Experiment Design for
<u>An Experimental Study of Onshore Bar Movement</u>

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Abstract:

In order for an experiment to run smoothly, experimental design is essential. This entailed collecting and analyzing data from both large scale laboratory and field experiments which focused on sediment accretion. Also, using these data I tested existing parameters for prediction of beach erosion or accretion. My research encompassed examining four previous experiments with accretionary cases. From these data sets I was able to compute a Dean number and apply parameters defined by Dean and Dalrymple (2002)[2] to determine the probability of accretion. I found that these criteria worked well for lab but not for field experiments. In addition to accretion predictions, I was able to use the collected data to quantify laboratory experiment relevance. Scaling between experiments gives field sediment diameters that are fine to medium grain sand, meaning that lab simulations will be useful for real life applications. I also studied Equilibrium Beach Profiles (EBP) and their applicability. I found that when estimating between the bar crest and shore the EBP was extremely accurate. In addition to data analysis I worked with calibrating instruments and testing their interaction in the LWF. Examining the OBS calibration data that was collected I found a linear relationship between concentration and voltage. Lastly, I performed a sieve analysis of the sediment in the LWF. My results showed that sediment diameter was greater onshore and was smaller offshore, and was well sorted. Overall, my research was useful in practicing good experimental methods, as well as learning valuable data analysis. All of which helped contribute to experimental design for <u>An Experimental Study of Onshore Bar Movement</u>.

Introduction:

Currently many experiments have studied sediment erosion, yet experiments that focus on accretionary conditions (i.e. onshore sediment movement) are few. In nature it has been observed that during storm wave conditions sediment transport is typically in the offshore direction. After the storm, when wave conditions are milder, sediment moves back onshore. While it is known that the beach will rebuild, scientists have yet to learn the specifics of why and how the sediment moves. Learning more about how sediment responds to mild wave conditions will enable specialists to predict a beach's recovery state; hence, improve our coastal management guidelines.

CROSSTEX (CRoss Shore Sediment Transport EXperiment) is a multi-university involved experiment including: Oregon State, Ohio State, Cornell, Delaware, Florida, Woods Hole Oceanographic Institution, and the Naval Postgraduate School. These experiments will study cross shore sediment movement in the inner surf zone. Dr. Merrick Haller, Oregon State University, Dr. Tuba Ozkan-Haller, Oregon State University, and Dr. Jim Kirby, University of Delaware, are conducting a part of the series of CROSSTEX experiments entitled <u>An Experimental Study of Onshore Bar Movement</u>. These experiments will focus on observing wave conditions that will likely produce onshore sediment movement and will be performed in the Large Wave Flume (LWF), at the O.H. Hinsdale Wave Research Laboratory (WRL), Oregon State University.

My contribution to the experiment was to work on experimental design. This entailed collecting and analyzing data from both large scale laboratory and field experiments which focused on sediment accretion. Also, using these data I tested existing parameters for prediction of beach erosion or accretion. Lastly I worked with calibrating instruments, performing sieve analysis, and setting up instruments in the LWF to test how the apparatus interacted with the bathymetry.

Methods:

Before running the experiment in August, we needed to know what real life conditions we would be simulating in the lab, and if those conditions were useful. To accomplish this knowledge I read four previously performed experiments that displayed cases of onshore sediment movement. These included Duck 1982[6], Duck 1994[3], Lip Delta Flume[4], and Supertank[5]. Both Duck 1982, and Duck 1994 were field experiments performed in Duck, North Carolina in the corresponding years. Lip Delta Flume and Supertank were laboratory experiments performed in 1995 and 1994, respectively. My task was to collect data from each of these experiments where accretion was observed. Parameters I collected included:

- Wave Height
- Wave Period
- Sediment Diameter
- Distance Offshore to Bar
- Water Depth Over Bar
- How Far the Bar Migrated
- How Long it Took the Bar to Migrate

Collecting these data allowed me to compare each of the experiment's setup, and also to conceptualize what range of wave conditions and bathymetry our experiment would be simulating. Also from data I calculated a Dean number which was used to predict accretionary conditions given a certain threshold. These relationships are described by Dean and Dalrymple (2002)[2] and are listed below.

