Cox: OSU
van de Lindt: CSU

DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 5 PROGRESS REPORT
July 1, 2019 – June 30, 2020 (Updated 12/15/2020)

I. INTRODUCTION

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

Additional Research Participants/Partners:
NHRAP/Hazus Program Manager, FEMA DHS
Regional Flood Map Geospatial Lead, FEMA DHS
Geospatial Risk Analyst, FEMA DHS
Federal Emergency Management Agency's Deputy Assistant Administrator for Mitigation, FEMA, DHS
Federal Insurance and Mitigation, Risk Management | Engineering Resources Branch, FEMA
Doug Bausch, NiyamIT Inc.
Jordan Burns, NiyamIT Inc.

Short Project Description ("elevator speech"):

This project will apply 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 Texas 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. Depth-damage functions were requested by the Hazus team to align with their current software structure, so these will be started by mapping the fragility methodology to depth-damage functions. The investigators will work with DHS FEMA Hazus and their consultants at NiyamIT Inc. to lay out the steps needed to implement the depth-damage functions in Hazus

II. PROJECT NARRATIVE

1. Project overview:

   This project focuses on Theme 1 – Coastal Infrastructure Resilience; Topic 1a – Coastal Infrastructure Planning and Design. As building stakeholders seek to mitigate damage, risk to property and structure loss it is becoming apparent that exiting design methodologies such as those outlined in the FEMA Coastal Construction Manual are

inadequate to incorporate the range of building types, storm conditions, and potential for resulting damage. More effective decision support tools such as FEMA's Hazus-MH rely on a framework of multi- hazard fragility curves to relate the hazard and affected buildings to compute/predict an expected level of damage and subsequent losses. Hazus-MH is a software package that allows the user to determine the damage and financial losses over a region of interest using embedded databases and fragility functions. The fragility functions are based on past work and expert elicitation during the software development phase. Hazus-MH will be updated over the next decade, so the project described herein is occurring at an ideal time to contribute to its body of knowledge through technology transfer of the science created over the first three years. Although there have been significant advances in this correlation for wind and earthquake loading and some preliminary work for tsunamis, the coastal surge and wave response of structures remains poorly defined, primarily due to a lack of large-scale data and the complexity of the fluid/structure interaction modeling. This data was generated in the first three years of this project and served to validate a new fragility type for combined surge and waves. The investigators have worked with Hazus management to lay out the steps needed to release the new fragilities, and incorporate matching/similar depth-damage functions into Hazus. The overall goal of this project is to develop accurate fragilities for near-coastal structures against overland surge and wave forces and corresponding depth-damage functions for input to Hazus-MH to improve damage and loss estimation.

We outline these specific objectives to be completed in two years in order to provide (1) improved accuracy for wave and surge analysis in Hazus-MH; and (2) innovative advances in risk-informed design methodologies to enhance coastal infrastructure resilience:

- ***Objective 1:*** Develop additional fragilities based on input from Hazus-MH management, i.e. based on most needed, such that a basic loss analysis can be performed.
- ***Objective 2:*** Demonstrate Hazus-MH loss analysis for a portion of the New Jersey shoreline, including working to procure FEMA data to validate the loss modeling, documenting gaps that likely result as a function of the current approach.
- ***Objective 3:*** Demonstrate the surge and wave fragilities for the same location as in Objective 2, showing improved accuracy to actual loss values.

This project will have a direct impact on estimating probable damage and loss of existing coastal infrastructure by providing improved load-response relationships to Hazus-MH for surge and wave and develop a risk-informed framework for estimating loss avoidance and benefit analysis for mitigation. While beyond the scope of this study, the results could also help improve the potential designs associated with the retrofit of existing structures funded through FEMA hazard mitigation grant programs and the implementation of improved coastal building codes.

2. **Results:**

Fragilities were developed for five building archetypes at three different elevations above grade, i.e. elevated coastal structures. These represent four types of single-family dwelling and one multi-family apartment/condominium style building. This suite of buildings provides a (albeit small) suite of archetypes to populate the community selected along the Texas coastline.

3. **End users:**

Hazus personnel and related consultants all provided feedback on several on-line meetings throughout the year. This included planning for the remainder of year 5, the conversion from fragilities to depth-to-damage functions and instructions on the hindcasting process. The latter included outlining and helping to formulate the formal data request from FEMA-DHS which may contain personally identifiable data.

4. **Transition:**

The project team worked with FEMA-DHS and their consultant to outline a plan for hindcasting to ensure the results align with actual damage estimates at the community level. This involved a formal data request and direction on the process that FEMA goes through to release data on Github.

5. **Project Impact:**

The depth-damage relationships for Hazus-MH were initially developed for riverine flooding. To use Hazus-MH in the coastal environment where wave and surge loads are expected to have a significant impact on the building damage, it is necessary to (1) develop new damage functions that can account for wave and surge and then to (2) demonstrate their validity using hindcast data from recent storms. The impact of this project is that damage estimates for coastal damage will be more accurate in Hazus and therefore enable better community planning and mitigation efforts, of ten funded by FEMA and other federal agencies, e.g. HUD and USDA.

6. Unanticipated Problems:

The work in the latter part of Year 5 was numerical/computer-based in nature, so the project team has not had any direct impact to the project as a result of COVID-19.

