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Carderock Division
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Ship Dynamics in the Surf Zone Model Testing

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Abstract

The aim of this project was to generate data to identify the forces and motions on a ship model while positioned in breaking surf. The two types of breaking waves analyzed were plunging and spilling waves. A 140 feet long model test basin at the Naval Surface Warfare Center Carderock Division (NSWCCD) was used to create the waves with a flap wave maker and the heave motions, pitch motions, and surge forces found acting on the model were measured. To create a breaking wave, a beach was built to represent an actual beach slope and continental shelf slope. The ship model tested is similar to landing craft that currently that operate in the surf zone. All data will be utilized in a Master's thesis where it will be thoroughly analyzed and used to create a transfer function that will help predict ship motions and forces in actual seaways.

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1. Introduction

1.1. Mission Statement

To obtain an understanding of ship dynamics in the surf zone, a model was exposed to different breaking waves while subsequent motions and forces were measured. The approach included construction of a representative beach to create breaking waves in a 140 feet long model-testing basin at NSWCCD in West Bethesda, MD. A flap wave maker generated different waves. The characteristics were estimated by ocean water wave theory. The test program obtained a set of data that subsequent to this report will be used in a Master thesis to create a transfer function relating different waves and their effects on surface ships.

1.2. Background

The U.S. Navy anticipates transitioning to a seabasing concept in the future, a vital element of which is the ability to transport troops and supplies from ship to shore. Seabasing is the use of ships offshore allowing the Navy to establish a base of operations without requiring a land-based port. In ideal conditions, existing landing craft can provide ship to shore delivery with LCACs shown in Figure 1, LCMs shown in Figure 2, or LCUs shown in Figure 3. However traversing through breaking waves is hazardous and may damage vessels. Understanding the type of forces and motions vessels will experience is valuable and will provide the US Navy a better understanding of the operational impact of various beach environments.

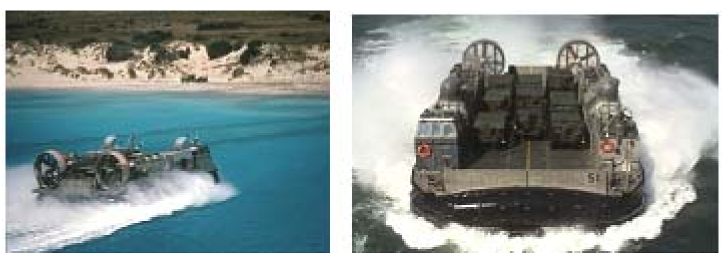

Figure 1: LCAC (Courtesy of US Navy Photography)

Figure 2: LCM MK 8 (Courtesy of US Navy Photography)

Figure 3: LCU (Courtesy of US Navy Photography)

Breaking surf is a phenomenon that occurs near the coast when the water depth is relatively shallow. Waves are created by offshore storms that generate swells radiating to surrounding coasts. As the waves propagate toward shore, energy is conserved within each wave train. The leading wave at the front of a wave train slowly "dies" and a new wave slowly builds in the rear of the wave train. Since wave energy is conserved, estimating wave heights and types of breaking waves in the ocean can be achieved by using a dispersion relation and the shoaling equation, which can be seen in the Preliminary Beach Design section of this report. As these waves approach the shore, the wave height increases as wave speed decreases and the wave becomes unstable, breaking.

Using the surf similarity parameter, the wave characteristics in different swell conditions can be characterized. There are three main waves in the ocean: Plunging, Spilling, and Surging breakers. Plunging and Spilling breakers are the two types of waves typically seen at beaches around the world:

- Plunging breakers can be caused by larger waves or the change in bathymetry, in other words slightly steeper beach slopes. A plunging breaker is very evident because the crest travels much faster than the wave, becoming unstable and tumbling over creating a tube as seen in Figure 4.
- Spilling breakers are quite different from plunging breakers because the crest crumbles down the wave when it breaks. Most spilling breakers are the product of smaller waves or very moderately sloped beaches as seen in Figure 5.
- Surging breakers are a special type of waves. Typically when surging breakers become large they become known as "tsunamis". For this project, the surging breaker case was not tested since tsunamis are very difficult to recreate and occur rarely.

The two options available were to recreate plunging and spilling breakers. One was to build a representative beach, or, the second option, have more than one wave coalesce at a certain point. Having more than one wave coalesce at a certain point creates a larger wave that becomes unstable and breaks without the presence of a beach.

This project report focuses on how the breaking wave was generated and how the ship model was situated to interact with the breaking surf.

Figure 4: Plunging wave

Figure 5: Spilling wave

2. Beach Design

2.1. Preliminary Beach Design

The 140 feet long model basin at NSWCCD was the site for all the experimental work in this effort. The tank is 140 feet long, 10 feet wide, and 5 feet deep. The wave maker is a flap type that can generate regular and irregular waves. For this project only regular waves were used. A simple theory on the generation of waves by wave makers is proposed at Reference 1 "*the water displaced by the wave maker should be equal to the crest volume of the propagating wave form*." This theory is represented by the following equation:

$$\left(\frac{H}{S}\right)_{flap} = \frac{kh}{2}$$

Equation 1: Wave flap equation

where H is the wave height created by the wave maker, S is the total distance the flap can travel, k is the wave number, and h is the water depth (approximately 5 feet). The wave number is equal to 2π/L, where L is the wavelength. To find the wavelength for Equation 1 the dispersion relation must be used:

$$\omega^2 = gk\tanh(kh)$$

Equation 2: Dispersion relation

where g is gravity (32.2 ft/sec^2) and ω is the angular wave frequency. From wave data on offshore buoys, the typical wave period for waves range from 8-10 seconds. Using this knowledge of wave properties, the values can be inserted into Equation 2 to find the correct wave number. To ease the calculations of the wave number, the shallow water dispersion relation approximation can be used for the dispersion relation:

$$\omega_{shallow}^2 = gk^2h$$

Equation 3: Shallow water dispersion relation

From numerous hand calculations, the results from Equation 3 are very close to the results from the original equation. Knowing all the wave properties, the model scale wave height can be determined.