If $D < 0.85$, then accretion is likely for lab (Equation 1)

If $D < 2.00$, then accretion is likely for lab (Equation 2)
or
If $D < 2.50$, then accretion is likely for field

If $D < D'$, where $D' = \left(\frac{\left(\frac{Ho}{Lo} \right)}{0.0007} \right)^{(1/3)}$ (Equation 3)

If $P = g*Ho*D/w2 < 10{,}400$, then accretion is likely for lab (Equation 4)
or
If $P = g*Ho*D/w2 < 26{,}500$, then accretion is likely for field

Where D is the Dean Number defined as:

$$D = \frac{Ho}{w \cdot T} \quad \text{(Equation 5)}$$

Where Ho is defined as the deep water wave height in meters, w is the sediment fall velocity in meters/sec, and T is the period in seconds. Lo is the deep water wavelength in meters defined as:

$$Lo = \frac{g \cdot T}{2 \cdot \pi} \qquad \text{(Equation 6)}$$

Where g is acceleration of mass given in (m/s^2). Computing these parameters I was able to qualify the Dean numbers associated with the reports I analyzed, and check to see if they did in fact predict accretion. These results are listed in Table 1, and discussed further on in this report.

Also from the data I collected I was able to scale the previous experiment parameters to the size we would use in the LWF. Further evaluating these wave conditions I computed what sediment diameter they represented in real life applications. I did this using the Dean number and setting it equal for both lab and field. Fixing the sediment fall velocity for the lab, I was left to solve for the field sediment fall velocity which I related to sediment diameter.

Before I began working on this project, Dr. Haller and graduate student, Jason Magalen, ran waves in June of 2005 in the LWF. I was given beach bathymetry profiles of before and after the waves ran. The first displayed a barred beach, and the latter showed that the bar had moved onshore, illustrating accretionary wave conditions. With these two profiles I then fit an Equilibrium Beach Profile (EBP) to the two curves, which gives an estimated bathymetry for when the change in beach profile has roughly reached zero. The EBP is defined by Dean (1977)[1] and given in Equation 7:

$$h = A \cdot x^{(2/3)} \qquad \text{(Equation 7)}$$

Where h is the water depth measured from the still water line in meters, A is a dimensional scale parameter based on sediment diameter values given in units $m^{(1/3)}$, and x is the cross-shore distance measured in meters. A-values were taken from Dean and Dalrymple (2002)[2] . To determine which of these A-values would best fit the June profiles I wrote a Matlab program which would compute the best fit EBP. The program used a Least Square Value, Equation 8, which was calculated by comparing water depths. This value was computed between the most onshore data point to the crest of the bar. Computations were done in this manner to compare with Supertank data analysis done by Wang and Davis (1998)[7]. The Least Square Value is given to be:

$$LSV = \sum (h_{EBP} - h_{acc})^2 \qquad \text{(Equation 8)}$$

Where LSV is the least square value, h_{EBP} is the water depth given by the Equilibrium Beach Profile in meters, and h_{acc} is the water depth given by the accretionary beach profile in meters. Finding the smallest difference between these two depths along the profile gave the closest fit between the EBP and the accretionary data.

In preparation for the experiment in August we needed to calibrate our instruments as well as see how they interact when inserted into the LWF. For this experiment mainly two instruments will be used: an Optical Backscatter Sensor (OBS) and an Advanced Doppler Velocimeter (ADV). The OBS is used to measure sediment concentration in a specified volume of water. The instrument does this using infrared light which reflects off the sediment particles, and this amount of reflection is sent back to the OBS, which in turn gives a related voltage reading. This voltage reading then has to be converted to a sediment concentration which is why calibrating is necessary. While calibrating we found a voltage to concentration relationship as well as an error off-set for each OBS. An ADV works using Doppler radar. It measures a specified volume of water and observes Doppler shifts which indicate velocities. The ADV measures velocity in three-dimensions: x, y, and z and does not need calibrating. Combining the use of these two instruments we will be able to quantify what concentration of sediment is suspended in a volume of water and where this measured volume is moving.

The procedure used to calibrate the OBS's was to observe water with a known concentration of sediment. To do this we used a racetrack (Figure. 1) which circulates the water and sediment. We started with a concentration of zero grams per liter, and took an initial voltage reading. After this we added a gram per each liter of water in the testing tank, giving an overall concentration of one gram per liter. We then took voltage readings at the concentration level. We continued to add a concentration of one gram per liter until each of the OBS's reached its maximum voltage reading of five volts. With our collected data we plotted concentration vs. voltage and created a best fit line and an associated equation that can be used to convert voltage to concentration, as well as account for a zero-offset.

Figure 1: Jennifer Miller adding 1g/L to racetrack (left). Experiment set up, including: racetrack, personal computer with DAQ card, and weighing scale (right).

Another testing process that took place in order to prepare for the official experiment in August 2005 was to observe how our instruments will affect the data we are trying to collect. To do this, we inserted our testing apparatus into the LWF while other experiments were running. This allowed us to see if our testing equipment would cause bed scouring, as well as extra turbulence that would alter our data results.

