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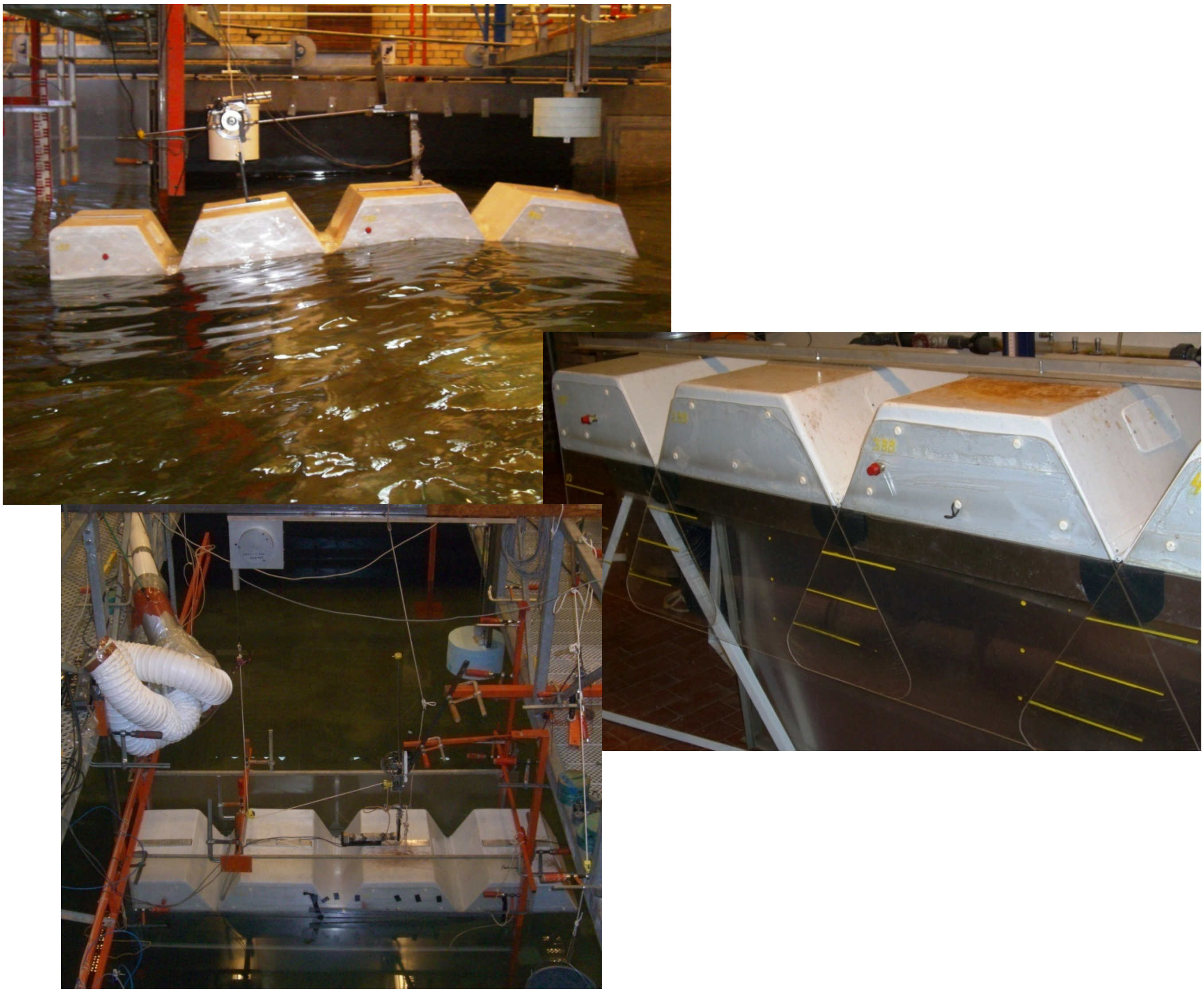

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Aalborg University
Department of Civil Engineering
Water and Soil

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Hydraulic evaluation of the Crest Wing wave energy converter

by

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M. Antonishen

September 2008

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Preface

This report presents the results of an experimental study of the wave energy converting abilities of the Crest Wing wave energy converter (WEC). The Crest Wing is a WEC that uses its movement in matching the shape of an oncoming wave to generate power.

Model tests have been performed using a scale model (length scale 1:30), provided by WaveEnergyFyn, in regular and irregular wave states that can be found in *Assessment of Wave Energy Devices. Best Practice as used in Denmark* (Frigaard et al., 2008). The tests were carried out at Dept. of Civil Engineering, Aalborg University (AAU) in the 3D deep water wave tank. The displacement and force applied to a power take off system, provided by WaveEnergyFyn, were measured and used to calculate total power take off.

The tests have been performed by Jens Peter Kofoed and Mike Antonishen, AAU, in co-operation with Henning Pilgaard, WaveEnergyFyn, who was present in the laboratory during the tests. The testing took place during the period June to August, 2008. The report has been prepared by Jens Peter Kofoed and Mike Antonishen (tlf.: +45 9635 8474, e-mail: jpk@civil.aau.dk).

Aalborg, September, 2008

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1. Introduction

The Crest Wing Wave Energy Converter is currently being developed by **Henning Pilgaard, of WaveEnergyFyn,** Denmark. It is meant to act like a carpet on the water, conforming to the shape of each wave and using that movement to generate power. The thought of making a WEC that acts like a carpet on top of the waves is not new; ongoing or past projects such as the Pelamis and Cockerel Raft were designed with this thought in mind. The real difference with the Crest Wing is that it has skirt drafts, seen in Figure 8, that extend down into the water and create suction; this increases the effective mass of the WEC while minimizing the material use. Special attention was given to the design of the first and last floaters as they are meant to act as a smooth transition between wave and machine. Their purpose is to make sure that no air gets under the two middle floaters so that suction is not broken and the device continues to function well. To get a feeling for how much these skirt drafts actually affect the device, immerse a bucket in a pool of water and let it fill. Trying to pull the bucket out of the water while its open end faces downwards is a surprisingly hard task!

In many WEC's there are two possible ways to actually harvest the power; movement of the WEC relative to a fixed power take off (PTO) set up or with a PTO set up that captures the energy from the relative movement of elements on the WEC. The fixed PTO set up corresponds to a fixed structure or a secondary floating reference frame in the ocean that the WEC is attached to. Movement relative to this fixed point generates power. Prior to testing it was hypothesized that a fixed reference PTO would generate more power. The main question was whether it would produce such a great amount that it would be worth it to build a long lasting fixed structure in the ocean. If all things are considered it is usually more efficient and affordable to use a relative reference system since it can be quite expensive to construct a fixed structure in the ocean that is meant to last a significant amount of time. The PTO system that uses relative motion of elements on the WEC to generate power is a widely used concept in wave energy. Both the Pelamis and Cockerel Raft are examples of WEC's that use this type of PTO.

As a final note, every figure given in this paper will be at scale 1:30 unless otherwise noted.

2. Test Set Up

All testing was performed at a scale of 1:30 and all data points were recorded at a sample frequency of 25 Hz. Before taking any data, waves were run in order to observe the movement of this WEC qualitatively in order to choose a reasonable model for anchoring. The converter is anchored at both ends with springs and the characteristics of the anchoring system in calm water can be seen in Graph 1[1]. Data was taken on the force that these anchors must withstand while the WEC is producing power but it is not yet processed since it is not yet pertinent to the project at this stage. Waves were measured using 8 separate wave gauges placed in front of and around the device. The PTO used for testing was supplied by the Client**.** It involves a disc brake through which the loading provided to the system can be easily adjusted. In full scale this represents a PTO including a generator. Loading the PTO was done by placing masses in a bucket hanging vertically down from the hand control for the disc break.

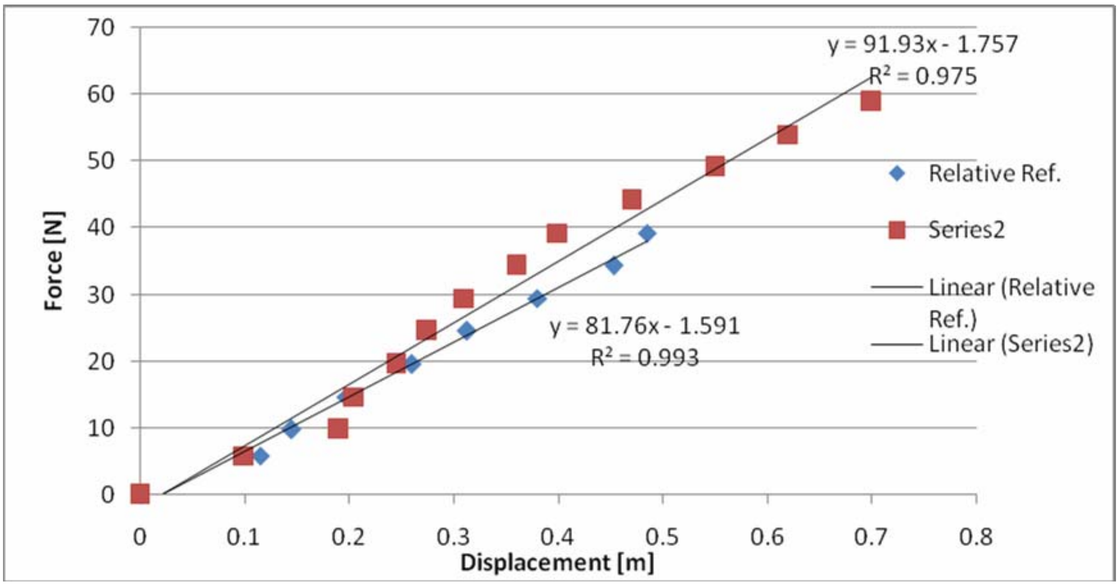

Figure 1: Anchoring characteristics for both set ups.

2.1. Fixed Reference

In the fixed point PTO case, measurements of the force, *F*, applied to the PTO system were collected using a strain gauge equipped bone installed parallel to the third floater of the device as shown below. In order to ensure pure 2-D motions of the device (to avoid damage to the bearings of the PTO) Plexiglas guide walls were placed on either side of the device. Their purpose was to help guide its movement so that the only forces measured were the ones affecting the displacement. Special attention was given to their installation so that they did not in any way affect the movement of the device aside from their original purpose.

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[1] An effort was made to make the anchoring characteristics as close as possible between fixed reference and relative reference tests.

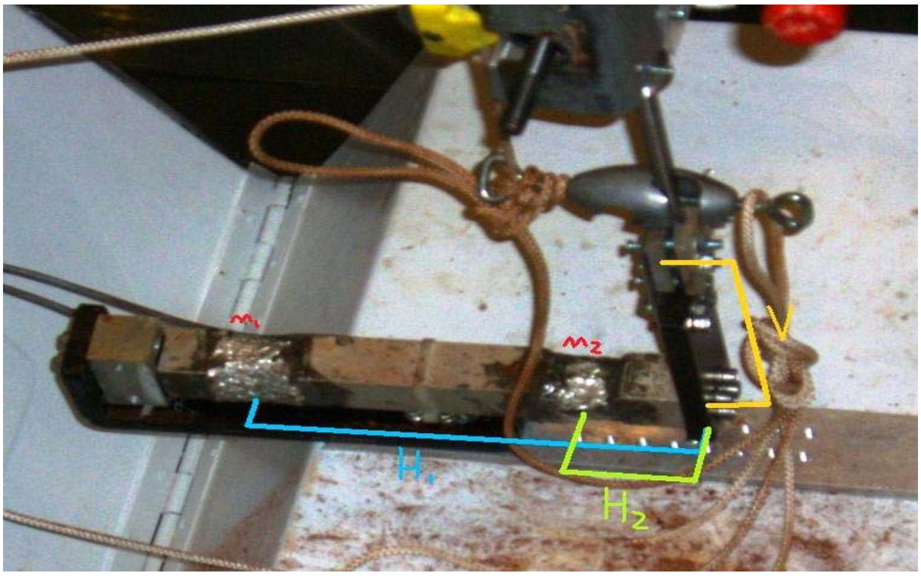


Figure 2: The bone set up connected to the fixed PTO. Values of H1, H2, and V are all known.

The two thinner parts of the bone marked m_1 and m_2 are where the measurements are taken. Since the distances H_1, H_2, and V are all known then using known equations it is easy to see that no matter what direction the force is in,

$$F_{res} = \sqrt{F_v^2 + F_h^2}$$

where F_{res} is the total force, F_v is the vertical force on the bone, and F_h is the horizontal force on the bone. As in the picture, let the two moments be called m_1 and m_2. Finding the bending moments at m_1 and m_2 and solving for F_h and F_v gives

$$F_v = \frac{m_2 - m_1}{H_2 - H_1} \quad \text{and} \quad F_h = \frac{m_1}{V} - \frac{H_1}{V} F_v$$

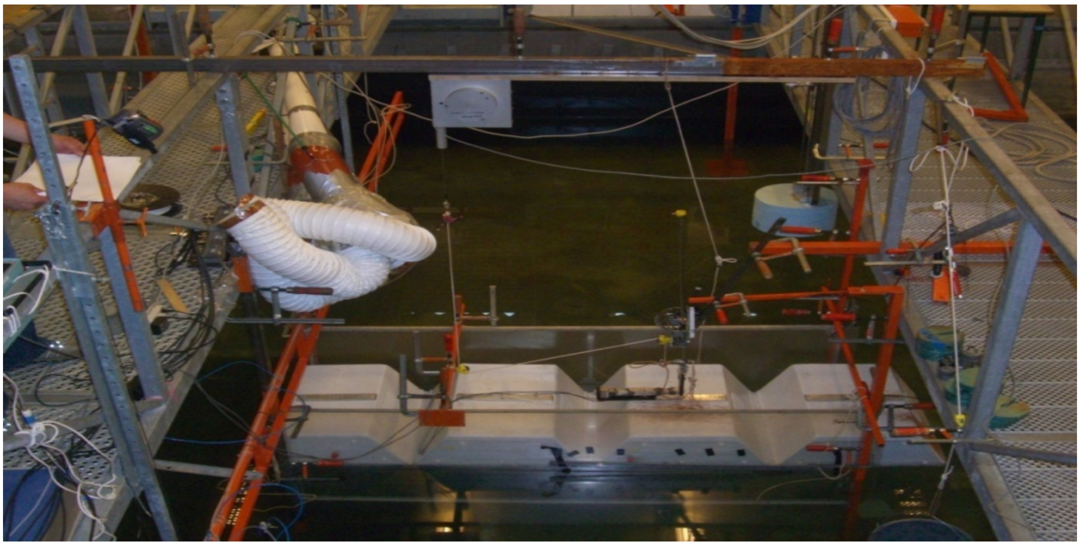


Figure 3: Set up of the Crest Wing WEC with fixed point PTO.

