The Citadel
Department of Civil and Environmental Engineering
171 Moultrie Street
Charleston, SC 29409

July 10, 2018

Deron Nettles
SI Seawall and Fencing Systems, LLC
1466 Fiddlers Marsh Drive
Mount Pleasant, SC 29466

Re: Wave Dissipation System – OC/SS/BWE/HI
Final Report – May 28, 2018

Mr. Nettles:

Now that the subject studies are officially complete and the systems have been removed from the subject properties, this report is being provided to you as a closure report that covers the time period from December 2016 until now and provides a brief history of Wave Dissipation System (WDS) research activities and report findings prior to December 2016. This report also provides a summary of Citadel researchers' technical (i.e., scientific/engineering based) responses to the WDS Monitoring Report developed by GEL Engineering (2016) and technical responses to the DHEC Board's Decision Letter dated June 8, 2017. All studies at Ocean Club/Seascape (OC/SS), Beachwood East (BWE), and Harbor Island (HI) concluded in the Spring of 2018 when all full scale structures were removed from the subject sites. Citadel research monitoring of the subject sites ended when the systems were removed.

The main purpose of this report is to make final conclusions on the technical performance of the WDS that include final monitoring of the systems from July 2017 until January 2018. As you are aware, our previous study results (2013-2016) led us, in reports dated 11/28/2014 and 8/28/2016, to conclude that:

> "…the Wave Dissipation System is able to:
> 1) protect structures, dunes, flora, and fauna that are landward of the system
> 2) minimize the potential for negative impacts that are associated with hardened devices, and
> 3) allow for natural beach elevation changes while providing better protection of dune lines by using a multi-tier system in areas of higher wave energy and a single line system in areas of lower wave energy"

We are happy to report that the results of this final 4 site study time period have not changed the conclusions made in the previous reports and that the research team believes that the WDS should be allowed as an alternative to sandbags (in emergency situations) along the coast in South Carolina. On the contrary, please note that we have made many recommendations regarding its use that should be

adhered to in order to ensure the optimal performance of the system. The main issue to note is that the WDS is a dynamic system that must be configured appropriately for optimal performance and that its use will require modifications and some degree of sand replenishing after severe erosion events. OCRM did not allow most of the recommendations developed and proposed by Citadel researchers to be applied or adhered to during studies conducted after the 2013-2014 pilot, because they claimed the results (to be reflected in the surveys) would be affected. As a result, optimal performance could not be maintained throughout any of the studies since 2014. Nevertheless, even without implementation of measures to optimize the system, good performance was observed. Citadel researchers expect system performance would have been further enhanced if optimization measures recommended by Citadel faculty were implemented. As a final note, although the WDS was not designed for hurricane conditions, it is important to mention that it survived the effects of many tropical systems, most notably those from Hurricane Matthew and Hurricane Irma.

This report contains the following sections:

**Brief History of Previous Research Activities**

The Citadel research team completed its first full-scale study at Seascape around four years ago (2014). The contractor (Deron Nettles) was on and off the beach at Seascape during a one-year period. During this study, OCRM had reasonable measurement and performance requirements, and The Citadel followed their data gathering requirements exactly as summarized in the final report issued on 11/28/14. During that study, the system was used as it should be used and the results were outstanding. Appendix A (taken from the 11/28/14 report) documents one example of how the system was tuned to the wave conditions and accretion was optimal (during a natural accretion period) both in front of and behind the system. The purpose of the study was to find a better alternative to sandbags for sites in emergency conditions (Figure 1.1).

Figure 1.1. Overall purpose of all research was to find an alternative to sandbags for sites in an emergency situation.

When the 2013-2104 study was complete, OCRM/DHEC requested that more studies be performed to verify that the conclusions for the one site (Seascape) would be applicable to other sites along the South Carolina coast. The contractor and OCRM worked out the details of four additional sites and these sites were the locations for all studies since 2015. On the Isle of Palms, the selected sites were Ocean Club/Seascape (OC/SS) and Beachwood East (BWE) and at Harbor Island (HI), a row of four home sites was chosen for testing as well. Appendix B presents the executive summary and the sandbags vs. WDS comparison summary as contained in the 8/28/2016 report. These sections are presented here for completeness and as the basis for findings discussed elsewhere in this report. Appendix C contains information regarding how the system should be used as recommended by Citadel researchers. These recommendations were made in the 8/28/2016 report and reflect how the system should be used to optimize performance.