The wave heights generated by the wave maker are approximately 3 inches, which is very small and the effects of surface tension can be significant. In order to create a breaking wave the beach slope must be long enough to allow for shoaling. If the beach is short and steep, reflection can cause a problem. To calculate the effects of the beach slope, the shoaling equation (Equation 4) is very useful:

$$\frac{H_1}{H_2} = \left(\frac{c_{g2}}{c_{g1}}\right)^{1/2}$$

Equation 4: Shoaling equation

The wave height ratio is equal to the square root of the inverse ratio of group speed. Where group speed and its shallow water approximation (Equation 5) are:

$$c_g = \frac{\omega}{2k}\left[1 + \frac{2kh}{\sinh 2kh}\right]$$

and

$$(c_g)_{shallow} = \frac{\omega}{k}$$

Equation 5: Group speed and shallow water approximation

Again, the shallow water approximation (Equation 3) can be used.

Using the above equations; the wave height can be found as a wave propagates along the sloping beach; hence shoaling can be seen as the wave height increases. Again, it is very important to note that reflection can cause a problem if the slope is too steep and it is not accounted for in the above equation; therefore, the results from the above equation should only be used for a gently sloping beach. To find the height and location of where the waves will break, Equation 6 was implemented in MATLAB along with the shoaling equation, Equation 4 above; and at the intersection of the data is where breaking should occur (as shown at Annex A).

$$\left(\frac{H}{L}\right)_{break} = 0.12\,\sinh(kh)$$

Equation 6: Breaking wave height and length relation

With the above equations the beach can be designed with all the constraints and assumptions known. To start the beach design, a water depth of 5 feet was used since that is the usual water depth of the model basin. The main concern with the design of this beach was to create a breaking wave while keeping the beach as short as possible to conserve space in the model basin and reduce cost of materials. The design chosen has a beach slope of 1/20 and then a continental shelf slope of 1/5.

The most important wave process is shoaling. The longer the beach or continental shelf the more time shoaling can occur. Periods of 8-10 seconds, at full scale will break. It is also important to note that the first set of waves will not create a breaking wave because the energy needs to propagate the length of the tank, this is also applicable to the last set of waves since the energy will start to decay because the wave maker will have stopped.

To theoretically find what type of breaker was generated, the surf similarity parameter in Equation 7 was used:

$$\xi = \tan\beta \left(\frac{H}{L}\right)^{-1/2}$$

if, $\xi < 0.5$ wave will be a spilling breaker

$0.5 < \xi < 3.3$ wave will be a plunging breaker

Equation 7: Surf similarity parameter

Through Froude number scaling, the period was scaled to model scale.

With the theoretical background described above, all equations were coded in MATLAB and approximate wave heights and the breaking locations were found with a beach having a slope of 1/5 for the continental slope and 1/20 for the beach slope. The estimated wave height at breaking was 5.5 inches and the location from the end of the beach is approximately 12 feet (see Annex A). With these calculations as a basis, the beach design was completed. The profile view of the beach can be seen in Figure 6.

2.2. Beach Construction

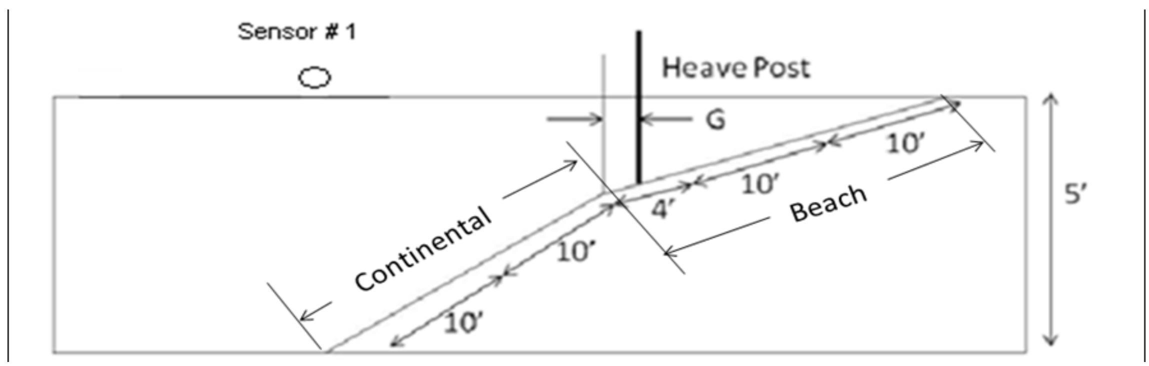

Figure 6: Beach slope layout

The beach design is modular allowing for different configurations while in the tank. This design scheme was implemented for ease of transportation and ease of assembly. Each module was 10 feet square consisting of oriented strand board (OSB) plywood with support from 2 inch by 4 inch by 10 feet pieces of wood as a underlining frame. Pieces of wood, 4 inch by 4 inch by 10 feet, were used as legs to support the decks and also facilitate the desired slopes. To achieve the desired beach two modules were connected in the tank to create the 1/20 slope and then two more modules were assembled and connected to the beach, noting that the tip of the beach should be at the still water line.

The frame, constructed of 2 inch by 4 inch by 10 feet pieces of wood, was measured, cut, laid, and screwed together for each module. Pieces of OSB plywood were laid onto the frame and screwed into place. Holes were also drilled on specific sides of the frame to attach two 9 feet 11 inch wide by 10 feet long sections together while in the water. Small holes were drilled through the top to release trapped air (Figure 7). Legs cut from pieces of 4 inch by 4 inch by 10 feet wood to create the desired angle created the slopes of the beach. Once two sections were in the water, bolts were installed through the holes drilled onto the side of the frame to keep two sections together. Weights were used to keep the beach submerged.

