# WAVE DISSIPATION SYSTEM

## COLLABORATION

The Wave Dissipation System was designed and constructed by the University A research team under the supervision of Professional Engineer A, a professor in the Civil and Environmental Engineering Department at the university, and the Principal Investigator for the project. All graduating seniors, approximately 40 students, worked on the project as part of their senior Capstone Design course. In addition, a few students made more significant contributions as part of independent studies directly related to the project.

During the spring 2014 semester portion of the project, students met twice a week with Professional Engineer A to discuss the project and to go over possible design changes to the system. Licensed Coastal Engineer A, Licensed Coastal Engineer B, Licensed Geotechnical Engineer A, and Licensed Materials Engineer A provided critical input at key times throughout the project. The coastal engineers provided practical guidance regarding what information should be recorded during the experimental testing phase of the project. They were uniquely familiar with coastal erosion issues in State A and knew instinctively what questions outside reviewers would ask regarding project results. Geotechnical Engineer A helped the University A research team design for uplift by providing key assumptions related to the saturated sand conditions and dynamic loading on site. In order to model the structural foam used inside the housing units, material properties for the foam were required. The foam manufacturer could not provide the University A research team stress-strain curves for the material. Materials Engineer A had load testing equipment that allowed the team to correctly model the behavior of the stiff foam like material used inside the units. It is clear that constant communication with licensed professional engineers and conclusions made based on their unique expertise were paramount to the success of this research project.

Outside of engineering, many other professions were involved in the project. Attorneys (regulatory and patent), contractors, geologists, state legislators, state coastal regulatory agency representatives, Army Corps of Engineers representatives, and surveyors were heavily involved. In addition to direct interaction with the research team, one student was able to participate in the site surveys alongside the licensed surveyor. Several of these professionals gave one to two hour presentations on their role in the project.

## BENEFITS

The Wave Dissipation System was designed with the primary purpose of protecting the health, safety, and welfare of the public. After completing the analytical and experimental studies described above, the Wave Dissipation System was fully installed in front of a beach front building structure occupied by many people on a daily basis. The wall is in place with a sole purpose of protecting the building foundation from erosion that could lead to collapse of the entire structure. Being involved in the design of a project (prior to graduation) that is then actually built has been very gratifying for the students. They were excited when the first storm impacted the system and felt a part of something much bigger than themselves when the results were presented all over the news. Seeing the obvious merit of this system as it relates to state citizens, state legislators in State A are currently voting on bills that will allow the use of this system all along the coast in State A. Many of the students found the politics surrounding engineering the highlight of the process. One student was so excited about being involved in the design of a real structure that he voluntarily built a small scale model of the system and a working wave tank for no additional course credit.

## KNOWLEDGE AND SKILLS GAINED

A conclusion made almost each week by the students was that the Wave Dissipation System research project was replete with surprises. Although the students were aware that they would be involved in the actual design and experimental testing of a system intended to dissipate wave energy and to protect structures, flora, and fauna behind it, the most critical lesson learned was that as students, they couldn't do any of it by themselves. They learned that licensed engineers are required, expertise in specific engineering disciplines is paramount, and engineering judgment is almost always involved in making key decisions. One of the early questions asked by the students was "what code do we use to design the Wave Dissipation System?" They found it hard to believe that there was not one. Sometimes engineers have to find applicable resources and design using those. Other times, the most applicable resource is another licensed engineer.

The publicity received by the project did great things. It made the students feel like they were making a difference, but it also brought uninvited individuals to the table to discuss their concerns regarding environmental issues and general retreat policies. Some of the students had a difficult time handling both sides of the fence on these heavily debated political issues. On the contrary, they enjoyed watching state regulators tackle these issues and more. The most important skill that was learned in this project was how to interact professionally with others, particularly when they don't share your opinion. Having so many outside professionals involved in the project allowed for many such opportunities.