**Technical Comments on GEL Engineering's WDS Monitoring Report**

When the four site one-year study ended in July of 2016, The Citadel issued a final report stating that the system met all requirements that would define the system as a qualified system and that it was as good as or better than sand bags for emergency applications. It should be noted that, during the study period, OCRM, through an RFP process, retained the services of GEL Engineering, LLC in Charleston, SC to serve as an independent expert. OCRM sought to base their recommendations on the findings of multiple recognized experts in coastal engineering systems, rather than rely on findings/recommendations of only Citadel faculty researchers. Citadel faculty were made aware of the OCRM decision to use an independent expert in the Fall of 2015 and agreed that it was a good idea.

To perform the services of the independent expert, GEL Engineering, LLC hired Matt Goodrich, P.E. (a Principal at WEC from 2011 to present) to write the technical report for the company. Intentionally, Citadel faculty did not contact Matt Goodrich during the study, given OCRM's noted desire for the expert to provide independent discovery and review services. Matt Goodrich is a well-respected coastal engineer who is well qualified to perform the services necessary and to author the independent expert report.

Citadel researchers watched (online) the December 8, 2016 DHEC board meeting where findings and conclusions of the experts were presented by OCRM staff (selectively taken from Citadel and GEL reports). OCRM staff used this information and their own "observations and evaluations" to present a recommendation to not allow continued use of the WDS. OCRM staff concluded that the WDS had not been successful in addressing an erosional issue and that it should not be permitted for future use in South Carolina. OCRM staff noted the system's inability to "hold the scarp line", its inability to increase or retain landward sand accretion, and issues with scour and adjacent property effects similar to sea walls in its justification for not recommending continued use of the system.

Some of these technical points will be addressed subsequently in this same section; however, it should be noted here that holding the scarp line and continued accretion were never part of the WDS study nor are they features associated with the WDS or sandbags. These two major criteria developed by OCRM at the end of the study were not provided to the researchers when definitions of success were requested (prior to the study beginning) nor should they be used. Note that the two criteria are consistent with a seawall; a seawall holds the scarp line behind it and completely retains sand placed behind it. Seawalls reflect (i.e., do not dissipate) wave energy. As a general rule, the WDS allows moving water behind it and scarp line effects during major erosion events are expected. More importantly, most of surveyed movement of the scarp line noted by OCRM was due to tropical storm and hurricane effects that created wave conditions beyond those expected during the one-year study. As a second general rule, when a beach is continuing to accrete sand, the WDS will continue to accrete sand in front of and behind the system. Accretion and sand loss are cyclical, yet trending. As shown in the 2013-2104 study, the accretion can be optimized when the system is used appropriately. When the beach is losing sand, the WDS simply slows the loss process.

Dr. Mays listened to OCRM staff present findings from both reports (Citadel and GEL) and was taken aback by how data was presented and how OCRM's own expert's conclusions were totally misstated (some not presented at all) during the presentation. Dr. Mays was most offended by the fact that OCRM staff actually stated that The Citadel report and the independent export report had "completely different findings." Dr. Mays immediately, for ethical reasons, reached out to Matt Goodrich, P.E. (OCRM's expert) to make him aware of the issue. OCRM's expert made it very clear to Dr. Mays that (1) OCRM did not inform him about how they would present his findings or seek clarifications on his

findings, (2) that he took no exceptions to the use of the WDS for emergency applications, (3) that Dr. Mays was reading his conclusions correctly, and (4) that the Citadel's findings and his findings were in harmony with each other.

The Budget Proviso Qualification Criteria listed in Table 1.1 presents traits of a Wave Dissipation System that make it qualified (i.e., technically permitted for use) based on design or performance criteria. Citadel researchers and OCRM's expert GEL Engineering, LLC (Matt Goodrich, P.E.) unanimously agree that the WDS meets the criteria on all counts. It is interesting to note that based on the expert opinions provided to OCRM and their own "observations and evaluations," OCRM formulated a conclusion that only criteria 1 and 6 are met by the WDS.

