ABSTRACT

The experimental design process consists of the following key steps: literature review, scaling of the model, physical design and construction of experiment, and creation of a numerical model. This summer’s REU term allowed me to take an active role in each of these steps except the last. The two projects I was involved in were investigation of the effect of erosional hot spots on shoreline change and the investigation of whether the USACE instrument cage is large enough to affect the wave climate and sediment transport readings its sensors collect just outside of the mouth of the Columbia River. Detailed descriptions of each of these steps as they applied to these experiments are presented. Overall, this summer has given me valuable experience in the design process which I will use when I am in graduate school.

INTRODUCTION

Experimental design can be defined in a broad sense as all the tasks required for an engineer to complete prior to the first run of a proposed experiment that ensure relevant and accurate conclusions. In coastal engineering, a pre-existing knowledge of wave theory and coastal processes is required in order to begin the process of designing a well reasoned experiment. The purpose of this paper is to outline all the steps necessary to complete the experimental design process and then detail the process as it applied to the research projects performed during this summer’s REU session.

The first required task for a knowledgeable coastal engineer is to conduct a literature review. The role of literature review in an experimental design is to see where the proposed experiment stands in the history of the topic to be explored. This includes verification of past case studies and laboratory experiments and the subsequent analysis of their conclusions and results.

The next step in the design process is the determination of an appropriate scale. The data from the field studies and the final scaling used in any past laboratory experiments are used to verify that the proposed experiment is modeling relevant wave characteristics and beach conditions. The scaling procedure is the most delicate step in the experimental process as it takes everything into account to produce a compromised scale that best fits the experimental equipment to be used as well as maintaining relative agreement with the cited field data.

The end purpose of the experimental process is to test a new numerical model that may demonstrate previously undiscovered phenomena. A numerical model is a computer driven mathematical model that is used to predict changes in the general coastal processes resulting from a man-made change in the coastal environment. This could include the dredging of a pit or the construction of a jetty or breakwater. There are other numerical models that try to describe in more detail the normal undisturbed behavior of waves or currents. These laboratory experiments and numerical models are outside the scope if this paper and will be subsequently disregarded.

The final step in the design process is to design and construct the actual experiment. This involves ensuring that all experimental equipment is in working order, construction of any models to be used, and the actual cohesive setup of all the individual elements with a data collection system to form a controlled, fully monitored experiment. At this point the actual experiment is conducted and the data collected. The experimental data is then compared to the numerical model's predictions and the results and conclusions are then written up with the required background and experimental setup information in a final report to benefit the coastal engineering community as a whole.

GENERAL EXPERIMENTAL DESIGN PROCESS

For a literature review to be truly useful in aiding an engineer in designing an experiment it must be thorough and objective. If any relevant paper is left out or if any non-relevant paper is allowed to influence a decision relating to the experiment, it could have a detrimental effect on the experimental design. The primary purpose of a literature review is to collect and organize as many relevant papers as possible to help the engineer get a better grasp for how he should attack the rest of the design process.

Field studies are extremely important as they report on what is actually happening in the real world. Data from field studies are collected using a variety of in situ data collectors which should not interfere with the environment they are collecting data from. Ultimately, all laboratory experiments hope to replicate their associated field studies as closely as possible. Laboratory studies are nearly as important as field studies to the engineer. They have a lesser degree of importance mainly because the experiments they discuss were designed for the laboratory and equipment available to that engineer at the time of his experiment. These may, and usually are not, the same equipment available to the engineer performing the literature review. This is an important fact to note because (as will be discussed later) the scaling of their experiment- and therefore what parameters were given priority- depends significantly on the dimensions and capabilities of the laboratory equipment available. Despite this, laboratory tests do serve an important function in that they offer results from a controlled environment. Field studies, even those who span a large time frame, are subject to whatever environmental conditions were present during their scope of observation. This could be undesirable in the event that anomalous conditions are prevalent in the time frame considered. The worst case scenario for this would be if the anomalous conditions were unusually less severe than would otherwise be expected for that region. This may lead an engineer to assume that he would only need to concern himself with modeling smaller waves or slower currents than the project actually requires. If the opposite were true, and the conditions were very severe, then it could benefit the engineer as he would see the real world results of a worst case scenario. It is beneficial to the engineer to tabulate all the relevant wave, beach, and structure parameters for all case and lab studies that he found relevant during his review. It is also important to note that the literature review is usually an ongoing process. Should the engineer find a relevant paper some time after the bulk of his literature review has been conducted, it should be treated with the same relevancy as the others and any adjustments that the new information justifies should be made.

