GEOTECHNICAL OBSERVATIONS OF HURRICANE IMPACTS ON NATURAL AND HYBRID INFRASTRUCTURE

NAVID H. JAFARI[1], JACK A. CADIGAN[2], JASMINE BEKKAYE[1], QIN CHEN[3], LING ZHU[3], BRITT RAUBENHEIMER[4]

1. *Department of Civil & Environmental Engineering, Louisiana State University, 3255 Patrick F. Taylor Hall, Baton Rouge, LA 70820, USA. njafari@lsu.edu, jbekka1@lsu.edu.*
2. *U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, 3909 Halls Ferry Road, Vicksburg, MS 39180, USA. Jack.A.Cadigan@usace.army.mil.*
3. *Department of Civil & Environmental Engineering, Northeastern University, 400 Snell Engineering Center, Boston, MA 02115, USA. q.chen@northeastern.edu, l.zhu@northeastern.edu.*
4. *Department of Applied Ocean Physics & Engineering, Woods Hole Oceanographic Institution, Falmouth, MA 02543, USA. braubenheimer@whoi.edu.*

Abstract: Effective coastal hazard mitigation requires integrative field observations and numerical modeling to characterize dynamic coastal processes at appropriate space and time scales. This study is focused on geomorphic and geotechnical measurements to better understand the response of natural and hybrid infrastructure impacted by hurricanes. The paper investigates the role of geotechnical properties and stratigraphy in controlling the magnitude of shoreline retreat. The coupled effects of erosive removal of overlying sediments by storm-driven overwash, inland deposition of suspended sediments, and consolidation of the soft wetland sediments characteristic of RWR can create significant differences in the forecasted surface elevation over long time periods. These differences become critically important to predicting the viability of shoreline protection projects in coastal Louisiana, where an estimated $50 billion worth of restoration projects are underway or planned (Harris et al., 2020). Therefore, there is an important economic and engineering rationale for understanding if and how the geomorphological effects of major storms differ between shorelines protected by engineered systems such as breakwaters and natural unprotected shorelines. Integration of the morphodynamic modeling system with the field data collected during and after Hurricane Laura has the potential to transform our understanding of NHI solutions to coastal resilience for deltaic coasts.

Introduction

Engineered solutions to mitigate hurricane impacts have historically relied on hard approaches, with design, performance, and maintenance metrics informed by the geotechnical and coastal engineering community. While well-designed and constructed hard infrastructure can be effective during hurricanes, they are not only expensive to build but also costly to maintain and retrofit for relative sea level rise and intensifying hurricanes. In contrast, natural and nature-based infrastructure (NNBI) consists of dunes, salt marshes, mangroves, coral or oyster reefs, and barrier islands that mitigate coastal flooding and shoreline retreat caused by wave action and storm surge, while also providing ecosystem benefits. However, the effectiveness of NNBIs as a "line" of coastal defense and how they work together with hard infrastructure to provide flood risk reduction remains lacking. There are geotechnical knowledge gaps, specifically the development of models that can quantify the response and capacity of NNBI to withstand coastal storms, and provide decision support tools for coastal communities.

Fig. 1. Examples of (a) Hybrid and (b) Natural Infrastructure at Rockefeller Wildlife Refuge.

Hurricane Laura, a category 4 hurricane, made landfall on the southwest Louisiana coast near Cameron, LA on 26 August 2020. Before Laura's landfall, supported by the NSF Nearshore Extreme Events Reconnaissance (NEER) Association (NSF#1848650/1939275), we deployed an array of surge and wave sensors, collected unmanned aerial vehicle (UAV) imagery, and conducted pre-event topographic surveys at the Rockefeller Wildlife Refuge (RWR) which was Laura's hardest hit area (Fig. 1). After the surge water receded, the field team retrieved the sensors, collected elevations and multispectral UAV imagery, and surveyed infrastructure damage along the southwest corridor of Louisiana, from Abbeville to Cameron. Only six weeks after Hurricane Laura, the Category 3 Hurricane Delta made landfall 20 miles west of RWR. The field team conducted another post-storm reconnaissance to collect repeat elevations as well as geotechnical and ecological data. These field observations from both hurricanes documented in Cadigan et al. (2022) form the basis for this study that investigates the geotechnical properties of the RWR shoreline, breakwater, and wetlands and incorporating these field measurements into morphodynamic modeling.

The objective of this study is to advance our understanding of the morphodynamic response of NNBI to extreme events. We are focused on the spatial variability of waves and morphological change caused by the two major hurricanes with and without the presence of low-crested breakwaters in southwest Louisiana. The specific focus of this paper was to understand how do geotechnical properties and stratigraphy control the magnitude of Gulf Coast Chenier Plain (GCCP) shoreline retreat to hurricanes.