Table 1.1. Qualified Wave Dissipation System Definition and Expert's Opinions*

| Criteria | Citadel Research Conclusion | GEL Engineering, LLC Conclusion |
|---|---|---|
| 1 - A qualified wave dissipation device is placed mostly parallel to the shoreline | Yes | Yes (see page 123 of GEL report) |
| 2 - A qualified wave dissipation device is designed to dissipate wave energy | Yes | Yes (see page 123 of GEL report; page 120 states that it "clearly conveys" this) |
| 3 - A qualified wave dissipation device is designed to minimize scouring seaward of and adjacent to the device by permitting sand to move landward and seaward through the device | Yes – Although the system is designed to minimize scour, proper use requires the future permit holder to follow the recommendations for use and maintenance in order to minimize scour. As detailed in 8/28/2016, appropriate maintenance was not permitted by OCRM during the study. | Yes (see page 123 of GEL report). Notes that scour is not eliminated (nor is that required under "minimize"). Notes that "if the WDS is actively managed as compared to a passive seawall or bulkhead, then the effects of scour could be minimized as compared to a passive seawall or bulkhead." Page 124 refers to scour as "limited." |
| 4 - A qualified wave dissipation device has horizontal panels that can be deployed within one-hundred twenty hours or less and can be removed within one-hundred twenty hours or less | Yes – With proper notice and fully implemented private funding as an approved product, removal speeds in the field suggest that full time removal could include the horizontal panels at each study site within the noted time constraint. | Yes (see page 130 of GEL report) |
| 5 - A qualified wave dissipation device does not negatively impact or inhibit sea turtle nesting or other fauna | Yes – per state and federal experts noted comments. Citadel faculty recommend horizontal panels be removed during turtle season. | Yes (see page 131 of GEL report) |
| 6 - A qualified wave dissipation device can be adjusted after initial deployment in response to fluctuations in beach elevations | Yes | Yes (see page 131 of GEL report) |
| 7 - A qualified wave dissipation device otherwise prevents down-coast erosion, protects property, and limits negative impacts to public safety and welfare, beach access, and the health of the beach dune system | Yes | Yes (see page 127-130 of GEL report). Note that any impacts discussed are considered insignificant or related to background erosion. |

* Based on the expert opinions provided to OCRM and their own "observations and evaluations," OCRM formulated a conclusion that only criteria 1 and 6 are met by the WDS.

**Technical Comments on the DHEC Board's Decision Letter**

Most of the technical comments in the previous section are also applicable to the DHEC Board's Decision Letter and these comments are not repeated here. In addition, although it was hoped that Citadel researchers would (in response to the DHEC Board's Decision Letter) be able to continue the study for another year in accordance with the recommendations contained in the their 8/28/2016 report, subsequent legal issues limited the ability to do detailed and more involved studies. As will be shown in the next section, the research team was able to do some small studies prior to project completion.

A few notes should be made regarding future studies. The June 8, 2017 DHEC letter says that in future studies, The Citadel is to "implement adequately refined parameters and scope of work . . . and . . . identify and assess control locations with shoreline dynamics comparable to the WDS sites, have a plan for implementing changes, and establish Department approved measurements and criteria for success of the study."

It is important to state that DHEC's request to identify and assess control locations with shoreline dynamics comparable to the WDS sites is an entirely impossible task. Most importantly, the Isle of Palms beach is not similar to the beach in Florida. There, long stretches of beach have parallel contours with similar wave characteristics, etc., and creating a true control is possible. Secondly, such a request conflicts with the local conditions and applications of the device. The device is only permitted (for studies and long term if approved) in emergency areas. The subject areas have varying characteristics that are dynamic in nature in both directions along the beach. Finally, and for the record, Dr. Mays did reach out to OCRM's expert regarding this request for a control and he agrees with Dr. Mays on this issue.

Luckily, the way the previous study was managed (see Appendix B) created a control of sorts. We now know that under the worse possible circumstances (which is installing the system and not being allowed to modify it or correct scour) the system still results in good performance (as concluded by both experts independently and on all counts) even when system optimization is not allowed.

Now that all the systems have been removed and adequate findings have been obtained, it is the Citadel researchers' understanding that no additional testing is required and a decision can be made on the permanent use of the Wave Dissipation System.

**Summary of Research Activities and Findings for the period July 2017 until January 2018**

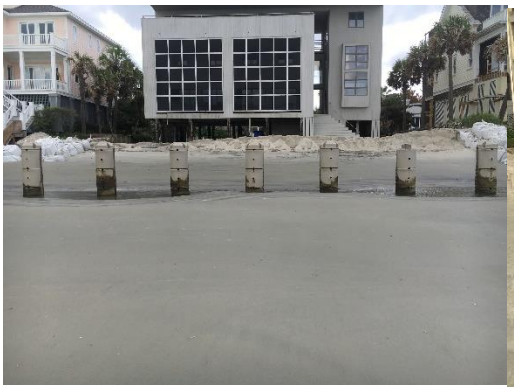
Within the time period required by DHEC in the June 8, 2017 DHEC letter, The Citadel notified DHEC that it planned to continue to study the WDS at the same sites where the systems were already installed. Citadel researchers had hoped and planned to implement their recommendations as presented in the 2016 report (see Appendix C) from July until renourishment occurred at the Isle of Palm sites (January 2018). Unfortunately, legal actions (not presented in this report) led to requirements to temporarily remove the horizontal panels and a lack of funding from homeowners to perform significantly different studies at the subject sites. Even so, the research team was able to show the following:

1. Appropriate placement of horizontal slots and openings in the WDS help eliminate scour around the system (see Table 1.1 Qualified WDS definition Criteria 4) – As shown below (July 2017), strategically placed slots and openings minimized scour over a few days (i.e., tide cycles).