7. Student Involvement and Awards:

a) Students involved in research:

At OSU:

- Sean Duncan, MS student, was supported in Year 5 to conducted test for surge/wave forces and progressive damage of elevated structure and analyze data.
- Caileen Yu, Summer Undergraduate Research Student, analysis of LiDAR images of progressive damage to on-grade and elevated structures

b) Student Demographics

- S Duncan – Grad – Male, white, non-Hispanic
- Robert Lewis – Ugrad – Male, Hispanic
- Ihan-Jarek T. Acevedo – Ugrad – Male, Hispanic
- Caileen Yu – Ugrad – Female, Asian

c) Degrees Attained

- MS obtained by S Duncan (OSU) June, 2020. Civil Engineering.

d) Student Awards

N/A

8. **Interactions with CRC education projects:**
    - In summer 2019, we had two SUMREX students from the University of Puerto Rico Mayaguez (Robert Lewis; Ihan-Jarek T. Acevedo)

III. RESEARCH ACTIVITIES AND TRANSITION MILESTONES

1. **Year 5 Research Activities and Milestone Achievements:**

Year 5 Research Activities and Milestones: Status as of 6/30/2020			
Research Activity	Proposed Completion Date	% complete	Explanation of why activity/milestone was not completed
RA3: Hazus-MH analysis using RA1 fragilities. Two sets of analyses will be performed for comparison: (1) Hazus analysis as it is currently performed; and (2) the new analysis developed during the first several years of this project within the CRC. These two damage and loss estimates will be compared to quantify the level by which Hazus under predicts damage and loss in coastal areas without inclusion of waves and surge using the building damage and loss data collected by FEMA	4/15/21	50%	There was a delay in obtaining the data from FEMA. As a result the analysis results will be provided to FEMA and they have agreed to do a detailed comparison of the analysis versus documented damage and loss.
RA4: Comparison of the RA2 and RA3 analyses. Comparison will show the benefit of the new fragilities for damage and loss estimation	5/15/21	50%	Same as above. However, we were asked by FEMA to modify the fragilities to depth-to-damage functions for incorporation into Hazus, so have focused on this effort while the data negotiations are on-going. The change to depth-to-damage function is not trivial

			and requires extensive computer/computational efforts. This has been completed for archetype 1 and the other four archetypes are underway.
Research Milestone			
RA3: Documentation of RA4 as a peer-reviewed journal paper submission *(J. of Natural Hazards Review)*	6/1/2020	0%	The analysis is underway and will be completed with collaboration from FEMA in early 2021 as indicated above.

2. **Year 5 Transition Activities and Milestone Achievements**:

Year 5 Transition Activities and Milestones: Status as of 6/30/2020			
Transition Activity	Proposed Completion Date	% Complete	Explanation of why activity/milestone was not completed
TA3: Webex meeting. Continue periodic webex meetings with project team and End Users for project update and feedback	Held every other month	100%	We have consistently held meetings with the project team and end users.
TA4: Documentation of fragility methodology. Prepare technical report with details of tools and methods used to develop building fragilities subjected to surge and waves for review by End User team	4/15/2020	25%	This is started, but will require completion of the analysis for the four remaining archetypes. The change from fragilities to depth-to-damage functions, as requested by FEMA, added significant analysis.
TA5: Detailed outline of Hazus hindcast. Prepare detailed outline of Hazus hindcast for review by End User team	4/01/2021	0%	The team is currently building the inventory profile for the hindcast area building by building.
TA6: Final report of Hazus-MH hindcast and prepare manuscript for peer reviewed journal paper.	5/01/2021	0%	Cannot be completed until all the work is finished.
Transition Milestone			
TM3: Technical report of fragility development provided to end user team	9/01/19	100%	This was done as a PowerPoint presentation on-line.

TM6: Final report submitted to end user team for review and develop manuscript for peer reviewed publication.	6/01/2021	0%	All work needs to be completed before the report can be written and completed.

3. **Research Project Product Delivery.** N/A

IV. PUBLICATIONS AND METRICS

1. Publications:

a) 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 145, 6, doi.org: 10.1061/(ASCE)WW.1943-5460.0000527.
- 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* 146(1), 04019177, doi.org: 10.1061/(ASCE)ST.1943-541X.0002472.

b) 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.

c. 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.
- Duncan, S. *Physical Modeling of Progressive Damage and Failure of Wood Framed Coastal Residential Structures Due to Waves and Surge Forces,* (2020), MS Thesis, Oregon State University

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)	Year 5 (7/1/19-6/30/20)
HS-related internships (number)					0
Undergraduates provided tuition/fee support (number)	0	0	0	0	0
Undergraduate students provided stipends (number)	0	0	0	0	0
Graduate students provided tuition/fee support (number)	2	2	2	1	1
Graduate students provided stipends (number)	0	2	2	1	1
Undergraduates who received HS-related degrees (number)	0	0	0	0	0
Graduate students who received HS-related degrees (number)	0	0	0	0	0
Graduates who obtained HS-related employment (number)	0	0	0	0	0
SUMREX program students hosted (number)	2	2	2	2	0
Lectures/presentations/seminars at Center partners (number)	0	3	0	1	0
DHS MSI Summer Research Teams hosted (number)	0	0	0	0	0
Journal articles submitted (number)	0	2	2	2	1
Journal articles published (number)	0	2	0	2	1
Conference presentations made (number)	0	1	2	2	0
Other presentations, interviews, etc. (number)	0	0	2	2	3
Patent applications filed (number)	0	0	0	0	0
Patents awarded (number)	0	0	0	0	0
Trademarks/copyrights filed (number)	0	0	0	0	0
Requests for assistance/advice from DHS agencies (number)	0	0	0	0	0
Requests for assistance/advice from other agencies or governments (number)	0	0	0	0	0
Dollar amount of external funding	$355,000	$355,000	$0	0	$20,000
Total milestones for reporting	4	5	4	4	4
Accomplished fully (research activity/milestone)	0	2	3	2	2
Accomplished partially (research activity/milestone)	4	3	1	1	1
Not accomplished (research activity/milestone)	0	0	0	1	1