Dan Cox, OSU

DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 4 PROGRESS REPORT
July 1, 2018 – June 30, 2019

Project Title:

Experimental and Numerical Study to Improve Damage and Loss Estimation due to Overland Wave and Surge Hazards on Near-Coast Structures

Principal Investigators:
Dr. Daniel Cox, (PI) Professor, Oregon State University
Dr. John van de Lindt (Co-PI), Professor, Colorado State University

Other Partners/Institutions:
FEMA DHS

Short Project Description ("elevator speech")

This project applies the wave-surge fragility method developed in years 1-3 of the project to determine damage to several additional building types. A HAZUS analysis over a region of the New Jersey shoreline will be conducted using (1) the existing HAZUS methodology, and (2) the new fragilities developed herein. This will require utilizing the ADCIRC work of others within the Center of Excellence as input. The investigators will work with DHS FEMA HAZUS developers to lay out the steps needed to implement the new fragility types in HAZUS, including any additional validation steps needed.

1. Introduction and project overview:

Hurricanes Sandy in 2012, Ike in 2008, and Katrina and Rita in 2005 have underscored the significant and growing risk to coastal communities due to surge and wave hazards. Hurricane-induced economic losses in the United States have increased steadily over the past 60 years and are now $35.8 billion annually. Approximately 50 percent of the U.S. population lives within 50 miles of a coastline, and the physical infrastructure to support this population was estimated in the 1990s to be over $3trillion in the Gulf and Atlantic regions. These problems are compounded by global climate change resulting in increased sea levels and increases in the intensity and frequency of extreme windstorms. The overall vision for this project is to support the broader vision of the CRC to increase the resilience of near-coast structures to coastal hazards. Resilience is the ability of a system to absorb and recover from a sudden disturbance.

Our project is linked to "Mission 5: Ensuring Resilience to Disasters" as listed in the DHS Strategic Plan Fiscal Years 2012 – 2016. Goal 5.1 is to Mitigate Hazards by "strengthening the capacity at all levels of society to withstand threats and hazards." Moreover, Objective 5.1.2 Mitigate Risk To Communities will "improve community capacity to withstand disasters by mitigating known and anticipated threads and hazards." Our project will link directly to Goal 5.1 and Objective 5.1.2 by understanding the damage to the built environment as a result of coastal hazards produced by hurricanes and other coastal windstorms. The overall aim of the DHS CRC is to improve the Nation's ability to safeguard people, infrastructure and economies from catastrophic coastal disasters. By improving FEMA's (HAZUS-MH) ability to predict damage and loss estimates due to waves and surge and developing a framework for new design methodologies for near-coast structures, this project will enhance the resilience of the Nation's coastal infrastructure to hurricane and other coastal hazards. By improving the predictions of damage and loss, we will be better positioned to anticipate and manage cascading consequences and interactions between infrastructure and hazards. This project will help reduce losses from hurricanes in the United States. and will assist FEMA's mission in the National Windstorm Impact Reduction Program and the National Flood Insurance Program by improving damage and loss assessment tools consistent with FEMA's program for HAZUS modernization.

2. Results:

Do, T, JW van de Lindt, DT Cox (2019) "Hurricane Surge-Wave Building Fragility Methodology for Use in Damage, Loss, and Resilience Analysis," J. Structural Engineering (accepted).

ABSTRACT: Physics-based fragility for damage, loss, and resilience analysis are needed to model a community to loading by earthquakes, hurricane wind, tornado, or flood. Currently, most building flood fragilities such as those available in assessment tools such as HAZUS-MH do not account for the hydro-dynamic forces caused by surge and waves, only the depth of a flood. In this paper, a methodology to evaluate forces on all building components including windows, doors, walls and floor systems for elevated coastal buildings under a combination of hurricane surge and waves is proposed. The model was validated by comparing vertical and horizontal forces from existing laboratory test results of a one-tenth scale elevated structure under wave loading. A full-scale wood-frame residential building was then modeled as an example to illustrate the method and is intended to be representative of an elevated coastal structure in a typical coastal region of the United States. The hurricane was modeled as a combination of two intensity parameters, namely significant wave height and surge level at the building location and is better able to represent the loading condition and thus damage to the structure than static flood alone. Fragility surfaces for four damage states for the building as a whole were generated as a damage combination of all damageable building components. Finally, a comparison of the loss estimated using the fragility surfaces versus the current loss model in HAZUS-MH is provided to illustrate the effect on loss estimates when including wave height in predicting damage for near-coast buildings under hurricane wave and surge. By calibrating the physics-based fragilities with empirical data, the surface fragilities developed in this paper are ready to use in HAZUS-MH or other loss and resilience-focused analysis at the community level for coastal communities subjected to both waves and storm surge during hurricanes.