In order to have good quality control in the upcoming experiment it was important to take sediment samples throughout the flume and to perform a sieve analysis. This was useful for a few reasons. We wanted to know if the sediment diameter varied greatly throughout the flume. If it did then this may throw off OBS voltage readings. Also we wanted to know how our sediment size compared to the Equilibrium Beach Profiles results I found as well as Wang and Kraus (2005)[8] analysis of the Supertank data. Mr. Magalen, fellow R.E.U. student Jenna Brown, and I collected sediment samples from six separate cross-shore locations (Bays 3, 5, 7, 9, 10, 12). We chose these bays because theoretically sediment diameters vary more within the surf-zone, and are more uniform further off-shore. Bays 3, 5, 7, and 9 are located between on-shore and the bar crest. The sediment samples were dried in ovens overnight, and then placed into sieve pans and shaken for ten minutes. The distributed sand was weighted and analyzed to determine a d50, which describes what sediment grain size fifty-percent of the sand passes through. I also computed statistical analysis to determine if the sediment was well sorted. To evaluate this I used criteria defined by Dean and Dalrymple (2002)[2] which are listed below.

$$\sigma_\phi = \frac{\phi_{84} - \phi_{16}}{2} \qquad \text{(Equation 9)}$$

Where σ_ϕ quantifies sorting, ϕ_{84} describes the phi value for d84, and ϕ_{16} describes the phi value for d16. A well sorted sieve analysis is defined if $\sigma_\phi < 0.65$. Dean and Dalrymple[2] also define phi values using $\varphi = -\log_2(d)$.

Results:

Evaluating the Dean number and using the criteria described by Dean and Dalrymple[2] I was able to validate whether or not their criteria accurately predicted accretionary conditions. I found that these thresholds worked much better for laboratory experiments as opposed to field. Results showed that Supertank fit three out of the four criteria and Lip fit one of the four. Both Duck 1982 and Duck 1984 failed to satisfy any of the thresholds defined by Dean and Dalrymple. These results are listed below in Table 1, where "yes" indicates that the criteria was confirmed by the experimental data, and "no" indicates that the criteria were not satisfied.

Table 1:

Experiment	Test Number/ Date	D Dean Number	Lab or Field	Criteria 1	Criteria 2	D'	Criteria 3	P	Criteria 4
Supertank	Aug.14-16	1.74	Lab	No	Yes	1.75	Yes	6630	Yes
Duck 82'	Feb. 24-May 17	5.35	Field	No	No	2.46	No	87200	No
Duck 82'	May 17- Aug. 24	3.19	Field	No	No	2.06	No	31700	No
Duck 94'	Sept 23-27	3.00	Field	No	No	1.91	No	33100	No
Lip	Test 1C	2.75	Lab	No	No	1.99	No	23800	Yes

Further examining my tabulated data from the four experiments and scaling the parameters I was able to determine what field sediment diameters we would be simulating in the lab. The scales and scaled sediment diameters are listed below in Table 2.

Table 2:

Experiment	Test Number/Date	Scale Ratio	Scaled Sediment Fall Velocity Field (m/s)	Scaled Sediment Diameter (mm)
Duck 82'	Feb. 24-May 17	5.38 to 1.00	0.060	0.400
Duck 82'	May 17- Aug. 24	4.92 to 1.00	0.059	0.380
Duck 94'	Sept 23-27	3.15 to 1.00	0.046	0.300
Lip	Test 1C	1.23 to 1.00	0.029	0.230

Using Matlab I was able to simultaneously compare one-hundred different Equilibrium Beach Profiles with the two June profiles. Using the Least Square Method, which was defined previously, I determined a best fit EBP. This in turn I could relate back to a corresponding A-value and sediment diameter. I plotted the most accurate EBP which is shown below in Figure 3. Its results give that the best fit A-value is 0.103 $m^{(1/3)}$, which relates to a d50 sediment diameter of 0.21mm. This is very close to what Wang and Kraus (2005)[8] found for the Supertank data. Fitting the EBP to the data as I did they found an A-value of 0.1 $m^{(1/3)}$ which corresponds to a sediment diameter of 0.20mm. I actually found that these values were the second best fit to the June profiles. Comparing with these authors results was a great method to check my computations. This also showed that the type of wave conditions that ran in June in fact caused onshore sediment movement, and reached an EBP that corresponded to the sediment size used in the LWF. Therefore, validating the EBP theory. Also shown in Figure 3 is the Supertank data plotted against the June profiles as well as the EBP. Shifting the still water lines so that they are equal, the data are relatively close and correspond to each other well.

