COASTAL LEVEE CONSEQUENCE ASSESSMENT TO SUPPORT RISK-INFORMED DECISION MAKING IN DESIGN

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INCREMENTAL AND RESIDUAL LEVEE RISK

A key understanding of any levee system is to accurately estimate the residual flood risk that remains for the population after a levee project is in place and to quantify the portion of the risk related to overtopping (non-breach risk) compared to the risk related to levee performance (incremental risk). The incremental risk is a product of the frequency of the hazard, the performance of the system given the hazard, and the resulting consequences of the system These risks are present for any dam or levee project, to include Coastal Storm Risk Management (CSRM) systems of levees, dunes, floodwalls, seawalls, gates, and many other features. In order to make resilient, risk-based decisions for coastal levee designs, design teams need to have a thorough understanding of the coastal hazards, associated breach and non-breach consequences, and how the design performance affects the incremental and residual risks. This paper discusses the linkages between high-fidelity understandings of each of these three aspects – hazards, consequences, and performance – in a way to make smart, risk-informed decisions for design.

RESPONSE-BASED COASTAL HAZARDS

Coastal flood hazards include wind-driven surge and waves that can result in wave overtopping of levees and dunes, still water level overflow of embankments and walls, and destructive wave impact forces at structural elements. Additionally, the same driving hazard of a hurricane or tropical storm can result in precipitation-driven riverine and excess rainfall flooding within a leveed area. The response of these hazards can occur across a levee system differently depending on the storm characteristics including storm track, speed, radius of maximum wind, and many other factors. This variability is typically accounted for by simulating the full range of storm conditions using a Joint Probability Method where surge and wave models can be coupled for hundreds or thousands of synthetic storm events to generate responses across large model domains. Due to the computational requirements and number of scenarios required to run the coupled coastal hazard models, adding time-dependent breach and consequence models into this framework greatly compounds the computational requirements and data management. Some amount of simplification needs to be incorporated into the modeling framework to pair statistical, coastal, hydraulic, breach, and consequence models in a single workflow.

EVENT-BASED CONSEQUENCE MODELING

A simplified approach was developed to utilize complex, probabilistic coastal forcings by adapting them to breach and consequence model inputs. This approach characterizes the responses across a given levee system, selects storm events which reasonably achieve a desired level of response across the system, and generates hydraulic boundary conditions of surge and wave overtopping. These boundary conditions can then be applied to a HEC-RAS hydraulic model (HEC-RAS, 2022) for the without-breach condition to be compared against various specified-breach scenarios. Finally, the resulting time-series inundation results for breach and without-breach can be routed through the RMC-LifeSim (RMC-LifeSim, 2023) consequence model to estimate incremental life-safety and economic consequences. RMC-LifeSim is an agent-based consequence model capable of modeling population redistribution during an evacuation to evaluate potential life loss and economic damages that result from the hydraulic model inundation.

ASSESSING RISK DURING DESIGN

With an understanding of both the hazard and the consequences, risk teams can evaluate the proposed designs to ensure the probability of design failure given the hazard is acceptably low so that the risk – the product of the failure probability and the associated consequences – is acceptably low. In some cases, where consequences are low, it may be tolerable to accept lower factors of safety. For example, for seepage related potential failure modes given short durations of storm loadings on levees, costly seepage mitigation may not significantly buy-down risk. In other cases, a dune may provide insufficient risk-reduction in areas where consequences are high and hazards are driven more by surge than waves. By understanding each component of risk, smarter risk-informed decisions can be made about how to build structural measures or whether to build structural measures at all, perhaps instead pursuing non-structural alternatives to reduce risk.

SUMMARY

This approach aims to have a better understanding of not just the coastal loading and the engineered factors of safety of the system, but the entire risk of the system to include hazard, performance, and consequences. Some example cases can be shared where this type of hazard and consequence analysis was performed for the New Jersey Back Bays CSRM project or where other coastal projects throughout the United States have identified gaps in the expected performance of designs, once the hazards and consequences were better understood.

REFERENCES

HEC-RAS. (2023). Retrieved 12 October 2023 from: https://www.hec.usace.army.mil/software/hec-ras/

RMC-LifeSim. (2023). Retrieved 12 October 2023, from https://www.rmc.usace.army.mil/Software/LifeSim/