Once a satisfactory literature review has been completed, the engineer can begin work on determining an appropriate scale for his experiment. For this, the engineer must have at least a basic knowledge of the performance criteria for the wave generator that he will be using for the experiment. The reason for this is that it does the engineer no good to develop a scale that results in a modeled wave climate that the wave generator cannot produce. Once an approximate range of periods and wavelengths that the generator can make is established, the engineer must then turn to the literature review to get an idea for the average wave climate that is present in the papers read. A good way to ensure field-model wave consistency is to ensure field-model kh consistency. This dimensionless wave parameter is the product of the wave number (k) and the water depth at the location in question (h). The equation for the wave number is k = 2*pi/L, where L is the wavelength. Keeping the kh values close will aid in determining the water depth necessary at any critical points for the model waves to behave as closely to the field waves as possible.

The engineer should then tabulate all the parameters that need to be scaled and determine which one of these is the most restrictive. This parameter will be the starting point for the rest of the scaling process. Examples of parameters that are usually involved in the scaling process are wavelengths, wave periods, water depth, and sediment fall velocity. Now the scale must be adjusted until it falls within the wave generator's performance curve and also meets as closely as possible the ideal scales for time and length as determined by investigation of the previously mentioned parameters. This will almost never result in all the parameters scaling down ideally, therefore the engineer is responsible for any decisions regarding scale manipulation to best suit the experiment. After a suitable compromise scale has been developed, everything must be scaled back up from model to field. This is to ensure that the wave climate, sediment size, and any relevant distances are reasonable. Also, this enables the engineer to clearly state in his final report what exact field conditions his experiment was modeling.

The physical design of all gauge and sensor mounting apparatuses as well as beach and structure modeling is the final step in the experimental design process. The first step in this process is to assess how many and what kinds of sensors and gauges will be required. This will also tell the engineer the minimum number of channels the DAS will need to have. The wave machine and all necessary sensors and gauges for the experiment must first be tested to ensure that they are working and behaving predictably. If anything is malfunctioning then the next step is to fix this immediately. Ideally, these two steps are performed during the early stages of the project, usually around the time that the literature review is being conducted, so as to give any unforeseen circumstance time to be resolved. The decision of modeling the beach with either sediment or concrete slabs is dependent on the experimental criteria. The decision to use sand is usually made only if the experiment is going to deal with sediment transport. If sediment is going to be used then adequate time must be allotted for running waves at the model beach until the sediment particles settle into their equilibrium profile. Now the man-made coastal modification that is being tested must be scaled down according to the length scale previously determined and constructed and implemented in the model out of appropriate materials. The next step is to construct any required mounting devices and ensure that they do not interfere with the experiment. Once the mounting structures are in place it is time to mount all the gauges. They must then be connected to the DAS and calibrated. Care must be taken in this step as an error in the calibration of any of the sensors will result in that sensor's data being thrown out.

Once the experiment has been setup, experimental runs will be performed for all required wave conditions deemed necessary by the literature review. All gauges and sensors must be constantly monitored to make sure that they are functioning properly. After all experimental runs have been completed; the engineer must then analyze all the resulting data. This data is then organized into charts and graphs to more clearly show any relationships and hopefully reveal any new phenomena.

These results are then compared to the numerical model's predictions. If there is a reasonable agreement between the two, then the experimental process is finished and it is time to write up the final report and publish the conclusions drawn from the experiment. If the two are not in agreement then care must be taken in determining which of the two is wrong. The engineer cannot assume it to be either one without further investigation lest he alter the one that was correct. In most cases, it is the numerical model that will need to be changed. Unless investigation of the experiment proves that something – such as a badly calibrated sensor - went wrong. If it is determined to be the numerical model, then the author of the model must figure out where the error in his code lies and try to fix the bug. If the experiment was at fault, then its source must also be discovered and corrected before running the experiment again. After this, the experiment and model should be in relative agreement and the experimental results can be published. If an agreement of the two cannot be reached, then that will be reported as the conclusion of the experiment.