BWE (7/28/2017)

BWE (8/4/2017)

2. Quick removal of WDS horizontal panels is feasible and measurable (see Table 1.1 Qualified WDS definition Criteria 4) – As shown below (August 2017), the horizontal panels at the sites were removed as mandated by OCRM. One man-hour resulted in approximately 2 horizontal panel areas removed. As such, it can be assumed that one person can remove the horizontal panels between two piles every thirty minutes or 16 spaces of horizontal panels every 8-hour day (tide permitting). When faster removal is required, more than one person can remove the panels and increase the removal time linearly.



BWE (8/25/2017)

OC/SS (8/24/2017)

3. The WDS is turtle friendly when the horizontal panels are removed (see Table 1.1 Qualified WDS definition Criteria 5) – As shown below (August 2017), the horizontal panels at the sites were removed as mandated by OCRM. On Harbor Island, the horizontal panels around an entire home were removed when a nest was found in proximity to the system.

HI (8/25/2017)

OC/SS (8/24/2017)

4. The WDS can be used in conjunction with other emergency measures such as scraping. As shown below (October 2016), the spacing of the piles accommodates the use of equipment needed to place sand behind the system after major erosion events. During the final study, OC/SS hired the product developer (SI Seawall and Fencing Systems, LLC) to direct the scraping projects onsite which resulted in a significant reduction in water volumes behind the systems and eliminated trenching at the sites.

OC/SS (8/15/2017)

OC/SS (8/16/2017)

5. When the beach elevation drop is excessive, the WDS can be placed further landward to better protect the dunes and structures behind the system. As shown below (October – December 2017), the WDS was removed at all sites at Beachwood East except at the Slotchiver's residence. This structure maintained protection by having the system reinstalled closer to the structure. Comparing the photos over a one half month tide cycle period shows clearly how the erosion of sand behind the system is delayed relative to the adjacent properties that had no protection. Note that no trenching occurred at the Slotchiver reset location.

BWE (11/21/2017)

BWE (12/8/2017)

BWE (11/21/2017)

BWE (12/8/2017)

**Conclusions and Recommendations**

Conclusions:

Based on the results of all studies performed to date, Citadel researchers have concluded that the Wave Dissipation System is able to:

1) protect structures, dunes, flora, and fauna that are landward of the system
2) minimize the potential for negative impacts that are associated with hardened devices, and
3) allow for natural beach elevation changes while providing better protection of dune lines by using a multi-tier system in areas of higher wave energy and a single line system in areas of lower wave energy.

At all sites, the WDS protected the structures behind the system, despite the fact that most recommendations made by Citadel faculty to optimize performance were denied by OCRM. The team expects that results will be even more impressive when the WDS is allowed to be tailored to address unique site circumstances. If any future studies are performed, the team believes that an experimental design with control sites is not feasible, due to the non-uniform nature of the South Carolina shoreline (as compared to other areas of the Eastern coast) and the OCRM requirement for testing only in emergency locations.

However, The Citadel researchers want to make it very clear, as they always have, that the system is not a one-size fits all solution and that it is a dynamic system that must be designed separately for each particular site, and monitored/adjusted as necessary to optimize its performance.

Recommendations:

1. The WDS should be used in conjunction with sand renourishment behind the system. This renourishment is necessary to help minimize the volume of water that gets behind the WDS. The renourshment can be brought in as beach compatible sand or reclaimed using the natural accretion that occurs at different times.

Renourishment behind WDS at Ocean Club in 2017.

2. Scour of the system should be minimized by proper use and maintained of the system and the site. This includes, opening up the system to expedite natural restoration and adding beach compatible sand after significant erosion events. In some site specific cases, retreat of the system to a more landward location may be beneficial.
3. During significant accretion events behind the system, dune rebuilding by moving sand already behind the system should be utilized. This will help eliminate the need for bringing in beach compatible sand. The system's capability was shown clearly in the earlier Seascape studies, but was not permitted by OCRM during these studies when requested by the research team.

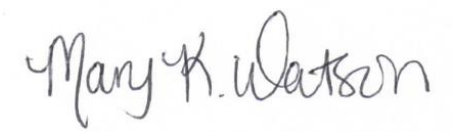
Dune restoration study at Seascape in 2014.

