

FRAGILITY ANALYSIS OF DUNES REINFORCED WITH GEOSYNTHETIC SAND CONTAINERS

Brian Maggi, University of Rhode Island, brianmaggi@uri.edu
 Christopher Baxter, University of Rhode Island, cbaxter@uri.edu
 Annette Grilli, University of Rhode Island, annette_grilli@uri.edu

INTRODUCTION

Encroachment of infrastructure on the natural beach system constrains dune volumes and necessitates construction of structural and nonstructural mitigation measures to improve coastal resilience. Nature-based solutions, such as dunes reinforced with geosynthetic sand containers (GSCs), are increasingly being used to stabilize coastlines and protect communities from smaller storm events (e.g. 50-year storms) while at the same time providing flexibility in design considering the uncertainty regarding rates of sea level rise and the increasing destructive power of storm events. Using risk-based hazard assessments, such as fragility curves, it is possible to quantify the resiliency of reinforced coastal systems to address these dynamic conditions. A fragility curve represents the conditional probability of failure of a coastal structure (e.g. natural dune, reinforced dune, seawall, etc.) as a function of a certain stress acting on the structure (typically water level, wave height/period; Gruhn et al. 2012). The main advantage of a fragility curve, compared to a damage function that quantifies a deterministic degree of damage directly to a stress, is that it can account for uncertainties in both the structural resistance (i.e. capacity) and the environmental stress (i.e. demand) of the system. The objective of this research is to present a fragility analysis of a U.S. Federally funded GSC-reinforced dune in Montauk, NY. This dune was constructed in 2016 and experienced significant erosion of the protective berm and sand covering the GSCs during a 1-year storm event that same year.

DEVELOPMENT OF FRAGILITY CURVES FOR A REINFORCED DUNE AND BEACH SYSTEM

To perform the fragility analysis for the GSC-reinforced dune in Montauk, NY, project design and survey data were used to develop the topobathy model. Calibration of 2-D and 1-D erosion models was conducted using the morphodynamic model XBeach and field observations collected over a 3-year period. Monte Carlo simulations of erosion at a critical transect for the project site were performed using the U.S. Army Corps of Engineers (USACE) North Atlantic Coast Comprehensive Study data to develop distributions of surge level and significant wave height for storms with return periods of 1 - 50 years. Damage states were identified as berm erosion (DS1), GSC exposure (DS2), and GSC displacement (DS3) which was estimated using published relationships between a stability number and the surf similarity parameter (Oumeraci et al. 2003). The methodology developed for this fragility analysis (Fig. 1) can be incorporated into various hazard mitigation and loss prevention tools to better inform all stakeholders about the benefits and drawbacks of adaptive, nature-based coastal protection systems.

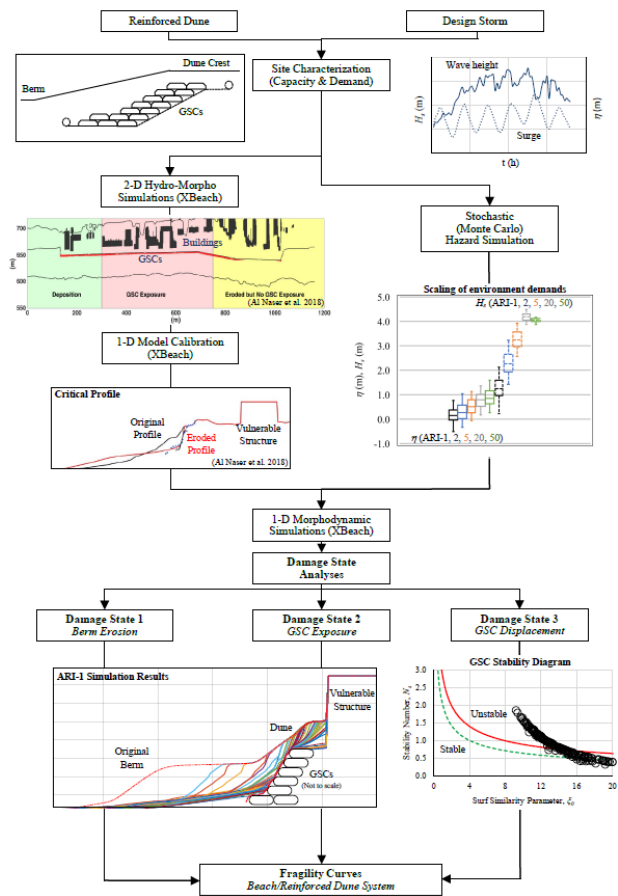


Figure 1 - Methodology for the development of fragility curves for a reinforced dune and beach system