The displacement, *d*, is measured by an ASM draw wire displacement sensor as seen in Fig. 3**.** Using data power generation was calculated using the simple equation

$$P(t) = F(t) \cdot \frac{\Delta d}{\Delta t}\,.$$

2.2. Relative Reference

The test set up for relative reference testing is shown in Figure 2. Displacement is measured electrically by a non-contact ultrasonic displacement sensor while force measurements were taken by a bone installed under the PTO model in a different orientation than before. Watching the movement of this device it was hypothesized that F_v should be very close to 0 because none of the force coming in this direction has any effect on the displacement of the device and therefore it should not be included when calculating power generated. Another thing that was noticed while looking at the results was that the displacement measurement had a lot of noise in it. Due to this, results were filtered to ensure maximum reliability using a low pass filter before any formal power calculations were made. In this case the power calculation was done by taking

$$P = \left[\frac{F_{hm_1} + F_{hm_2}}{2}\right] \cdot \frac{\Delta d}{\Delta t}$$

Where F_{hm_1} is the horizontal force calculated from moment 1 and F_{hm_2} is the horizontal force calculated from moment 2.

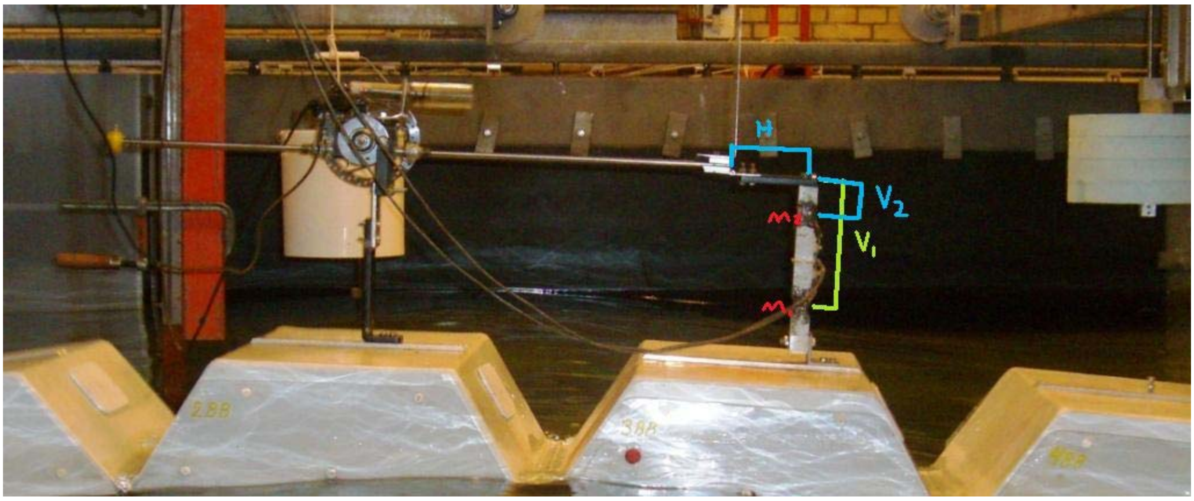


Figure 4: Relative PTO set up.

It should be noted that during all relative reference testing the WEC was anchored by one elastic band on each side of the device, this can be seen in figure 7.

3. Test Program

In both fixed reference and relative reference testing the main goal is to establish the efficiency of the device as well as an estimate for power production per year. Before testing in irregular wave states to find the power production, the optimal loading conditions on the PTO must first be found. Optimal loading conditions are found by running short 60 second tests in regular wave states similar to the irregular ones that the power production will be later calculated for. The full scale wave states used in this lab testing can be found in Frigaard et al. (2008). For lab testing these states were scaled down using a length scale of 30. The report just mentioned also contains probabilities of each wave state occurring. Using the probability of the wave state, the amount of energy per meter in each wave, and the efficiency of the device in the given wave state it is then very simple to calculate the average power production per year as well as the efficiency per year.

Sea State	**H**	**T**
	m	s
R1	.026	1.02
R2	.052	1.28
R3	.078	1.53
R4	.104	1.79
R5	.130	2.04

Sea State	**Hs**	**Tp**	**Energy Flux**	**Prob. Occur**
	m	s	W/m	%
I1	.037	1.02	.49	46.8
I2	.073	1.28	2.43	22.6
I3	.110	1.53	6.6	10.8
I4	.147	1.79	13.6	5.1
I5	.183	2.04	24.28	2.4

Figure 5: Regular (R) and irregular (I) sea states used in lab (Frigaard et al., 2008).

The numbers given in Fig. 5 represent the Danish sector of the North Sea, scaled to model scale using a length scale of 1:30. The waves chosen for the regular sea states are chosen to maintain the energy contents of the corresponding irregular waves, ie. $H = \frac{H_s}{\sqrt{2}}$

3.1. Fixed Reference

Additional tests on the fixed reference PTO set up consisted of a period analysis where the period of the waves was varied and the wave height was held constant, moving the connector arm from vertical to the angle ***x*** as seen in Fig. 6, and connecting the two middle floaters.

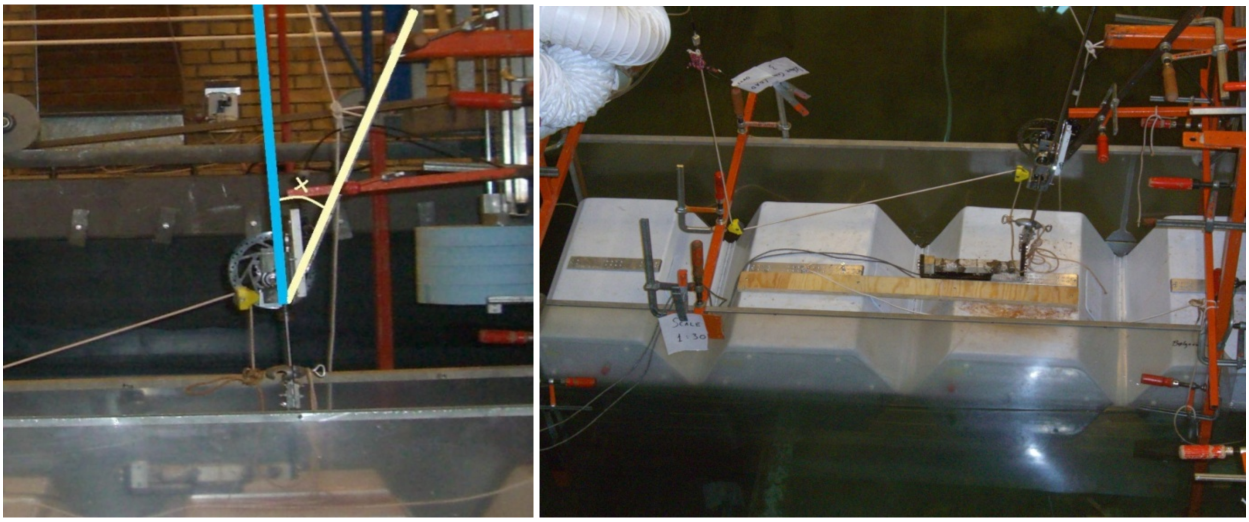


Figure 6: Left: New angle with respect to vertical on the connector arm to a fixed point. The connector arm is highlighted in tan. Right: Two middle floaters interconnected.

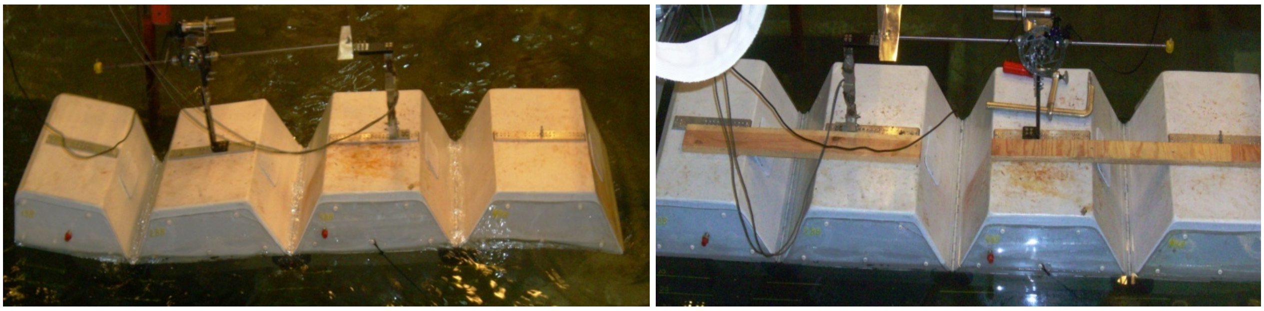
3.2. Relative Reference

There were over 244 different tests of length one minute to thirty minutes taken in relative reference testing. The overview of data gathered is shown in tables 1 and 2 below.

Regular Waves	Load Optimization & Comparison	Wave Height Analysis	Periodic Analysis	Inlet and Outlet Devices
Original	X	X	X	
Floaters Connected	X			
Floaters Connected -PTO Reversed[2]*	X	X	X	X
Floaters Connected -PTO active both ways	X			
Floaters Connected -PTO Reversed - Original Skirt Drafts			X	
Floaters Connected -PTO Reversed - Aluminum Skirt Drafts			X	X

Table 1: Regular wave state testing matrix.

The original set up referred to in Table 1 (shown in fig. 7) is the case where the floaters remain free of each other, the PTO is working in tension, and 40cm skirts are attached. It can be noticed that after a certain point all tests were performed with the two outer sets of floaters connected. This was because it was noticed very early on that connecting those sets of outer floaters greatly increased the efficiency of the device. In the wave height analysis the period is held constant and wave height varied while in the periodic analysis the wave height is held constant and the period varied.



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[2] When it is said that the PTO is working in reverse it means that the PTO is active (the load is applied) in compression. When the PTO is working "normally" it means that the PTO is active in tension.

*This set up is the same as the "Original Irregular" set up in Table 2.

Figure 7: *Left:* “Original” set up. *Right:* Floaters connected – PTO Reversed.

The original skirt drafts referred to are the plastic skirts that can be seen in Fig. 8. For testing there were lengths of 40cm, 20cm, 10cm, the mini skirt in Fig. 8, and nothing attached. To compare these skirts and the aluminum skirts a full periodic analysis was done on each one at each skirt length. This was done in order to isolate the natural frequency of the device as well as provide data on wave states near the ones shown in Fig. 5.

Figure 8: *Left:* The mini skirt referred to in the text is the metal skirt attached to the bottom of the WEC. It extends down approximately 8cm. *Right:* Original skirts extending down 40cm from the device.

For testing with aluminum skirt drafts, only a certain amount of material could be obtained so tests with 40cm skirt drafts could not be done. Instead tests with skirts of draft 30 cm, 20cm, 10cm, and nothing attached were all performed. The aluminum skirts are much lighter than the plastic original skirts and all friction between skirts is gone as well. The friction between the original skirts was never measured but it is surely greater than the aluminum, this means that at least one factor of possible error was eliminated when using aluminum skirts. The inlet and outlet devices are simple additions to the front and back of the device that are meant to keep any air from getting under it. They can be seen in Fig. 9.

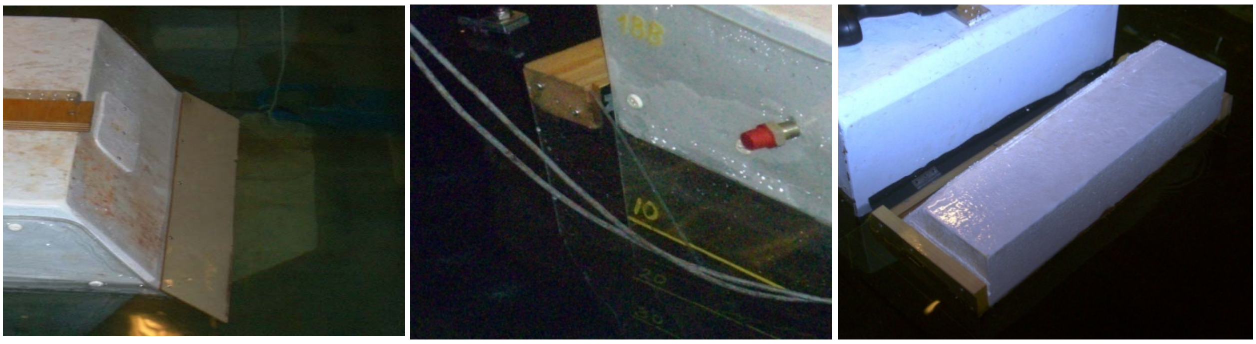

Figure 9: Both back and front attachments to the device, meant to keep it from lifting out of the water and letting air break the suction.

Irregular Waves	WS1	WS2	WS3	WS4	WS5	WS6	3D WS4
Original Irregular	X	X	X	X	X	X	
Original Irregular - No Skirts	X	X	X	X	X	X	X
Original Irregular - 10cm Aluminum Skirts	X	X	X	X	X		X

Table 2: Irregular wave state testing matrix.

The original irregular set up referred to in Table 2 corresponds to the floaters connected with PTO reversed and 40 cm skirt draft set up in the regular testing matrix. Two 3D sea state tests were performed in order to give insight to any researcher planning future testing.

4. Results

Before looking at any results it should be noted that in lower wave states, regular and irregular, the forces and displacements experienced are low enough so that electronic noise in the measurements can play a relatively large role in the results. In order to ensure good results, some of the signals were run through low pass filters. Very careful attention was given to the filtering of these results to ensure that it was done well and only when needed. Another item to be noted is that the anchoring system used in relative reference testing inhibited the movement of the second floater in wave states with lower energy content. Because of this the results for regular testing show power production jumps at two major points of resonance for the WEC; when wave length is equal to the size of the first floater and energy is sufficiently low single body resonance is achieved due to the second floater not moving and when wave length is equal to the total length of the device another two body resonance is achieved. In future testing the anchoring system should be attached to the device at its hinges or another well thought out place that does not inhibit the motion of the WEC.

