MPC-561
December 11, 2017

Project Title:
Reliability-Based Assessment of Landslide Risk Along Roadways

University:
Utah State University

Principal Investigators:
John Rice
Associate Professor
Utah State University
Phone: (435) 797-8611
Email: john.rice@usu.edu
ORCID: 0000-0002-2523-9400

James Bay
Associate Professor
Utah State University
Phone: (435) 797-2947
Email: jim.bay@usu.edu
ORCID: 0000-0002-5536-8238

Research Needs:
Roadways through areas susceptible to landslides are subject to damage and potential closure due to landslide movement. In general, the landslide hazard is often concentrated into portions of the roadway alignment that have geologic conditions (features) susceptible to landslide movement; including colluvium filled swales, steepened cuts, and preexisting landslides to name a few. Thus, by assessing the annual probability of failure of each individual geologic feature, and then combining the probabilities for the roadway in question, the total probability of failure for the roadway can be assessed. Then, by assessing the consequences of failure (economic impact of road closure, repair costs, etc.) the total annual risk due to landslides can be assessed for the length of roadway in question. In addition to providing an understanding of the risk for an agency's portfolio of susceptible roadways, the assessment also provide a tool for assessing the effects of mitigation measures by assessing the reduction of risk that is realized when individual geologic features are mitigated.

This research will adapt a procedure that the PIs have previously developed for assessment of underseepage and internal erosion risk for levees (Boulware and Rice 2017, Polanco and Rice 2014, 2012) to the problem of landslide disruption of roadways. Models will be developed for each geologic feature type that can assess the stability of the feature for ranges of geometric parameters (depth of deposit, slope inclination, groundwater level, etc.) and material properties (unit weight, strength, etc.). Depending on the complexity of the analysis, the landslide model may be represented by a closed-form equation or, in the case of a large number of input

parameters, a response surface (a multi-dimensional function representing the relationship between input parameters and the failure potential). A Monte Carlo analyses will then be performed for each feature along the stretch of roadway using probability density functions (pdfs) representing the likelihood of a given parameter having a certain value over the range of possible values. The failure probability can be annualized by considering triggering events (such as rainfall events having calculated return frequencies) and assessing the effects of multiple levels of these events. The resulting fragility curve ties the probability of failure to the likelihood of the triggering event. This method will provide a tool for agencies to assess their annual risk due to landslide hazards and will give these agencies a means for optimizing their mitigation efforts.

Research Objectives:

1. Develop functions, consisting of either closed-form equations or response surfaces, that can be used to calculate the failure potential for each type of geomorphic feature (colluvium filled swales, steepened cuts, preexisting landslides, etc.).
2. Develop guidance for selecting pdfs for input parameters (depth of deposit, slope inclination, groundwater level, etc.) that provide the input for the above models.
3. Develop a Excel and @Risk based program for performing the Monte Carlo analyses for the functions for each of the above models.
4. Develop guidance for combining hazards and risks for reaches of roadway incorporating multiple landslide risks.

The objective of this research is to develop a framework by which the landslide risk can be assessed in a reliability-based analysis that incudes the uncertainty of relevant input parameters. The framework consists of assessment of hazard potential and risk for each geometric feature that has potential to produce landslide movement impacting the roadway. The individual hazards and risks from each feature will be combined to assess the total landslide hazard for the roadway length.

Research Methods:

The research will consist of numerical modeling to develop the functions along with literature research to develop likely pdfs for input parameters.

1. Numerical modeling will consist of limit-equilibrium and finite element analyses to develop the functions for each geomorphic feature. Three or four geomorphic features that represent the landslide risk along a stretch of roadway will be analyzed. The analysis for each feature will consist of:
    a. Parametric analysis of all prospective input parameters to evaluate which parameters have a significant effect on the potential for failure.
    b. In cases where more than three parameters are found to be significant, the number of parameters to be included in the function will be reduced by combining parameters into parameters such as geometric ratios and pore pressure ratios. Comparative analyses will be performed to assess the difference between the simplified model and the model containing all parameters.
    c. A comparison will be performed between the limit-equilibrium and finite element analyses methods and sources of differences will be resolved.

2. Literature review will be performed to assess methods for developing pdfs for input parameters for use in the Monte-Carlo analyses. The review will include:
    a. Assessment of the range of values typically encountered for different geomorphic feature types.
    b. Assessment of the type of pdf distribution (i.e. normal distribution, log-normal distribution, uniform distribution, etc.) that best describes the typical distribution of values of each parameter.

Expected Outcomes:
The outcome of this work will provide a methodology for assessing the total landslide hazard and risk for a length of roadway. The method may also be used to assess the reduction of risk that can be accomplished with various landslide mitigation measures allowing agencies to assess how mitigation measures can most economically be implemented.

Relevance to Strategic Goals:
- State of Good Repair
- Safety

This work will increase the design life and state of good repair for roadways by providing a logical manner in which landslide risk can be assessed. It also provides a method by which the effectiveness of mitigation measures on the risk can be analyzed, leading to optimization of available maintenance and upgrade funds.

Educational Benefits:
This research will support one graduate student and will be used to generate a Plan A Master's thesis. These modeling approaches will be incorporated into the Earth Structures graduate course.

Tech Transfer:
This work will be submitted to the Transportation Research Board for presentation and publication as well as other leading geotechnical and risk assessment journals.

Work Plan:
1. Literature research on landslide models and statistics of input parameters for pdf development
2. Create limit equilibrium base models for various types of landslides
3. Create finite element base models for various types of landslides
4. Use models to develop functions and response surfaces for various landslide types
5. Apply models to case study
6. Draft TRB article

The first task consists of literature research on landslide models and statistics of input parameters for pdf development. The task will be conducted by Dr.Rice and a graduate student during 2018. Next we will create limit equilibrium base models for several (up to 4) types of landslides. The task will be conducted by Dr.Rice, Dr. Bay and a graduate student during the first 4 months of 2019. We will then create finite element base models for the types of landslides. The task will be

conducted by Drs. Rice, Bay and a graduate student during Months 4-8 of 2019. We will use models to develop functions and response surfaces for various landslide types. The task will be conducted by Drs. Rice and Bay during Months 5-9 of 2019. Finally we will apply the models to case study of an actual stretch of roadway. This task will be performed by Drs. Bay and Rice during Months 8-12 of 2019. A Draft TRB article will be prepared at the end of the project by Drs. Bay and Rice at the end of the project.

Project Cost:

Total Project Costs:	$100,000
MPC Funds Requested:	$50,000
Matching Funds:	$50,000
Source of Matching Funds:	Utah State University - Utah Transportation Center

References:

Boulware, L. and Rice, J. (2017). A Method for Reliability-Based Assessment of Three-Dimensional Internal Erosion Potential Due to Geomorphic Features, *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, 143-4.

Polanco, L. and Rice, J. (2014). A Reliability-Based Evaluation of the Effects of Geometry on Levee Underseepage Potential. *Geotechnical and Geological Engineering Journal* (Springer), 32-4.

Polanco, L. and Rice, J. (2012). Reliability Based Underseepage Analysis in Levees Using a Response Surface-Monte Carlo Simulation. *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 138, No. 7, pp 821-830.