SPR RESEARCH PROGRAM
SECOND-STAGE PROPOSAL SUMMARY

PROBLEM NUMBER AND TITLE

25-23 Enhancing Seismic Resilience: Developing Next-Generation of Bridge Fragility Models for Oregon's Transportation Network

PROBLEM SUMMARY

After a major earthquake, ODOT emergency managers would require immediate understanding of field conditions to coordinate responses and dispatch bridge inspection resources. The ShakeCast alerting system utilizes real-time ground-shaking maps from the United States Geological Survey and precalculated bridge fragility relationships to rapidly estimate bridge damage. The limitations of the current fragility models for Oregon's bridge infrastructure will reduce the value of the results. Existing models are both obsolete and a poor match for Oregon's bridge inventory. This may result in unrealistic estimations of regional seismic vulnerability. Addressing these limitations will enhance post-earthquake emergency response, restoration of network mobility, and capital resource allocation for seismic safety improvements. Developing next-generation parametrized fragility models tailored to Oregon's unique infrastructure is important to a quick and efficient response after a major seismic event, like a Cascadia Subduction Zone Earthquake.

ODOT OBJECTIVES

The final product will consist of an updated set of parametrized fragility models specifically designed for the diverse array of bridge classes in Oregon. These fragility models will incorporate recent advances in seismic design philosophy, accounting for a range of bridge attributes. Parameterized models offer flexibility by accommodating variation in design details within a portfolio, enabling efficient uncertainty propagation. Moreover, the final product will provide detailed seismic damage state definitions that are explicitly linked to post-earthquake response and recovery.

The research will also produce detailed documentation, guidelines, and tools for the utilization of the results within the existing alerting and response system. The documentation and tools would facilitate easy access and utilization of the models by State agencies, emergency responders, engineers, and researchers.

BENEFITS

The primary benefits from this research will be realized following a large earthquake. First, inspection crews can prioritize bridge structures based, in part, on the projected condition from ShakeCast. Second, response efforts of all types can more accurately predict transportation corridor functionality based on the results in Shake Cast. These benefits advance the goals of safety, mobility, and economic and community vitality. A secondary, but more immediate benefit would be more accurate vulnerability assessments of Oregon's bridge inventory for inclusion in the new NBIS.

SCHEDULE, BUDGET AND AGENCY SUPPORT

Estimated Project Length: 24 months.
Estimated Project Budget: $350,000
ODOT Support

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FOR MORE INFORMATION

For additional detail, please see the complete STAGE 2 RESEARCH PROBLEM STATEMENT online at:
https://www.oregon.gov/odot/Programs/ResearchDocuments/25-23.pdf

SPR RESEARCH PROGRAM
SECOND-STAGE PROBLEM STATEMENT
FY 2025

PROBLEM NUMBER AND TITLE

25-23 Enhancing Seismic Resilience: Developing Next-Generation of Bridge Fragility Models for Oregon's Transportation Network

RESEARCH PROBLEM STATEMENT

After a major earthquake, ODOT emergency managers would require immediate understanding of field conditions to coordinate responses and dispatch bridge inspection resources. The ShakeCast alerting system enhances situational awareness by utilizing real-time ground-shaking maps from the United States Geological Survey and precalculated bridge fragility relationships to rapidly estimate bridge damage. The limitations of the current fragility models for Oregon's bridge infrastructure hinder post-earthquake emergency response and planning. Existing models are both obsolete and a poor match for Oregon's bridge inventory. This may result in unrealistic estimations of regional seismic vulnerability. Addressing these limitations will enhance post-earthquake emergency response, restoration of network mobility, and capital resource allocation for seismic safety improvements. Developing next-generation parametrized fragility models tailored to Oregon's unique infrastructure is a pressing research need to ensure that Oregon will respond more quickly and efficiently after a widespread impact of a major seismic event, like a Cascadia Subduction Zone Earthquake.

RESEARCH OBJECTIVES

The final product will consist of an updated set of parametrized fragility models specifically designed for the diverse array of bridge classes in Oregon. These fragility models will incorporate recent advances in seismic design philosophy, accounting for a range of bridge attributes. Parameterized models offer flexibility by accommodating variation in design details within a portfolio, enabling efficient uncertainty propagation. Moreover, the final product will provide detailed seismic damage state definitions that are explicitly linked to post-earthquake emergency repair needs, traffic capacity assessments, and engineering metrics. These refined fragility models will be crucial for post-earthquake emergency response planning and the prioritization of bridge inspections, enhancing the State's capacity to address and recover from seismic events.

In addition to the fragility models, the research will produce detailed documentation and guidelines for the utilization of these models within the existing alerting and response system, enabling emergency managers and decision-makers to incorporate this updated information seamlessly. Furthermore, the final product will encompass a user-friendly tool (such as an Excel file) housing these embedded parametrized fragility models and their associated documentation. Such a tool would facilitate easy access and utilization of the models by State agencies, emergency responders, engineers, and researchers.

WORK TASKS, COST ESTIMATE AND DURATION

The project's goal is to develop an advanced Multi-dimensional Fragility Assessment Framework through 10 interrelated tasks. The following section outline the general scope, requirements, and deliverables of these tasks.

Task 1: TAC Meeting. The research team will meet with the TAC to review research plans and identify prototype bridges, focusing on the most common bridge types in Oregon, to serve as the basis for developing the multi-parametrized fragility framework.

Task 2: Compile Bridge Parameters. This task involves estimating bridge design parameters and characteristics while accounting for uncertainties in geometric configurations and material properties. We will achieve this by analyzing bridge plans and collecting bridge data from available sources such as the National Bridge Inventory (NBI). Subsequently, we will create statistical distribution models for each parameter to propagate uncertainty. These details will serve as inputs for developing the fragility models.

