

**TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT**

Lead Agency (FHWA or State DOT): Washington State Department of Transportation

INSTRUCTIONS:

Lead Agency contacts should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

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|---|--|---|
| Transportation Pooled Fund Program Project # TPF-5(459) | Transportation Pooled Fund Program - Report Period: <input type="checkbox"/> Quarter 1 (January 1 – March 31), 2025 <input type="checkbox"/> Quarter 2 (April 1 – June 30), 2025 <input type="checkbox"/> Quarter 3 (July 1 – September 30), 2025 <input checked="" type="checkbox"/> Quarter 4 (October 1 – December 31), 2025 | |
| TPF Study Number and Title: TPF-5(459), Developing and Calibrating Fragmental Rockfall Models using Physics Engines | | |
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| Lead Agency Project ID: Click or tap here to enter text. | Other Project ID (i.e., contract #): Click or tap here to enter text. | Project Start Date: 8/11/2020 |
| Original Project Start Date: 8/11/2020 | Original Project End Date: 8/31/2025 | If Extension has been requested, updated project End Date: 12/31/2026 |

Project schedule status:

| | | | |
|---|--|--|--|
| <input checked="" type="checkbox"/> On schedule | <input type="checkbox"/> On revised schedule | <input type="checkbox"/> Ahead of schedule | <input type="checkbox"/> Behind schedule |
|---|--|--|--|

Overall Project Statistics:

| Total Project Budget | Total Funds Expended This Quarter | Percentage of Work Completed to Date |
|----------------------|-----------------------------------|--------------------------------------|
| \$700,000 | \$34,651 | 88% |

Project Description:

Background:

Managing rock slopes adjacent to highway infrastructure involves consideration of possible rock slope instability and making decisions about how to manage potential mitigation efforts for rockfall. The selected method often involves the removal of loose blocks by slope scaling, re-establishing the catchment area, and/or the construction of a variety of types of rockfall barrier structures to retain the debris. When designing a slope scaling program, a rockfall catchment area or a rockfall barrier structure, the potential trajectories of the rocks released from the slope must be considered. In order to make appropriate preparations for rock slope scaling, such as protecting the highway surface, existing rockfall barrier structures, and adjacent waterways, rockfall fragments must also be considered. Sometimes temporary barricades will be erected to retain the rock fragments generated by slope scaling in a controlled manner.

Generally, the potential path and distribution of falling rocks is modelled using a rockfall simulation model. Given the variability and uncertainty in modelling rockfall physics, reasonable ranges of input parameters are inputted into the simulation in order to assess the potential hazard. The results are used to evaluate the trajectory, bounce height, energy and runout distance of potential rockfall events, in a probabilistic sense. Most of the models available are based on the physics of a single block, moving as a solid non-fragmenting lumped mass, by bouncing, rolling and sliding along a 2D section cut through the 3D model of the slope surface. The implementation of a 3D slope surface and a realistically shaped block is available in only a very few models. Experience with rockfall simulation indicates that the use of readily available, easy to use rockfall models, which utilize a single circular block on a 2D surface, tend to significantly overestimate the length of travel path taken by real falling blocks of rock. This in turn leads to more expensive and extensive protection being used, than is required, during rock slope maintenance and slope scaling work. No commercially available software package currently simulates rockfall fragmentation, or considers the presence of joints and pre-existing geological structure within the rock mass.

In recent years, our ability to model rockfall is being transformed by the adoption of the engines created for the video gaming industry (Harrap et al, 2019). Game engines incorporate sophisticated representation mechanisms for materials, physics engines, databases to store unique and repeating spatial features, methods for procedural generation of entire environments, dialog and interaction AI systems, and physically accurate models for light and sound. The physics engines generally include at least two core components – i) collision detection / collision response, and ii) simulation of dynamics to solve the forces acting on the moving, simulated objects. These are in the form of standardized libraries contained within the engines that support generalized spatio-temporal simulations. In addition, the engines provide easily implemented world building tools that can accept complex geometry. The physical parameters are defined for each game object and, when the game is run, the behavior of the object under various forces is simulated. In the case of rockfall, this includes fragmentation of the falling blocks and interaction between fragments.