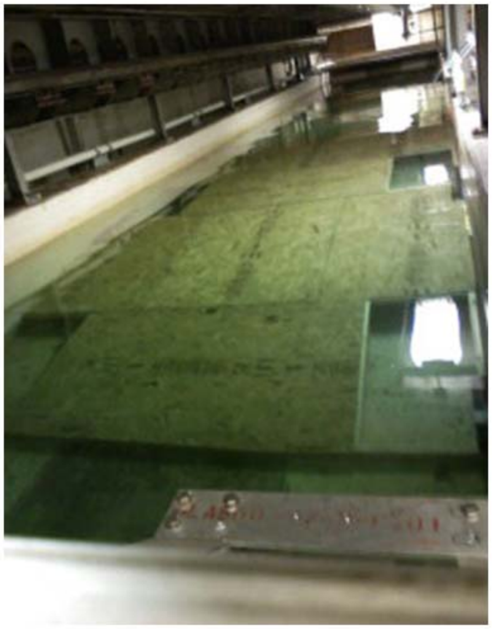

Figure 7: Beach: front view and section view

3. Model Design

3.1. Preliminary Model Design

The ship model for this project represents a generic monohull design similar to amphibious vehicles and landing craft hulls. Research was conducted on various vehicles such as an LCAC (Figure 1), LCM (Figure 2), and LCU (Figure 3). All of these landing crafts have a similar mission to bring cargo, equipment, troops, and other vehicles ashore; therefore, they all encounter breaking surf. Desirable characteristics in choosing the model consisted of a monohull, broad beam, and a shallow draft.

	LCU	LCAC	LCM MK 8
Length (ft)	135 ft	87 ft 11 in	73 ft 7 in
Width (ft)	29 ft	47 ft	21 ft 1 in
Height (ft)	17 ft 9 in	23 ft 8 in	-
Displacement (tons)	437 tons	181.6 tons	105 tons

Table 1: Vehicle comparison

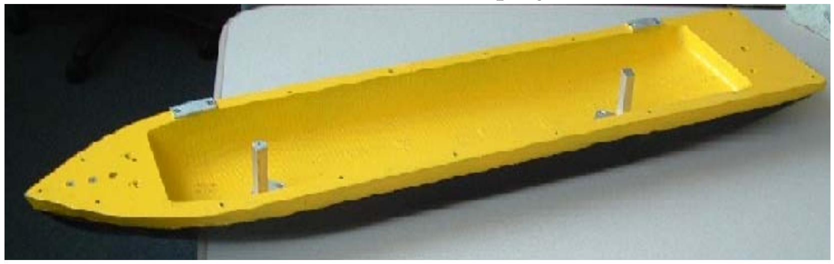

Figure 8: Heavy lift ship model

To avoid building a new model, a heavy lift ship model (Figure 8) provided by the Center for Innovation in Ship Design (CISD) was chosen, as it was an appropriate geometry and dimensions. The model had all the relevant characteristics for this project, a broad beam, shallow draft and monohull. The scaled ratio for this model is 1:158 relative to the full size heavy ship, but for the purposes of this experiment a scaling ratio of 1:20 was chosen to allow the heavy lift ship model to represent a landing craft geometry and size when operating in the surf zone.

	Length	Width	Height	Displacement
Heavy lift ship (Full Scale)	513.5 ft	103.0 ft	111.9ft	23.6 ft
Heavy lift ship (Model)	39 in	7.8 in	8.5 in	1.8 in

Table 2: Heavy lift ship comparison

3.2. Construction

Although the CISD heavy lift ship model had the relevant characteristics for the proposed test program. A problem with this model was that it had a bulbous bow. The bulbous bow was removed and a new bow attached, allowing the model to represent a generic hull with out any extreme form changes (Figure 9). To make the bow replaceable it is attached by screws from the top. The model was sanded fair and then repainted to seal the surfaces.

Figure 9: Bow construction

3.3. Instrumentation

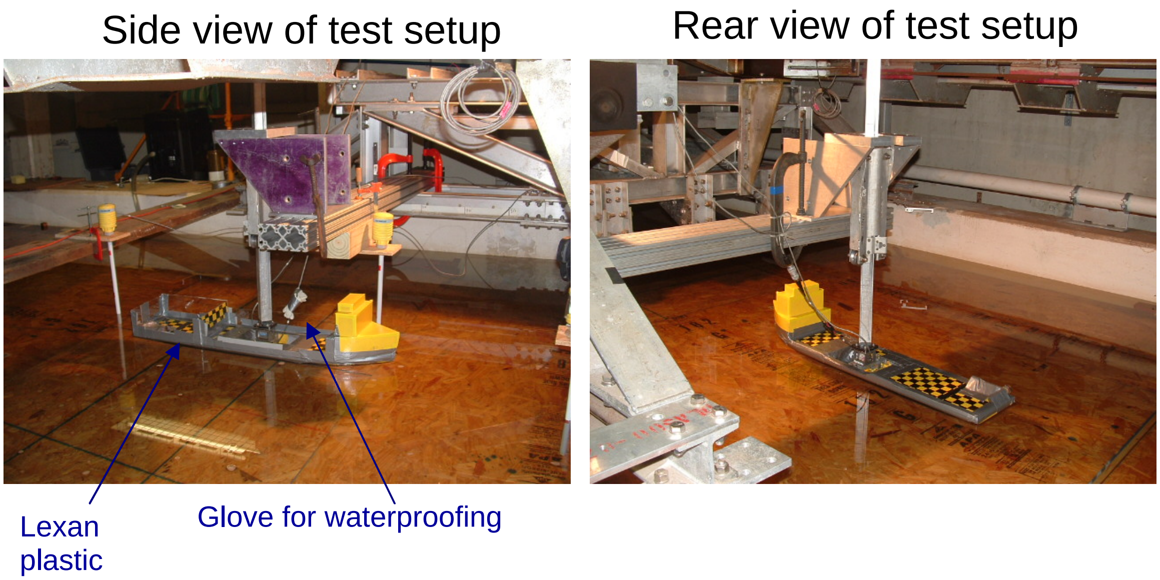

Figure 10: Experimental test set up

To test the model in breaking surf at different locations, the 140' basin towing carriage was utilized. The attachment of the model to the towing carriage consisted of a cantilever beam, heave post holder and heave post, block gage, and pitch pivot as shown in Figure 10. The heave post holder was clamped onto the end of a cantilever beam to allow the holder to sit in the center of the tank. A heave post was used to allow the model to move freely vertically. The heave post restricted the model in surge as only the surge force was measured. A block gage, (Figure 11) was attached to the bottom of the heave post to measure the surge force on the model. Orientation of the block gage was important due to the flexors on the gage.