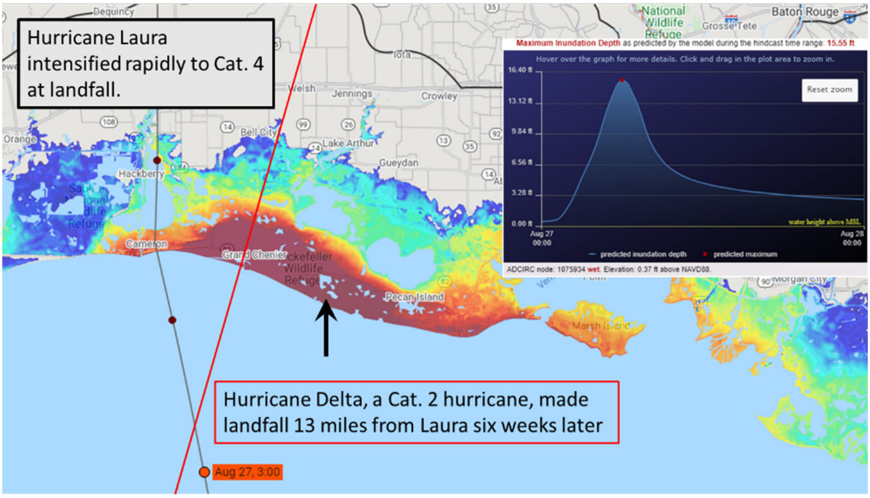

Fig. 2. Overview of Hurricanes Laura and Delta tracks superimposed on max inundation of Laura from CERA hindcast.

Shoreline Geomorphological Results

The elevation profiles for the breakwater protected shoreline and natural shoreline on 25 August 2020, 4 September 2020, and 26 October 2020, are presented in Fig. 2. The August 25th profile represents a pre-storm baseline with which the post-storm effects of Laura and Delta can be compared. Following Hurricane Laura, there is a significant loss of elevation at the shoreline in both the natural Fig. 3A and breakwater-protected Fig. 3B transects. The material which composed this elevation appears to have been pushed inland, rather than eroded and transported offshore. After the storms, both transects show a more shallow, rounded ridge at the shoreline than in the pre-storm condition when the ridges were very steep on the side facing the Gulf of Mexico, and slightly less steep on the landside. The high elevation peak present near the shoreline prior to storm landfall is characteristic of elevation profiles at RWR. The natural transect appears to feature more severe overwash and rounding of the beach ridge, as well as more in-land deposition. The half-width of the ridge on the natural transect prior to the passage of Hurricane Laura is approximately 20 m. Following the passage of Hurricane Laura, the half-width of the ridge on the natural transect broadened to 50 m. For the breakwater-protected transect, the half-width of the ridge broadened to 40 m. The location of the high elevation point on the shoreline is located 80 m inland from the shoreline following Hurricane Laura on the natural transect, indicating that the high point was pushed 60 m inland. The location of the high elevation point on the shoreline for the breakwater transect was located 40 m inland, indicating that the high point was pushed 20 m inland after Hurricane Laura.

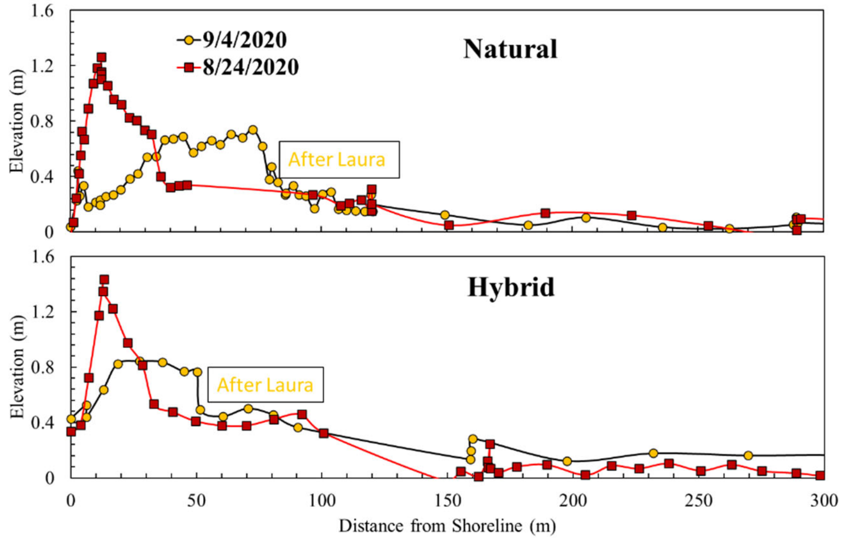

Fig. 3. RTK-GPS elevation transects from the shoreline inland for the (A) natural shoreline and (B) the breakwater protected shoreline.