Tomiczek, T, A Wyman, H Park, DT Cox (2019) "Modified Goda Equations to Predict Pressure Distribution and Horizontal Forces for Design of Elevated Coastal Structures," J. Waterway Port Coastal and Ocean Engineering (accepted).

ABSTRACT: A 1:10 scale physical model was constructed to measure horizontal and vertical pressures and forces on an elevated structure under nonbreaking, impulsive breaking, and broken wave conditions. Regular wave trials with varying wave heights and periods were used to diagnose phase-averaged horizontal pressure distributions at the time of the maximum horizontal force for a range of structural air gap conditions. Measured pressures were then compared with those predicted ASCE 7-16 (2016) design equations and modifications to the Goda (2010) equations for wave pressures on a vertical caisson breakwater modified by Wiebe et al. (2014) for near-coast structures. The modified Goda equations showed good agreement with measured pressures and total horizontal force per unit width for nonbreaking wave conditions over a range of structural elevations from at grade to 0.28 m above the still water level. While generally conservative for nonbreaking, breaking, and broken waves, the modified Goda equations were more accurate than the ASCE 7-16 (2016) equations, which significantly over-predicted pressures and forces in nearly all cases. Results suggest that the modified Goda equations may be used to improve design guidance for at grade or elevated coastal structures.

3. **End users:**
   Primary end users are at FEMA.

4. **Transition:**

HAZUS - Coastal Resilience Center (CRC) Workshop. June 10 and 11, 2019. FEMA HQ in Washington DC.

Attendees:

- Doug Bausch, NiyamIT, CDS
- Ryan Blanton, University of North Carolina (UNC), Chapel Hill
- Suman Biswas, NiyamIT
- Jordan Burns, NiyamIT, CDS
- Dan Cox, Oregon State University (OSU)
- Andrew Ditmore, IBM, CDS
- Daniel Eglovitch, NiyamIT, CDS
- Andrea Jackman, IBM, CDS
- Katie Jones, LSU
- Carola Kaiser, Louisiana State University (LSU)
- End user, FEMA
- End user, FEMA
- Rick Luettich, UNC Chapel Hill
- End user, FEMA
- Alexis Richmond, Nodi Solutions, PM Team
- End user, FEMA
- End user, FEMA
- End user, DHS
- Robert Twilley, LSU
- Nikolay Todorov, NiyamIT, CDS
- Ujvala Sharma, NiyamIT, CDS
- John van de Lindt, Colorado State University
- Stephen Veith, Nodi Solutions, PM Team

Agenda:

- Coastal Damage Functions Brief
- Coastal Preliminary Flood Risk Assessment (PFRA) Brief
- Interdependent Networked Community Resilience Modeling Environment (IN-CORE) Brief
- Advanced Circulation (ADCIRC) storm surge model Brief
- Coastal Emergency Risk Assessment (CERA) Visualization Tool Presentation / Discussion
- Reducing Repetitive Loss Post-Storm Project

Summary: van de Lindt and Cox to be involved in FEMA-MH hindcast study for Bolivar Peninsula for Hurricane Ike (2008) damage and loss prediction. Hindcast will show the relative merits of physics-based fragility functions.

5. Project Impact:

The improved fragilities are the first fragilities developed using experimental data and then validated using FEMA community-level inspections following a storm. Thus, the project results can be used for better risk-informed decision-making and loss avoidance calculations for hazard mitigation due to hurricane wave and surge on coastal residential structures. Further, HAZUS currently does not have fragilities for flood, but uses stage-damage functions, and therefore is unable to propagate uncertainty.

6. Unanticipated Problems:

There were no unanticipated problems.

7. Student Involvement and Awards:

We included the following students in Year 4.