Figure 11: Block gage attached to the pitch pivot

Figure 12: Close up of potentiometer

A pitch pivot with an attached potentiometer was mounted to the model to measure the pitch motion and was also mounted onto the block gage. The pivot was mounted at the water line and placed at the model's longitudinal center of gravity. The pivot was mounted 20 millimeters off the transverse center of gravity and rotated freely. A digital inclinometer was used to measure the angle of the model at various postion and a potentiometer (Figure 12), measured the resistance by providing a voltage output. The voltage output was related to the angle though this calibration process. Since the block gage was mounted off center, a calibration test was conducted to ensure the forces measured by the block gage were consistent as if the block was attached in the center. To calibrate the block sensor, known weights were applied. A relationship correlated the sensor measurement and the actual weight applied. A check was made to see if being off center would affect the measurements, during the same calibration process. After analyzing the data, the values were observed to be identical and it was determined that mounting the block gage off center would not affect other measurements.

Figure 13: Heave sensor installation

With limited mounting locations available for an ultrasonic heave motion sensor, the heave sensor was mounted onto a piece of wood attached to the heave post above the model (see Figure 13). A plate was placed 1.5 ft under the sensor which allowed the output signal to be reflected and read by the sensor. To calibrate the sensor, it was positioned at different heights to create a calibration curve used to translate voltage output to inches of heave.

All sensors were connected and collected through an MS-DOS program that output the data to a Microsoft Excel spreadsheet.

A plastic false deck was used to help keep water out of the model. As the pivot needed to be located at the water line, portions of the deck were removed to allow the heave post room to move. A superstructure block was attached onto the bow of the ship to help keep green water off of the model while in the breaking surf. To prevent excess water from entering the model, lexan walls were added around the deck.

4. Test Plan

4.1. Preliminary Test Plan

The model was strategically placed to interact with the waves. The model was orientated both bow seaward and stern seaward to have a full understanding of the ship dynamics.

The first test location was bow forward, just before the wave breaks. The second test was at the same location but stern forward.

The next series was to test the model in the breaking surf; with the model located at three test points. The first position was with the breaking point ¼ of the length from the bow, the second position was with the breaking point at mid-ship, and the last position was at ¼ of the length from the stern. The final sets of tests were undertaken with the model located just aft of where the wave broke.

As regular waves were used, every wave was theoretically expected to break at the same point, but this was not the case in reality and judgment was used to place the model for each case. A spreadsheet of the original test plan is at Annex C. Video of each testing event was collected and enabled confirmation of the data with visual inspection.

4.2. Testing

All sensors and measurement devices were calibrated prior to testing. After each wave sensor was calibrated, they were installed in strategic locations, one close to the wave maker to analyze the open water waves, one just before the continental slope, one just before the beach slope, and three surrounding the model. This array of sensors was to allow an understanding of the shoaling process and measure how the waves increase in size before they break. An overview of the sensor set up and their locations can be found in the Annex D.

Using Froude number scaling for the period of the waves, it was calculated that an 8 second wave would have a model frequency of 0.55 Hertz at model scale. Inputting a 0.55 Hertz frequency generated a plunging wave that plunged at the calculated location, 12 feet from the end of the beach.

To generate a spilling wave, the wave period was reduced to 6 seconds (full scale), increasing the model frequency to 0.75 Hertz at model scale. Applying this frequency, the wave maker generated a spilling wave closer to shallow end of the beach but with enough water depth for measurements. Other frequencies were experimented with, but only these two frequencies, at specific amplitudes, generated breaking waves that suited the experiment’s needs.

Once the waves were characterized, the breaking locations were noted. For each test moving the carriage to the appropriate location relocated the model. The three wave sensors that surrounded the model were also attached to the carriage to alleviate the need of relocating the sensors.

5. Results

5.1. Plunging Surf

Creating a plunging wave was the most arduous part of this project. Using a frequency of 0.55 Hertz and applying the largest voltage amplitude, a 2.5 inch amplitude wave was created. Once the wave train interacted with the beach, the wave height grew to approximately 3.5 inches and plunged. During Trial 10 the model's bow was positioned in the breaking wave; a series of photos (Figure 14) show the plunging wave.

There were numerous trials, but the case cited was chosen for discussion because it appeared dynamic on video. The data truly correlates to the video and provides confidence that the data is reliable.

It is clear that the maximum force occurs when the wave breaks on the bow. Isolating this instance, (Figure 15 and Figure 16) show the same time frame when the wave breaks onto the model.

The maximum surge force occurred independently of the maximum pitch motion occurred. The maximum pitch motion occurred immediately after the maximum surge force, which shows that the maximum force was caused by the plunging wave and the maximum pitch occurred as the model travels over the wave. The maximum surge force in this case is approximately 5 lbs.