DISCUSSION OF EROSIONAL HOT SPOTS EXPERIMENTAL SETUP

The steps that have been detailed above were used in designing this summer's REU experiments. The two projects to be discussed in detail are the investigation of the effect of erosional hot spots on shoreline change and the investigation of whether the USACE instrument cage is large enough to affect the wave climate and sediment transport readings its sensors collect just outside of the mouth of the Columbia River. A literature review was required only for the erosional hot spots investigation. The instrument cage investigation did not require a literature review because it dealt with such a specific issue that a literature review was deemed unnecessary. The scaling process and experimental design were conducted for both while only the erosional hot spots experiment had an associated numerical model. Therefore, the majority of this paper will discuss the erosional hot spots experiment as it most closely followed the plan outlined previously and is more typical of a coastal engineering experiment.

The literature review for the erosional hot spots research spanned a total of seven papers before it was decided that there was enough information to begin designing the experiment. It included four field studies, two laboratory experiments, and two numerical model reports. The reason for this is that one of the papers (Demir et al. 2002) reported on both a field study in the Black Sea and the SWAN numerical model. The papers were all recent written with publishing dates ranging from 1977 – 2002. While all the papers dealt with offshore dredge pits and their resulting effects on the nearby shoreline, they covered a wide range of wave climates, beach conditions, and pit characteristics. The specific details of these data for all the papers read are given in Table 1. The observations given by all the papers are summarized in Table 2.

The literature review confirmed that offshore dredge pits due in fact induce shoreline change. Mainly they cause the shoreline leeward of the pit to accrete while eroding the shore just outside the edges of the pit. This is caused by the transformation of waves as they pass over the pit because of the sudden change in depth. The resulting shadow zone lasts for five wavelengths. The shadow zone is defined as the region shoreward of the pit where the waves are still diffracting and refracting and have not returned to a uniform equilibrium state. If the shoreline is farther than five wavelengths away from the pit then the shoreline will remain unchanged. This is confirmed in the Sandbridge, VA numerical model verification study of RCPWAVE (Maa et al, 2001). Another factor that will limit the effect of the pit is the water depth of the sea bed prior to dredging. If the water is sufficiently deep so as to be at least equal to the depth of closure for the associated wave climate of the region, then the waves will not “feel” the change in depth cause by the pit. Here, the depth of closure is defined as the water depth that narks the seaward limit of active sediment movement due to wave action.

After the literature review was conducted, it was determined that the limiting factor for the scaling process was the ratio between the water depth of the surrounding sea bed to the total water depth inside the pit. This ratio had an average value of 0.8 in the field and laboratory studies alike. It was therefore deemed critical to preserve this ratio in the experiment to be conducted in the circular wave basin. The next step in the scaling process was to determine an adequate sediment size that would not be so fine as to be prohibitively expensive but also not be so coarse as to scale up to an unrealistic size. After several trial calculations it was determined that the best grain size to use was sand with a D_{50} of 0.22 mm. Once this was determined, the estimated equilibrium profile of this grain size was determined with data provided by Dr. Robert Dean of the University of Florida. The resulting profile graph is provided in Figure 1. With the water depth ratio and the beach profile determined, it was now possible to determine where the pit was going to be placed relative to our modeled shoreline.