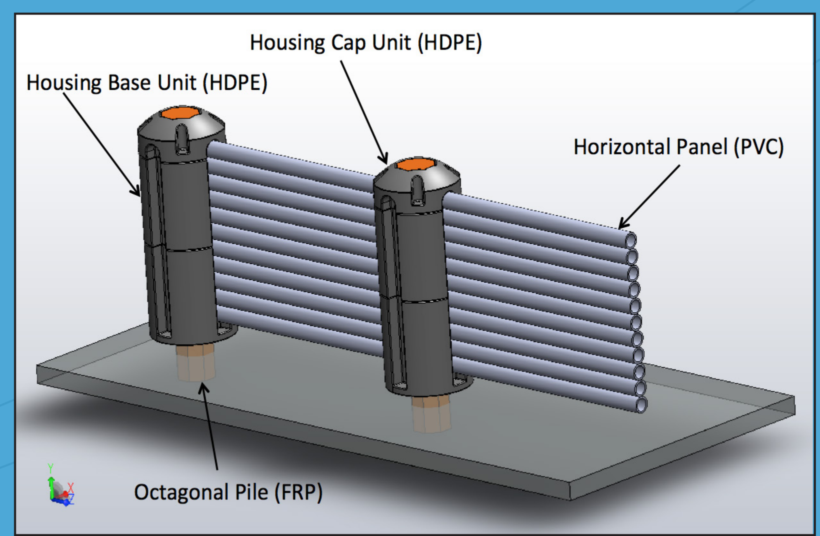
## PROJECT DESCRIPTION

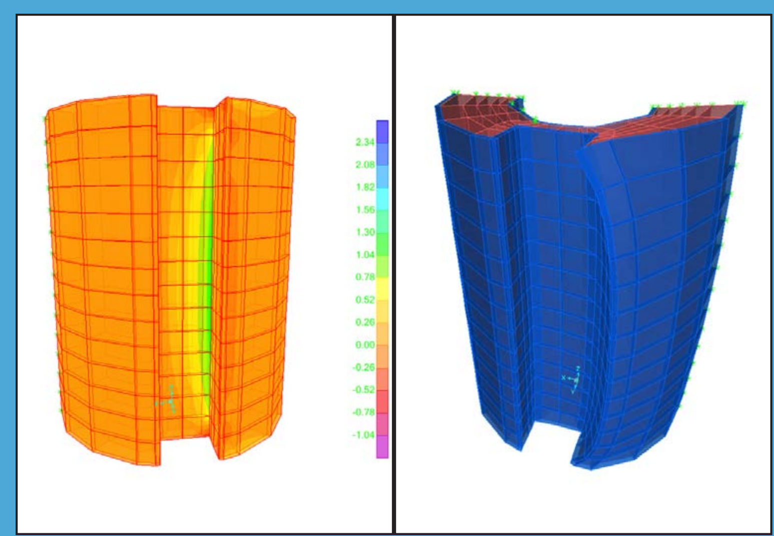
Beach erosion affects most beaches in the United States. Waves and currents, particularly those associated with storm events, can wreak havoc on public beaches and can undermine the foundations of structures built too close to the shore. For property owners in State A, the only feasible and permitted solution is often the continuous and expensive stacking and replacing of large sandbags in front of their threatened structure. Seawalls, not permitted for new construction in most states, act as a rigid structure and thus reflect (i.e., they do not dissipate) the associated wave energy. The turbulence created by breaking waves, broken waves, and other moving water adjacent to the seawall actually results in scour at the seawall-beach interface, expedited erosion in front of the seawall, loss of usable beach area in front of the seawall, and damage to adjacent property as a significant amount of moving water is forced to wrap around the wall which then impacts adjacent properties.

The purpose of this research was to design, analyze, and experimentally test a novel system capable of protecting structures, dunes, flora, and fauna that are landward of the system while minimizing the potential for negative impacts that are associated with hardened devices as described above. Working with a local marine contractor funding the project, the University A research team began the study in May of 2013.

The finite element method was used to model the Wave Dissipation System under dynamic loading effects such as those caused by 2 ft to 4 ft breaking waves crashing into the system. The structure was designed and detailed to dissipate wave energy via three mechanisms: splashing of water through the structural system, structural deformations, and soil-structure interaction. The Wave Dissipation System does not behave like a traditional seawall since it does not retain sand behind it and it allows the free passage of water and sand through its horizontal panels. After an extremely successful full-scale prototype installation on the beach in State A, the state's Coastal Regulatory Agency granted special permission to continue the study as a full installation designed to actually protect a building's foundation from the effects of erosion.