Figure 14: Breaking wave progression

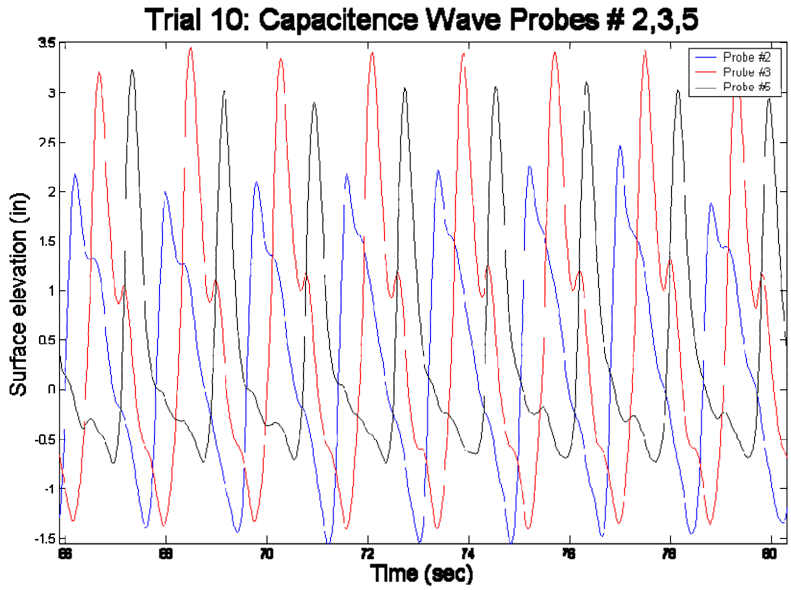

Figure 15: Plot of time frame for a plunging wave

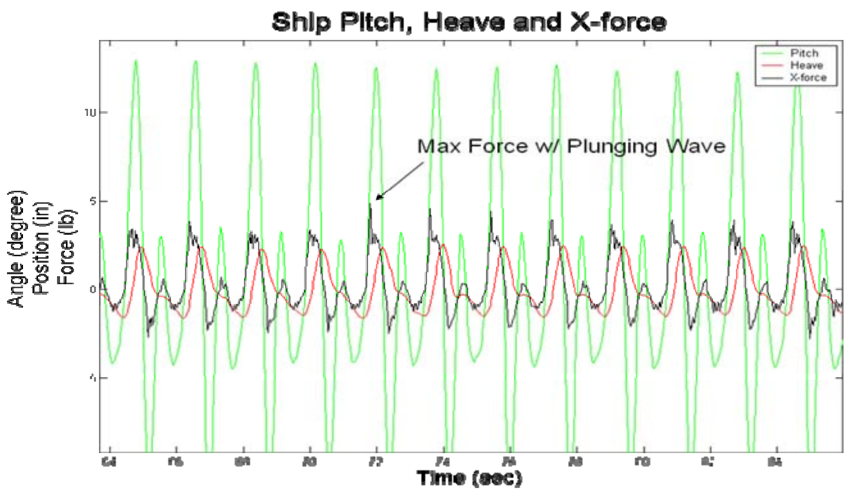

Figure 16: Corresponding motions and force plot

5.2. Spilling Surf

The model scale frequency of 0.75 Hertz was used for spilling waves and represents a 6 second wave at full scale. This frequency is quite low, but was the only frequency that provided consistent spilling waves. The input voltage amplitude was slightly smaller than the voltage amplitude for plunging, with the wave amplitude just under 2 inches. Below (Figure 17, Figure 18) are plots of a spilling wave and its corresponding motions and forces. The incoming wave height is small (blue line) and then grows (red line) then reduces as the wave breaks (black line). It is also important to understand that there is a phase present in the data and black curve is offset in time from the same wave as it passes the other sensors. This segment of data was used because it produced the maximum surge force for a spilling wave, which was approximately 4 lbs.

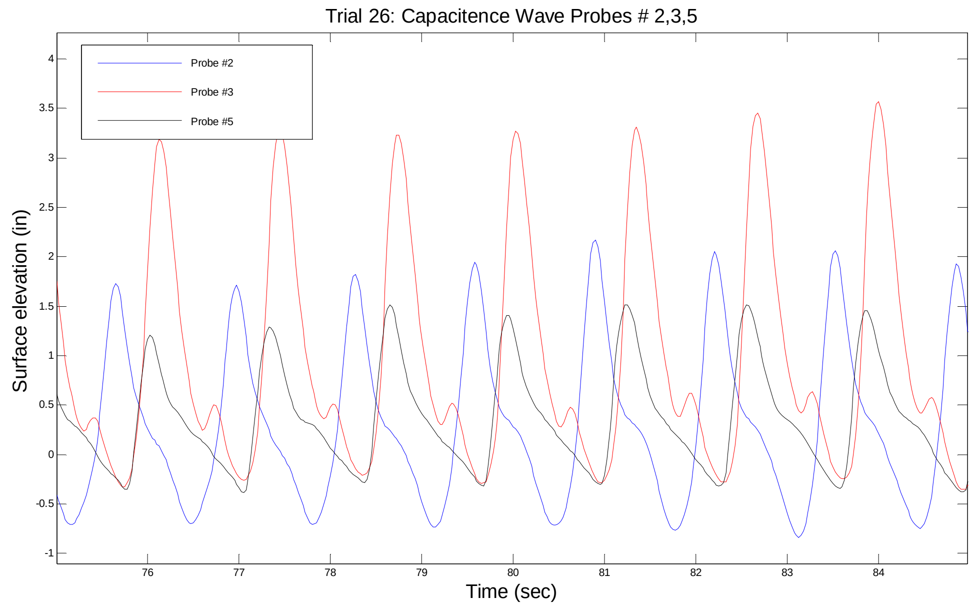

Figure 17: Wave profile for spilling wave

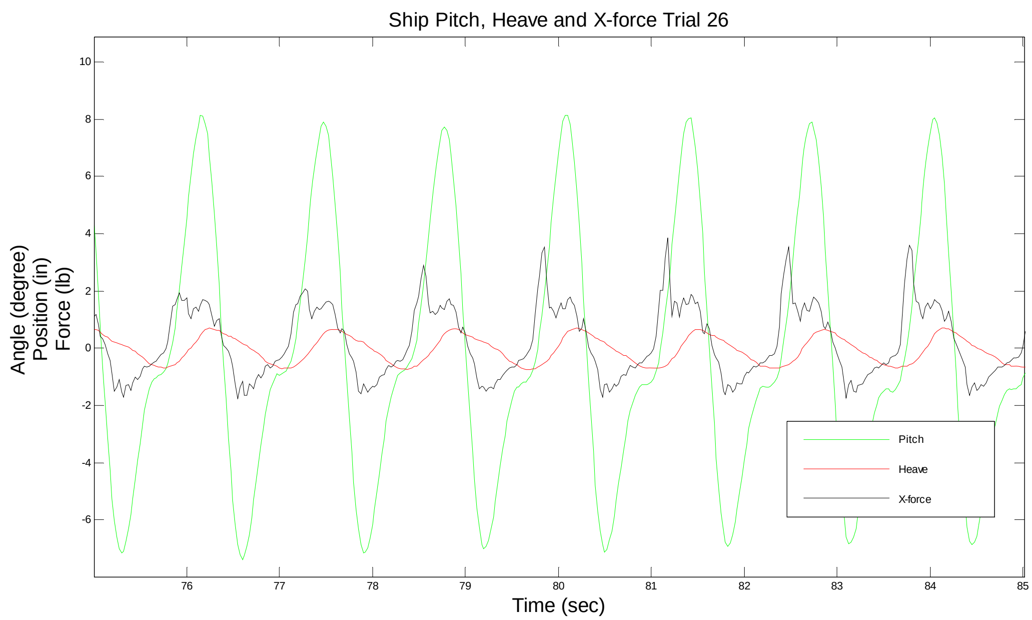

Figure 18: Motions and force for spilling wave

5.3. Experimental Issues

Two main issues arose during the testing process when using the spilling wave for measurements. First, the model's keel was too close to the beach and proper measurements were not possible. The second issue occurred with the model stern seaward. It was decided to test the model stern seaward, towards the spilling wave first since the waves were smaller. After a minute of testing the model flooded with water and began to sink. As the block gage and potentiometer were not waterproof, it was decided to terminate testing with the model's stern to seaward.