4.1. Fixed Reference Results

4.1.1. Load Optimization, Regular Sea States

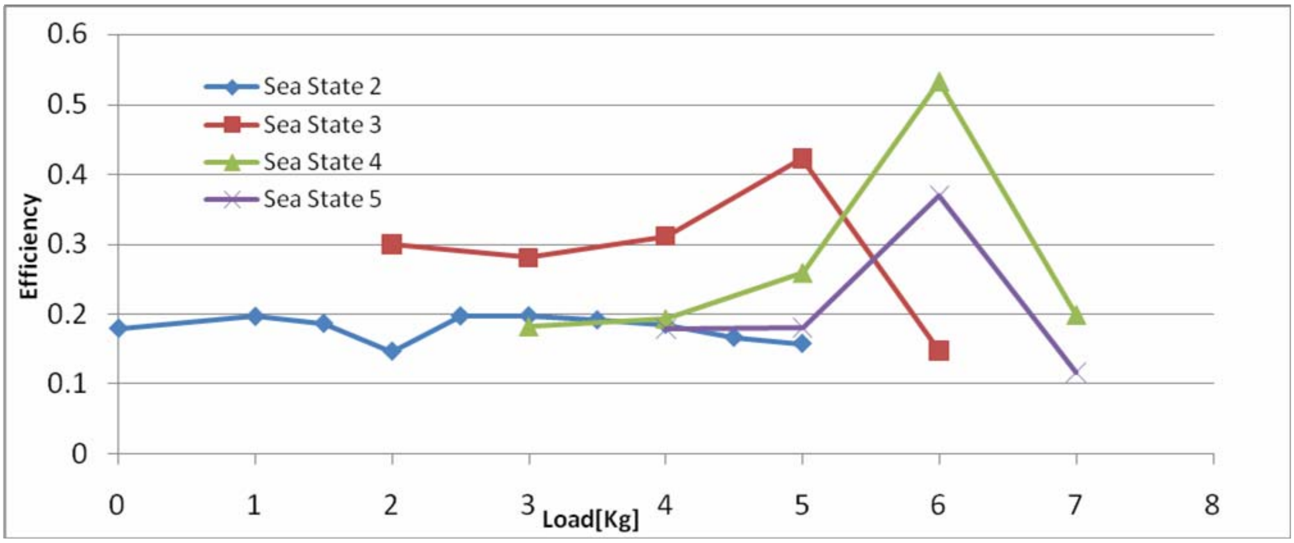

Figure 10: Optimal loading conditions for each sea state. Data can be found in Appendix A.

In regular sea state 1 (R1) no displacement was observed, this means that with this device at this scale no power can be produced in this sea state, thus the power curve for R1 is not included in this graph. Results were even a little sporadic in wave state 2 as seen in Fig. 10. The error that caused this odd looking power curve was probably the non-uniform resistance of the PTO model or electrical noise as mentioned earlier. In the next sequence of tests on this WEC the scale or size of the device should be changed as well as the PTO system redesigned for lower loads so that more power can be harvested from wave states 1 and 2 due to their high probability of occurrence. In this round of laboratory testing many uncertainties arose from the difficulty of the PTO system to provide uniform and repeatable loading conditions. As mentioned earlier it also did not have a low enough loading range to let wave state 1 and 2 reach optimal power production conditions.

4.1.2. Power Production Data

Sea State	Hs	Tp	Energy Flux	Prob. Occur	Device Efficiency	Total Annual Power Production (Full Scale)
	m	s	W/m	%	%	MWh
I1	.037	1.02	.49	46.8	0	0
I2	.073	1.28	2.43	22.6	26.8	114.6
I3	.110	1.53	6.6	10.8	19.8	109.5
I4	.147	1.79	13.6	5.1	13.0	70.2
I5	.183	2.04	24.28	2.4	24.7	112.3
I6	.220	2.30	39.34	1.4	0	0

Table 3: Power and efficiency values for The Crest Wing WEC.

In order to calculate the average annual power production tests of length 1800 seconds were run with the irregular wave states given in Table 1. The waves in irregular wave state 1 (I1) were not large enough to produce anything but noise so no power was recorded. Irregular wave state 6 (I6) was not able to be measured due to how large the forces were, when attempting to gather data in I6 all of the signals were being clipped and the forces on the bone were well over what it is meant to handle.

After gathering the data from all of the other wave states the energy flux per meter was taken and adjusted with the devices efficiency, a dimensionless constant, defined as the ratio between the average power recorded (product of force and displacement in PTO model) and the wave power arriving at the width of the device, and probability of occurrence in each wave state to give estimates on expected power production in the Danish sector of the North Sea. The average annual power production of this device is just the sum of all the values in the annual power production column, giving about 407 megawatt hours per year. As mentioned earlier this number could be increased if the scale of the tests is changed so that the real size of the WEC is smaller compared to the waves, this would help generate power in the most probable sea state which will increase the overall performance of any device. In this case the overall efficiency of the WEC across the wave states in table 3 is 15.8 percent.

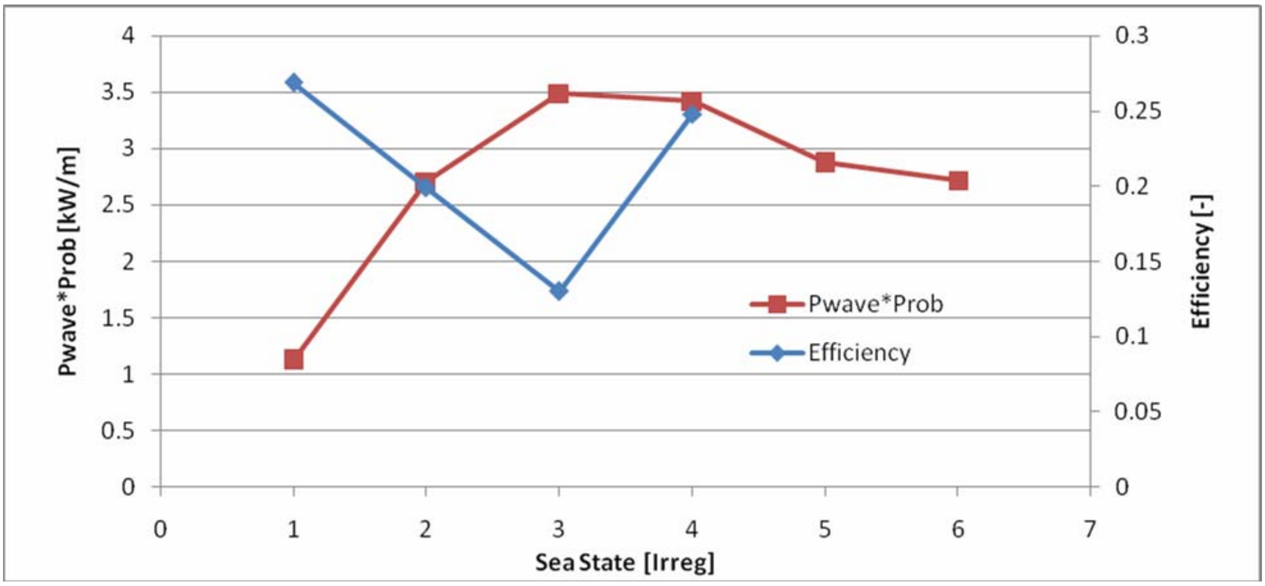

Figure 11: This graph shows the relation between the devices efficiency and the power available in each wave state. The scaling of the device can be changed to move these curves so that the power production is optimized for the set of sea states in a certain area. Data for all irregular testing can be found in Appendix B.

4.1.3. Analysis of Efficiency With Respect to Wave Period

In order to determine how efficiency is related to wave period the wave height was fixed and the period of waves was varied.

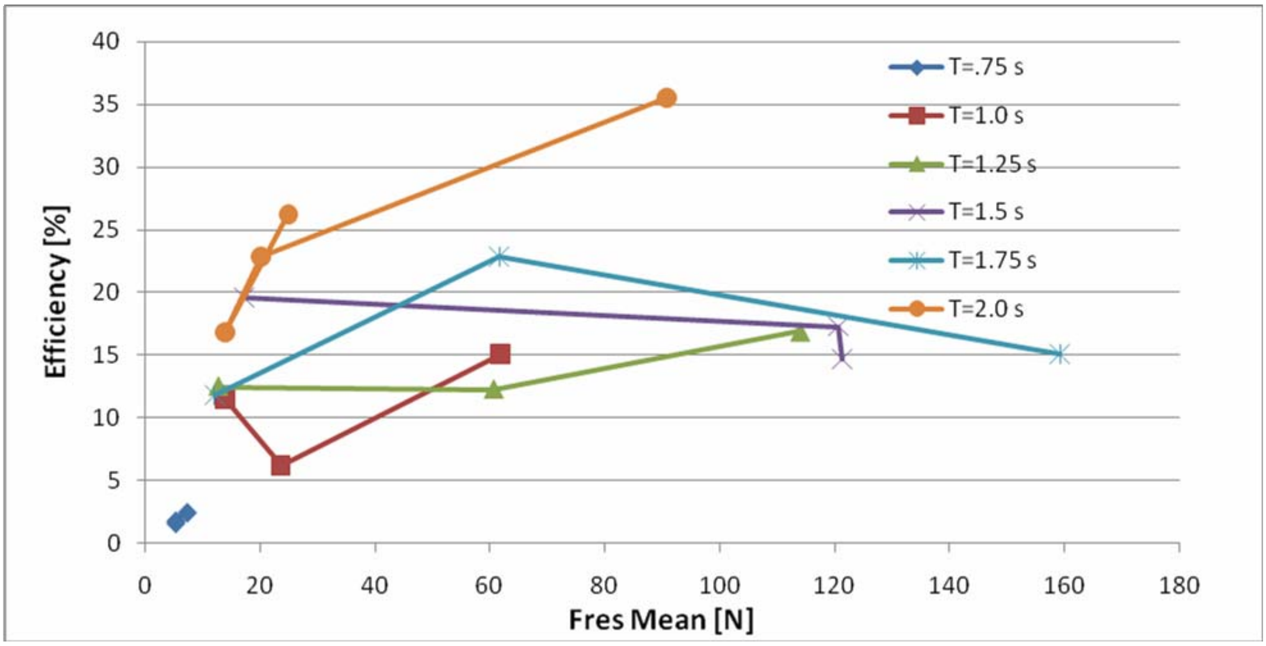

Figure 12: This graph shows a sequence of tests where the wave height was held constant at 10 cm and the period varied. Data for all supplemental testing can be found in Appendix C.

From The data on Graph 4 one can deduce that a longer period makes this device more efficient, just as expected and qualitatively observed in the lab. Fres mean is a measurement of the actual forces on the system as taken by the bone equipped with a strain gauge. It is shown in most graphs from here on because it is the true measurement of how much loading the PTO is supplying. With the current PTO system it is hard to control this number. This is one of the largest causes of error in many of the tests because in order for the tests to make sense the device must be working at maximum efficiency which means optimal loading conditions must be found and reproduced easily.

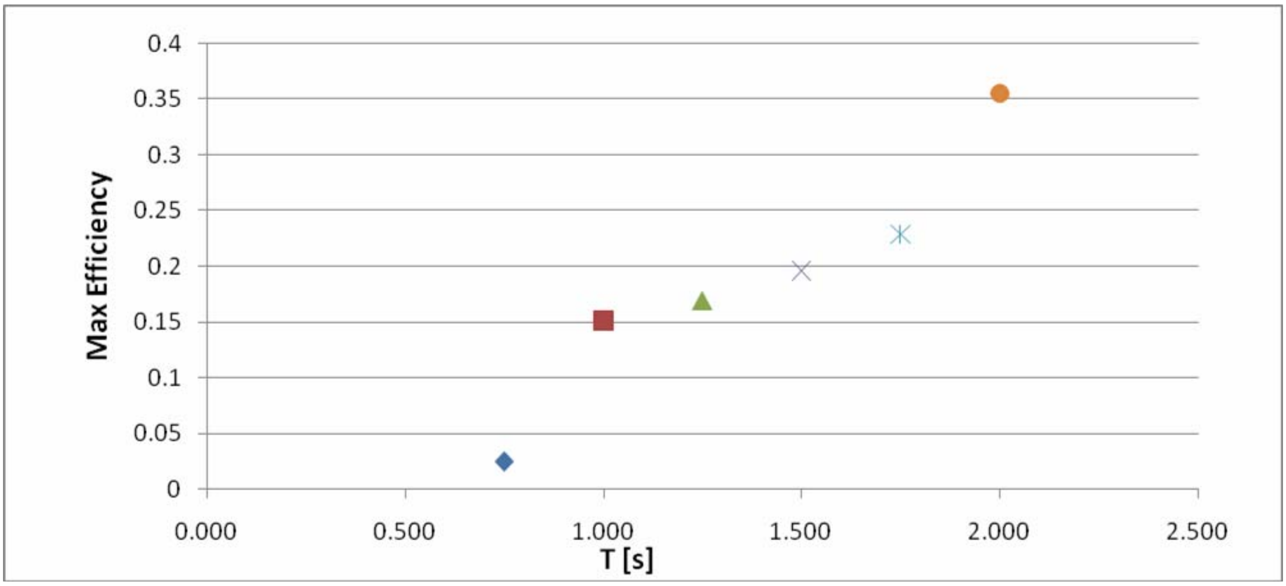

Figure 13: This graph shows the relationship between max efficiency and period at a fixed wave height of 10 centimeters with scale 1:30.

The curve in Fig. 13 will most likely not be observed in reality because if the Crest Wing is installed at full scale somewhere it will be attached to an anchoring system that floats with it as opposed to a fixed one. The curve will not keeping going up with the period, it is merely approaching the natural frequency of the anchoring system where it can produce the most power.

