Modeling How Shoreline Shape Affects Tides and How Underwater Structures Attenuate Wave Energy: An Example of the Georgia Bight

Ryndell E. Langford[1], Erika L. Schumacher[2], Theodore A. Uyeno[3], and Joshua S. Reece[4]*

[1] *Valdosta State University, 1500 North Patterson Street, Valdosta, GA 31698, relangfo@valdosta.edu*

[2] *Valdosta State University, 1500 North Patterson Street, Valdosta, GA 31698, elschumacher@valdosta.edu*

[3] *Valdosta State University, 1500 North Patterson Street, Valdosta, GA 31698, tauyeno@valdosta.edu*

[4] *Valdosta State University, 1500 North Patterson Street, Valdosta, GA 31698, jreece@valdosta.edu*

Abstract

Two demonstrations are presented that lead students to a greater understanding of ocean tides and wave energy, using the unique tidal range and wave action of the Georgia Bight as an example. The goal is to explain how varying geological features in coastal regions create different wave energies and how the shape of a coastline affects the magnitude of the tidal range. These mechanisms were demonstrated to students in an upper-division college course prior to attending a field trip, in which they would evaluate real-world examples of coastlines with high and low wave energy, and regions with large and small tidal magnitudes. Here, the method of applied learning proved to be successful in guiding students to better comprehension of concepts when relating demonstrations to firsthand observations in the field.

1. Background

Teaching through demonstrations is one way to gain the interest of students while motivating them to form questions and more effectively grasp concepts and understand course material [1]. In addition to lecture and discussion, demonstrations can lead students to a more in-depth understanding, rather than a standard recollection of facts [2]. Here, we develop demonstrations that enable comprehension of what affects ocean tides and wave energy using the unique tidal range and wave energy of the Georgia Bight as an example.

Within the South Atlantic Bight is the Georgia Bight, which spans from the Florida-Georgia border to South Carolina. Along this region, the continental shelf has a shallow slope and extends for about 145 km into the Atlantic [3], which causes an attenuation of the wave energy [4]. Additionally, the concave shape of the coastline increases the magnitude of the difference between high and low tides; this difference is greatest at the center of the Georgia Bight, which can have a tide range reaching 3 meters [5; 4]. In comparison, at the northern and southern edges and outside of the Georgia Bight, tide range is around 0.3 meters [5].

Our goals in these exercises are twofold. First, we want to demonstrate how coastal geology affects wave action and how underwater plants such as seagrasses and mangroves attenuate wave energy in shallow water. Secondly, we want to show that irrespective of wave energy, the magnitude of tidal influence (the difference between high tide and low tide) is impacted by the shape of the coastline. The demonstrations included here illustrate both of these points using hands-on exercises and affordable materials. These exercises were implemented with great success in an upper-division college course on coastal biodiversity in Georgia and Florida.

2. Materials

2.1 To Illustrate the Effects of Tides

- 2 tin foil pans (Dimensions of the pans used in this demonstration were 30 cm x 23 cm x 6 cm. However, other sized pans can be used as long as large enough to easily observe water level.)
- 2 wood pieces to place under and tilt each foil pan (Dimensions of the wood pieces in this demonstration were 5 cm depth and 10 cm width. However, other sizes can be used, but they should match in width to ensure pans are sloping equivalently.)
- 11 kg bag of plaster of paris

2.2 To Illustrate Wave Attenuation

- Large plastic storage container (Dimensions of the container in this demonstration were 1 m x 51 cm x 18 cm. However, other sizes can be used, but wood pieces listed below should be sized to match the length of the smallest axis of the container.)
- Plywood measurement to create continental shelf simulation:
  - Piece 1: 44 cm x 46 cm
  - Pieces 2 & 3: (2) 9 cm x 48 cm
  - Pieces 4 & 5: (2) 9 cm x 45 cm
- Plywood used to create waves and barrier for the plaster of paris during mold of beach slope, Piece 6, measuring 44 cm x 30 cm
- 8 drywall screws to secure continental shelf box, each measuring 2-3 cm
- Power drill
- Ruler
- Measuring cups
- Buckets
- Water
- Duct tape
- Thick grade plastic wrap
- Fishing weights (Small flat fishing weights were used in this demonstration. However, other types can be used, but they should be small/ flat enough as to not impact wave attenuation.)
- Plastic doormat
- Pipe cleaners

3. Methodology

3.1 How Geology of the Coastline Affects Tides

Before beginning the first demonstration, plaster of paris will need to be mixed and poured into the two tin pans. Each pan will need to form a different shaped coastline, one straight and the other curved as shown in Figure 1. The straight coastline can be made by placing a barrier across the middle of the pan, ensuring that it is secure and leak resistant, and pouring the plaster of paris mixture to one side of the barrier. Using a curved shaped barrier, such as the side of a bucket, and then pouring the plaster of paris mixture to one side of the convex barrier, can create the desired curved/concave coastline. Allow both pans to fully dry before removing the barriers. Then, add about 3 to 4 centimeters of water to each tin pan, ensuring that the water levels in each pan are identical.

Before performing the demonstration, ask students what they predict will be the effect of tilting the containers. Allowing the water to move toward the plaster, tilt both pans to the same incline, resting them on bases of equal height. Use a ruler to measure and show students the difference in height of the water accumulated in the center of the plaster coast for each pan, and again at the edges of the coast near the edge of the pan. Gravitational pull of the water moving toward the plaster is analogous to the effect of the moon's gravity on water causing ocean tides.

There should be a noticeable difference in water level measurements between the flat coastline and concave coastline representations, and also between the center and edge measurements of the concave coastline. The difference is due to an accumulation of water in the center of the concave portion of the plaster, similar to what occurs along the eastern coast of the United States. This demonstration helps to explain the increased magnitude of tidal patterns along the coast of the Georgia Bight.

3.2 How Geology and Underwater Plants Affect Wave Action

First, make the plaster of paris mixture by slowly adding it and stirring into the measured amount of water in the bucket, using slightly more water than the plaster of paris instructions recommend, as the mixture will need to be fairly fluid. Place the plastic container on a flat surface, then use plywood Piece 6, enclosed in plastic wrap, as a barrier. Located about 15 centimeters from the end, the barrier will need to be duct taped in place to avoid movement during setting and to prevent leaking while the plaster hardens. Immediately pour the plaster mixture into the area between the end of the plastic container and the barrier, creating a flat floor on one side of the container about 5 centimeters deep. Once this is dry, another batch of plaster mixture will need to be made. Prop up the empty side of the large container in order to create a slope with the plaster floor portion at the bottom of the slope. Immediately after the plaster mix is prepared, pour the plaster mixture into the corner of the large container, on top of the plaster floor already created, as seen in Figure 2. This should create an even plaster slope with a flat edge at the bottom. This sloped piece represents the "beach" of the coastline.

Next, a box will need to be constructed out of plywood in order to create the simulated continental shelf. Using Piece 1 as the base, screw together Pieces 2 through 5 around the sides of Piece 1, to create a box (See Figure 3). Thereafter, a third and larger batch of plaster of paris mixture needs to be mixed and poured into the box, filling the box about 3-4 centimeters deep (for a total height of 5cm, matching the height of the flat plaster floor previously created). Once it is mostly dried, carefully remove the plywood sides of the box.

Before beginning the demonstration, ask students to predict the difference that inserting a simulated continental shelf will cause when creating waves in the large container. Afterwards, fill the container with water until it is about 10 centimeters deep. There are two different methods to creating waves for this demonstration. The simplest approach utilizes manpower by placing plywood Piece 6 horizontally in the water of the large container on the side opposite of the simulated beach. Hold the plywood piece on each side being sure to use consistent and gentle back and forth movements to create uniform waves. Measure and observe the height of the wave produced against the plaster beach.

Then, carefully insert the simulated continental shelf, placing it in the bottom of the large container and making sure that it abuts the flat area at the bottom of the simulated beach. Additionally, the depth of the water in the large container should be no more than 2 cm above the simulated continental shelf. As before, use the plywood piece at the opposite end of the container to create waves with a consistent back and forth motion. Again, measure and observe the wave height formed against the plaster beach.

The other method of creating waves for this demonstration involves a more complicated process in which a unique motor system has been created to ensure more consistent waves and allowing for less human error. Appendix 1 explains this method in more depth. However, the results should be very similar and show a significantly lower wave height against the plaster beach when the simulated continental shelf is inserted than when it is removed.

Wave energy attenuation is also attributed to underwater plants and/or roots, for example from seagrass beds or mangroves. Seagrass and mangroves play a more important role in wave attenuation in more tropical climates, but their importance in mitigating shore erosion and storm surges are of global importance [6].

Mangroves and seagrass beds decrease wave energy through drag dynamics [7]. To simulate these effects, we cut a plastic outdoor doormat (Figure 4) to fit on top of our plaster of paris continental shelf model, held down with a few fishing weights. The strands of the doormat simulate blades of seagrass. When the experiment is repeated, wave energy is further attenuated and dissipated as the water moves through the faux seagrass bed. Lastly, we created a second plaster of paris continental shelf identical to the first, but as the plaster was drying, students prepared what looked like spiders (with varying numbers of legs) by twisting and tying together pipe cleaners. These were stuck into the wet plaster of paris (Figure 5) and simulate the prop roots of mangroves such as the red mangrove (*Rhizophora mangle*). Again, wave energy is even further dissipated by these simulated mangrove forests, illustrating the importance of mangroves and seagrass beds for attenuating wave energy.