The wave maker could only generate spilling or plunging waves at certain frequencies that had to be entered into the wave maker's control software through LabVIEW. If the frequency was too low, the waves behind the wave maker would resonate and water was sloshed over the back of the model basin. The wave maker is a flap wave maker that uses pistons to oscillate the flap. During this process, the pins holding the pistons to the flap sheared quite frequently, which greatly reduced testing time. Regular waves were used for testing due to calculation approximations. When irregular waves were attempted to create better breaking waves, the pins immediately sheared and this scheme was terminated.

Only one frequency was successful in generating plunging wave; this was mostly due to the movement of the beach, which happened to resonate with the frequency of the waves to create extra energy assisting the waves to plunge; however, the beach was designed to stay stable and rigid. Wedges were placed between the walls of the model basin and the beach sections to prevent movement, as well as weights for submergence. Despite all efforts taken, the beach oscillated, which assisted in creating a breaking wave but added to experimental errors.

The capacitance wave probes had a 2-5 Volt measurement range. When testing in spilling waves, the towing carriage was placed at the upper part of the beach, where the water depth became very shallow; only a few inches of the probes were able to remain in the water, so collecting data at that location was not as accurate as previous trials.

6. Conclusions

Creating plunging and spilling waves was a difficult task, but valuable data was obtained. There is too much data to plot and analyze in this report within the allowable schedule of the project. A more thorough analysis will be completed, and the results will appear in the thesis. The fabrication process was quite difficult due to the location of the 140 feet model basin relative to shop support and the construction materials available.

Breaking waves were created experimentally to meet the requirements. The data appears to be representative of the breaking wave events when compared to the video of the testing. This provides confidence in the data. The change in wave height of a single wave before, during and after breaking has been clearly identified.

Due to the large amount of data, a disc is attached to this report with the raw data and MATLAB code that could be used for analysis.

7. Recommendations

To further develop this project, two significant recommendations are advanced. Firstly use a model that is designed specifically for this testing process. During the tests, the model took on water and put the measurement and sensors at risk. A larger model, with a sealed deck would allow the instrumentation on board to remain dry.

The next recommendation would help create more consistent waves. Wood is not an appropriate material for the model beach as it oscillated due to the energy of the waves. A more rigid beach would benefit the effort.

8. References

1) Dalrymple, Robert A., and Dean, Robert G. Water Wave Mechanics. Word Scientific, 1991.

9. Bibliography

McCormick, Michael E. Ocean Engineering Wave Mechanics. New York: Wiley-Interscience, 1973.

Silvester, Richard. Coastal Engineering, 1 4A Developments in the Geotechnical Engineering. New York: Elsevier Scientific, 1974.

Sorensen, Robert M. Basic Coastal Engineering. New York: Wiley-Interscience,1973.

U.S. Army Corps of Engineers. 2002. Coastal Engineering Manual. Engineer Manual 1110-2-1100, U.S. Army Corps of Engineers, Washington, D.C. (in 6 volumes).