4.1.4. Analysis of Efficiency With Respect to Arm Angles

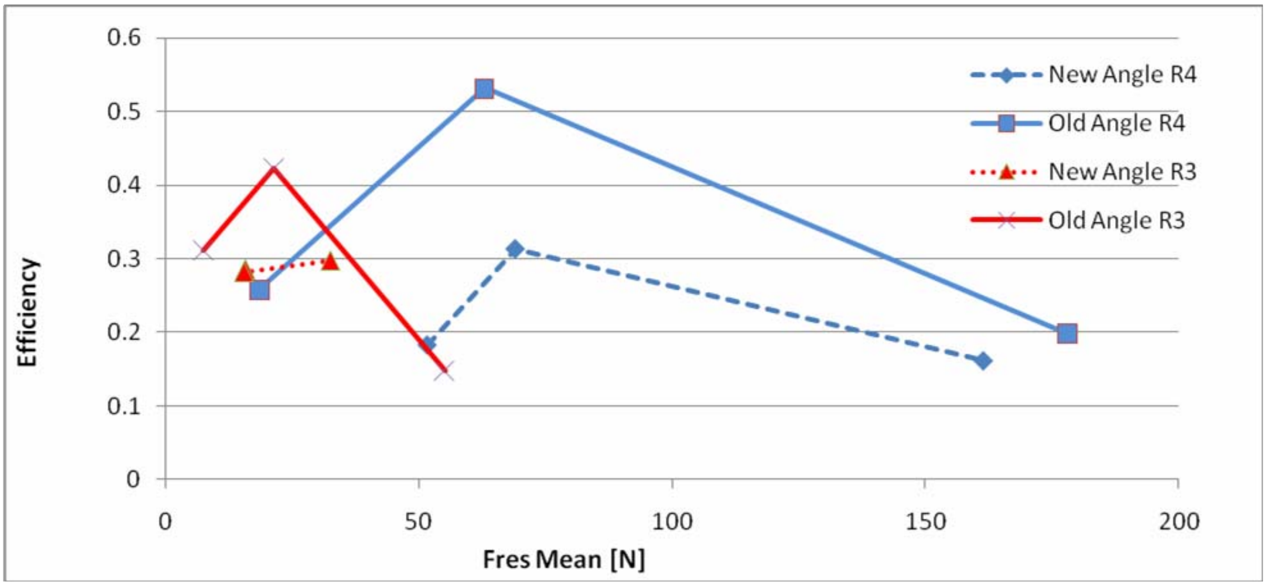

Figure 14: New arm angle refers to the change in angle x from Figure 3. Old Arm angle refers to the arm in its vertical position. The data for these graphs can be found in Appendix C.

Fig. 14 suggests that the efficiency of the device is less with the arm angled as pictured in (Fig. 6, *left)*. With the same amount of average force over the time period there is much less efficiency and therefore less power is generated. The exact angle does not matter at this stage because the one test performed was just meant to see if the results changed. Since the results did change further testing is warranted to ensure maximum efficiency of the WEC.

4.1.5. Analysis of Efficiency with Two Center Floaters Interconnected

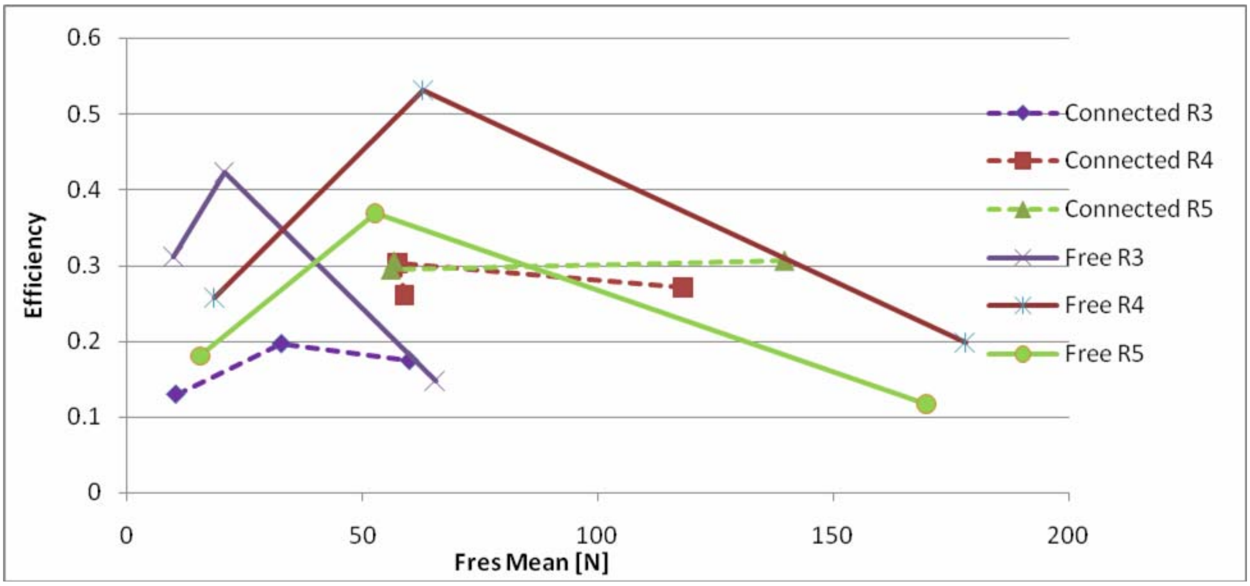

Figure 15: The data for the free sea states comes from corresponding load and sea state data from Appendix A. The data for the connected cases comes from Appendix C.

It is quite easy to see from Graph 6 that when the two center floaters are connected, the efficiency of the device is much lower. These results are complete enough so that no further testing is warranted here.

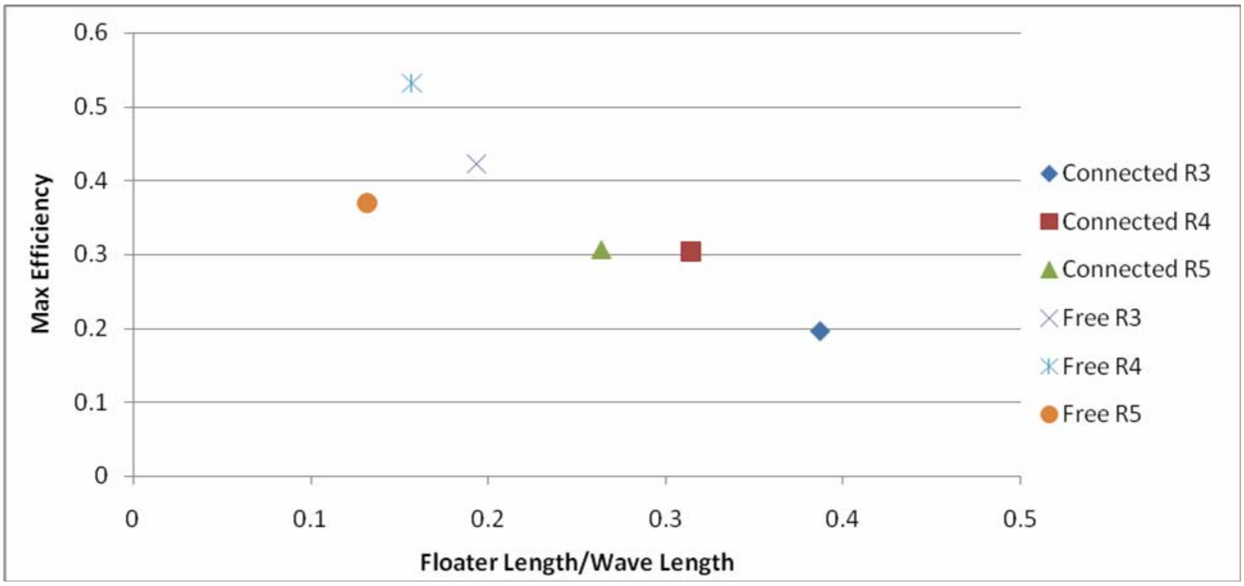

Figure 16: A comparison of max efficiency to the ratio of floater length to wave length.

The graph above shows a very clear relation between floater length and wave length. This result is only for the PTO in one position on one floater though. In order to completely discard the idea of connecting floaters in fixed reference testing, tests should be performed where the PTO is on other floaters in different positions along the device.

4.2. Relative Reference Tests

During the course of relative reference testing, the test set up was changed two times due to more efficient set ups being found. First there were 4 free floaters with 40 cm skirts, then it was noticed that if the two sets of outer floaters were fixed to each other the efficiency went up significantly. Testing with the two sets of outer floaters connected was carried out to completion and as a final test the skirts were cut down in increments of 10cm to see if they had an effect on the efficiency. After processing the data it was noticed that the floaters connected with no skirts on gave the highest efficiencies out of any set up previously tried. More tests were carried out to confirm these results and since it was confirmed that a more efficient set up had been found load optimization was done again as well as irregular testing. In the end the most efficient set up was with the floaters connected and the skirts taken completely off.

4.2.1. Load Optimization, Regular Sea States

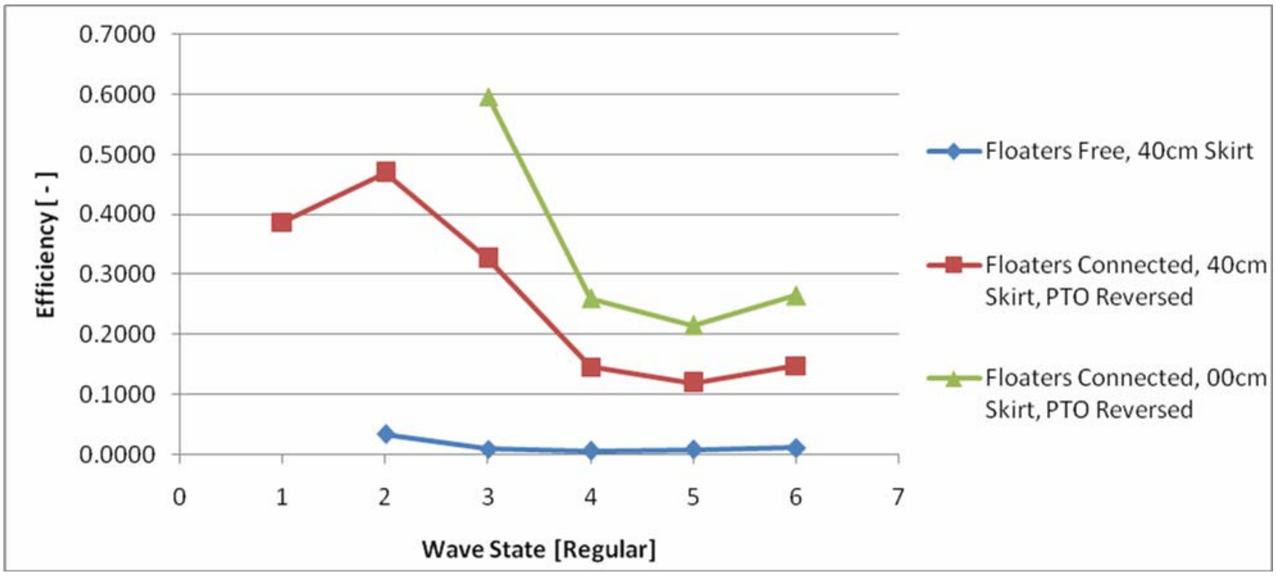

Figure 17: Maximum efficiency in each sea state shown for those set ups that were all considered at one time to be the most efficient. The data used to make this graph can be found in Appendix D.

Obviously the floaters connected with 00cm skirt and PTO reversed was the most efficient so it was the set up used to find total power production. In wave state 1 with floaters free, 40cm skirt there was no displacement in the PTO so no power was generated and the load could not be optimized. In wave states 1 and 2 on the floaters connected, 00cm skirt, PTO reversed case load optimization did not need to be done since in all other testing the efficiency was already as high as it could be with the PTO loaded minimally at 4 kilos. It is worth mentioning again that this project would seriously benefit from a PTO system that has a larger range of loading conditions and is easily manipulated into certain Fres conditions.

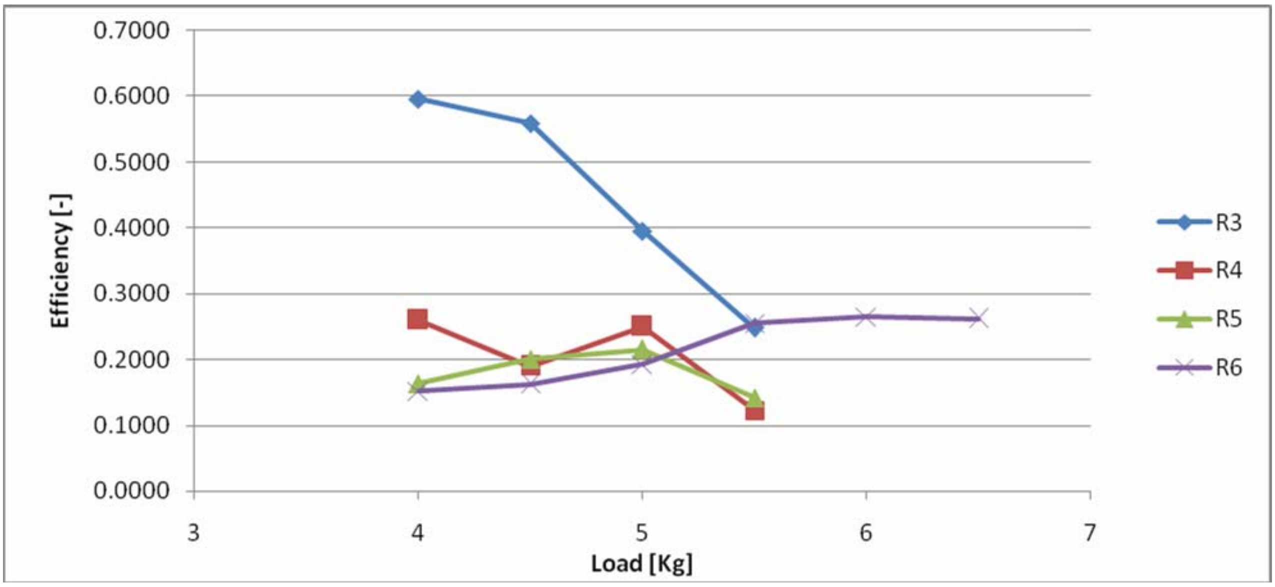

Figure 18: Load optimization for regular sea states 3-6 with floaters connected, 00cm skirt, and PTO reversed. The data used to make this graph can be found in Appendix D.

4.2.2. PTO Set up Optimization

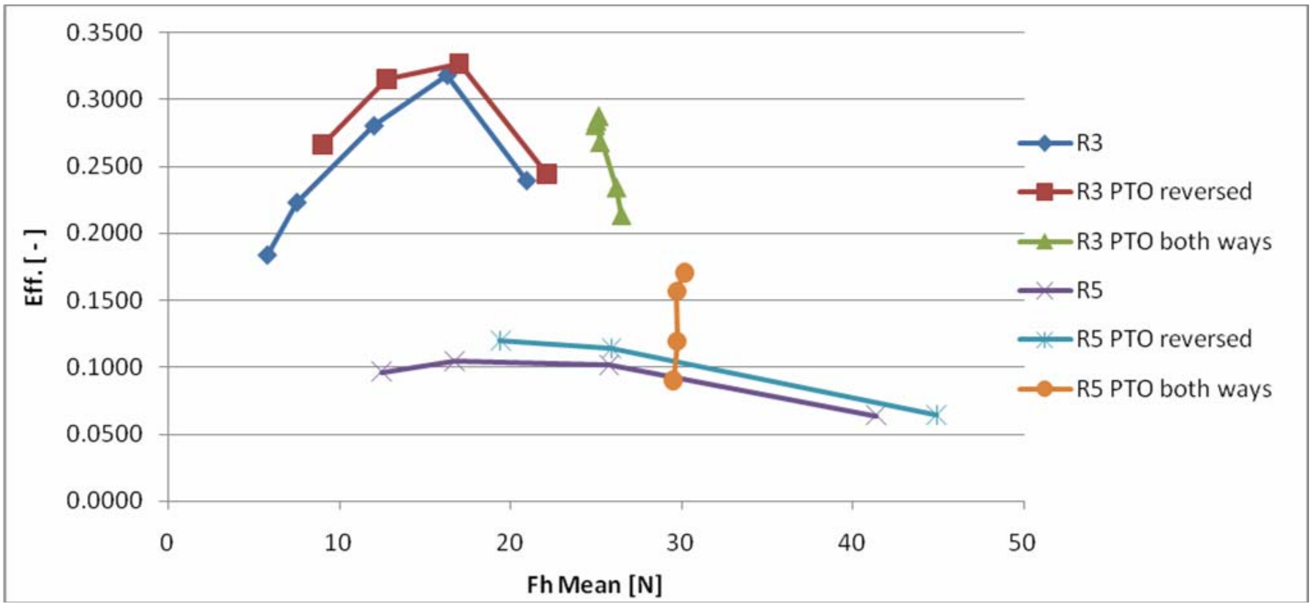

Figure 19: Comparison of different possible set ups for the PTO. The data used to make this graph can be found in Appendix D.

As described in the test program there are three different ways of setting up the PTO in relative reference testing. In the graph above the PTO reversed and “normal” situations are both very close to each other with the PTO reversed set up winning out by a small margin. The PTO reversed set up was the chosen set up for irregular testing because of this but it should be noted that it is not necessarily better than the normal situation since the difference between the two set ups is small enough that it easily lays within the accuracy of the tests. As can be seen in the graph the PTO both ways situation gives many different efficiency readings for a small range of force levels on the system. This, again, is due to the limited adjustment possibilities of the PTO. The desired loading condition for the PTO both ways tests was about half of the loading used in the other set ups, this was far below the range of the PTO in use.

4.2.3. Analysis of Efficiency with Changing Wave Height and Period

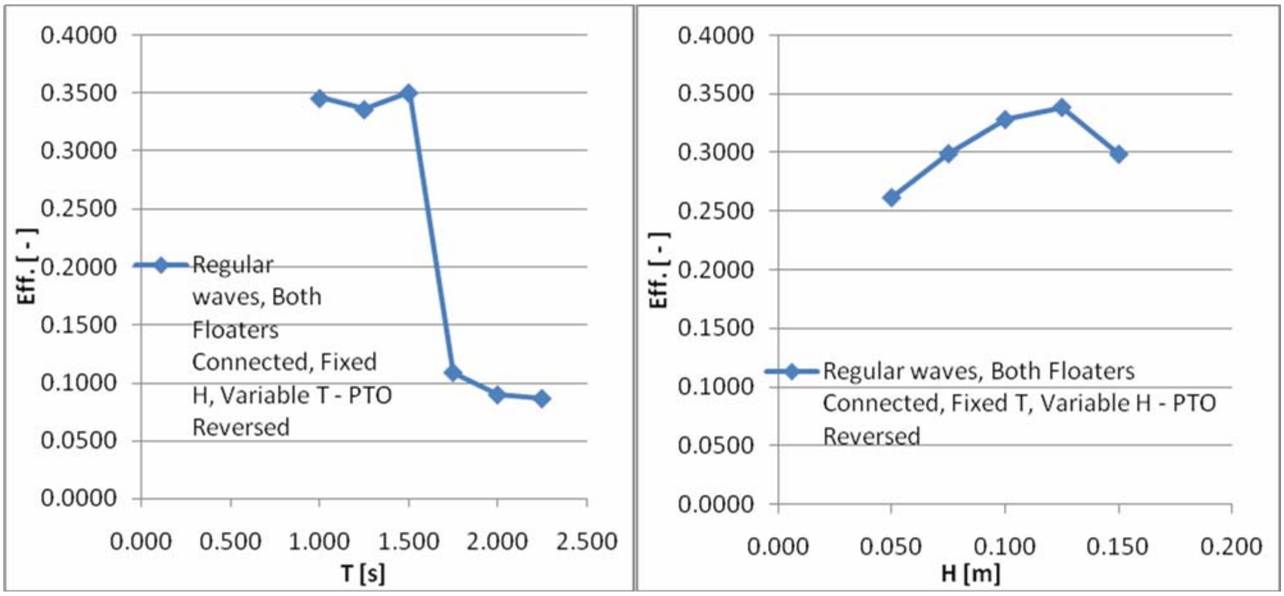

Figure 20: *Left:* Efficiency compared to changing wave period, fixed wave height: 10 cm. *Right:* Efficiency compared to changing wave height, fixed period: 1.5 seconds. Data can be found in Appendix F.

The results of both graphs shown above are the maximum efficiencies after load optimization in each different wave state. In the efficiency compared to changing wave period graph a large drop in efficiency can be seen between 1.5 and 1.75 second periods. This could be because at 1.5 second period the wave length is approximately equal to twice the size of one connected floater of the WEC. Thus, wave period is at one of the natural frequencies of the WEC spoken about earlier and the efficiency here should be one of the highest since resonance is found easily in regular wave states. However, this result alone does not suffice to explain the large drop in efficiency between the two periods. In theory it should be a much less dramatic change but in the same overall direction.

In the changing wave height fixed period graph the relation shown also needs some explanation. In theory the device should be less efficient the larger the waves get but once again there was too much internal resistance in the PTO so the states with less energy could not be fully optimized in the smaller wave heights.

4.2.4. Analysis of the Effects of Skirt Drafts

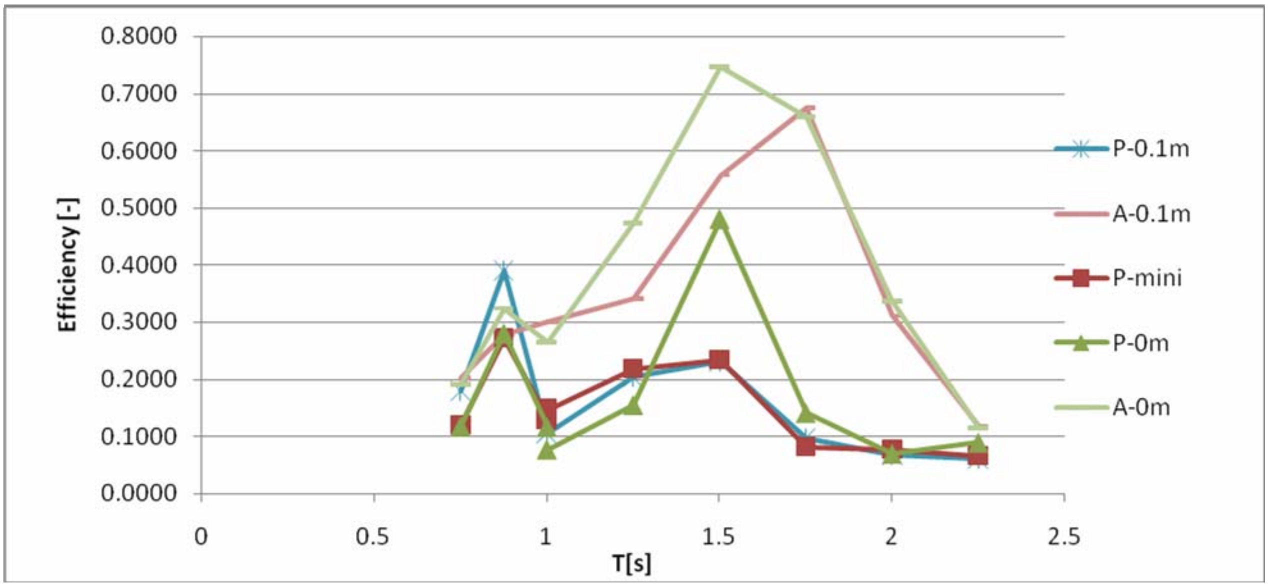

Figure 21:Data for the affect of skirts on the Crest Wing WEC's efficiency. All points to the left of 1 second have a wave height of .075m and all points to the right have a wave height of .1m. P denotes plastic skirts and A denotes aluminum skirts. The data used to make this graph can be found in Appendix F.

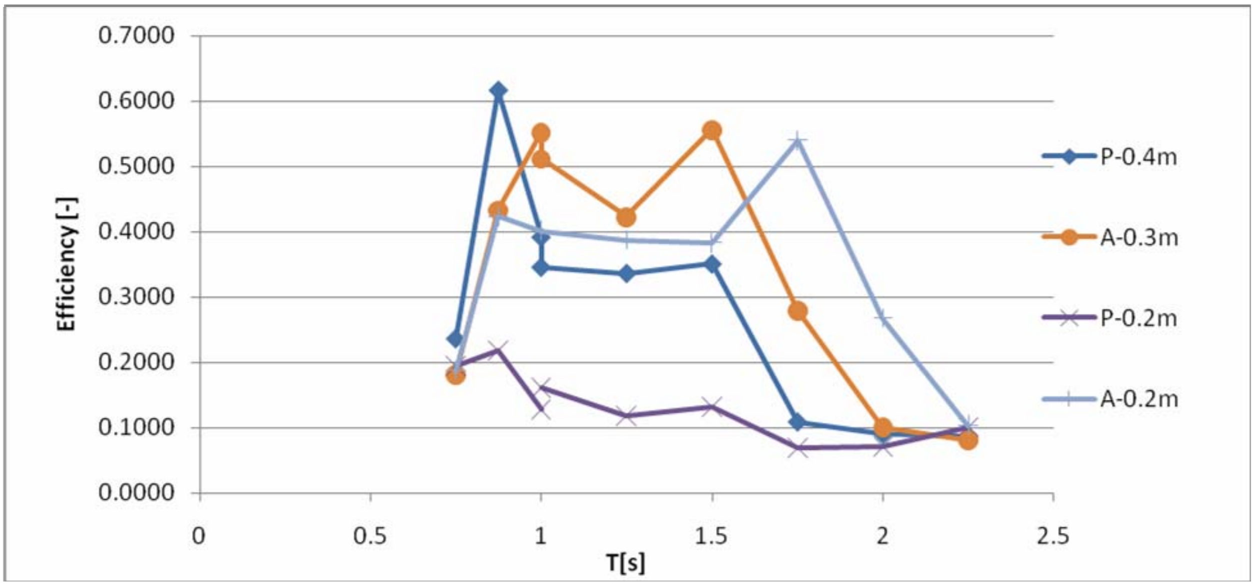

Figure 22:Data for the affect of skirts on the Crest Wing WEC's efficiency. All points to the left of 1 second have a wave height of .075m and all points to the right have a wave height of .1m. P denotes plastic skirts and A denotes aluminum skirts. The data used to make this graph can be found in Appendix F.

The data taken here suggests that there is more than one force changing when the skirts are changed. The skirts are supposed to have a positive effect on the movement of the device because they create a suction to the water surface, however another well known force is present that was not considered until now. As a wave runs down the device, the parts running alongside it (as opposed to those running under it) turn in to the device to compensate for the energy lost in the part of the wave under the device. When the skirt drafts are present no energy can be drawn from this, but when the skirt drafts are absent it seems that this energy is at least partially tapped. As the skirt drafts are decreased in size the amount of contribution from the bending effect is increased while the positive contribution from the skirts is decreased. To explain the non-linearity within each curve, note that Fig. 21 shows two major peaks at periods around .8 seconds and 1.5 seconds for each curve. These periods correspond to wavelengths that allow the WEC to oscillate at its natural frequencies, maximizing force and displacement. Because of these two interacting forces it is hard to predict how the Crest Wing will act with a certain size of skirt. Because of this, irregular tests were run with three different set ups; 40cm plastic skirts, 10cm aluminum skirts, and no skirts at all (00cm). The results of these irregular tests are given in the next section.

4.2.5. Power Production Data, Irregular Wave States

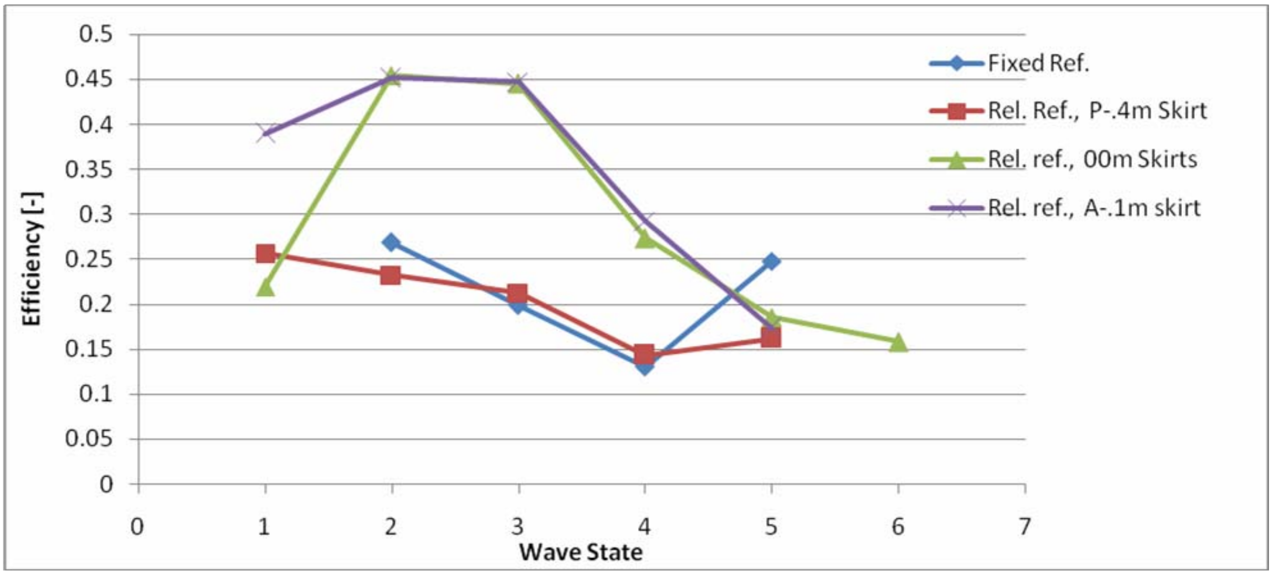

Figure 23: This graph is a comparison of all irregular testing done on this device. In all three relative cases the PTO is reversed and the outer sets of floaters are connected. The data used to make this graph can be found in Appendix E.