- Jason Burke (MS, Oregon State University; currently USN-NAVFAC)
- Matt Karney (MS, Oregon State University; currently USN-NAVFAC)
- Bryan Acevedo (SUMREX, UPRM; currently enrolled at UPRM)
- Jorge Santiago (SUMREX, UPRM; currently grad student at UF)
- Ana Lopez (REU Cal Poly SLO; currently applying to graduate school)

Student Demographics

- 1 (out of 5) female
- 3 (out of 5) from underrepresented group
- 3 (out of 5) undergraduate

Degrees Attained

- MS Civil Engineering, 2018 (Burke)
- MS Civil Engineering, 2018 (Karney)

8. **Interactions with education projects:**

- 2 SUMREX students from UPRM (Acevedo; Santiago)

9. **Publications:**

Journal Papers

- Park, H., Tomiczek, T., **Cox, D.T., van de Lindt, J.W.**, Lomonaco, P. (2017) "Experimental Modeling of Horizontal and Vertical Wave Forces on an Elevated Coastal Structure," *Coastal Engineering*, 128, 58-74. DOI: 10.1016/j.coastaleng.2017.08.001
- Do, Trung, **van de Lindt, J., Cox, D.T.** (2016) "Performance-Based Design Methodology for Inundated Elevated Coastal Structures Subjected to Wave Load Engineering Structures," *Engineering Structures*, 117, 250 – 262. DOI: 10.1016/j.engstruct.2016.02.046
- Park, H., Do, T., Tomiczek, T., Cox, D.T., van de Lindt, J.W. (2018) "Numerical Modeling of Non-breaking, Impulsive Breaking, and Broken Wave Interaction with Elevated Coastal Structures: Laboratory Validation and Inter-Model Comparisons," *Ocean Engineering*, 158, 15, 78-98. DOI: 10.1016/j.oceaneng.2018.03.088
- Tomiczek, T, A Wyman, H Park, DT Cox (2019) "Modified Goda Equations to Predict Pressure Distribution and Horizontal Forces for Design of Elevated Coastal Structures," *J. Waterway Port Coastal and Ocean Engineerin*g (accepted).
- Do, T, JW van de Lindt, DT Cox (2019) "Hurricane Surge-Wave Building Fragility Methodology for Use in Damage, Loss, and Resilience Analysis," *J. Structural Engineering* (In Press).

Conference Papers

- Do, T., Tomiczek, T., **van de Lindt, J. Cox, D.** (2017) "Development of Physics-Based Building Fragility Surfaces for Near-Coast Community Modeling," *International Conference on Coastal and Ocean Engineering*, Osaka, Japan.
- Lomonaco, P., P. Arduino, A. Barbosa, D. Cox, T. Do, M. Eberhard, M. Motley, K. Shekhar, T. Tomiczek, H. Park, J. W. van de Lindt, A. Winter (2018) "Experimental Modeling of Wave Forces and Hydrodynamics on Elevated Coastal Structures Subject to Waves, Surge or Tsunamis: The Effect of Breaking, Shielding and Debris, *International Conference on Coastal Engineering*, ASCE.
- Park, H., Do, T., Tomiczek, T., **Cox, D., van de Lindt, J.W.** (2018) "Laboratory Validation and Inter-Model Comparisons of Non-breaking, Impulsive Breaking, and Broken Wave Interaction with Elevated Coastal Structures using IHFOAM and FLUENT," *International Conference on Coastal Engineering*, ASCE.
- Tomiczek, T., Wyman, A., Park, H., **Cox, D.T.** (2018) "Application and modification of Goda Formulae for Non-impulsive Wave Forces on Elevated Coastal Structures," *International Conference on Coastal Engineering*, ASCE.

- Tomiczek, T., Park, H., **Cox, D.T.**, Lomonaco, P., **van de Lindt, J.W.** (2018) "Application and modification of Design Formulae for Impulsive Wave Forces on Elevated Coastal Structures," *International Conference on the Application of Physical Modelling in Coastal and Port Engineering and Science (Coastlab18)*, IAHR.
- Do, T, JW van de Lindt W, DT Cox (2018) "Physic-Based Component Fragility Model for Near-Coast Residential Wood Building Subjected to Hurricane Wave and Surge" Engineering Mechanics Institute Conference 2018, Cambridge MA.

Thesis/Dissertation and Reports

- Trung Q. Do. *Fragility Approach for Performance-Based Design in Fluid-Structure Interaction Problems, Part I: Wind and Wind Turbines; Part II: Waves and Elevated Coastal Structures*, (2016), Ph.D. Dissertation, Colorado State University.
- William Short. *A laboratory study of horizontal and vertical regular wave forces on an elevated structure*. (2016). MS Thesis, Oregon State University.
- Benjamin Hunter. *Exceedance Probabilities of Hurricane Wave Forces on Elevated Structures*. (2016). MS Thesis, Oregon State University.
- Jason Burke. *Design and Structural Testing of a 1:6 Scaled, Light-frame Construction, Near-coastal, Residential Structure*. (2018). MS Thesis, Oregon State University.
- Matt Karney. *Hydrodynamic Testing on a 1:6 Scale, Wood Framed Near-Coast Residential Structure*. (2018). MS Thesis, Oregon State University.

