COX, OSU and VAN DE LINDT, CSU

DHS Coastal Resilience Center

Research Project:

Annual Project Performance Report

Covers reporting period January 1, 2016 – June 30, 2016

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 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 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 have contacted the following people to schedule a meeting in DC in January 2017 to begin the End-User Transition:

- Eric Berman, HAZUS Program Manager at FEMA HQ
- Ed Laatsch, FEMA Building Science Division

If an in-person meeting is not possible because of schedule constraints, then we will convene a video conference call prior to the February center meeting. At the February meeting we will be able to provide direct information on the end-user transition process.

Additional possible end-users include the USACE, FEMA, and ASFPM:

- Ty Wamsley, USACE-ERDC, Vicksburg, MS
- Marc Gravens, USACE-ERDC, Vicksburg, MS
- Julie Rosati, USACE-HQ, Washington, DC
- Christina Lindemer, Coastal Engineer, FEMA Risk Analysis Branch, Atlanta GA
- Chad Berginnis, ASFPM Executive Director and CRC Advisory Board Member

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). At the January, 2017 meeting with the end-users in Washington D.C. we will explain the benefits in a presentation and report back on end-user plans. 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:

There are two major limitations within HAZUS-MH when estimating damage and loss due to hurricanes that can be addressed in this study:

(1) Characterizing the inland hazard with respect to wave climate. Currently, HAZUS-MH uses WHAFIS to characterize the wave climate inland. Although this model can calculate wave climate efficiently, it is formulated as a "transect model", meaning that the three dimensional effects (wave refraction, diffraction, reflection) are not included in the model. This is problematic for complex shorelines. Further, there has not been extensive validation of WHAFIS for overland surge/waves.

(2) 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. We have initiated a request to meet with Eric Berman and Ed Laatsch, and we can report out on this after the meeting. The meeting will either be in-person (in DC in January 2017) or by video conference

10. Research Activity and Milestone Progress:

Research Activities and Milestones: Progress to Date

Reporting Period 1/1/2016 – 6/30/2016			
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%	
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	50%	Experiments are currently underway at Oregon State University. Experiment was extended so that additional tests could be performed to increase the wave and airgap conditions. Also, additional testing allowed us to include 2 SUMREX students on the project.
Numerical Model (CSU) – Task 2.1, develop numerical model of a building and calibrate with existing experimental data	3/31/2016	100%	The numerical model has been developed in ANSYS and calibration shown for a wall and bridge specimen using two existing data sets from past OSU experiments.
Fragility Formulation – Task 2.2, develop initial fragility limit states in cooperation with CRC, DHS/FEMA.	6/30/2016	50%	Under development; the structural models are being refined more than originally planned. Originally, the limit states for the fragility development was going to be force, but it was decided to move this to structural failure which requires a more detailed structural load-response model and is more time consuming. This type of models is more realistic and will improve accuracy for use in risk-based design and analyses.
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	3/31/2016	90%	Draft experimental plan complete and will be finalized by Aug 31, 2016.

(Item 8).			
Progress Report 2: Physical Model Data Base Report summarizing completed experiment. To be reviewed by project partners and end users.	6/30/2016	10%	Daily logs are kept for experiment. 90% draft report to be completed by September 30, 2016.
Progress Report 3: Technical Brief summary of Task 2.1 calibration accuracy in a technical brief format and	3/31/2016	75%	A journal paper is underway and will be used as the outline to pull the brief from.
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	50%	Limit states have not been finalized because structural model underway (see above). Once this is complete in approximately one month, the methodology will be summarized.