4. It is recommended that the system be installed with the horizontal panels fully in place during times outside of turtle season. During turtle season, it is recommended that the system be completely open (only vertical elements in place with the exception that horizontal panels underground can possibly remain if they are placed sufficiently below grade at all times to not inhibit turtle nesting; 1.5 ft minimum based on past results).
5. The horizontal panels have performed well overall but the longevity of the panels, if left unmodified, in areas of significant daily wave impacts was brought into question during the study. SI Systems, LLC needs to develop a better material wrapping of the ends of the

panels to reduce the spinning and banging of the panels against the housing units in these areas. This is a simple engineering fix that will cost SI Systems, LLC additional money when constructing similar lines of resistance.

Very truly yours,

Timothy W. Mays, Ph.D., P.E., Professor, P.I.



Mary K. Watson, Ph.D., Assistant Professor

**APPENDIX A – EXCERPT FROM 2013-2014 STUDY**

Average beach elevations at the center housing unit of the front WDS line were measured regularly. Using a datum of the existing elevation at install, Table 2 presents front WDS line elevations during the project. Figure 3 shows example elevations at the front WDS line.

Table 2. Front WDS line elevations as compared to the elevation at install.

| | |
|---|---|
| October 9, 2014 (at install) | +0 in. |
| October 10, 2014 | -6 in. |
| October 11, 2014 | -6 in. |
| October 14, 2014 | -9 in. |
| October 15, 2014 | -3 in. |
| October 16, 2014 | +12 in. |
| October 17, 2014 | +17 in. |
| October 18, 2014 | +22 in. |
| October 20, 2014 | +18 in. |
| October 21, 2014 | +18 in. |
| October 23, 2014 | +18 in. |
| October 25, 2014 | +18 in. |
| October 29, 2014 | +18 in. |
| November 1, 2014 | +19 in. |
| November 3, 2014 | +12 in. |
| November 4, 2014 | +10 in. |

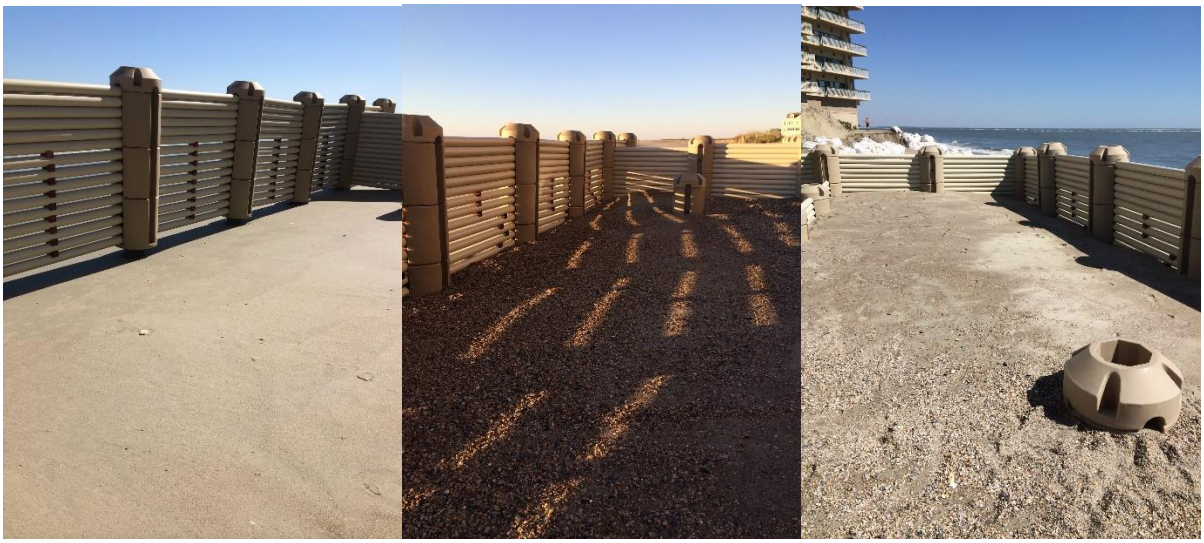


Figure 3. Sample (October 10, 2014 – left; October 16, 2014 – middle; October 18, 2014 - right) beach elevations at front WDS line during the study.

The two tier WDS system performed extremely well during the project period by fully protecting the building, the dune line, and allowing more free sand movement at the front WDS line. Changes made to

the system (as noted above and compared to the previous May-September study) proved to eliminate all Citadel noted issues as presented in the previous study report. It should be noted that the ¾ in. slots may be excessive. Although they allow more free sand movement (a good thing), they do reduce the wave energy dissipation characteristics of the front WDS line, possibly by 50% or more. 3/8 in. slot spacers were recommended for this study, but it was determined that they were too difficult to create at that time and the study moved forward with ¾ in. slot spacers instead. Future studies should attempt to optimize the slot size by comparing the results of smaller spacers as well.

**APPENDIX B –EXECUTIVE SUMMARY AND SANDBAG/WDS COMPARISON FROM 2016 CITADEL REPORT**

**Executive Summary**

Although it was the opinion of Citadel researchers that the 2013-2014 studies performed at Seascape showed clearly that the WDS should be considered a viable alternative to sandbags for emergency use in South Carolina, OCRM staff maintained that more studies at different sites were needed before they could reach a definite opinion. Therefore, SI Systems, LLC, without the help of The Citadel, began to try to find the type of sites that OCRM was requesting and homeowners willing to pay for such a study. The three sites mentioned in this report (OC/SS, BWE, and HI) were proposed to OCRM and approved.

Any good research project requires a hypothesis, and since the study was being performed solely for the benefit and demand of OCRM, Citadel researchers formally approached OCRM about providing a definition of "success". During the kickoff meeting on July 6, 2015, the WDS research team and OCRM agreed to meet together to jointly define what "success" would mean. The research team made it very clear that doing a study without a goal was unreasonable and that the definition needed to be defined immediately. Although further discussion never took place, all parties seemed to agree that something related to "as good as sandbags" would be part of the formal definition. At a follow up formal meeting (October 30, 2015) where Dr. Mays discussed his concerns over no guidance from OCRM as to what success actually means, OCRM updated the team saying they would consider, per Dr. Mays' request, the "as good as sandbags" language as they review project results, but that they would not come up with an agreed upon definition but would instead base their decision on how well the system adheres to the language in the regulations (which is how they view their charge).

The performance summaries presented in the subsequent three sections of this report are intended to describe and detail the overall performance of the system at each of the three study sites. Although researchers are happy with the overall performance of the system and its ability to dissipate energy from waves, some concerns are expressed in the recommendations and conclusions section of this report. Readers should carefully note that unlike research at other universities where structures can be tested in a university wave pool where wave period, wave height, and tide levels can be controlled, these structures were completely loaded by whatever events God allowed to occur at each site over a one year period. As such, the now infamous 1,000 year storm, many nor'easters, and several tropical storms impacted the system. The WDS survived all the events, some of which were beyond levels considered in the original design of the system. It is also important for the reader to note that Citadel researchers were not permitted by OCRM to optimize the system's performance and that the way the systems were tested over the last year is in no way indicative of how they should be used in practice. On the other hand, even though not optimized for performance, the WDS did protect the structures behind the systems for the duration of the study period described in this report.

It is the opinion of the project's principal investigator that OCRM has always had the overall mindset (regarding a study) that the system should be built and then the research team should just step back and watch what happens over the next year. This approach is not applicable to sandbags and should not be applied to the WDS. The research team has always stressed that the WDS is dynamic and needs to be

built and modified as often as necessary to address changing beach elevations and dune situations behind the system. To help minimize the negative side effects of hardened structures, the WDS allows water to move behind the system. However, the amount of water allowed through the system should be controlled by renourished sand placed behind the system and dune rebuilding which the system allows via natural accretion needed for such activities.

The only major concern that the research team noted during the study is the temporary local trenching that occurred at times at each site. The trenching never occurred in the previous Seascape studies nor at Ocean Club this year until the last portion of the study period covered in this report. The trenching appears to be related to scour caused by extreme tides, significant erosion events, and the uncontrolled volume of water that is allowed to pass through the system (this same volume of water must escape as the tide goes back out). Although the system is self-healing in all cases, the time required to self-heal after event related local trenching is site specific, and it is the opinion of Citadel researchers that self-healing should not be permitted in all cases. Removing just the horizontal panels in areas of local trenching almost immediately restores the beach profile by eliminating the trenching effect and the horizontal panels are easily removed for this purpose. Researchers spent a lot of time developing vertical panel designs and prototypes for removing the trench since this alternate approach would be much more cost effective (particularly during a study) than complete lowering of the system and since vertical panels could be installed in isolated locations as needed versus lowering which requires a significant portion of the system to be lowered at one time. The use of the vertical panels was not permitted by OCRM. Although an earlier Citadel report stated that "although lowering may alleviate the trenching, we are not planning that this will be the solution. We only propose it to increase energy dissipation," OCRM correspondence to Dr. Mays did not permit the vertical panels and instead OCRM suggested the use of lowering the system which no one was willing to pay for during a short term study. If the sand elevations behind the WDS are maintained on a bimonthly schedule or so, some of this beach compatible sand can be easily and quickly moved to eliminate any potential concerns caused by the temporary trenching on site.