10. <u>Year 4 Research Activities and Milestone Achievements:</u>

Reporting Period 7/1/2018 – 6/30/2019			
Research Activity	Proposed Completion Date	% Complete	Explanation of why activity/milestone was not completed
RA1: Development of fragilities for two additional building types for combined surge and waves; these are in the form of fragility surfaces. Within this technical task, the research team will conduct scale-model tests to validate the global forces and subcomponent damages predicted by the numerical model and will test the overall applicability of the fragility functions.	3/31/2019	100%	
RA2: HAZUS-MH analysis of 4 to 6 blocks of New Jersey shoreline	4/30/2019	0%	Decide to work with FEMA Hazus team to identify appropriate hindcast area. Determined Bolivar Peninsula, TX, is better
Research Milestone			
RM1: Documentation of RA1 as a journal paper submission (J. of Structural Engineering)	3/31/2019	100%	
Documentation of RA2 as a journal paper submission to peer reviewed journals such as the *Journal of Ports, Waterways, Coast and Ocean Engineering and Natural Hazards*, etc.	4/30/2019	100%	

11. Year 4 Transition Activities and Milestone Achievements:

Year 4 Transition Activities and Milestones: Status as of 6/30/2019

Reporting Period 7/1/2018 – 6/30/2019			
Transition Activity	Proposed Completion Date	% Complete	Explanation of why activity/milestone was not completed
TA1: In-person meeting with FEMA HAZUS-MH in Denver to discuss timeline transition, hindcast study location, building archetypes, and FEMA data	11/1/2018	100%	Note: HAZUS-MH meeting held June 10 and 11, 2019. Date determined by FEMA.
TA2: Webex meeting: Establish periodic webex meetings with project team and end users for project update and feedback	Held every other month	50%	Discussions are continuing following June Hazus meeting
Transition Milestone			
TM1: Timeline for work plan agreement between project team and HAZUS-MH Technical staff	12/1/2018	50%	Progressing since June 2019 Hazus meeting

12. Tables:

Table 1: Research Project Product Delivery

Product Name	Product Type (e.g., software, guidance document, knowledge product)	Delivery Date	Recipient or End User(s)
HAZUS-MH Hindcast	Knowledge product to demonstrate the value of new fragilities for coastal residential structures subjected to hurricane surge and waves	End of Year 5	FEMA Hazus Development Team

Table 2: Performance Metrics:
COX/van de LINDT PERFORMANCE METRICS

Metric	**Year 1** (7/1/15-6/30/16)	**Year 2** (7/1/16-6/30/17)	**Year 3** (7/1/17-6/30/18)	**Year 4** (7/1/18-6/30/19)
HS-related internships (number)				
Undergraduates provided tuition/fee support (number)	0	0	0	0
Undergraduate students provided stipends (number)	0	0	0	0
Graduate students provided tuition/fee support (number)	2	2	2	1
Graduate students provided stipends (number)	0	2	2	1
Undergraduates who received HS-related degrees (number)	0	0	0	0
Graduate students who received HS-related degrees (number)	0	0	0	0
Graduates who obtained HS-related employment (number)	0	0	0	0
SUMREX program students hosted (number)	2	2	2	2
Lectures/presentations/seminars at Center partners (number)	0	3	0	1
DHS MSI Summer Research Teams hosted (number)	0	0	0	0
Journal articles submitted (number)	0	2	2	2
Journal articles published (number)	0	2	0	2
Conference presentations made (number)	0	1	2	2
Other presentations, interviews, etc. (number)	0	0	2	2
Patent applications filed (number)	0	0	0	0
Patents awarded (number)	0	0	0	0
Trademarks/copyrights filed (number)	0	0	0	0
Requests for assistance/advice from DHS agencies (number)	0	0	0	0
Requests for assistance/advice from other agencies or governments (number)	0	0	0	0
Dollar amount of external funding	$355,000	$355,000	$0	0
Total milestones for reporting	4	5	4	4
Accomplished fully (research activity/milestone)	0	2	3	2
Accomplished partially (research activity/milestone)	4	3	1	1
Not accomplished (research activity/milestone)	0	0	0	1