The Wave Dissipation System has received much publicity and recognition. The structure has been on the cover of state newspapers and discussed on state radio and TV shows. The project Principal Investigator and licensed professional engineer, Professor A, has been asked to present the results of the research to the state Senate and to the state House of Representatives. Based on these results, the state Senate has voted to allow the use of the Wave Dissipation System, and at the time of this submittal, the state House of Representatives plans to vote on allowing its use.



# Abstract

All seniors in the undergraduate program at University A, approximately 40 students, participated in the analysis, design, and experimental testing of the Wave Dissipation System that is currently installed and protecting a large building along the coast in State A. The system (see Figure 1) is an extremely lightweight structure composed of plastic materials including PVC, HDPE, and FRP. It was designed to serve as an alternative to sandbags which are currently the only structural element that is state-approved for erosion control. The Wave Dissipation System was detailed to dissipate energy associated with breaking waves and fast moving broken waves via three mechanisms: splashing of water through the structural system, structural deformations, and soil-structure interaction. The structure does not behave like a traditional seawall since it does not retain sand behind it and it allows the free passage of water and sand through its horizontal panels.

Figure 1. Wave Dissipation System with sandbags shown beyond.

The Wave Dissipation System was first modeled analytically using the finite element method. These results were used to optimize the structural shapes, cross-sectional properties, and pile embedment requirements. Next, a prototype full scale system was installed at a specific site along the coast in State A. Students were involved in economic, environmental, social, political, and manufacturability decisions and discussions. Interaction with licensed coastal engineers, structural engineers, a geotechnical engineer, a materials engineer, coastal geologists, regulatory officials, state legislators and attorneys led directly to the students' better understanding of how engineering and other disciplines must work together to design a solution.

The Wave Dissipation System has received much publicity and recognition. The structure has been on the cover of state newspapers and discussed on state radio and TV shows. The project Principal Investigator and licensed professional engineer, Professor A, has been asked to present the results of the research to the state Senate and to the state House of Representatives. Based on these results, the state Senate has voted to allow the use of the Wave Dissipation System, and at the time of this submittal, the state House of Representatives plans to vote on allowing its use. It is anticipated that by the time the winners of the 2014 NCEES Engineering Award for Connecting Professional Practice and Education have been selected, the University A research team designed Wave Dissipation System may actually be permitted by state law as an alternative to sandbags commonly used to protect building foundations from the effects of coastal erosion.

# Project Description

Beach erosion affects most beaches in the United States. Waves and currents, particularly those associated with storm events, can wreak havoc on public beaches and can undermine the foundations of structures built too close to the shore. The erosion and possible buildup of specific beach areas involve complex coastal geological processes and are a natural phenomenon. As such, many states enforce or support some sort of "retreat" policy that encourages new structures be built further from the beach. The sleeping giant remains the existing infrastructure (e.g., hotels, homes, and major roads) that are already too close to the shore. Should these structures be protected? Should state and federal funding be used to increase their probability of survival? Should repair of these structures be permitted when the natural erosion process undermines their foundation? In State A, politicians have supported retreat policies, but have maintained specific regulations that protect existing beaches and homeowners on beach front property. Currently, in State A, minor renourishment, sand scraping, and the use of sand bags are permitted but only under Emergency Order Regulations. An emergency is defined by State A regulations as "any unusual incident resulting from natural or unnatural causes which endanger the health, safety, or resources of the residents of the state including damages or erosion to any beach or shore resulting from a hurricane, storm, or other such disturbance." For property owners, the only feasible and permitted solution is often the continuous and expensive stacking and replacing of large sandbags in front of their threatened structure. See Figure 2 for an example sandbag application in State A. Sandbag criteria in State A can be summarized as follows.

### Criteria for Sandbag Application

- To qualify, erosion must be within 10 feet of the structure
- Biodegradable sandbags must be used
- Large sand bags are allowed (smaller ones disappear very quickly)
- Bags must be placed no farther seaward than necessary
- Bags must be stacked at an angle less than 45 degrees
- Bags must be filled with clean sand similar to the beach sand on site
- Property owners are responsible for maintenance and removal when ordered by the state

Figure 2. Typical sandbag installation following a storm event.