The wave generator’s performance criteria suggested that it was capable of producing wave periods in the range of 0.5 seconds to 3.0 seconds. With this information the intermediate wavelengths and k values were calculated. It was previously determined that the maximum kh value for the model waves was to be

1.0. This was the criteria used to determine which wave period would be best for the experiment, along with maximizing the offshore distance of the pit relative to wavelengths. This resulted in a period of 2.0 seconds being selected, as it gave a kh value of approximately 1.0 and an offshore distance of the pit of 2.3 wavelengths. The associated wavelengths and kh values for the entire range of wave periods for the wave generator can be seen in Table 3. Since this is significantly less than the five wavelengths necessary for a shadow zone we expect a more pronounced effect on the shoreline due to the pit. Examining the period data from the field studies revealed that the field periods ranged from six to 20 seconds. This results in a range for the time ratio of 1:40 to 1:4. With a 2.0 second laboratory wave it was decided that the best time ratio to use would be 1:9 in order to model an 18 second field wave. This is a relatively large wave and would therefore demonstrate the effects of storm conditions which are the most detrimental to shoreline erosion. With the time scale established, the length scale was determined in accordance to Froude consistency so that the length scale would be the square of the time scale, or 1:81. The velocity scale for the sediment fall velocity is equal to the time scale and therefore resulted in a scaled up field D_{50} of 1.7 mm.

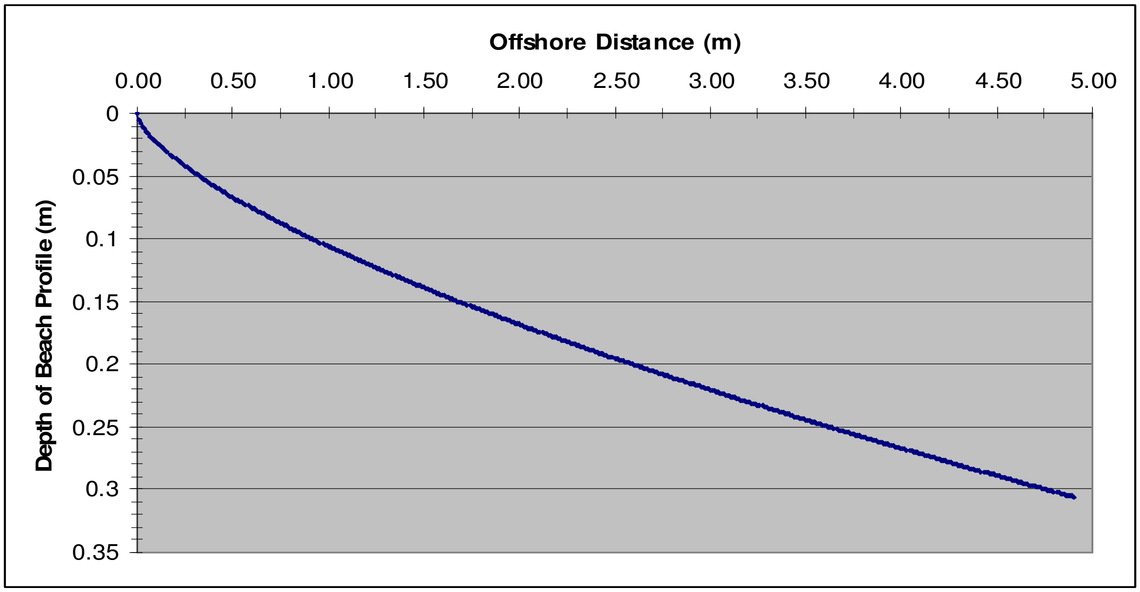

Figure 1: Equilibrium beach profile for an average sediment size of 0.22 mm as determined by the equation provided by Dr. Robert Dean.

Since this experiment was designed to be implemented in the circular wave basin that had not been used for any other previous experiments, there was a greater need for construction of gauge mounting apparatuses. The geometric properties of the basin made this task especially challenging since it is difficult to mount gauges in a radial and circumscribed fashion. This problem was met by the construction of two 20 feet long cantilevered 4x4 beams that extended inward from the outer edge of the basin 16 feet and point to the center of the wave generators. It is planned to mount an eight feet long 2x2 to each cantilevered beam so that a third 2x2 can be attached to the far end of each beam. This will result in half of a circumscribed hexagon that will allow four wave gauges to be mounted as shown in Figure 2 to measure long shore wave data. This way, the wave gauges will all be in line with the circular waves produced by the generator. There will also be four wave gauges mounted to the wave generator walkway to record cross shore wave data.