Based on the results of all tests performed to date, the Citadel researchers have concluded that the Wave Dissipation System is able to:

1) protect structures, dunes, flora, and fauna that are landward of the system
2) minimize the potential for negative impacts that are associated with hardened devices, and
3) allow for natural beach elevation changes while providing better protection of dune lines by using a multi-tier system in areas of higher wave energy and a single line system in areas of lower wave energy

At all sites, the WDS protected the structures behind the system and when used as recommended (not as detailed in this study) the results will be even better.

However, The Citadel researchers want to make it very clear, as they always have, that the system is not a one-size fits all solution and that it is a dynamic system that must be designed separately for each particular site, and monitored/adjusted as necessary to optimize its performance.

**Sandbags vs. WDS**

The purpose of this section of the report is to compare and contrast the subjective and objective relative merit of sandbags versus the WDS in regards to beach erosion. Currently, in South Carolina, minor renourishment, sand scraping, and the use of sandbags are permitted, but only under emergency order regulations. For some property owners, the only feasible and permitted solution is often the continuous and expensive stacking and replacing of large (or small in some cases) sandbags in front of their threatened structure. See Figure 34 for a side by side comparison of a sandbag versus WDS applications on the Isle of Palms.

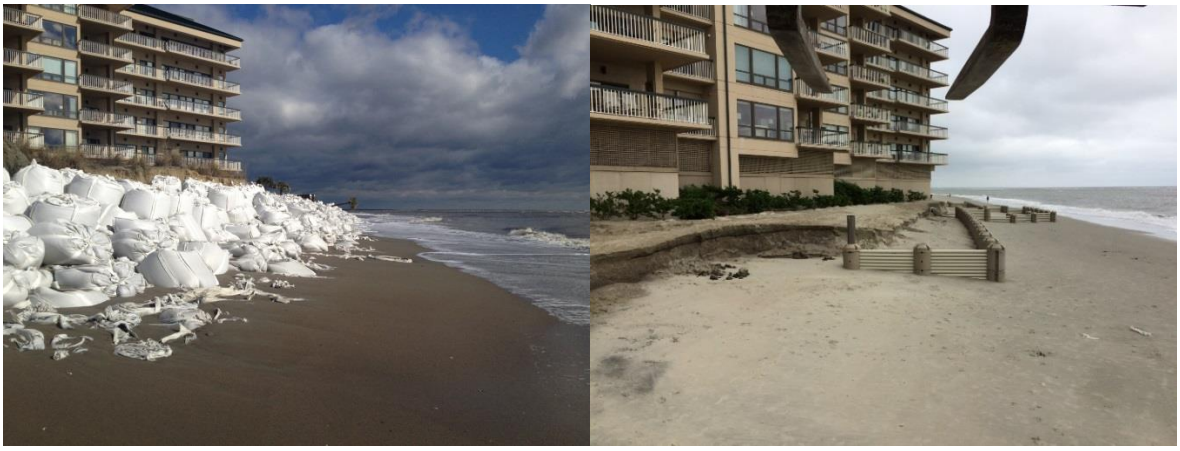


Figure 34. Sandbags and WDS providing erosion and building foundation protection.

Although Figure 34 shows clearly the aesthetic benefit of the WDS, the situation with sandbags can very quickly deteriorate as sandbags fall apart, fall over, or become buried as dynamic surf pounds the bags. Although the home and building owners are ultimately responsible for their removal, the bags often times wind up permanently buried or floating out to sea (see Figure 35).

The previous sections of this report attempted to show that the WDS could provide a similar level of protection and erosion control to that provided by sandbags. The results are somewhat misleading since the WDS was not tested in the manner recommended by The Citadel but rather using fictitious constraints mandated by OCRM. The remaining portion of this section provides a more quantitative environmental comparison of sandbags versus the WDS.

Figure 35.  Deteriorated/buried sandbags and individuals pulling sandbags from the surf.

## APPENDIX C – CONCLUSIONS AND RECOMMENDATIONS FROM 2016 CITADEL REPORT

**Conclusions and Recommendations**

Conclusions:
Based on the results of all tests performed to date, the Citadel researchers have concluded that the Wave Dissipation System is able to:

1) protect structures, dunes, flora, and fauna that are landward of the system
2) minimize the potential for negative impacts that are associated with hardened devices, and
3) allow for natural beach elevation changes while providing better protection of dune lines by using a multi-tier system in areas of higher wave energy and a single line system in areas of lower wave energy

At all sites, the WDS protected the structures behind the system and when used as recommended (not as detailed in this study) the results will be even better.