Recent work by Ondercin (2016), Sala (2018) and Sala et al (2019) has demonstrated that rockfall models built in game engine environments replicate the observed pathway and fragmentation sizes of rockfall events observed from change detection between time sequential point clouds. The implementation of realistic 3D surfaces, based on data from LiDAR or photogrammetry models, and the potential to model fragmentation and block interaction, creates models that appear much more realistic. By varying the rockfall physics parameters, the simulated events can be shown to generally match the volume of fallen blocks distributed across and at the toe of the slope (Sala et al, 2019). This has been shown for two or three rockfall case history instances.

As with any simulation model, it is possible that changes to the input parameter values and ranges can significantly change the output. The possibility of significant variations in output results increases when highly variable and complex rock slope surface geometry and the fragmentation of the block is added to the simulation. At this point, there is no guidance or method for simulating rock block fragmentation, nor is a database available to provide calibration case histories. So, the development of the rockfall simulation tool must involve the assessment of real rockfall behavior to assess reasonable ranges of input parameters. These parameters are dependent on lithology, structural geology, slope rock mass characteristics and condition, slope geometry, and the potential for fragmentation during the rockfall event. This information then supports the development and coding of useful and probabilistically representative functionality in the physics engine simulation.

Objectives:

The objectives of the research work are to:

1. Develop a field data collection methodology to observe rockfall events, generated by scaling projects. Develop a detailed database of rockfall events, collected and analyzed from DOT rock slope scaling projects, and utilize this database to define ranges of input parameters needed to simulate rockfalls.
2. Build a user interface with the selected physics engine to permit model self-calibration based on observations and generate numerous simulations providing probabilistic output data. Define and produce useable metrics such as runout distance for a defined % of the volume, bounce height and energy etc.
3. Determine the basis for decisions related to goodness of fit of simulations and simulate many known rockfall events to define appropriate ranges of input parameters to generate realistic fragmental rockfall models for different geological settings and slope condition states.
4. Simulate the interaction between falling fragments and the underlying slope, considering geology, geometry and whether the blocks will be impacting outcropping rock, talus, soil, and possibly vegetation, to refine the fragmentation model.

Scope-of-Work:

Phase 1 – Development of field data collection techniques / review of existing information to define the behavior of real rockfall cases, including block fragmentation.

Phase 2 – Rock slope and rockfall field data collection from partnering agency locations during slope scaling operations, development of a database to store the information, and development of modeling/simulation tools.

Phase 3 – The interpretation and simulation of the field data that has been collected, definition of calibration workflow, and a review of the software functionality.

Phase 4 – The development of simulation software, a user’s manual that includes input parameter guidance related to rockfall behavior and fragmentation and training, and recommendations for future management and maintenance of the software program.

Progress this Quarter

(includes meetings, work plan status, contract status, significant progress, etc.):

All the rock slope LiDAR and photogrammetry models are ready for calibration. We have purchased a laptop that will be used to deliver the simulation to users for testing. It has been configured and is ready for use. We worked on building a workshop for users to try out the simulation and give us feedback on calibration of the simulation. This is the presentation we will give at TRB in 2026. Our work on the first paper is ongoing due because we pivoted to preparing the TRB workshop in December.

Anticipated work next quarter:

We plan to attend TRB 2026 in January and hold a workshop for the TAG members to give them a project update and also have the simulation ready for use so that the users can provide us with feedback on their user experience. We will spend the quarter finishing the first paper, calibrating the simulation variables to real world rock parameters, incorporating user feedback, and then writing the second paper.

Significant Results:

Circumstance affecting project or budget. (Please describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).

Potential Implementation: