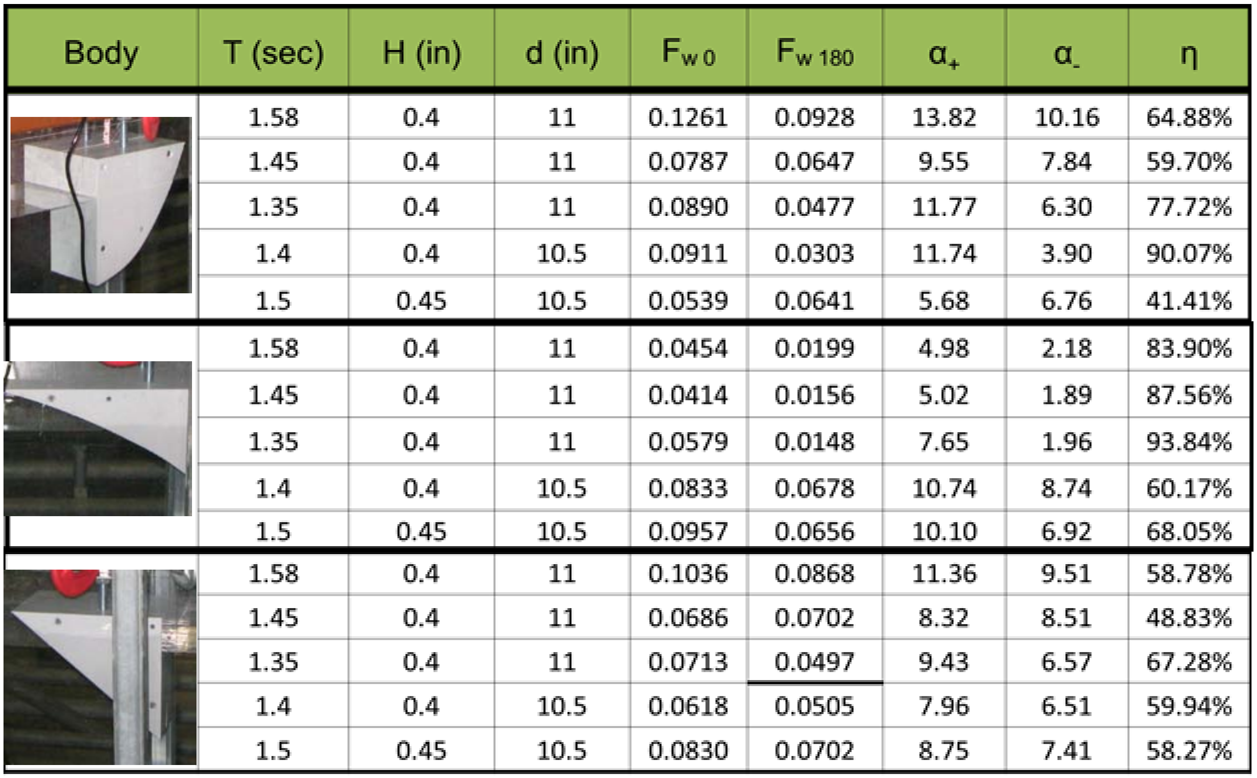
A load cell was used to measure the excitation force of the incident wave on a fixed body. The excitation force equation (1) corresponds to the diffraction problem, which is experimentally studied.

Detailed procedure:

1. Produce an incident wave defined by wave height (H), period (T), and water depth (d)
2. Measure F_w via load cell
3. Calculate the radiated wave amplitude at positive infinity (α_+)
4. Rotate the body 180°
5. Produce identical, incident wave
6. Measure F_w via load cell
7. Calculate the radiated wave amplitude at negative infinity (α_-)

The plastic floater models have the same width as the wave flume (i.e., 6 in) for a two-dimensional set-up. The bodies have equal drafts of 5 in and waterline cross-sectional areas of 36 in^2. The load cell is calibrated with the body in the water, therefore the only force recorded is from the incident wave. Wave gages were placed before and after the body, so as to determine the reflection coefficient.