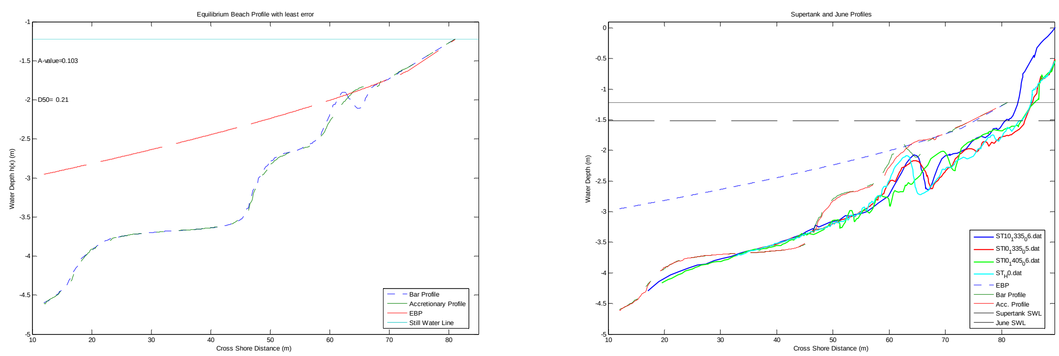

Figure 3: June bathymetry profile and EBP (left), June bathymetry profiles, Supertank bathymetry profiles, and EBP (right).

Further evaluation to check the validity of the Equilibrium Beach Profile was confirmed through the sieve analysis. Computing the d50 of the varying cross shore sediment samples we found that the average sediment diameter was around 0.21 mm. I also calculated a sorting, σ_ϕ, value of 0.309. The plotted sieve analysis is shown in Figure 4. This figure illustrates that sediment located more onshore has a greater sediment diameter. This diameter variation is not much, yet it is still a noticeable trend. The d50 ranges from 0.203mm to 0.216mm, at bays 12 and 3, respectively. In addition to validating my EBP results the sieve analysis also impacted OBS calibration results. The sediment diameter size varies only slightly, ranging a maximum difference of 0.013mm. This minute difference indicates that the OBS voltage readings will not contain inaccuracies due to non-uniform sediment sizes. To explain further, because the sediment sizes are generally uniform, each grain will return and equal voltage reading.

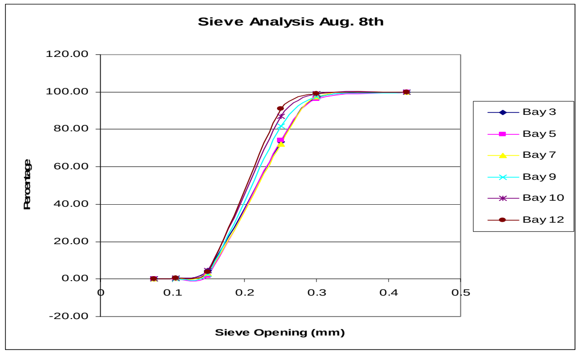

Figure 4: Sieve analysis results, illustrating that sediment diameter is slightly greater closer on-shore.

Calibrating the Optical Backscatter Sensors returned results that gave a linear relationship between voltage and sediment concentration. This plot is shown in Figure 5 for a single OBS. We also found that the OBS's could accurately read concentrations up to 9g/L before they reached their 5 volt maximum. Using a best fit line we were able to find the slope intercept formula for each OBS. Each of these best fit lines had an accuracy of 99%, which was determined by configuring the R-squared value in excel. This value describes the how close the distance between the best fit line and the data points are. An R-squared value of .99 corresponds to 99 percent accuracy.

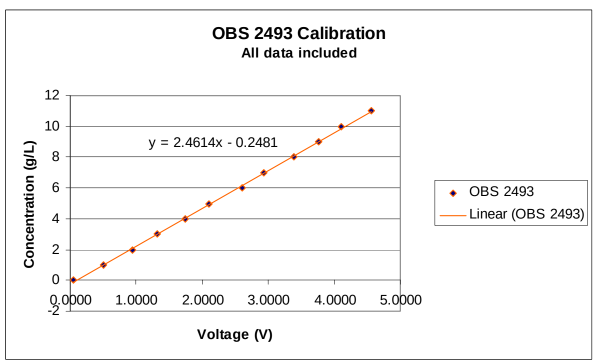

Figure 5: OBS calibration plot. Displays linear correlation between voltage and concentration.