From the onset of the project it was understood that the wave generators in the circular basin were not going to be functioning in time to perform the actual experiment. Therefore, there were no actual experimental runs or data analysis performed. The numerical model for this experiment is still a work in progress by David Michalson and thus far there is nothing concrete to report on it.

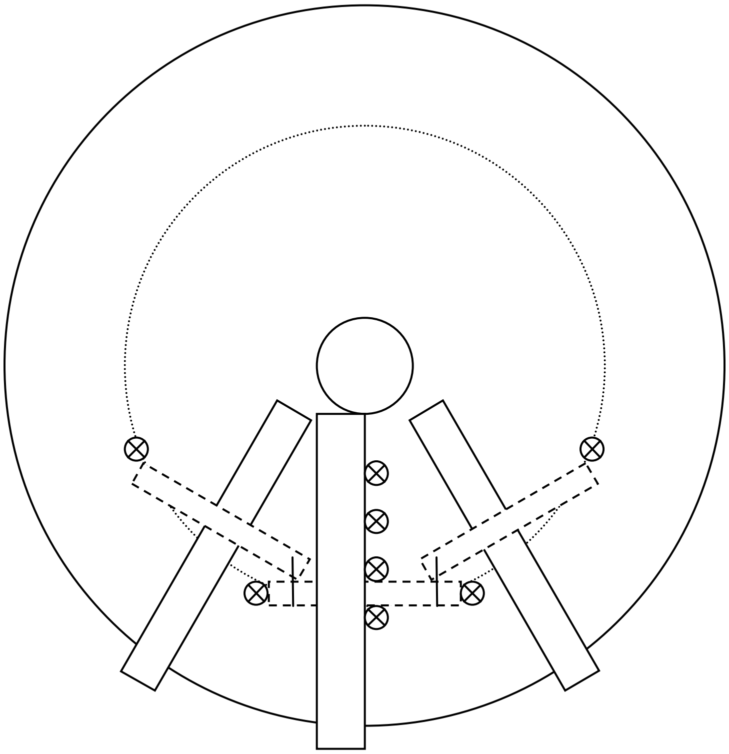

Figure 2: Rough sketch of wave gauge mounting apparatus for circular tank. Sold shapes indicate beams already put into place. Center beam is walkway to wave generators. Dark dashed lines indicate proposed beams. Circles with inscribed X's indicate proposed wave gauge mounting location. Large solid circle is the outer edge of the tank; small solid circle is the wave generator. Dashed circumscribed circle is imaginary circle that the wave gauges line up with.

USACE INSTRUMENT CAGE EXPERIMENT

The USACE instrument cage project was considerable less complicated as it required significantly less background research in preparation for the experiment. As previously mentioned, no literature review was conducted. The limiting factor for the scaling process was deemed to be the water depth. In the field, the cage will be deployed in approximately 30 feet of water. The ideal water depth in the 2-D flume is ten feet. This resulted in a 1:3 scaling which also provided the largest possible model to minimize distortion due to mismatching Reynolds number.

Consistency in the Reynolds number is important for this experiment because its main goal is to determine the effect of the instrument cage on the eddies created by the fully turbulent flow caused by wave action. This will be measured by an OBS turbidity meter which will calculate the suspended sediment kicked up by the eddies. The turbidity meter is used to calculate the concentration of suspended solids by measuring the amount of light refracted by those solids. In order for this to provide useful data it must first be calibrated according to its instruction manual. This process involves adding ten equal pre-weighed measures of sediment to ten liters of water in a black bucket and stirring the mixture a drill powered paint stirrer after adding each sample. The resulting voltage readouts are recorded and plotted against the known sediment concentration in g/L. The calibration process also allows for the gain to be adjusted so that data is not lost due to it being set too high and also for an optimal data resolution to be obtained by ensuring that the gain is not set too low.

The 1:3 scale model of the instrument cage was made out of angled aluminum for the main cage body and two channel pieces bolted together back to back to create the I-beam triangular base. The feet were made out of concrete poured into six inch diameter molds to add enough weight to hold the model to the flume bed without any other added securing devices that could interfere with the experiment. Upon construction the model was spray-painted flat black so that the light reflected off the aluminum frame would not interfere with the turbidity meter's sensor.