Experimental Results



Body	T (sec)	H (in)	d (in)	$F_{w\,0}$	$F_{w\,180}$	α_+	α_-	η
	1.58	0.4	11	0.1261	0.0928	13.82	10.16	64.88%
	1.45	0.4	11	0.0787	0.0647	9.55	7.84	59.70%
	1.35	0.4	11	0.0890	0.0477	11.77	6.30	77.72%
	1.4	0.4	10.5	0.0911	0.0303	11.74	3.90	90.07%
	1.5	0.45	10.5	0.0539	0.0641	5.68	6.76	41.41%
	1.58	0.4	11	0.0454	0.0199	4.98	2.18	83.90%
	1.45	0.4	11	0.0414	0.0156	5.02	1.89	87.56%
	1.35	0.4	11	0.0579	0.0148	7.65	1.96	93.84%
	1.4	0.4	10.5	0.0833	0.0678	10.74	8.74	60.17%
	1.5	0.45	10.5	0.0957	0.0656	10.10	6.92	68.05%
	1.58	0.4	11	0.1036	0.0868	11.36	9.51	58.78%
	1.45	0.4	11	0.0686	0.0702	8.32	8.51	48.83%
	1.35	0.4	11	0.0713	0.0497	9.43	6.57	67.28%
	1.4	0.4	10.5	0.0618	0.0505	7.96	6.51	59.94%
	1.5	0.45	10.5	0.0830	0.0702	8.75	7.41	58.27%

Table 1. Experimental data of wave period T, wave height H, water depth d, excitation force F_w, and calculated radiated wave amplitude α and power absorption efficiency η.

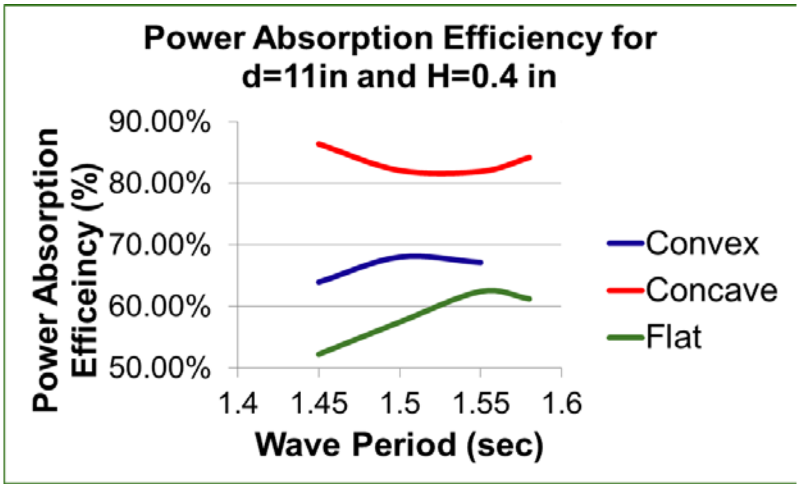


Figure 4. Plot of power absorption efficiency of three different floater shapes

Preliminary Conclusion

Based on the wave flume experimental results presented in Table 1 and Figure 4, it seems that the flat face is typically the least efficient in power absorption while the concave face has the highest efficiency.

On-Going Research

- Further wave flume experiments with a wider range of wave conditions and more floater shapes
- Numerically study the diffraction problem for a large number of shapes to ultimately find the most efficient shape by applying the software AQWA
- Numerically study the radiation problem with the body moving in one-degree of freedom for multiple shapes by applying software packages AQWA and OrcaFlex

References

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- Backer. Hydrodynamic Design Optimization of Wave Energy Converters Consisting of Heaving Point Absorbers Ph.D. Thesis, University of Ghent (2010)
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