Figure 2 begs the question: why can't a solid wall, or seawall, be installed in front of buildings to protect them from imminent danger? Seawalls have been debated in the coastal community for years. Most experts agree that the permanence of seawalls combined with their negative side effects make their use unjustified. The two most commonly cited seawall issues involve their direct effect on beach profiles in front of and adjacent to the seawall.

When impacted by waves, seawalls act as a rigid structure and thus reflect (i.e., they do not dissipate) the associated wave energy. The turbulence created by breaking waves, broken waves, and other moving water adjacent to the seawall actually results in scour at the seawall-beach interface, expedited erosion in front of the seawall, loss of usable beach area in front of the seawall, and damage to adjacent property as a significant amount of moving water is forced to wrap around the wall which then impacts adjacent properties. As a result, construction of new seawalls is not permitted by state law in State A.

The purpose of the research described herein was to design, analyze, and experimentally test a novel system capable of protecting structures, dunes, flora, and fauna that are landward of the system while minimizing the potential for negative impacts that are associated with hardened devices as described above. Working with a local marine contractor funding the project, the University A research team began the study in May of 2013. Conceptual designs for horizontal panels, housing units, and piles were sketched on paper and economical solutions were proposed (see Figure 3).

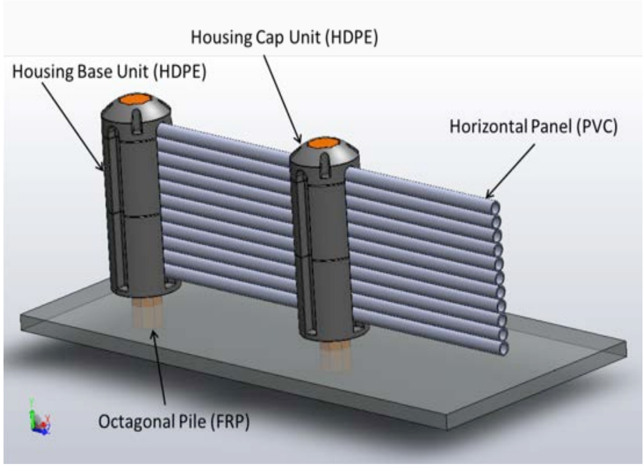



Figure 3. Wave Dissipation System elements as designed by University A.

After finalizing the general configuration of the Wave Dissipation System, the finite element method was used to model the different components shown in Figure 3 under dynamic loading effects such as those caused by rapidly moving 3 ft high walls of water (i.e., broken waves) and 2 ft to 4 ft breaking waves crashing into the system. Based on strength and stiffness requirements, the horizontal panels were designed using Polyvinyl Chloride (PVC) material and detailed to deform as necessary to dissipate energy from the moving water using a splashing mechanism where significant water and suspended sand blasts between the members. The most complicated finite element model was that needed for the housing units. These elements were to be produced by a rotational molding process using High Density Polyethylene (HDPE) material. As such, the housing units are hollow once constructed. The lower failure strength associated with the HDPE material required the use of structural foam fill for applications were larger wave forces might be expected. Figure 4 shows a typical application where half of a housing base unit was modeled and the structural foam was also included in the model. Material properties for the foam were difficult to obtain, but were finally provided by Licensed Materials Engineer A who had equipment capable of testing small cylinders of foam at impact loading rates. The piles, constructed of Fiber-Reinforced Plastic (FRP), were also modeled to determine the appropriate depth needed to ensure that permanent deformations at the top of the piling were minimized such that resetting of piles would only be required following storms significantly larger than typical storms impacting the area each year. Working directly with Licensed Geotechnical Engineer A, it was determined by the University A research team that 10 ft to 15 ft pile embedments would be required.

Once the Wave Dissipation System was fully designed, permission was granted by the State Coastal Regulatory Agency to install the first prototype Wave Dissipation System at a specific site on the coast in State A (see Figure 5). Following the intitial research performed by the project Principle Investigator, the system was installed in November of 2013. Licensed Coastal Engineer A, Coastal Engineer B, and various regulatory officials provided recommendations on what type of data should be recorded during the test to show conclusively that the Wave Dissipation System was performing as necessary. Sand elevations in front of and behind the system, permanent structural deformations, scarp line measurements behind and adjacent to the system, and survey profiles in front of and adjacent to the system were obtained on a

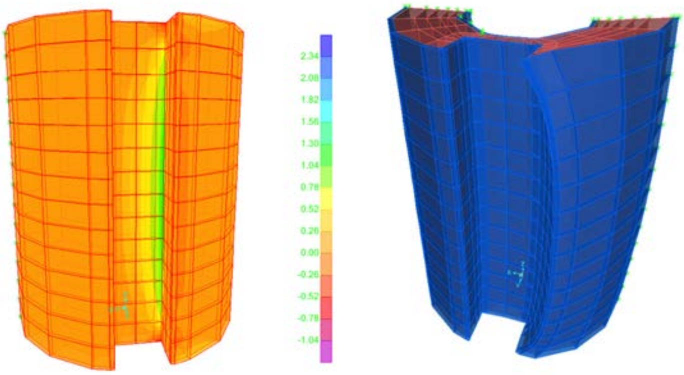



Figure 4. Finite element stress (ksi) and deformation results for typical housing unit design model.

regular basis. To everyone's delight, the Wave Dissipation System performed just as predicted. At the conclusion of the study, it was determined that the project was a total success which drew immediate interest from public news agencies and state regulators seeking solutions to growing erosion control problems all along the state's coastline. University A was then given special permission by the State Coastal Regulatory Agency to continue the study as a full installation designed to actually protect a building's foundation from the effects of erosion. This was a major development. Without the wall in place, water was already reaching the building foundation and permission to use sandbags was granted to the building owners. The building owners requested the Wave Dissipation System for protection and the full system was installed in April of 2014 (see Figures 6 and 7).

At the time of this submittal, a bill has been passed in the state Senate which permits the Wave Dissipation System for use as an alternative to sandbags. The state House of Representatives is currently considering a similar bill and it is expected that the Wave Dissipation System may be fully permitted for use along the state's coastline by the end of this summer. Students have been enthralled with the political developments and some actually watched the bill pass. Others have taken the time outside of class to watch PBS so they could hear state senators talk about the system and why they are approving its use. It is an exciting time to be a senior at University A, where at least this year, course design work has become an engineering solution to a real life problem.

Figure 5. Installation of prototype Wave Dissipation System.

Figure 6. Installation of complete Wave Dissipation System for building protection as an alternative to sand bags. Aproximate cost was $500 per linear ft.

Figure 7. Sand accretion behind Wave Dissipation System following high tide.

# Engineering Collaboration

The Wave Dissipation System was designed and constructed by the University A research team (see Figure 8) under the supervision of Professional Engineer A, a professor in the Civil and Environmental Engineering Department at the university, and the Principal Investigator for the project. All graduating seniors in the program worked on the project as part of their senior Capstone Design course. In addition, a few students made more significant contributions as part of independent studies directly related to the project. During the spring 2014 semester portion of the project, students met twice a week with Professional Engineer A to discuss the project and to go over possible design changes to the system. Licensed Coastal Engineer A, Licensed Coastal Engineer B, Licensed Geotechnical Engineer A, and Licensed Materials Engineer A provided critical input at key times throughout the project. The coastal engineers provided practical guidance regarding what information should be recorded during the experimental testing phase of the project. They were uniquely familiar with coastal erosion issues in State A and knew instinctively what questions outside reviewers would ask regarding project results. Geotechnical Engineer A helped the University A research team design for critical limit states associated with the Wave Dissipation System. Most importantly, a serious design consideration was the lightweight of the system. The entire prototype wave dissipation system weighed less than two filled 50 gallon sandbags. Figure 6 shows 50 gallon sandbags used on an adjacent property to the Wave Dissipation System. When the system is fully immersed in water without sufficient pile embedment, the hollow base units can result in buoyant forces that can pull the piles out of the ground. Based on saturated sand conditions and dynamic loading, Geotechnical Engineer A provided information necessary for the team to determine how deep the piles needed to be set in the ground to avoid failure via this limit state. In order to model the structural foam used inside the housing units, material properties for the foam were required. The foam manufacturer could not provide the University A research team stress-strain curves for the material. Materials Engineer A had load testing equipment that allowed the team to correctly model the behavior of the stiff foam like material used inside the units. The presence of the foam greatly decreases bending stresses in the walls of the HDPE units as will be required for future installations. It is clear that constant communication with licensed professional engineers and conclusions made based on their unique expertise were paramount to the success of this research project.