The final element of this experiment was the sand. It was deemed unnecessary to purchase sand once several bags of silica sand were found in the wave lab. A problem was presented in determining the size of the sand as the bags did not provide this information and the company that made the sand (U.S. Silica) did not have the required information either. A sieve analyses was subsequently performed on a 300 gram sample of the sand. The results indicated that the sand had a D_{50} of 0.16mm.

CONCLUSION

Having two experiments to work on allowed me to gain experience in the entire experimental design process for two uniquely different projects. It also forced me to manage my time better to ensure that everything got done. This will help me in the real world when I will constantly be involved in multiple projects. The dredge pit project gave me the most experience since I was an integral part of the project team. The experience gained from the dredge pit project will serve me most in graduate school when I will again be designing an experiment for my thesis. The instrument cage project gave me insight into model building and instrument calibration. I have a better understanding of the importance of calibration and the accuracy required for building a model. I learned that it doesn't have to be exactly perfect to provide valid results. Time should not be wasted on trivial details that in the end will not affect the experimental outcome.

REFERENCES

Bender, C.J. (2001) “Wave Field Modifications and Shoreline Response Due to Offshore Borrow Areas”, M.S. thesis, University of Florida.

Dean, R. and Dalrymple, R. (2002), Coastal Processes with Engineering Applications, pg. 32.

Demir et al. (2002) “Effects of Dredge Hole on the Shoreline Change in the Black Sea”, M.S. Thesis, Bogazici University.

Horikawa et al. (1976) “Mathematical and Laboratory Models of Shoreline Changes due to Dredged Holes”, Journal of the Faculty of Engineering, The University of Tokyo(B). Vol. XXXIV, No. 1, 49-57.

Maa et al. (1998) “Physical Impact of Waves on Adjacent Coasts Resulting from Dredging at Sandbridge Shoal, Virginia”, Journal of Coastal Research, 14(2), 525-536.

Maa et al. (2001) “A Criterion for Determining the Impact on Shorelines Caused by Altering Wave Transformation”, Journal of Coastal Research 17(1), 107-113.

Work et al. (2002) “Nearshore Dredging Impacts, Folly Island, SC, USA”, Unknown Source, 1-14.

ACKNOWLEDGEMENTS

I would like to thank Dr. Merrick Haller and Dave Michalson for their mentorship and guidance throughout my experience here at REU. I would also like to thank Dr. Cox for answering all my questions about the USACE instrument cage. Terry Dibble and Christopher Scott proved themselves to be invaluable aids in the laboratory for whatever problems the day brought, big or small. Finally, I would like to thank Aaron Erickson, Nathan Papini, Joe Tiebel, and Neil Clayton for making the time in and out of the lab as enjoyable and rewarding as possible. I would also like to thank NSF for making this summer experience possible, in particular grant number NSF-EEC-02-44205.

BIOGRAPHY

My name is Luis Bellón. I am a Cuban-American who grew up for most of his life in Miami, Florida. I go to school at the University of Florida in Gainesville. My undergraduate major is in Civil engineering and plan to graduate in December of this year. Upon graduation I have plans to work for the Army Corps of Engineers in their Jacksonville office. I will be working in the coastal planning and navigation section under Bradd Schwichtenberg. This will be a co-op position as I plan to continue my engineering education in the field of coastal and ocean engineering. I plan on applying to the coastal and ocean master’s programs at UF, UC Berkeley, Oregon State, and Texas A & M. Upon receiving my acceptance letters I will make my decision as to where I will go, and hopefully continue to work for the USACE. My hobbies include surfing, guitar, movies, music, and video games, to name a few. I thoroughly enjoyed the time spent at REU and highly recommend any interested engineering undergraduates to apply.

Discussion of the Experimental Design Process as it Relates to:
Quantifying the Effects of Erosional Hot Spots on Shoreline Change
and
Investigation into the Effect of the USACE Instrument Cage on the Wave Climate Near the Mouth of the Columbia River

Luis Bellón

August 21, 2003

Mentor: Dr. Haller
Graduate Student: David Michalson