FRAGILITY CURVES FOR MONTAUK, NY

Fragility curves showing the probability of failure as a function of water level (i.e. surge, η) for four identified damage states are shown in Fig. 2. Also shown are the relationships between water level and wave period (T_p) for Annual Return Intervals (ARI) ranging from 1 to 50 years. The fragility curves for Damage States 1 and 2 (Fig. 2) clearly indicate the vulnerability of the berm and dune to relatively frequent storm events and emphasize the level of maintenance required to manage a reinforced beach system. These conditions were observed during the 1-year storm in 2016 and after most of the storms surveyed throughout the three years of field studies, none of which had combined surge and significant wave height demands exceeding the conditions for storms with an Annual Return Interval of one year (ARI-1). Better understanding of DS1 and DS2 curves can aid in the planning of maintenance activities (e.g. annual replenishment) that a community is

responsible for when GSCs are exposed or berm elevations erode below a required elevation. The USACE Coastal and Hydraulic Laboratory's (2007) has published guidance to communities regarding how a nourished beach may change dramatically in response to storms and this fragility analysis quantifies those impacts.

The almost one meter difference in surge between Damage States 2 and 3 highlights the increased capacity of the coastal system provided by the GSC-reinforcement. If an unreinforced dune were considered for the current site cross-section at Montauk, a significant Damage State (e.g. breaching of the dune) would plot between the Damage State 2 and 3 curves in Fig. 2 since infrastructure at this site encroaches on the dune and limits the potential effective flood protection cross-sectional area of an unreinforced dune to approximately 25 m². When compared to the minimum 40 m² cross-sectional area recommended to withstand storm surges with a return period of 50 years, this reduced capacity would lead to an increased probability of failure during more frequent storm events (Gruhn et al. 2012).

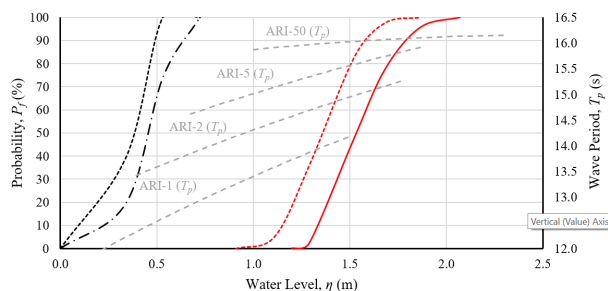


Figure 2 - From left to right, fragility curves for Damage States 1 (berm erosion), 2 (GSC exposure), 3 (GSC incipient motion/pullout) for the GSC-reinforced dune and beach system in Montauk, NY

SUMMARY AND CONCLUSIONS

The development of a fragility analysis of a GSC-reinforced dune that incorporates recognizable damage states, 2-D and 1-D erosion modeling, and field data from a reinforced dune in Montauk, NY offers a solution to reliably address uncertainties, assess performance, and understand the tradeoffs of GSC-reinforced dunes for coastal protection systems. It provides a framework to predict the performance of the project constructed by the USACE to stabilize the coastline in Montauk through probabilistic simulations of storm events with ARI's from 1 through 50 years. Identification of progressive damage states and failure criteria for each of the significant components of the system (i.e. berm, dune, GSC-reinforcement) led to the development of fragility curves that are a powerful tool to guide the analysis of potential resilient solutions for other locations or the development maintenance/risk management strategies for existing systems. For Montauk, the results clearly indicate the level of maintenance required to manage a reinforced beach system as was recognized by the Town of East Hampton where annual maintenance volumes for three out of four years were at least seven times the estimated volumes included in the project design.

The incorporation of fragility curves into hazard mitigation and loss prediction tools like FEMA's Hazus that can account for a range of damage from minor erosion to global stability failure will better inform all stakeholders about the benefits and drawbacks of adaptive, nature-based infrastructure. While the analysis presented in this research focuses on a specific site, the methodology can be applied to any location especially as access to calibration data is improving through efficient, precise, and cost-effective advanced survey tools and software.

REFERENCES

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