Mr. Magalen and I placed our testing apparatus into the LWF at Bay 9. This device holds three ADV's and four OBS's. These instruments hang from stingers that are screwed into a large plate that is flush with the wall. We were concerned that the large stingers would disrupt the natural water flow; therefore, introducing error to our measured results. After running waves with our instruments in the water we were able to observe some scouring in the sediment bed below our equipment. This indicated that the flows were altered from our apparatus, but we decided that the effects were not great enough to hinder our data collection accuracy.

Conclusions:

Preparing for an experiment requires acquiring a large amount of background knowledge as well as planning and initial testing. From my data collection I determined that the Dean Number only predicted accretion for laboratory conditions. The Dean number criteria did not work well for predicting accretion in field experiments. This could be a result of averaging data over long periods of time, especially for Duck 1982 data (a three month period). The Dean thresholds may be more applicable when analyzing shorter periods of time where wave conditions are more uniform.

Scaling between experiments gives field sediment diameters between 0.230 mm to 0.400 mm in the field, which describes fine to medium grain sand, respectively. Lab simulations will be relevant to real life applications because after sediment is scaled up to field size it is still within sand limits.

Using Matlab to analyze Equilibrium Beach Profile's I found that the simple form displayed in Equation 7 accurately predicted sediment movement between the bar crest and most onshore locations. My results also matched those found by Wang and Kraus (2005)[8] who analyzed Supertank data in the same LWF. Through my sieve analysis I was able to validate the EBP results, in that the sediment diameter in the LWF and the one I solved for using EBP were the same, d50=0.21mm.While there are more exact models discussed by Wang and Davis (1998)[7], I found that the basic EBP satisfied my analysis. Although, further investigation of the profiles using other models needs to be done for better comparison and more accurate conclusions.

Calibrations for the Optical Backscatter Sensors returned a linear relationship between voltage and sediment concentration with accuracy of 99 percent. Also the sediment is well sorted as defined by Dean and Dalrymple (2002)[2] where σ_ϕ<0.65. These results are satisfactory, but before the instruments are implemented in the experiment in August other methods of calibration need to be tested in order to evaluate the legitimacy of the method used. This may include taking sediment samples from the racetrack, drying the samples, and determining the concentration, which will in turn be compared to voltage readings. In addition to evaluating the accuracy of the OBS calibrations I found that the sediment diameter varied only slightly (max of 0.013mm). This indicates that the voltage readings will not be compromised within the LWF. Lastly, the testing apparatus that will be used caused some scouring in the bathymetry of the LWF; however, this effect is not great enough that it will hinder the usefulness of the data being collected.

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Biography:

In the following year I will be returning to University of Idaho where I will complete my B.S. in Mechanical Engineering and graduate in May of 2006. After I have accomplished this I plan to study abroad to enrich my learning perspective. I will also begin working in the engineering field in order to gain an understanding of the real life applications of my degree. Once I have decided what area of engineering I would like to specialize in I will return to obtain my master's degree, further I will work to receive my P.E.

References:

1. Dean, R.G., "Equilibrium Beach Profiles: U.S. Atlantic and Gulf Coasts," Department of Civil Engineering, Ocean Engineering Report No. 12, University of Delaware, January, 1977.
2. Dean, R.G., & Dalrymple, R.A. (2002). *Coastal Processes with Engineering Applications.* Cambridge, UK: Cambridge University Press.
3. Gallagher, E.L., Elgar, S., & Guza, R.T. (1998, February 15). Observations of Sand Bar Evolution on a Natural Beach. *Journal of Geophysical Research, 103(2),* 3203-3215.
4. Roelvink, J.A., & Reiners, A.J.H.M. (1995, January*), Lip 11D Delta Flume Experiments*. Delft, The Netherlands, Delft Hydrolics.
5. Smith, J.M., & Kraus, N.C. (1995, September). *Supertank Laboratory Data Collection Project*. Washington, D.C., U.S. Army Corps of Engineers.
6. Trowbridge, J., Young, D. (August 15, 1989). Sand Transport by Unbroken Water Waves Under Sheet Flow Conditions. *Journal of Geophysical Research, 94,* 10,971-10,991.
7. Wang, P., & Davis, R.A. (1998). A Beach Profile Model for a Barred Coast-Case Study from Sand Key, West-Central Florida. *Journal of Coastal Research, 14 (3), 981-991.*
8. Wang, P., & Kraus, N.C. (2005, May). Beach Profile Equilibrium and Patterns of Wave Decay and Energy Dissipation Across the Surf Zone Elucidated in a *Large-Scale Laboratory Experiment. Journal of Coastal Research, 21 (3),* 522-534.