Annex A: MATLAB Plot and Code to Approximate the Breaking Wave Location

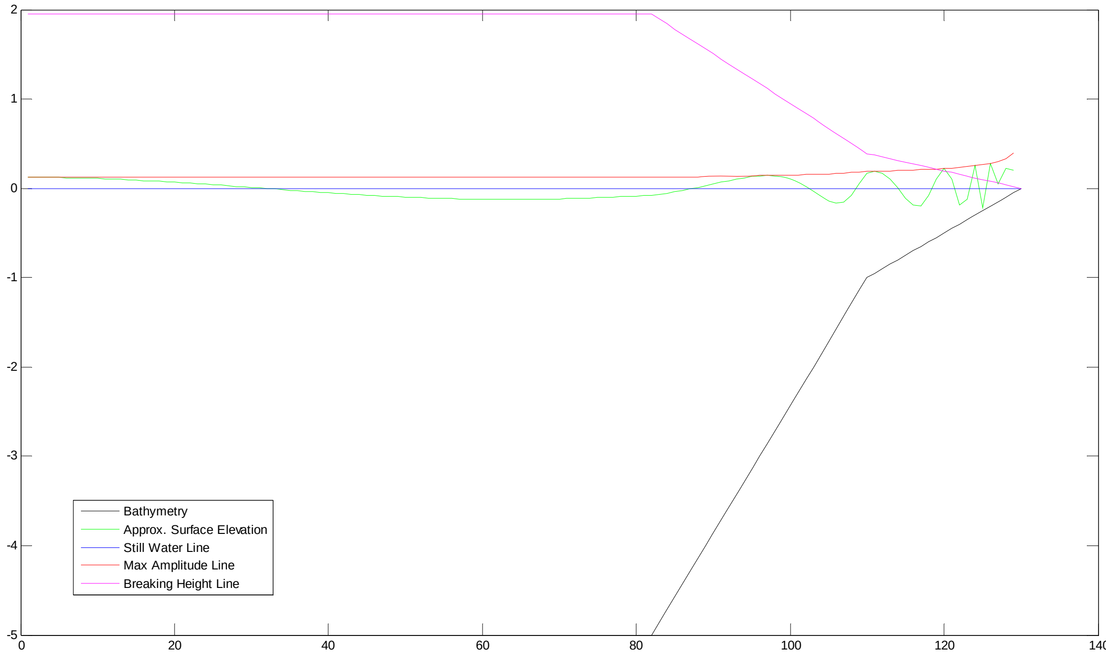

Figure 19 Breaking Location Prediction Plot

Code:

```
% Miguel Q.
% 5/20/08

% Beach breaking problem

 clear;clc;

T = 10;     % wave period
w = 2*pi/T;     % wave angular frequency
g = 32.2; % units of ft/sec^2
h = 5;    % tank depth in feet

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Slope
b_S = 1/20;              % beach slope
cs_S = 1/7;              % continental shelf slope
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Length
b_L = 20;                % beach length
cs_L = (h - b_S*b_L)/cs_S;   % continental shelf length
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
profile = nan*ones(130,1);
c = 1;
d = 1;
for i = 1:length(profile)
```

```
    if i <= 130-(b_L + cs_L)
        profile(i) = 0;
    elseif i > 130-(b_L + cs_L) && i <= 130-b_L
        profile(i) = c*cs_S;
        c = c+1;
    else
        profile(i) = (b_S * d) + (profile(130-b_L));
        d = d+1;
    end
end

% figure
% plot(profile)

% in the below loop, k will be found using shallow water approximation
% since I have solved both ways, it is sufficient
% I will also use shallow water approximation for cg ( group speed )

depth  = h-profile;

k = zeros(130,1);
cg = zeros(130,1);
for i = 1:length(depth)
    k(i) = sqrt(w^2/(g*depth(i)));
    cg(i) = w/k(i);
end

H = zeros(130,1);
H(1) = 3/12;    % Initial Wave height in feet
for i = 2:length(depth)
    H(i) = H(i-1)*sqrt(cg(i-1)/cg(i));
end


x = 1:130;  % Placement

eta = H/2 .* cos(k.*x');    % Surface elevation
 L = 2*pi./k;    % Wavelength


% Hb = 0.12*L.*tanh(2*pi*depth./L);   % Breaking Height
Hb = 0.78*depth;

figure
plot(x,-depth,'k',x,eta,'g',x,zeros(130,1),'b',x,H/2,'r',x,Hb/2,'m')


up = find(Hb > H);
bt = find(Hb < H);

breakingHeight = Hb(max(up))
locationBreakfromBeach = 130-max(up)
```

Annex B: Beach Construction Layout for Two Panels

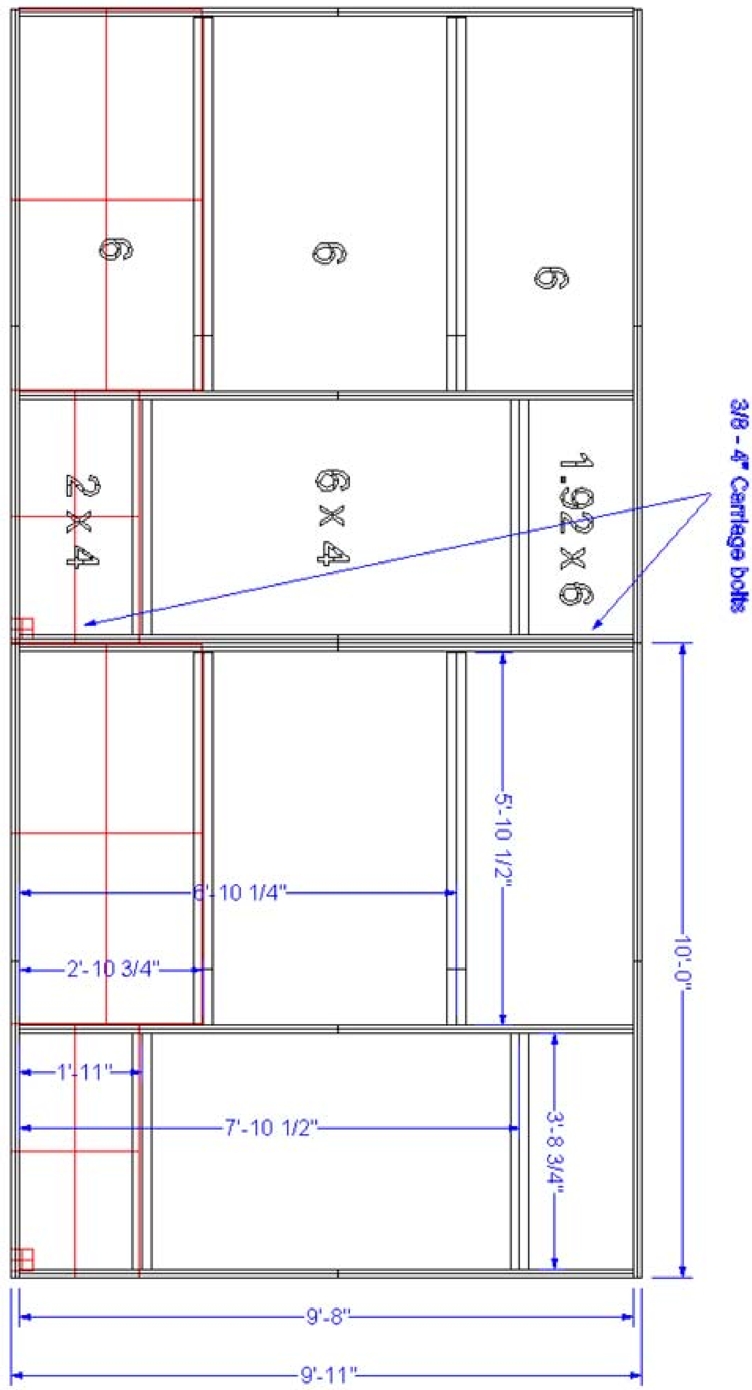

Figure 20 Beach Construction Diagram

Annex C: Preliminary Testing Plan

Preliminary testing plan

All times are approximate (times from previous page)

	Work Time (hours)	Reconfigs	Total Time (hours)
Build Beach	120	1	120
Install Beach	72	1	72
Test and set up wave conditions	2	5	10

TESTING	Time per trial (min)	Number of trials	
Motion Measurements			
Plunging Surf			
Arranged bow towards incoming wave			
Placed just before breaking	15	5	1.25
Placed in surf			0
Bow line placed at breaking location	15	5	1.25
Mid ship placed at breaking location	15	5	1.25
Stern line placed at breaking location	15	5	1.25
Placed just after breaking	15	5	1.25
			0
Arranged stern towards incoming wave			0
Placed just before breaking	15	5	1.25
Placed in surf			0
Bow line placed at breaking location	15	5	1.25
Mid ship placed at breaking location	15	5	1.25
Stern line placed at breaking location	15	5	1.25
Placed just after breaking	15	5	1.25
			0
Spilling Surf			0
Arranged bow towards incoming wave			0
Placed just before breaking	15	5	1.25
Placed in surf			0
Bow line placed at breaking location	15	5	1.25
Mid ship placed at breaking location	15	5	1.25
Stern line placed at breaking location	15	5	1.25
Placed just after breaking	15	5	1.25
			0
Arranged stern towards incoming wave			0
Placed just before breaking	15	5	1.25
Placed in surf			0
Bow line placed at breaking location	15	5	1.25
Mid ship placed at breaking location	15	5	1.25
Stern line placed at breaking location	15	5	1.25
Placed just after breaking	15	5	1.25