The results are not so clear, but it seems that the Crest Wing WEC functions better in irregular wave states with smaller or no skirt drafts. It is good to see that, regardless of skirts, the relative PTO can be just as efficient as the fixed reference for it is much easier to install a floating internal reference device than one that needs a fixed point to produce power.

Sea State	**Hs**	**Tp**	**Energy Flux**	**Prob. Occur**	**Device Efficiency**	**Total Annual Power Production (Full Scale)**
	m	s	W/m	%	%	MWh
I1	.037	1.02	.49	46.8	0.2193	38.74
I2	.073	1.28	2.43	22.6	0.4544	193.8
I3	.110	1.53	6.6	10.8	0.4452	245
I4	.147	1.79	13.6	5.1	0.2733	147.3
I5	.183	2.04	24.28	2.4	0.1855	84.03
I6	.220	2.30	39.34	1.4	0.1580	67.6

Table 4: Power production values for the Crest Wing WEC with outer floaters interconnected, PTO reversed, and 00cm skirt.

All power calculations were performed in exactly the same way as before. The efficiency of the WEC under these new conditions is 30.2 percent.

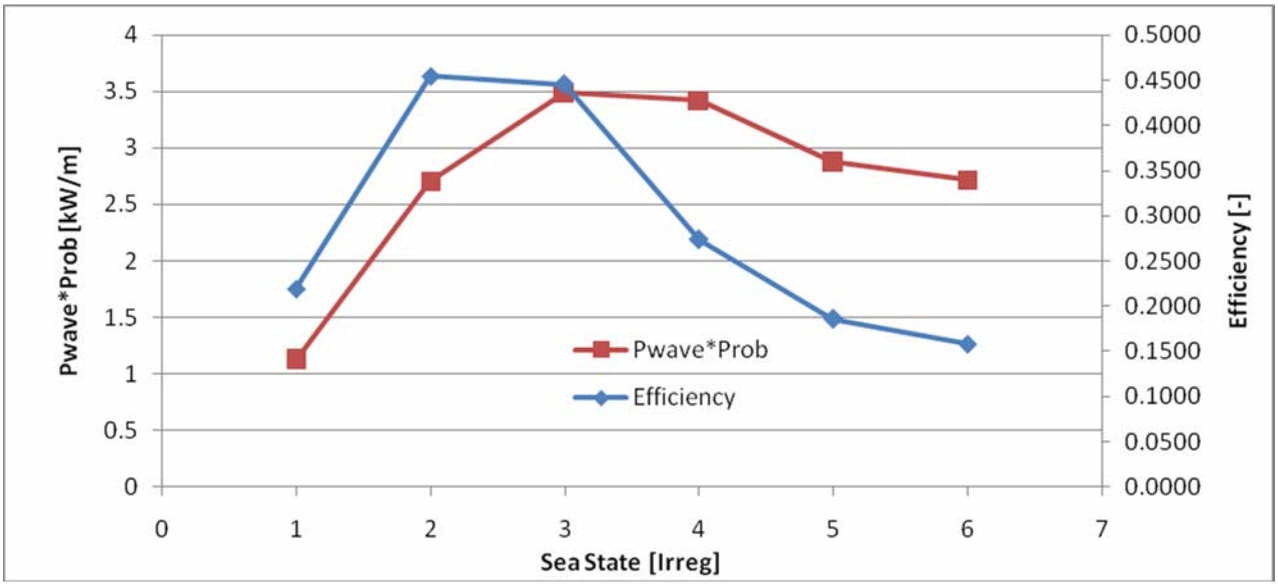

Figure 24: This graph shows the relation between the devices efficiency and the power available in each wave state.

4.2.6. Inlet and Outlet Devices

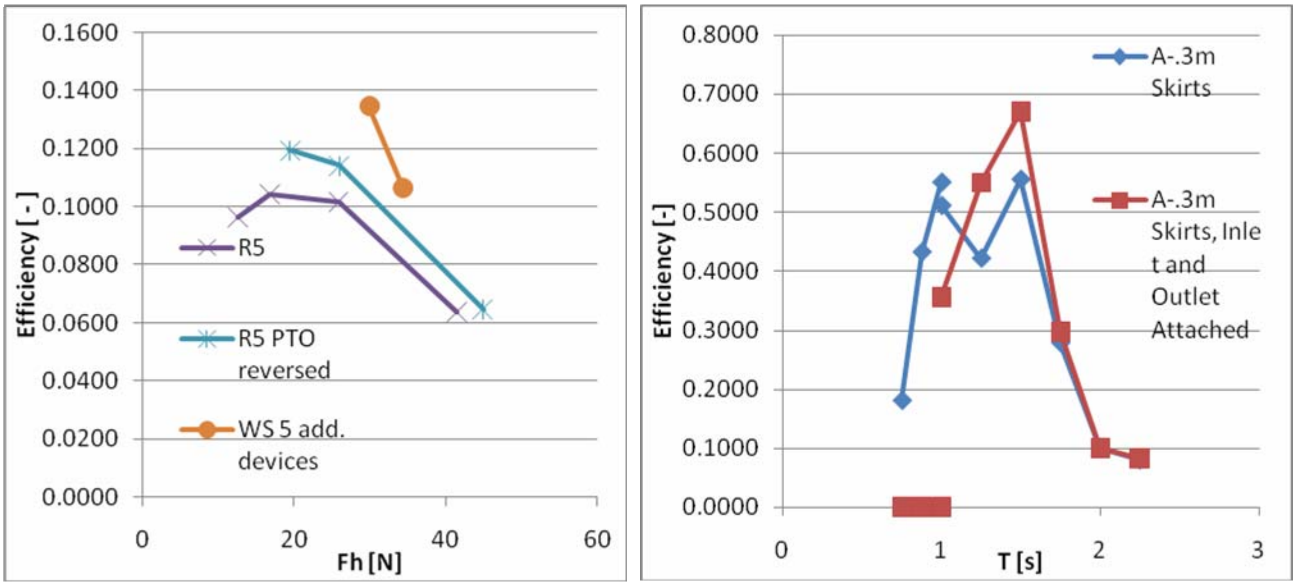

Figure 25: Data from the tests with front and back attachments to the WEC as seen in Fig. 9. The data used to make these graphs can be found in Appendix D.

The data provided in Fig. 25 suggests that inlet and outlet devices on the Crest Wing do increase the power production. In Fig. 25 (right) there was no displacement in the PTO below and at a period of 1 second. This was partly because the inlet device was absorbing most of the energy in the waves and not passing it on in a productive way to the rest of the WEC. This result does not need to be considered though because when things are scaled up it turns out that waves of period less than 1 second (model scale) have an extremely low probability of occurrence for the seas being testing for. Finally, these results suggest that in the future much more testing should be done on inlet and outlet devices and their combinations with different skirt lengths in order to further investigate the potential of such changes.

4.2.7. Three Dimensional Wave States

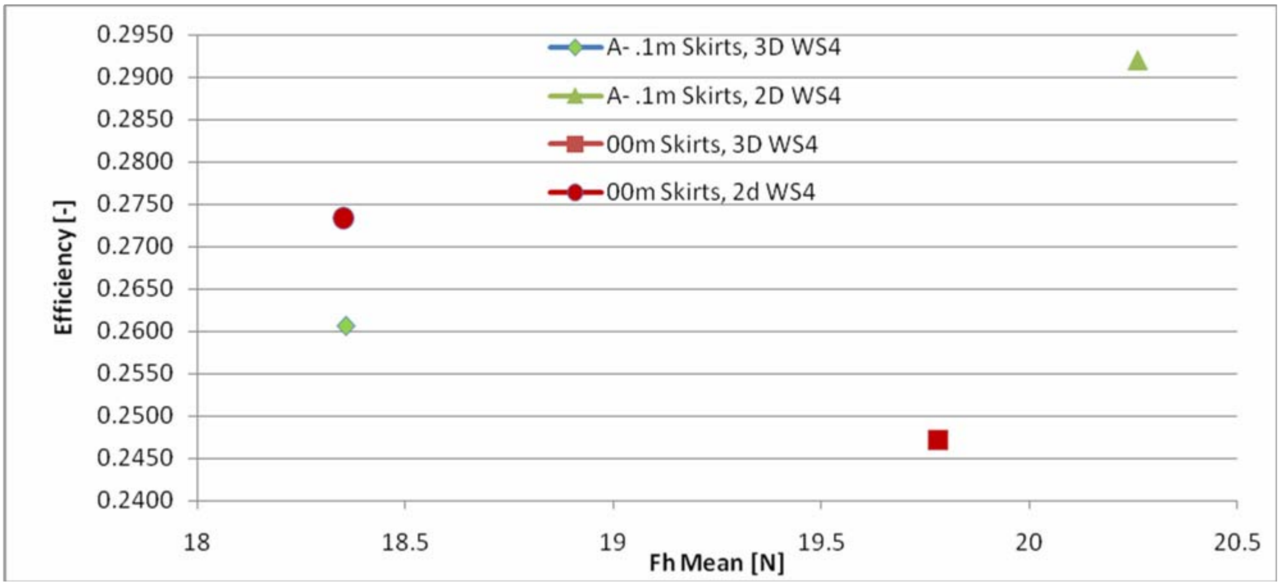

Figure 26: 3D Irregular wave state data (spreading 40) versus corresponding 2D irregular wave state data.

In the final days of testing it was decided that a few 3D wave states should be tested in order to assess the Crest Wing's ability to deal with waves coming from more than just one direction. Both 3D tests have slightly lower efficiency than their corresponding 2D tests but not by much. This suggests a promising outcome of a full span of 3D testing when the time comes.

4.2.8. Repeatability

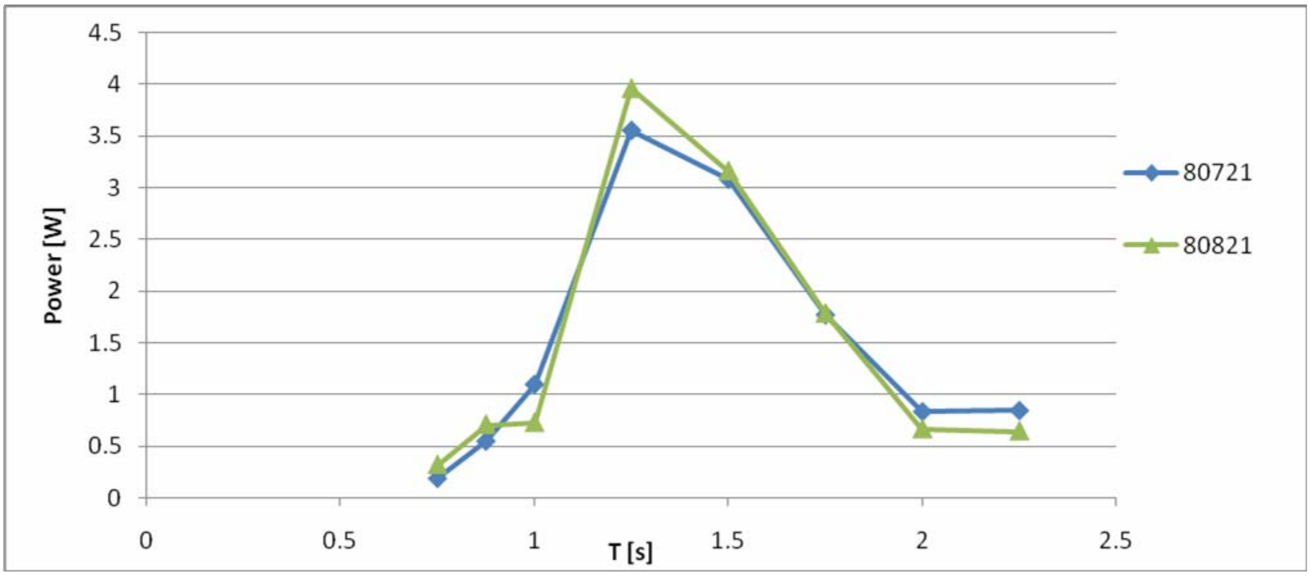

Figure 27: Two identical testing runs with the same device performed one month apart for repeatability statistics.

Even though optimization in low wave states, electronic noise, and other equipment short comings caused some problems in testing, repeatability of tests was quite good. Fig. 27 indicates that there can be a relatively high level of trust placed on the results obtained in testing throughout the test period.

5. Conclusions

From examination of the results presented in Section 4 the following conclusions have been drawn:

- It has been experienced throughout the tests that the control of the loading on the PTO model has not been as good as intended. This has lead to inaccuracies and sometimes made it hard to compare across various performed tests, as it sometimes has been hard to establish exact same loading conditions. Furthermore, due to internal friction in the PTO model the minimal obtainable loading has not been low enough to identify the optimal loading for the smallest wave states. However, in spite of these short comings it has been seen that repeatability of performed tests have been reasonable, max. 15 % deviation, typically far less.

- Through the comparison between tests using fixed and relative references for the PTO it has been found that the later is by far superior. For the best configuration using fixed reference, an overall efficiency of 15.8 % has been found, while the corresponding value for the relative reference tests has been found to 30.2 % (version with no skirts). Please note that these efficiencies does not include the losses in the PTO, generators etc – it is the efficiency of the conversion of the wave power into mechanical power available to the PTO.

- During the tests relative reference it has been found that optimal performance was obtained for a configuration with the two foremost and the two rear floaters interconnected. In this configuration the peak performance is found at a wave period of roughly 1.5 s (model scale), which corresponds to a wave length of 2 times the length of two interconnected floaters, where resonance is expected to occur. In the chosen model scale this wave period roughly corresponds to wave state between 2 and 3. Since these wave states statistically contributes the most to the average available wave power, this scale has been well chosen, when focusing on obtaining maximum overall efficiency of the device.

- One of the main features of the Crest Wing concept is the idea of equipping the floaters with skirts to increase the effective weight of the floaters (the skirts will force a large amount of the water to move along with the floaters). However, surprisingly it was found that reducing the skirt draft did not consequently reduce the efficiency, but rather the opposite. To investigate if this effect was due to the change in weight associated with the cutting off of the skirts, additional tests where carried out with light weight skirts, minimizing this effect. Again, no clear trend was obvious. It is concluded that the presence of the skirts have two effects changing the power production in opposite directions – the skirts will tend to make the floaters follow the waves more closely, which typically will lead to increased power production, but at the same time the presence of the skirts obstructs diffraction of the waves along the structure, and hereby the device “misses” some energy that is available when no or small skirts are present.