Beach Geotechnical Results

Figure 4 shows profiles from the Panda dynamic cone penetrometer (DCPT) in the hybrid system and natural wetlands. The beach profiles consist of tip resistances of approximately 1800 kPa, which corresponds to the sand and shell. Beyond the shell and sand mix, the profiles reflect a mudflat. This is evident with the linearly increasing tip resistance, which means a normally consolidated clay layer is present. The sand/shell layer thickness is greater in the hybrid system compared to the wetland transect. This is due to higher cross-shore transport. In comparison, the DCPT profile in the marsh suggests a normally consolidated layer extends to the depth of penetration, i.e., depth of 3 m for hybrid and 4 m for wetland. A weaker tip resistance found in the upper 50 cm could indicate the high organic content marsh root system. Because the area of the DCPT tip is minimal, it does not capture the root strength. The results from Fig. 4 suggest the beach layer is mobile and the tip resistances can be converted to drained friction angles to determine their likelihood of suspension during hurricanes.

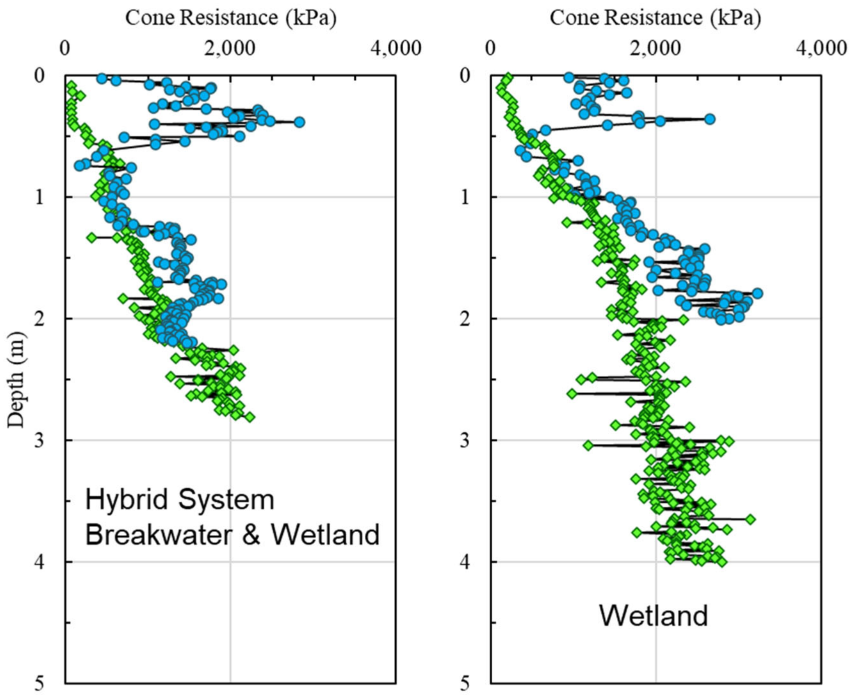

Fig. 4. Panda dynamic cone penetrometer profiles for (A) Hybrid System and (B) Wetland. The blue circles correspond to beach and green diamonds refer to marsh.

Conclusion

The coupled effects of erosive removal of overlying sediments by storm-driven overwash, inland deposition of suspended sediments, and consolidation of the soft wetland sediments characteristic of RWR can create significant differences in the forecasted surface elevation over long time periods. These differences become critically important to predicting the viability of shoreline protection projects in coastal Louisiana, where an estimated $50 billion worth of restoration projects are underway or planned (Harris et al., 2020). Therefore, there is an important economic and engineering rationale for understanding if and how the geo-morphological effects of major storms differ between shorelines protected by engineered systems such as breakwaters and natural unprotected shorelines. Integration of the morphodynamic modeling system with the field data collected during and after Hurricane Laura has the potential to transform our understanding of NHI solutions to coastal resilience for deltaic coasts.

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References

Cadigan, J.A., Bekkaye, J.H., Jafari, N.H., Zhu, L. et al., 2022. Impacts of coastal infrastructure on shoreline response to major hurricanes in southwest Louisiana. Front. Built Environ. 8:885215. doi: 10.3389/fbuil.2022.885215.

Harris, B. D., Johnson, C., Jafari, N.H., Chen, Q. and Ozdemir, C.E. (2020a). Effect Coupled Consolidation and Overwash Processes on a Low-Lying headland System. Coastal Eng. 160, 103746. doi:10.1016/j.coastaleng.2020.103746.