Force Measurements

Plunging Surf				
Arranged bow towards incoming wave				
Placed just before breaking	15	5	1.25	
Placed in surf			0	
Bow line placed at breaking location	15	5	1.25	
Mid ship placed at breaking location	15	5	1.25	
Stern line placed at breaking location	15	5	1.25	
Placed just after breaking	15	5	1.25	
			0	
Arranged stern towards incoming wave			0	
Placed just before breaking	15	5	1.25	
Placed in surf			0	
Bow line placed at breaking location	15	5	1.25	
Mid ship placed at breaking location	15	5	1.25	
Stern line placed at breaking location	15	5	1.25	
Placed just after breaking	15	5	1.25	
			0	
Spilling Surf			0	
Arranged bow towards incoming wave			0	
Placed just before breaking	15	5	1.25	
Placed in surf			0	
Bow line placed at breaking location	15	5	1.25	
Mid ship placed at breaking location	15	5	1.25	
Stern line placed at breaking location	15	5	1.25	
Placed just after breaking	15	5	1.25	
			0	
Arranged stern towards incoming wave			0	
Placed just before breaking	15	5	1.25	
Placed in surf			0	
Bow line placed at breaking location	15	5	1.25	
Mid ship placed at breaking location	15	5	1.25	
Stern line placed at breaking location	15	5	1.25	
Placed just after breaking	15	5	1.25	
	Testing Total:	50	hours	
		7	days (hrs/day)	8
	Overall Total:	252	hours	
		31.5	days (hrs/day)	8

Annex D: Sensor Placement and Distances

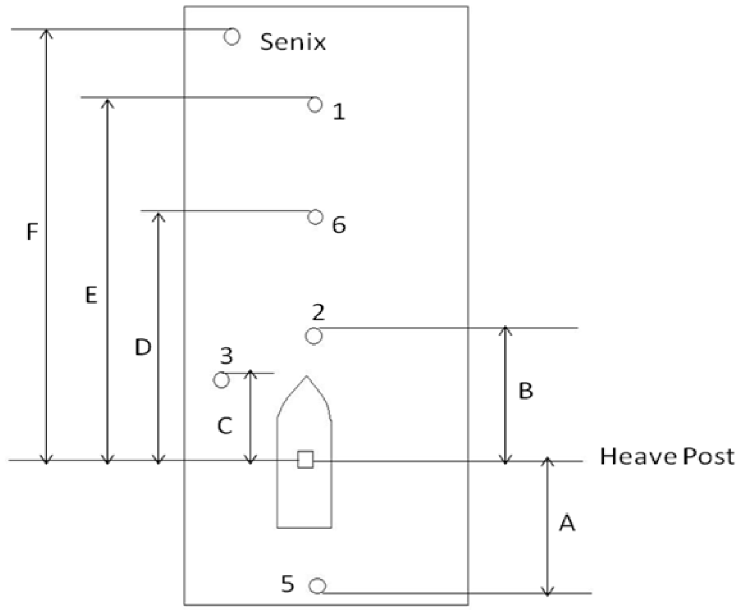

Figure 21 Top view of sensor layout

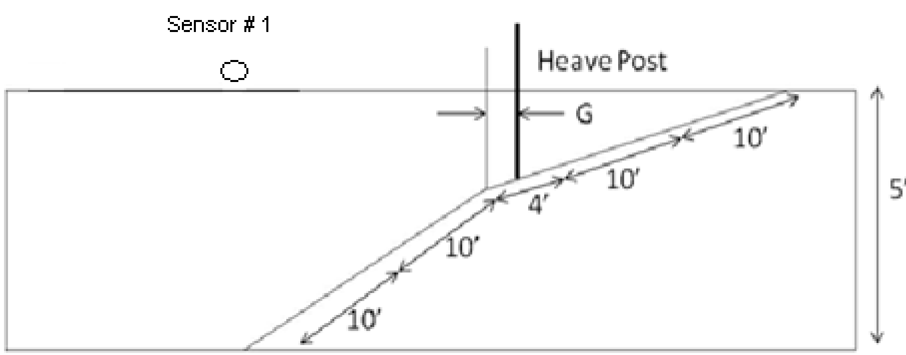

Figure 22 Profile view of sensor layout

The Senix sensor and wave probe # 1 were fixed for all measurements. The Senix sensor was approximately 20 feet from the wavemaker and wave probe #1 was above the beginning of the bathymetry change. Sensors 2, 3 and 6 were attached to the carriage and were permanent with respect to the model. See Table 3 below:

	Distances to heave post (ft, in)	Lateral distances to heave post (ft, in)
Sensor 6 (D)	6' 6"	5'
Sensor 2 (B)	3' 5"	9"
Sensor 3 (C)	1' 4"	9.5"

Table 3 Distances of sensors permanent on carriage

As sensor 5 was moved separate distances, the table below documents the change in distance for each trial. Also seen in Table 4 are the corresponding distances the heave post was moved from the fixed position seen in Profile view of layout figure.

Trial #	A (ft, in)	G (ft, in)
1	-	-
2	-	-
3	-	-
4 & 5	7' 1.25"	4"
6 & 7	4' 7.75"	6"
8 & 9	3' 6"	0
10 & 11	2' 4"	5' 2"
12 & 13 & 14	2' 4"	8'
15 & 16	*Experiment Aborted*	
17 & 18 & 19	3' 1"	8' 18.16"
20	7' 9"	7' 8"
21 & 22	9'	9'
23 & 24	5' 3"	13' 10"
25 & 26	3' 5"	15' 3"
27 & 28	3' 5"	16' 9"
29 & 30	3' 5"	16' 9"

Table 4 Distance movement of sensor 5 (A) and heave post (G) for each trial