- Three different PTO direction setups where tested in the relative reference tests. Two where the PTO was only active on one direction (tension or compression), and one where it was active in both. For the two one direction setups no significant difference was seen. However, the compression setting (also denoted ‘reversed’) was slightly superior, and there used in most of the performed tests. In the ‘both way’ setting, the loading on the PTO model could not be made small enough to establish the optimal loading (due to the internal friction), which is expected to near half of the one for the ‘one way’ settings.

- A few tests were performed looking at the effect of having minor inlet/outlet devices attached to the front and rear of the device. It was found that for the tested configurations with skirts attached the inlet/outlet devices has a positive effect.
- A few tests with directional wave spreading were performed, indicating some decrease of the power production relative to pure 2-D waves. The decrease amounted to roughly 10 % for large directional spreading.

In summary the Crest Wing functions and is able to produce power with a good overall efficiency. The configuration with relative reference PTO is superior. It has not been proven that the idea of mounting skirts on the floaters is leading to a better performance.

Thus, the study leads to the conclusion that the idea of making a simple hinged raft type device is good, and it is likely that the construction cost for a device of this type can be kept down. However, the study also leaves the chance that some limited draft of skirts in combination with inlet/outlet devices, could prove beneficial.

In case of further testing on this device, an effort should be made to design and construct a more easily and accurately controlled PTO model in the test setup. This could greatly improve the quality of the output of such tests.

References

Frigaard, Kofoed , and Nielsen: Assessment *of Wave Energy Devices. Best Practice as used in Denmark*. World Renewable Energy Congress (WREC X), Glasgow, UK. July, 2008.

Appendix A- Regular Testing, Load Optimization- Fixed Ref.

For all tests:

Water Depth =.675 m
Skirt Draft = .4 m

Wave cond	Load [kg]	Meas. H [m]	P_wave [W	FresMean [N]	FresStDev [N]	P [W]	Eff. [-]
1	2	0.017	0.3	2.102	1.09	0.06	0.306
2	0	0.046	3.4	6.603	3.63	0.36	0.179
2	1	0.046	3.4	6.415	3.67	0.39	0.196
2	1.5	0.047	3.5	6.673	4.01	0.38	0.186
2	2	0.045	3.1	13.85	13.72	0.27	0.146
2	2.5	0.047	3.4	6.976	4.16	0.4	0.197
2	3	0.046	3.4	6.705	4.37	0.39	0.197
2	3.5	0.046	3.4	7.087	4.22	0.38	0.191
2	4	0.047	3.5	7.189	5.02	0.38	0.184
2	4.5	0.046	3.4	9.543	8.35	0.33	0.166
2	5	0.046	3.2	15.45	15.01	0.3	0.157
3	2	0.071	9.3	8.608	6.42	1.66	0.3
3	3	0.074	10.3	8.367	6.2	1.72	0.28
3	4	0.074	10.5	9.736	7.41	1.95	0.311
3	5	0.075	10.7	20.57	21.36	2.71	0.422
3	6	0.076	11.3	65.46	55.11	1	0.147
4	3	0.104	25.9	10.74	6.84	2.82	0.181
4	4	0.104	26	10.88	7.21	3	0.192
4	5	0.105	26.3	18.51	17.09	4.08	0.258
4	6	0.109	25.7	62.9	58.9	8.19	0.531
4	7	0.113	23.4	178.1	121.3	2.79	0.198
5	4	0.106	27.5	11.64	8.36	2.94	0.178
5	5	0.106	27.6	15.41	14.24	2.99	0.18
5	6	0.106	28.2	52.61	51.8	6.26	0.369
5	7	0.105	29.6	169.8	118.93	2.07	0.116

Appendix B- Irregular Sea States Data, Fixed Ref.

For all tests:

Water Depth =.675 m
Skirt Draft = .4 m

Wave cond.	Load [kg]	Meas. H [m]	P_wave [W]	FresMean [N]	FresStDev [N]	P [W]	Eff. [-]
1	0	0.018	0.2	57.46	9.1	0	0
2	2	0.044	1.2	13.53	10.72	0.18	0.268
3	2	0.101	7.6	14.93	16.85	0.82	0.18
3	3	0.102	7.7	10.15	6.86	0.68	0.148
3	4	0.103	7.6	11.82	6.91	0.73	0.158
3	5	0.103	7.8	19.26	19.35	0.94	0.198
4	5	0.137	16.2	12.17	7.99	1.26	0.13
5	4	0.164	25.9	27.4	29.55	2.77	0.178
5	4.5	0.164	26	48.73	51.08	3.41	0.218
5	5	0.165	26.2	111.7	97.19	3.89	0.247
5	6	0.165	26.3	103.6	97.13	3.27	0.207

Appendix C-Supplemental Testing Data, Fixed Ref.

For all tests:

Water Depth =.675 m
Skirt Draft = .4 m

New Angles on Arm							
Regular waves							
Wave cond.	Load [kg]	Meas. H [m]	P_wave [W]	FresMean [N]	FresStDev [N]	P [W]	Eff. [-]
3	4.5	0.07	9.09	15.79	14.98	1.55	0.285
3	5	0.072	9.09	15.53	14.78	1.53	0.281
3	5.5	0.072	9.09	32.59	32.76	1.62	0.297
4	5.5	0.108	23.49	51.7	49.02	2.58	0.183
4	6	0.111	24.8	69.07	63.44	4.67	0.313
4	6.5	0.111	25.29	161.48	125.87	2.45	0.161

Two middle floaters interconnected							
Regular waves							
Wave cond.	Load [kg]	Meas. H [m]	P_wave [W]	FresMean [N]	FresStDev [N]	P [W]	Eff. [-]
3	4.5	0.075	9.95	10.27	5.98	0.77	0.129
3	5	0.077	10.32	32.74	32.22	1.21	0.196
3	5.5	0.076	10.33	59.98	52.44	1.08	0.174
4	5.5	0.109	24.33	58.87	55.57	3.8	0.26
4	6	0.109	24.22	57.35	56.28	4.4	0.303
4	6.5	0.112	26	118.26	107.95	4.22	0.27
5	5.5	0.11	24.785	56.69	58.34	4.53	0.305
5	6	0.108	26.66	56.01	60.28	4.71	0.294
5	6.5	0.107	26.26	139.67	119.83	4.82	0.306

Floaters back to regular

Regular waves, Fixed Height, VariablePeriod

Inp. H [m	Inp. T [s]	Load [kg]	Meas. H [m]	P_wave [W	FresMean [N]	FresStDev [N]	P [W]	Eff. [-]
0.100	0.750	5	0.094	6.2	7.35	4.75	0.09	0.024
0.100	0.750	5.5	0.094	6.13	5.3	3.04	0.06	0.018
0.100	0.750	6	0.097	6.55	5.3	3.46	0.06	0.016
0.100	1.000	5	0.093	9.08	13.95	13.81	0.62	0.114
0.100	1.000	5.5	0.092	8.83	23.66	34.9	0.32	0.061
0.100	1.000	6	0.093	8.94	61.95	71.63	0.81	0.15
0.100	1.250	5	0.103	14.84	12.66	13.18	1.11	0.125
0.100	1.250	5.5	0.105	15.38	60.65	54.86	1.13	0.122
0.100	1.250	6	0.105	15.35	114.06	86.97	1.55	0.168
0.100	1.500	5	0.0977175	16.46	17.3	13.77	1.94	0.196
0.100	1.500	5.5	0.09914	16.7	120.7	96.8	1.73	0.173
0.100	1.500	6	0.098865	16.72	121.38	98.34	1.47	0.146

Appendix D- Regular Testing, Load Optimization- Relative Ref.

For all tests:

Water Depth =.675 m

Regular waves, Floaters Not Connected, 40cm Plastic Skirt							
Wave cond.	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
2	4	0.059	2.5	1.38	1.74	0.05	0.034
2	4.5	0.059	2.5	1.12	2.39	0.05	0.030
2	5	0.059	2.5	1.48	1.99	0.03	0.020
3	4	0.102	9.3	1.96	1.44	0.05	0.009
3	4.5	0.1	8.8	2	1.72	0.04	0.007
3	5	0.1	8.8	3.12	2.03	0.05	0.010
4	4	0.137	19.6	1.77	1.36	0.04	0.003
4	4.5	0.137	19.6	2.11	1.48	0.04	0.003
4	5	0.137	19.5	5.4	2.51	0.08	0.007
5	4	0.14	22.3	1.83	1.19	0.05	0.003
5	4.5	0.14	22.4	2.38	1.71	0.04	0.003
5	5	0.14	22.5	7.68	3.00	0.11	0.008
6	4	0.133	20.5	2.27	1.50	0.09	0.007
6	4.5	0.133	20.7	4.16	2.61	0.08	0.006
6	5	0.133	20.7	6.27	3.55	0.14	0.011

Regular waves, Both Floaters Connected, 40 cm Plastic Skirt							
Wave cond.	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
3	4	0.099	8.6	5.83	2.95	0.96	0.184
3	4.5	0.099	8.6	7.57	4.64	1.16	0.223
3	5	0.1	8.9	12.07	10.84	1.51	0.280
3	5.5	0.102	9.1	16.35	12.48	1.75	0.318
3	6	0.098	8.4	20.99	16.75	1.21	0.239
5	5	0.137	21.1	12.49	9.64	1.22	0.096
5	5.5	0.142	22.8	16.78	12.80	1.43	0.104
5	6	0.141	22.8	25.8	19.69	1.39	0.101
5	6.5	0.142	22.9	41.42	29.55	0.88	0.064

Regular waves, Both Floaters Connected- PTO Reversed, 40cm Plastic Skirt							
Wave cond.	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
1	4	0.032	0.5	4.45	3.00	0.13	0.388
1	4.5	0.031	0.5	5.15	2.69	0.12	0.381
2	4	0.066	3.1	8.29	4.87	0.87	0.469
2	4.5	0.067	3.2	9.71	6.17	0.78	0.398
2	5	0.067	3.2	11.79	8.43	0.63	0.323
2	5.5	0.067	3.2	13.8	9.30	0.44	0.227
3	4	0.099	8.6	9.05	5.16	1.38	0.266
3	4.5	0.098	8.5	12.79	10.86	1.61	0.315
3	5	0.1	8.8	17.01	13.85	1.72	0.326
3	5.5	0.099	8.6	22.14	17.53	1.27	0.244
3	6	0.1	8.9	34.14	27.10	0.56	0.104
4	4	0.139	20.1	9.85	5.41	1.23	0.102
4	4.5	0.14	20.3	13.70	8.90	1.53	0.125
4	5	0.14	20.2	20.66	15.19	1.77	0.146
4	5.5	0.14	20.3	25.74	18.67	1.27	0.104
4	6	0.14	20.2	37.63	27.65	0.62	0.051
5	5	0.14	22.4	19.41	14.29	1.61	0.120
5	5.5	0.141	22.7	25.91	21.16	1.56	0.114
5	6	0.142	22.7	44.92	31.29	0.88	0.064
6	5	0.138	22.5	17.04	14.21	1.92	0.141
6	5.5	0.138	22.6	24.52	19.63	2.02	0.149
6	6	0.137	21.9	40.47	31.92	1.64	0.125

Regular waves, Both Floaters Connected- PTO Working Both Ways, 40cm Plastic Skirt							
Wave cond.	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
3	1	0.1	8.9	25.22	8.17	1.44	0.268
3	2	0.098	8.5	25.15	8.51	1.48	0.288
3	2.5	0.099	8.7	24.95	8.60	1.47	0.281
3	3	0.097	8.4	25.02	8.80	1.43	0.284
3	3.5	0.097	8.3	26.19	8.76	1.18	0.234
3	4	0.096	8.2	26.49	9.03	1.05	0.214
5	2.5	0.139	21.5	30.17	10.39	2.21	0.171
5	3	0.139	21.83	29.73	10.33	2.05	0.156
5	3.5	0.141	22.7	29.74	11.87	1.62	0.119
5	4	0.139	21.8	29.53	13.96	1.18	0.090

Regular waves, Both Floaters Connected- PTO Reversed- Additional Devices, 40cm Plastic Skirt								
Wave cond.	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]	
5	4.5	0.155	26.9	29.86	18.22	2.18	0.135	
5	5	0.151	25.4	34.36	20.96	1.63	0.106	

Regular Testing, PTO Reversed, Floaters Connected, 00cm Plastic Skirt							
Wave cond.	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
3	4	0.101	9	20.80	9.87	3.25	0.596
3	4.5	0.103	9.2	24.93	14.37	3.11	0.559
3	5	0.102	9.2	29.53	19.44	2.19	0.395
3	5.5	0.103	9.3	30.25	21.89	1.38	0.248
4	4	0.135	18.6	19.29	8.56	2.91	0.260
4	4.5	0.135	18.6	24.76	12.43	2.13	0.190
4	5	0.135	18.7	32.11	17.43	2.82	0.250
4	5.5	0.134	18.3	34.75	22.87	1.36	0.123
5	4	0.162	29.7	19.68	8.89	2.92	0.163
5	4.5	0.161	29.1	22.37	12.56	3.51	0.201
5	5	0.161	29.4	28.27	17.06	3.80	0.215
5	5.5	0.159	28.2	33.78	23.00	2.40	0.142
6	4	0.177	37	16.49	9.29	3.38	0.152
6	4.5	0.178	37.3	18.65	14.00	3.65	0.163
6	5	0.179	37.6	24.83	17.41	4.37	0.193
6	5.5	0.179	37.5	32.80	24.28	5.76	0.255
6	6	0.18	37.9	43.32	24.83	6.03	0.265
6	6.5	0.179	37.4	53.02	30.66	5.88	0.262

Appendix E- Irregular Testing Data, Relative Ref.

For all tests:

Water Depth =.675 m

Irregular Testing- PTO Reversed, Floaters Connected, 40cm Plastic Skirt

Wave cond.	Load [Kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
1	3.7	0.030	0.45	4.47	3.35	0.07	0.256
2	4	0.071	3.38	10.72	6.91	0.47	0.232
3	5	0.107	9.39	21.24	15.33	1.20	0.212
4	5	0.142	19.62	28.39	20.83	1.69	0.144
5	5	0.162	28.59	32.93	23.34	2.77	0.162
6	5	0.186	39.25	37.55	25.72	3.56	0.151

Irregular Testing- PTO Reversed, Floaters Connected, 00cm Plastic Skirt

Wave cond.	Load [Kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
1	4	0.032	0.48	4.54	3.46	0.06	0.219
2	4	0.074	3.40	11.53	7.49	0.93	0.454
3	4	0.105	8.50	16.53	9.51	2.27	0.445
4	4	0.142	17.95	18.35	10.20	2.94	0.273
5	5	0.171	28.74	27.67	18.90	3.20	0.186
6	6	0.197	40.45	43.22	32.73	3.83	0.158

Irregular Testing- PTO Reversed, Floaters Connected, 10cm Aluminum Skirt

Wave con	Load [Kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
1	4	0.03	0.38	6.65	4.56	0.09	0.389
2	4	0.07	2.77	12.11	10.26	0.75	0.451
3	4	0.10	7.30	17.50	13.51	1.96	0.447
4	4	0.13	14.74	20.26	15.08	2.58	0.292
5	5	0.16	24.32	32.12	25.38	2.53	0.173

Irregular Testing- PTO Reversed, Floaters Connected, 10cm Aluminum Skirt -- 3D Waves (Spreading 40)

Wave cond.	Load [Kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
4	4	0.11	11.35	18.36	13.98	1.77	0.261
4	4	0.12	11.95	19.78	15.21	1.77	0.247

Appendix F- Supplemental Testing Data, Relative Ref.

