COX, OSU

DHS Coastal Resilience Center

Research Project:

Annual Project Performance Report

Covers reporting period July 1, 2016 – June 30, 2017

1. **Project Title:**
   Experimental and Numerical Study to Improve Damage and Loss Estimation due to Overland Wave and Surge Hazards on Near-Coast Structures

2. **Principal Investigator / Institution:**
   Dr. Daniel Cox, (PI) Professor, Oregon State University
   Dr. John van de Lindt (co-PI), Professor, Colorado State University

3. **Other Research Participants/Partners:**
   - Bill Coulbourne, Applied Technology Council
   - Chris Jones, consulting coastal engineer; Chair, ASCE-7 Flood Loads

4. **Short Project Description ("elevator speech"):**

   This project will develop an accurate method to determine damage to buildings subjected to extreme surge/wave forces during hurricanes. The methodology will use large-scale hydraulic model testing combined with numerical simulations to improve existing risk software used by DHS/FEMA and to advance risk-based design methodologies to enhance coastal infrastructure resilience. The method will be consistent with other multi-hazard frameworks such as earthquake and wind engineering.

5. **Abstract:**

   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. Although there have been significant advances in this correlation for wind 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 project will significantly improve HAZUS input fragilities for surge and wave through a robust experimental and numerical study of the interaction of surge and waves with near-coast structures. The overall goal of this project is to develop accurate

fragilities for near-coastal structures against overland surge and wave forces for input to HAZUS-MH such that they can be used in a design framework consistent with the risk-based methods used in wind and earthquake engineering We outline these specific objectives to be completed in two years in order to provide (1) improved accuracy for surge and wave analysis in HAZUS-MH; and (2) innovative advances in risk-informed design methodologies to enhance coastal infrastructure resilience:

- ***Objective 1:*** Quantify wave forces on near-coast structures for a range of surge levels based on a mid-scale hydraulic model test program, and develop new predictive equations for horizontal and vertical forces.
- ***Objective 2:*** Develop the conditional probabilities (fragilities) for exceeding key thresholds which will be linked to damage levels available in HAZUS-MH.
- ***Objective 3:*** Illustrate next-generation risk-informed design for near-coast structures that have been shown to be vulnerable to hurricane surge and waves using the fragilities developed in (2). This will improve the ability of building occupants to return following the hurricane thereby improving the resiliency of the community.

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 future engineering design of near-coast structures. 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.

6. End users:

In addition to these Research Participants, we will have the following people involved in the End-User Transition:

- FEMA HQ
- HAZUS Program Manager, FEMA HQ Risk Management Directorate
- Risk Analyst, FEMA Region VIII
- FEMA Building Science Division
- ASFPM Executive Director and CRC Advisory Board Member

Additional possible end-users include the USACE:

- USACE-ERDC, Vicksburg, MS (x2)
- USACE-HQ, Washington, DC

We have described our project to the end users during the CRC meetings in Washington DC (July 27, 2015) and at UNC (March 1, 2016). We will update our progress at the next center meeting. The benefit of this project will show how HAZUS software can be improved using new fragility curves developed in this project.

7. Explanation of Changes:

There have been no changes to the work plan. The hydraulic model tests (Task 1) are currently underway. Numerical modeling (Task 2) is also underway and limit states for failure of elevated buildings are being computed using detailed modeling approaches. Colorado State researcher Dr. Trung Do will be on site at Oregon State University to collaborate with Dr. Hyoungsu Park to work on integration of Task 1 and 2 from Aug 2 to Sept 2, 2016.

8. Unanticipated Problems:

There have been no unanticipated problems.

9. Project Outcomes:

A major limitation within HAZUS-MH when estimating damage and loss due to hurricanes is addressed in this stud: improving hazard-damage relationships for structures. Although the existing practice is to use flood depth as the intensity measure, this project will develop improved intensity measures derived from the wave climate. One example would be the modification of Goda's formula which has been used successfully for wave loads on coastal structures and has been adopted by the USACE for breakwater design. A second example is the momentum flux which is a parameter used for tsunami-structure interaction and has also be used to predict runup and stability of coastal structures. Finally, fragility functions to relate the hazard intensity to building damage are limited in HAZUS-MH for coastal surge/wave loading.

Although direct implementation of the research outcomes into HAZUS is beyond the scope for this project (and would have to be directed by FEMA through their contract with a consultant), this project will make direct comparison between existing HAZUS methodology and improvements that can be gained by implementing the new methodology and communicate it effectively to FEMA contacts described earlier.