However, The Citadel researchers want to make it very clear, as they always have, that the system is not a one-size fits all solution and that it is a dynamic system that must be designed separately for each particular site, and monitored/adjusted as necessary to optimize its performance.

Recommendations:

1. The WDS should be used in conjunction with sand renourishment behind the system. This renourishment is necessary to help minimize the volume of water that gets behind the WDS. The renourshment can be brought in as beach compatible sand or reclaimed using the natural accretion that occurs at different times. Note that the research team requested the use of sand behind the system several times during the study. At the beginning of the study, OCRM was told that sand would be required to be brought in after significant erosion events in the same way that sand is placed behind sandbags. This action was not permitted. After the 1,000 year event, researchers informed OCRM that the site had changed considerably and that sand should be brought in to provide a similar baseline as was anticipated for the study. This action was denied. When significant accretion occurred on site at BWE, the research team requested the opportunity to show that dune rebuilding could be performed (as was shown in the earlier studies). This action was denied.
2. The local trenching that has occurred at times at all three sites is a significant concern to Citadel researchers. Local trenching never occurred in the previous Seascape studies nor at Ocean Club this year until the final portion of the study period covered in this report. It appears to be related to scour caused by extreme tides, significant erosion events, and the volume of water that is allowed to pass through the system (this same volume of water must escape as the tide goes back out). Although the system is self-healing, the time required to self-heal after event related local trenching is site specific, and it is the opinion of The Citadel researchers that self-healing should not be permitted in all cases. Opening up of the entire system in areas of local trenching has immediately restored the beach profile by quickly mitigating the trenching effect and the horizontal panels can be easily removed

for this purpose. The research team spent a lot of time developing vertical panels for removing the trench since this approach would be much more cost effective (during a study) than complete lowering of the system and since vertical panels could be installed in isolated locations as needed versus lowering which requires a significant portion of the system to be lowered at one time. The use of the vertical panels was not permitted by OCRM. Although our earlier report stated that "although lowering may alleviate the trenching, we are not planning that this will be the solution. We only propose it to increase energy dissipation," OCRM correspondence to Dr. Mays did not permit the vertical panels as discussed earlier in this report and instead OCRM suggests the use of lowering the system which no one was willing to pay for during a short term study. Finally, in conjunction with item 1 above, if the sand elevations behind the WDS are maintained on a bimonthly schedule or so, some of this beach compatible sand can be easily and quickly moved to eliminate any concerns caused by the temporary trenching on site.

3. During significant accretion events behind the system, dune rebuilding by moving sand already behind the system should be utilized. This will help eliminate the need for bringing in beach compatible sand. The system's capability was shown clearly in the earlier Seascape studies, but was not permitted by OCRM during these studies when requested by the research team.
4. It is recommended that the system be installed with the horizontal panels fully in place during times outside of turtle season. During turtle season, it is recommended that the system be completely open (only vertical elements in place) except when the structure behind the system is in immediate danger of losing structural support. During the turtle season as occurring during the studies discussed in this report, the system was completely closed off due to concerns over turtles getting trapped behind the system and since OCRM would not allow us to follow this recommendation since much of the system would have been wide open which would have "manipulated results."
5. The horizontal panels have performed well overall but the longevity of the panels, if left unmodified, in areas of significant daily wave impacts was brought into question during the study. SI Systems, LLC needs to develop a better material wrapping of the ends of the panels to reduce the spinning and banging of the panels against the housing units in these areas. This is a simple engineering fix that will cost SI Systems, LLC additional money when constructing similar lines of resistance.
6. For the two homes on Harbor Island, readers of this report should note the serious concerns that the principal investigator has regarding the shallow foundations on which these structures are built. The principal investigator is an expert in coastal construction, a licensed engineer (structural) in South Carolina, a foundation expert, an author or contributing author on V Zone construction and he has been shocked regarding some of the discussions about sandbags around the foundations of these structures (that don't consider the structural ramifications of moving the bags or removal actions). The discussions are not presented in this report. To the best of his knowledge, at the time these homes were constructed, the shallow foundations supporting these structures were approved by the local jurisdiction. Although as a Citadel employee, the project principal investigator is not

able to represent these homeowners as their structural engineer, the homeowners are advised to seek options regarding long term solutions in their special case situation which is very unique and requires input from experts in coastal construction, V Zone regulations, and structural engineering.