For all tests:

Water Depth =.675 m

Fixed H/Variable T, 40cm Plastic Skirt								
Inp. H [m]	Inp. T [s]	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
0.100	1.000	4.5	0.145	10.75	5.12	2.90	0.32	0.049
0.100	1.250	4.5	0.137	12.93	5.01	3.70	0.30	0.038
0.100	1.500	4.5	0.130	14.61	5.75	3.57	0.21	0.024
0.100	1.750	4.5	0.137	18.81	4.82	2.74	0.12	0.011
0.100	2.000	4.5	0.106	12.59	3.94	2.06	0.08	0.011
0.100	2.250	4.5	0.106	13.38	4.23	3.21	0.10	0.012

Fixed T/Variable H, 40cm Plastic Skirt								
Inp. H [m]	Inp. T [s]	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
0.075	1.500	4.5	0.091	7.08	4.09	2.15	0.13	0.031
0.100	1.500	4.5	0.129	14.37	6.27	4.60	0.26	0.030
0.125	1.500	4.5	0.161	22.00	7.40	4.55	0.27	0.021
0.150	1.500	4.5	0.195	32.36	10.78	6.76	0.46	0.024

Floaters Connected- Fixed H/Variable T- PTO Reversed, 40cm Plastic Skirt								
Inp. H [m]	Inp. T [s]	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
0.100	1.000	4	0.128	8.29	17.75	8.77	1.72	0.346
0.100	1.000	4.5	0.133	8.90	19.00	10.40	1.79	0.335
0.100	1.000	5	0.138	9.69	22.20	12.93	1.10	0.190
0.100	1.250	4	0.139	13.31	21.67	9.59	2.68	0.336
0.100	1.250	4.5	0.136	12.76	22.58	13.60	1.88	0.246
0.100	1.250	5	0.133	12.25	24.52	15.84	1.54	0.210
0.100	1.500	4.5	0.121	12.66	26.32	14.67	2.66	0.350
0.100	1.500	5	0.119	12.33	28.93	18.29	1.91	0.259
0.100	1.500	5.5	0.118	12.02	31.45	20.92	1.43	0.199
0.100	1.750	4.5	0.135	18.12	24.18	14.70	1.19	0.109
0.100	1.750	5	0.134	18.08	27.22	17.21	1.13	0.104
0.100	1.750	5.5	0.136	18.59	29.67	19.69	1.08	0.097
0.100	2.000	4.5	0.109	13.08	21.94	12.74	0.71	0.090
0.100	2.000	5	0.109	13.10	23.87	14.13	0.70	0.089
0.100	2.000	5.5	0.109	13.07	27.13	18.39	0.43	0.055
0.100	2.250	4.5	0.112	14.93	24.27	14.00	0.78	0.087
0.100	2.250	5	0.113	15.06	27.67	17.58	0.72	0.079
0.100	2.250	5.5	0.112	14.75	30.96	18.63	0.56	0.063

Floaters Connected- Fixed T/Variable H- PTO Reversed, 40cm Plastic Skirt								
Inp. H [m]	Inp. T [s]	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
0.050	1.500	4	0.058	2.94	12.91	5.50	0.46	0.262
0.050	1.500	4.5	0.058	2.88	14.07	6.57	0.34	0.195
0.075	1.500	4	0.092	7.36	18.26	8.85	1.32	0.299
0.075	1.500	4.5	0.093	7.46	18.65	11.10	1.25	0.279
0.075	1.500	5	0.093	7.55	21.67	14.38	0.93	0.206
0.100	1.500	4.5	0.126	13.75	25.92	12.44	2.71	0.328
0.100	1.500	5	0.124	13.38	27.90	17.85	1.82	0.227
0.100	1.500	5.5	0.125	13.44	30.60	21.32	1.46	0.181
0.125	1.500	4.5	0.158	21.41	31.03	13.98	4.35	0.339
0.125	1.500	5	0.159	21.69	33.50	17.50	3.93	0.302
0.125	1.500	5.5	0.159	21.79	37.36	27.31	2.51	0.192
0.150	1.500	4.5	0.198	33.52	32.23	15.27	5.48	0.272
0.150	1.500	5	0.195	32.53	36.72	20.52	5.83	0.299
0.150	1.500	5.5	0.191	31.48	42.64	27.02	5.58	0.295

Floaters Connected- PTO Reversed, 40cm Plastic Skirt								
Inp. H [m]	Inp. T [s]	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
0.075	0.75	4	0.076	2.08	11.76	7.82	0.29	0.236
0.075	0.875	4	0.095	3.91	20.33	13.39	1.44	0.616
0.075	1	4	0.096	4.69	18.80	11.48	1.10	0.392

Floaters Connected- PTO Reversed, 20cm Plastic Skirt								
Inp. H [m]	Inp. T [s]	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
0.075	0.75	4	0.094	3.26	15.08	10.91	0.38	0.194
0.075	0.875	4	0.096	4.04	18.57	11.38	0.53	0.218
0.075	1	4	0.099	5.00	18.29	10.43	0.38	0.128
0.100	1.000	4.5	0.137	9.57	32.83	21.49	0.93	0.162
0.100	1.250	4.5	0.146	14.81	28.46	20.03	1.05	0.118
0.100	1.500	4.5	0.131	14.82	35.41	28.21	1.18	0.133
0.100	1.750	4.5	0.148	21.82	35.80	27.02	0.91	0.069
0.100	2.000	4.5	0.121	16.17	30.65	21.26	0.70	0.072
0.100	2.250	4.5	0.124	17.97	34.64	22.07	1.09	0.101

Floaters Connected- PTO Reversed, 10cm Plastic Skirt								
Inp. H [m]	Inp. T [s]	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
0.075	0.75	4	0.095	3.25	11.66	6.23	0.35	0.181
0.075	0.875	4	0.097	4.04	17.69	11.79	0.95	0.391
0.075	1	4	0.103	5.36	14.21	8.07	0.34	0.105
0.100	1.000	4.5	0.139	9.76	19.13	13.71	0.62	0.107
0.100	1.250	4.5	0.148	15.18	28.08	23.98	1.86	0.204
0.100	1.500	4.5	0.133	15.33	36.37	25.98	2.12	0.231
0.100	1.750	4.5	0.133	17.51	35.08	25.11	1.02	0.097
0.100	2.000	4.5	0.125	17.26	30.07	21.11	0.69	0.067
0.100	2.250	4.5	0.132	20.21	33.09	20.35	0.74	0.061

Floaters Connected- PTO Reversed, mini Skirt								
Inp. H [m]	Inp. T [s]	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
0.075	0.75	4	0.091	3.06	15.06	8.03	0.22	0.120
0.075	0.875	4	0.095	3.87	17.93	11.78	0.63	0.273
0.075	1	4	0.094	4.45	15.29	10.45	0.35	0.130
0.100	1.000	4.5	0.125	7.89	19.41	14.22	0.70	0.148
0.100	1.250	4.5	0.141	13.72	28.50	24.53	1.80	0.219
0.100	1.500	4.5	0.134	15.44	38.63	28.43	2.18	0.235
0.100	1.750	4.5	0.152	22.96	38.40	27.22	1.12	0.081
0.100	2.000	4.5	0.120	16.11	30.72	21.30	0.74	0.077
0.100	2.250	4.5	0.123	17.78	34.59	21.96	0.71	0.066

Floaters Connected- PTO Reversed, 00cm Plastic Skirt								
Inp. H [m]	Inp. T [s]	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
0.075	0.75	4	0.097	3.37	11.48	5.94	0.24	0.117
0.075	0.875	4	0.100	4.40	16.58	10.23	0.74	0.280
0.075	1	4	0.114	6.64	14.59	8.83	0.46	0.116
0.100	1.000	4.5	0.143	10.26	18.97	10.67	0.47	0.077
0.100	1.250	4.5	0.157	17.04	32.12	27.44	1.58	0.154
0.100	1.500	4.5	0.136	15.95	38.32	21.92	4.60	0.481
0.100	1.750	4.5	0.136	18.47	39.23	27.71	1.56	0.140
0.100	2.000	4.5	0.126	17.49	31.43	21.20	0.72	0.069
0.100	2.250	4.5	0.131	20.17	33.19	18.91	1.07	0.089

Floaters Connected- PTO Reversed, 30cm Aluminum Skirt								
Inp. H [m]	Inp. T [s]	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
0.08	0.75	4.00	0.07	3.34	9.78	5.36	0.36	0.182
0.08	0.88	4.00	0.06	3.59	12.30	6.00	0.93	0.434
0.08	1.00	4.00	0.06	3.98	13.58	6.55	1.32	0.551
0.10	1.00	4.50	0.08	7.14	17.58	8.22	2.19	0.512
0.10	1.25	4.50	0.11	15.90	23.28	13.32	4.03	0.423
0.10	1.50	4.50	0.09	13.82	24.52	13.47	4.61	0.556
0.10	1.75	4.50	0.08	13.11	24.34	13.64	2.20	0.280
0.10	2.00	4.50	0.08	15.06	19.02	10.12	0.91	0.101
0.10	2.25	4.50	0.09	17.23	19.95	10.90	0.84	0.081

Floaters Connected- PTO Reversed, 30cm Aluminum Skirt with Inlet/Outlet Devices								
Inp. H [m]	Inp. T [s]	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
0.08	0.75	4.00	0.07	3.48	13.42	7.53	0.00	0.000
0.08	0.88	4.00	0.06	3.67	15.66	10.90	0.00	0.000
0.08	1.00	4.00	0.08	6.06	17.48	10.94	0.00	0.000
0.10	1.00	4.50	0.09	7.94	16.56	9.81	1.69	0.356
0.10	1.25	4.50	0.11	15.16	25.32	15.52	5.00	0.550
0.10	1.50	4.50	0.09	13.72	26.55	15.34	5.52	0.671
0.10	1.75	4.50	0.08	13.20	25.89	13.67	2.36	0.298
0.10	2.00	4.50	0.08	15.51	20.27	12.15	0.94	0.101
0.10	2.25	4.50	0.08	16.74	20.47	11.88	0.84	0.083

Floaters Connected- PTO Reversed, 20cm Aluminum Skirt

Inp. H [m]	Inp. T [s]	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
0.08	0.75	4.00	0.06	2.71	10.27	6.12	0.30	0.187
0.08	0.88	4.00	0.06	3.54	13.20	8.38	0.90	0.424
0.08	1.00	4.00	0.06	3.57	13.28	7.56	0.86	0.402
0.08	1.25	4.00	0.08	7.98	19.32	11.63	2.47	0.516
0.08	1.50	4.00	0.06	6.13	20.75	10.56	2.19	0.594
0.08	1.75	4.00	0.05	5.87	17.78	10.95	1.21	0.345
0.08	2.00	4.00	0.06	9.01	14.25	8.79	0.58	0.108
0.08	2.25	4.00	0.07	10.44	13.85	8.14	0.53	0.085
0.10	1.00	4.50	0.08	6.76	16.18	9.80	1.57	0.387
0.10	1.25	4.50	0.11	15.61	24.48	15.10	3.58	0.383
0.10	1.50	4.50	0.09	13.04	26.53	15.44	4.23	0.540
0.10	1.75	4.50	0.08	12.96	26.40	15.05	2.08	0.268
0.10	2.00	4.50	0.08	15.46	20.77	13.25	0.96	0.103
0.10	2.25	4.50	0.09	17.29	20.86	12.52	0.87	0.084

Floaters Connected- PTO Reversed, 10cm Aluminum Skirt

Inp. H [m]	Inp. T [s]	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
0.08	0.75	4.00	0.06	2.69	10.35	6.44	0.33	0.203
0.08	0.88	4.00	0.07	4.42	11.93	7.20	0.74	0.279
0.08	1.00	4.00	0.06	4.02	11.79	7.02	0.73	0.301
0.08	1.25	4.00	0.08	8.25	20.28	11.92	2.97	0.601
0.08	1.50	4.00	0.06	6.49	21.21	11.58	2.91	0.747
0.08	1.75	4.00	0.05	5.76	19.61	14.46	1.36	0.393
0.08	2.00	4.00	0.06	8.91	14.64	10.15	0.66	0.124
0.08	2.25	4.00	0.07	10.16	14.46	10.98	0.58	0.095
0.10	1.00	4.50	0.08	6.79	14.30	9.22	1.39	0.341
0.10	1.25	4.50	0.10	14.89	24.52	17.12	4.98	0.558
0.10	1.50	4.50	0.08	12.37	26.30	16.98	5.02	0.676
0.10	1.75	4.50	0.08	11.87	25.82	16.59	2.22	0.311
0.10	2.00	4.50	0.08	14.97	22.93	16.32	1.05	0.117
0.10	2.25	4.50	0.09	17.22	22.39	14.86	0.94	0.091

Floaters Connected- PTO Reversed, 00cm Skirt

Inp. H [m]	Inp. T [s]	Load [kg]	Meas. H [m]	P_wave [W]	F_h Mean [N]	F_h StDev [N]	P [W]	Eff. [-]
0.08	0.75	4.00	0.06	2.80	10.51	6.80	0.32	0.191
0.08	0.88	4.00	0.06	3.65	11.36	6.97	0.71	0.324
0.08	1.00	4.00	0.07	4.58	11.81	8.74	0.73	0.265
0.08	1.25	4.00	0.08	7.96	21.96	13.34	3.96	0.830
0.08	1.50	4.00	0.06	6.93	21.49	12.86	3.16	0.762
0.08	1.75	4.00	0.06	6.87	18.78	10.04	1.79	0.434
0.08	2.00	4.00	0.06	8.83	14.89	10.17	0.67	0.126
0.08	2.25	4.00	0.07	10.29	15.09	10.94	0.65	0.105