10. Research Activity and Milestone Progress:

Research Activities and Milestones: Progress to Date

Reporting Period 7/1/2016 – 6/30/2017			
Research Activity	Proposed Completion Date	% Complete	Explanation of why activity / milestone was not reached, and when completion is expected
Experimental Design (OSU) – Task 1.1, develop wave/surge boundary conditions; bathymetry; specimen design and placement; test matrix and protocols.	3/31/2016	100%	Experimental design complete

Physical Model Testing (OSU) – Task 1.2, conduct physical model tests in Directional Wave Basin at HWRL; test setup, data acquisition, demobilization; initial data QA/QC	6/30/2016	100%	Experimental tests complete
Numerical Model (CSU) – Task 2.1, develop numerical model of a building and calibrate with existing experimental data	3/31/2016	100%	Numerical modeling complete
Fragility Formulation – Task 2.2, develop initial fragility limit states in cooperation with CRC, DHS/FEMA.	6/30/2016	100%	Fragility surfaces for several building archetypes complete

Research Milestone			
Progress Report 1: Detailed experimental work plan summarizing experimental plan (Task 1.1). Work plan to be developed with input from project partners and end users (Item 8).	3/31/2016	100%	Experimental work plan complete. Progress report is essentially the MS thesis work of Mr. W. Short and Mr. B Hunter.
Progress Report 2: Physical Model Data Base Report summarizing completed experiment. To be reviewed by project partners and end users.	6/30/2016	100%	Experimental work plan complete. Progress report is essentially the MS thesis work of Mr. W. Short and Mr. B Hunter. Experimental work was presented via webinar to partners and end users
Progress Report 3: Technical Brief summary of Task 2.1 calibration accuracy in a technical brief format and	3/31/2016	90%	A manuscript is being jointly written by Dr. T. Do and Dr. H. Park. Manuscript is being edited by project PIs.
Progress Report 4: Summary of the fragility formulation methodology (Task 2.2) to be used within this project. To be reviewed by project partners and end users.	6/30/2016	90%	Fragility work is nearly complete. Computer simulation is computationally slow due to the size of the analyses.
Progress Report 5: Illustrate next-generation risk-informed design for near-coast structures.	6/30/2017	50%	Work is ongoing to demonstrate the new methodology using Galveston, TX, as the test case.

11. Transition Activity and Milestone Progress:

Transition Activities and Milestones: Progress to Date

Reporting Period 7/1/2016 – 6/30/2017			
~~Transition Activity~~	Proposed Completion Date	% Complete	Explanation of why activity / milestone was not reached, and when completion is expected
End User Meeting #1:, Denver, CO. FEMA Region VIII. The meeting took place with Cox, van de Lindt and two end users, HAZUS Program Manager, FEMA HQ Risk Management Directorate, Actuarial and Catastrophic Modeling Branch, and, Risk Analyst, FEMA Region VIII. Cox and van de Lindt presented their project results and discuss possible implementations with HAZUS.	Tuesday April 25, 2017	100%	
End User Meeting #2:, Washington DC. FEMA HQ. The meeting was organized by a stakeholder at FEMA HQ. Cox and van de Lindt gave a 1 hr presentation on the project to approximately 20 FEMA staff at the meeting and an addition 20 people participating via webinar. Question and answer session followed the presentation. A working lunch continued the discussion with about 3 FEMA personnel.	Friday May 19, 2017	100%	

12. Interactions with education projects:

We are hosting two SUMREX students from University of Puerto Rico - Mayaguez, **Hector Colon** and **Peter Rivera**. Hector and Peter were on the Oregon State University campus from June 18, 2017, to August 12, 2017. Both students are participating in an undergraduate research program with 17 other students and will complete a project report and presentation on August 9. Both students will work on hand-on experimental research projects related to coastal hazard engineering and are partially supported on grants from the National Science Foundation.

Visit to Univ. Puerto Rico – Mayaguez. Dr. Cox visit Puerto Rico from March 5 to March 9, 2017, at the invitation of Professors **Ismael Pagan** and **Ricardo Lopez**. On March 7, Dr. Cox visited the campus of the University of Puerto Rico Mayaguez campus, met with faculty in civil engineering and marine sciences, met with students, toured the facilities, and gave a seminar on coastal hazards engineering and resilience. On March 8 and 9, Dr. Cox attended the research symposium organized by Profs. Pagan and Lopez in San Juan. Dr. Cox met with

engineering practitioners from Puerto Rico and researchers from the USACE. Dr. Cox gave a keynote presentation on this research project.

13. Publications:

1. Tomiczek, T., Park, H., Cox, D.T., van de Lindt, J.W., Lomonaco, P. "Experimental Modeling of Horizontal and Vertical Wave Forces on an Elevated Coastal Structure," *Coastal Engineering*, (submitted 1/2017).
2. 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.
3. William Short. *A laboratory study of horizontal and vertical regular wave forces on an elevated structure*. (2016). MS Thesis, Oregon State University.
4. Benjamin Hunter. *Exceedance Probabilities of Hurricane Wave Forces on Elevated Structures*. (2016). MS Thesis, Oregon State University.

14. Tables:

Table 1: Documenting CRC Research Project Product Delivery

Product Name	Product Type	Approx. Delivery Date	Recipient or Anticipated End Users
NA			

Table 2: Documenting External Funding and Leveraged Support

External Funding			
Title	PI	Total Amount	Source
Collaborative Research: Fundamental Mechanics and Conditional Probabilities for Prediction of Hurricane Surge and Wave Loads on Elevated Coastal Structures	Cox	$215,000	NSF CMMI-1301016
Collaborative Research: Fundamental Mechanics and Conditional Probabilities for Prediction of Hurricane Surge and Wave Loads on Elevated Coastal Structures	Van de Lindt	$140,000	NSF CMMI-1266101
Leveraged Support			

Description	Estimated Annual Value
NA	

15. Metrics:

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