To assess wave attenuation in each of these exercises, visual inspection is sufficient to illustrate the point, but this exercise can be made more quantitative by placing a small ruler along the edge of the clear plastic container that serves as the wave tank. Students can measure wave height (trough to peak) near the wave-generating board, midway through the tank, and near the far end of the wave tank, at a faux shoreline or "beach" (Figure 6).

4. Results

4.1 How Geology of the Coastline Affects Tides

The presentation that utilizes tin pans, one with a curved plaster of paris barrier and the other with a straight barrier, is comparable to the concave coastal shape found in the Georgia Bight and the flat coastline situated along the outside of that area. This demonstration helps to illustrate the increased magnitude of the tide range along the coast of the Georgia Bight due to the shape of the coastline. Tilting the pans with the water traveling towards the plaster is analogous to the pull of the moon's gravity on water, causing ocean tides. In the pan with the concave-shaped plaster, the water accumulates in the apex of the curve, which depicts how the tidal range is greatest at the center of the Georgia Bight coastline.

4.2 How Geology and Underwater Plants Affect Wave Action

The incorporation of a large flat plaster mold, plastic doormat, and twisted pipe cleaners into the demonstration help students to see how the physical characteristics of different coastal floors and existence of underwater plants create different wave energies. The plaster of paris mold formed in the wooden box represents varying ocean floor geography near the coast, similar to the continental shelf off the coast of Georgia. Gradual sloping coasts slowly reduce the energy of the bottom of waves causing the wave to mildly topple over itself, but an abrupt slope causes this reduction of energy in the bottom portion of the wave to occur much more quickly, resulting in a plunging or surging break of the wave [8].

The variances in the waves seen in the demonstration are comparable to the different wave energies created by coastal areas. Those with a continental shelf decrease wave energy before reaching the coast, and those without a shelf allow for higher wave energy as it approaches the coastline. The plastic doormat and twisted pipe cleaners represent underwater vegetation, such as seagrass and mangrove prop roots. These types of plants also aid in wave attenuation as seen in the demonstration by a further decrease of wave height across the simulated continental shelf, when the doormat or pipe cleaners were applied.

5. Conclusion

The Georgia Bight, and its unique mix of low wave energy and high tidal range magnitude, is a globally important and biologically diverse region. Understanding the biological and geomorphological features [e.g., 9] that make this area distinct is an example of teaching science through mechanisms rather than labels. For example, after this experiment students understand why the Georgia Bight has a high tidal range, which is different than memorizing that it does without knowing why. The demonstrations were used to create a knowledge base on this topic prior to a field trip in which students would see real world examples of high and low energy coasts, of regions with high and low tidal range, and of areas with wave attenuation due to seagrass and mangroves. This method of applied learning proved to be successful in leading students to a better understanding of concepts when relating demonstrations to firsthand observations in the field.

References

[1] B.R. Shmaefsky, “The Rules of Research: Keeping Your Favorite Demonstrations Safe”, *Journal Of College Science Teaching*, 32(4), 2003, pp. 282-83.

[2] C. Crouch, A. Fagen, J. Callan, and E. Mazur, “Classroom Demonstrations: Learning Tools Or Entertainment?”, *American Journal of Physics*, 72(6), 2004, pp. 835-838.

[3] NOAA, “A Profile of the Southeast U.S. Continental Margin”, Retrieved from http://oceanexplorer.noaa.gov/explorations/04etta/background/profile/profile.html, 16 July 2012.

[4] L. Edwards, J. Ambrose, and L. Kirkman, “Maritime Ecoregion”, In *The Natural Communities of Georgia*, University of Georgia Press, Athens, GA, 2013.

[5] NOAA, “Tides & Currents”, Retrieved from http://tidesandcurrents.noaa.gov, 1 July 2015.

[6] D. Alongi, “Present state and future of the world's mangrove forests”, *Environmental Conservation*, 29(3), 2002, pp. 331-349.

[7] S. Hadi, H. Latief, and M. Muliddin, “Analysis of Surface Wave Attenuation in Mangrove Forests”, *Journal of Engineering and Technological Sciences*, 35(2), 2003, pp. 89-108.

[8] H. Thurman, and A. Trujillo, “Waves and Water Dynamics”, In *Essentials of oceanography*, Prentice Hall, Upper Saddle River, N.J., 2001.

[9] D. Passeri, S. Hagen, and J. Irish, “Comparison of Shoreline Change Rates along the South Atlantic Bight and Northern Gulf of Mexico Coasts for Better Evaluation of Future Shoreline Positions under Sea Level Rise”, *Journal of Coastal Research*, 68, 2014, pp. 20-26.