Figure 8. University A research team performing an assessment of the Wave Dissipation System following a storm event.

# Benefit to Public Health, Safety, and Welfare

The Wave Dissipation System was designed with the primary purpose of protecting the health, safety, and welfare of the public. After completing the analytical and experimental studies described above, the Wave Dissipation System was fully installed in front of a beach front building structure occupied by many people on a daily basis. The wall is in place with a sole purpose of protecting the building foundation from erosion that could lead to collapse of the entire structure. Being involved in the design of a project (prior to graduation) that is then actually built has been very gratifying for the students. They were excited when the first storm impacted the system and felt a part of something much bigger than themselves when the results were presented all over the news. Seeing the obvious merit of this system as it relates to state citizens, state legislators in State A are currently voting on bills that will allow the use of this system all along the coast in State A. Many of the students found the politics surrounding engineering the highlight of the process. One student was so excited about being involved in the design of a real structure that he voluntarily built a small scale model of the system and a working wave tank for no additional course credit.

# Multidiscipline and Allied Profession Participation

The design of the Wave Dissipation System involved several engineering disciplines. In addition to civil engineering, both coastal engineering and ocean engineering (e.g., wave mechanics) were heavily involved. As previously discussed, two licensed coastal engineers provided key input needed during the experimental phase of the project. Outside of engineering, many other professions were involved in the project. Attorneys (regulatory and patent), contractors (see Figure 9), geologists, state legislators, state coastal regulatory agency representatives, Army Corps of Engineers representatives, and surveyors were heavily involved in the project. In addition to direct interaction with the research team, one student was able to participate in the site surveys alongside the licensed surveyor. Several of these professionals gave one to two hour presentations on their role in the project. In the area civil engineering, geotechnical engineering was used to determine pile uplift and lateral capacities, materials engineering was used to determine properties needed for finite element modeling of the system components, structural engineering was used to design the Wave Dissipation System, and environmental engineering played a huge unexpected role in the project as the only outside resistance to this research has come from those actively pursuing sea turtle conservation and focusing primarily on retreat policies. The team was required as part of the course to fully consider opposing positions on beachfront construction and many of the students indicated this was actually the most critical part of the overall process. Several students designed improvements to the system in an attempt to make it even more sea turtle friendly.

Figure 9. University A research team meeting with marine contractor.

# Knowledge and Skills Gained

A conclusion made almost each week by the students was that the Wave Dissipation System research project was replete with surprises. Although the students were aware that they would be involved in the actual design and experimental testing of a system intended to dissipate wave energy and to protect structures, flora, and fauna behind it, the most critical lesson learned was that as students, they couldn't do any of it by themselves. They learned that licensed engineers are required, expertise in specific engineering disciplines is paramount, and engineering judgment is almost always involved in making key decisions. One of the early questions asked by the students was "what code do we use to design the Wave Dissipation System?" They found it hard to believe that there was not one. Sometimes engineers have to find applicable resources and design using those. Other times, the most applicable resource is another licensed engineer.

The publicity received by the project did great things. It made the students feel like they were making a difference, but it also brought uninvited individuals to the table to discuss their concerns regarding environmental issues and general retreat policies. Some of the students had a difficult time handling both sides of the fence on these heavily debated political issues. On the contrary, they enjoyed watching state regulators tackle these issues and more. The most important skill that was learned in this project was how to interact professionally with others, particularly when they don't share your opinion. Having so many outside professionals involved in the project allowed for many such opportunities.

Figure 10. Wave Dissipation System.

Finally, ethics, contracts and law played a major role in the entire project. Students were involved at the discussion level in the contract developed for the full installation of the Wave Dissipation System in April 2014. Prior to presenting conclusions to the state Senate, Professor A was asked ethics questions regarding funding to ensure that his conclusions were not biased. Students were even allowed to have an open discussion with state coastal regulators and questioned them on decisions made in the past that they felt may have involved ethical issues. Regarding law, the previous discussions about bills being considered at the state Senate and House of Representatives are obvious examples, but it is important to note that the only reason that the University A research team was permitted to build a structure on the beach in the first place was because a special exception exists in the state regulations allowing universities and state agencies to build structures (that would otherwise be illegal) on the beach as part of a study that might benefit the public.