11. Transition Activity and Milestone Progress:

Transition Activities and Milestones: Progress to Date

Reporting Period 1/1/2016 – 6/30/2016			
Transition Activity	Proposed Completion Date	% Complete	Explanation of why activity / milestone was not reached, and when completion is expected
PI will attend 5th HAZUS conference in Atlanta, GA. Develop better understanding of HAZUS User Groups (HUGs).	Dec 9-11, 2015	0%	Did not have travel funds available to attend meeting. We can consider attending future HAZUS conference meeting pending discussion with HAZUS program manager Eric Berman.
Meeting with Ed Laatch (DHS/FEMA) and others listed in Item 8 prior to the start of testing phase to gather additional information on potential adoption of fragilities in HAZUS. Discussion of what building types are needed. Meeting to be held at FEMA HQ in Washington DC. Attended by Cox, van de Lindt, Jones and Coulbourne. USACE will be invited (Wamsley, Gravens, Rosati)	Feb 2016	10%	Met with Jones and Coulbourne in Ft. Collins at Colorado State Univ. to discuss project. Did not schedule DHS/FEMA meeting due to travel schedule conflicts. We have requested a meeting with Ed Laatsch and Eric Berman.
Live video feed of physical model testing at OSU with overview explanation to project team and end users. Followed by discussion. Entire CRC personnel will be able to view the tests.	May 2016	30%	Live video feed is operational as of July 25 2016. http://wave.oregonstate.edu/live-views

We will also invite/coordinate national/local media coverage for DHS outreach			The experiment is complete (100%).
Transition Milestone			
Meeting minutes with action items Feb meeting at FEMA HQ	2/29/2016	0%	No meeting occurred. We have requested a meeting with Ed Laatsch and Eri Berman. We will report on that meeting after it occurs.
Summary of live demo and discussion.	2/29/2016	0%	Testing is not completed Summary reports are in progress.

12. Interactions with education projects:

Currently, we are hosting two SUMREX students from the University of Puerto Rico Mayaguez, Diego Delgado and Kevin Cueto. Kevin and Diego were on the Oregon State University campus from June 18, 2016, to August 5, 2016. Both students participated in a summer research experience for undergraduates (REU) program with 9 other students and will complete a project report and presentation on August 4. Because of budgetary issues, both students are supported on grants from the National Science Foundation which were in place when the travel arrangements were being made.

Image of Diego Delgado (REU student, left), Tori Johnson (post doctoral scholar, center) and Kevin Cueto (REU student, right) during the setup of the hydraulic model tests.

13. Publications: *List all articles published, or submitted for publication. Include author name(s), title of article, title of journal, date of submission, and anticipated publication date.* ***Provide full citation in format appropriate for your discipline.***

No publications to report at this time

***14.* CRC Performance Metrics:** *Complete the following Metrics Table and attach to your progress report.*

CRC Performance Metrics			
Metric	**Research**	**Education**	**Center**
Courses/certificates developed, taught, and/or modified		See Table	
Enrollments in Center-supported courses/certificates			
HS-related internships (number)			
Undergraduates provided tuition/fee support (number)	0		
Undergraduate students provided stipends (number)	0		
Graduate students provided tuition/fee support (number)	2		
Graduate students provided stipends (number)	0		
Undergraduates who received HS-related degrees (number)	0		
Graduate students who received HS-related degrees	0		
Certificates awarded (number)			
Graduates who obtained HS-related employment (number)	0		
SUMREX program students hosted (number)	0		
Lectures/presentations/seminars at Center partners	0		
DHS MSI Summer Research Teams hosted (number)	2		
Journal articles submitted (number)	0		
Journal articles published (number)	0		
Conference presentations made (number)	0		
Other presentations, interviews, etc. (number)	0		
Patent applications filed (number)	0		
Patents awarded (number)	0		
Trademarks/copyrights filed (number)	0		
Requests for assistance/advice from DHS agencies (number)	0		
Requests for assistance/advice from other Federal agencies	0		
Total milestones for reporting period (research			
Accomplished fully (research activity/milestone)	2/0		
Accomplished partially (research activity/milestone)	4/4		
Not accomplished (research activity/milestone)	1/2		
Product/s delivered to end-user/s (description and	See Table		
External funding received	See Table		
Leveraged support			
Articles on Center-related work published on website			
Coverage in media, blogs (number)			
Social media followers (number)			
Posts to social media accounts (number)			
Events hosted (number)			
Website hits (number)			

*Note: Table modified to report both research activities and milestones from Section 10 and 11.

Table for Documenting CRC Research Project Product Delivery

Nothing to report at this time

Table for 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