Figure 1. Formation of curved and straight coastline with plaster of paris in tin pans.

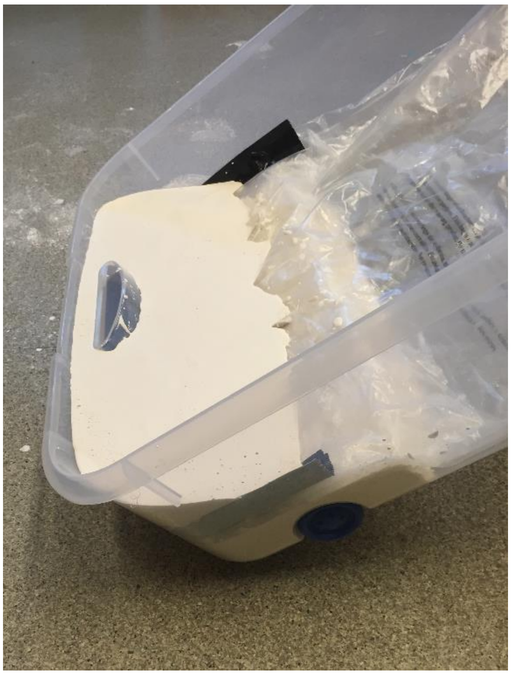

Figure 2. Large plastic container propped up in order to create a slope of plaster of paris poured on top of plaster floor. Placing plastic between the plaster floor already created and newly poured plaster slope is optional if wanting to enable the removal of the sloped portion.

Figure 3. Simulated continental shelf made from plaster of paris poured into constructed wood box.

Figure 4. Plastic doormat affixed to the top of the continental shelf to demonstrate wave energy attenuation of seagrass beds.

Figure 5. Students add twisted pipe cleaners, which simulate the prop roots of mangroves, such as the red mangrove (*Rhizophora mangle*), to the simulated continental shelf to measure their impact on wave attenuation.

Figure 6. Students measure the wave height at three places along the side of the wave tank.

Appendix 1

A wave table such as built here would benefit from an automated method of making waves. Desired parameters of such a wave generation system include production of waves of variable amplitudes and periods. There are a number of such wave generation systems that are available commercially, but they are often pricy and difficult to adapt to our wave table geometry. Here we describe a simple method of creating a wave generation mechanism using easy-to-source parts and a few components that can be built using now ubiquitous plastic rapid prototyping machines.

The practical methods by which commercial systems generate waves seem to be divided into three types. First are gravity fed wavemakers that function by filling a rotating, trough-like container beyond the tipping point in order to introduce a bolus of water into the table. This method is not feasible here as it requires a water flow through system. Second are wavemakers that utilize spinning impellers that turn on and off in a cyclic fashion, and thus produce periodic jets of water that simulate wave action. These wavemakers are designed for use in deep tanks and are a poor choice for wide water tables as they create waves around a point source rather than along a line. Third are wavemakers that produce waves by physical oscillations; such wavemakers include see-saw-like tables that slosh water from one side of the tank to the other or utilize moving walls that physically create compressions and rarefactions in the water column. Our wave generation machine is of this third type; specifically we are describing the use of an armature that raises and lowers a bar into and out of the water to create waves.

The physical construction of our wave generator has three components: the armature, the eccentric cam and the motor/controller. The armature is a beam that represents a third order lever. It is hinged on one end and the bar that raises and lowers into the water is affixed to the other side. Between the two ends, the beam rests on an eccentric pin that is affixed to a rotating gear wheel. The rotating gear wheel teeth mesh with a smaller drive gear in a 3:1 ratio. This drive gear can be driven by a smaller 12 volt DC motor (that can often be inexpensively salvaged from a laser printer, etc.) because of this 3:1 ratio arrangement in which the larger rotates more slowly, but with enough force to raise and lower the beam. These gears were designed in Sketchup and printed out using a rapid prototyper. Those unfamiliar with computer aided design can easily download gears from the thingiverse website or from the supplemental material accompanying this article. The output rotational speed of the motor itself is controlled using a pulse width modulation (PWM) unit capable of delivering a constant voltage while altering the duty cycle. This method of modulating the speed of the motor's rotation is preferable to simply reducing the voltage, because it dramatically lowers the stall speed of the small DC motor. This control can be easily achieved using inexpensive physical computing platforms such as Arduino and its clones, but we chose to use an even more inexpensive single channel PWM control unit that was developed for hobbyists and inventors. Regardless, the PWM unit should a) be able to handle the voltage and current draw of the motor, b) have a potentiometer to control rotational speed, and c) it is useful if it also includes a LCD speed indicator (from stop to 100% duty cycle).

We found this setup to be adequate to generate between 1 and 1300 waves per minute in our tank system.