Task 3: Ground Motion Excitation Suite. A suitable set of ground motions tailored to the Oregon bridge locations and Cascadia Subduction Zone Earthquake characteristics will be selected for the seismic analysis task.

Task 4: Finite Element Bridge Models. We will use OpenSees to generate three-dimensional finite-element models of bridges.

Task 5: Perform Nonlinear Time History Analysis. Nonlinear seismic analysis will be conducted to capture responses of critical bridge components. Engineering demand parameters (such as displacements and ductility values) for primary bridge components including columns, bearings, and abutments will be recorded during the nonlinear time history analysis. This computationally intensive process will be replicated for numerous bridges to generate training data for fragility modeling and subsequent machine learning-based analyses as outlined in subsequent tasks. Through Latin Hypercube Sampling, a large number of hypothetical bridge parameters (potentially thousands) will be generated based on the approach outlined in this task, designed according to Task 1 specifications, and analyzed accordingly by randomly pairing them with the ground motion sets.

Task 6: TAC Meeting. The research team will meet with the TAC to establish damage-state definitions and bridge capacities. A mid-term presentation will be delivered to demonstrate the progress of framework development, methodologies utilized, and initial findings.

Task 7: Machine-learning-based Multi-parametrized Models. Machine learning techniques will be used to identify influential parameters and establish relationships between seismic demands and bridge parameters. Our proposed approach offers a more advanced method for regional risk assessments. Instead of traditional methods grouping bridges into classes and generating fragility curves, we recommend employing a machine learning-based multi-parameter fragility approach. This approach creates bridge-specific fragility curves without the need for class grouping, conditioning on various input parameters encompassing uncertain geometric, material, and structural characteristics, as well as hazard intensity measures. Furthermore, this methodology aids in discerning the significance of individual parameters in shaping the fragility curves. This task involves three primary phases: I) applying feature selection techniques (such as the Least Absolute Shrinkage and Selection Operator and Forward Selection technique) to identify influential parameters by assessing each parameter's impact on the bridge response. II) developing surrogate probabilistic seismic demand models by implementing various machine learning algorithms, including parametric and non-parametric methods, to cover linear and nonlinear models with varying degrees of flexibility (such as Multi-parameter Linear Regression, Gradient Boosting, and Random Forest). To mitigate estimation bias, we employ a k-fold cross-validation approach for the data subset partitioning. III) validating the overall performance of the models using global and local goodness-of-fit measures.

Task 8: Generate Bridge Fragilities. Utilizing the seismic demands estimated in Task 7 and the bridge capacities defined in Task 6, fragility models will be constructed for primary bridge components and the system. The demand model established in Task 7 will provide the parameters necessary to formulate analytical fragility curves.

Task 9: TAC Meeting. In this meeting, ODOT seismic design professionals will get familiar with the methodology while also guiding the academic research team on the practical details and concerns of bridge engineers. A conclusive presentation will showcase the finalized framework, its functionalities, and the outcomes derived from its application to the case studies.

Task 10: Report and Tool. We will create a tool for implementing the framework. The end product will include a user-friendly tool (such as an Excel file or a similarly easy-to-use format) containing embedded parametrized fragility models and their accompanying documentation. Additionally, a technical report will be compiled to provide practical insights into enhancing bridge infrastructure through the multi-dimensional fragility assessment framework. This report will evaluate the application of the framework, document the process and lessons learned, and highlight challenges and accomplishments encountered throughout the research timeline.

Key Deliverables: Deliverables for this research project will a set of parameterized fragility models in a format specified by ODOT to be used to better represent the seismic performance of our entire bridge inventory. In contrast with fragility models developed by FEMA (and used currently by ODOT for our ShakeCast model), parameterized fragility models will enable ODOT to adjust several bridge characteristics with very little effort, which will yield to a more realistic prediction of seismic performance of that particular bridge.

Estimated Project Length: 24 months.
Estimated Project Budget: $350,000

IMPLEMENTATION

The primary implementation of this project will involve integrating the new fragility curves into the Oregon ShakeCast. The fragility curves will also facilitate the development of seismic vulnerability assessments that the new NBIS requires. This research would fit perfectly with the timeframe set for development of this information.

POTENTIAL BENEFITS

The primary benefits from this research will be realized following a large earthquake. First, inspection crews can prioritize bridge structures based, in part, on the projected condition from ShakeCast. Second, response efforts of all types can more accurately predict transportation corridor functionality based on the results in Shake Cast. A secondary benefits would be more accurate vulnerability assessments for the new NBIS. These benefits advance the goals of safety, mobility, and economic and community vitality.

PEOPLE

ODOT champion(s):

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STAFF REVIEW PAGE

Literature Check

TRID&RIP

☒ A review of TRID & RIP databases found no existing research that answers the research question.

The proposed research is unique to Oregon's built environment. The equivalent work that has been done was done long ago and is now outdated. Recent similar work in other regions doesn't address Oregon's built environment.

Technology & Data assessment

☐ No Identified T&D output

☒ At the end of this project, the implementing unit(s) within ODOT will need to coordinate the adoption of new technology or data to realize the full potential of this research.

While the results of this project will be folded into ShakeCast and NBIS, the research itself does not affect the deployment and use of those systems. ShakeCast is hosted outside of ODOT. NBIS will be evolving based on new federal requirements, but that is independent of this research.

Cross-agency stakeholders

- Many units in ODOT will be involved in ODOT's response to a future, large earthquake and thus will have an interest in the quality of the results of ShakeCast. First and foremost, will be Bridge Inspection and Maintenance. CCD, Rail, and Public Transit will likely also draw on the ShakeCast predictions.
- ShakeCast results will be available to, and of use to, many state and local agencies responding to a future, large earthquake.