SPR RESEARCH PROGRAM
SECOND-STAGE PROPOSAL SUMMARY

PROBLEM NUMBER AND TITLE
24-37: Real-Time Landslide Surface Monitoring for Improved Safety, Response, and Repair

PROBLEM SUMMARY
The recent, rapid, and overwhelming movement of the Hooskanaden landslide in 2019 and the Arizona Inn landslide in early 2023 greatly disrupted traffic along US 101 with several days of full road closure followed by prolonged reduced capacity and weeks of traffic control for repairs. Alarmingly, numerous precarious landslides exist throughout the state that can result in similar consequences, triggered by precipitation or erosion—both of which will be exacerbated with climate change. Real-time, on-site instrumentation is essential to characterize landslide kinematics as well as detect and predict movements that can disrupt the highway system. Real-time, on-site instrumentation can also help inform the timing of repair and estimation of material needs, improving both on-site safety and maintenance costs associated with repair. However, the standard methodology for landslide instrumentation requires costly drilling beneath the earth's surface—which is frequently unsafe, costly, and infeasible on an active landslide. Further, drilled subsurface instrumentation is oftentimes destroyed with landslide movement, providing only short-term usefulness for obtaining active landslide data. This project will develop and deploy low-cost <u>surface monitoring</u> strategies to monitor landslide movements, leveraging ODOT's recent proof-of-concept success using real-time kinematic global navigation satellite systems (RTK-GNSS) to monitor the Arizona Inn landslide failure, which enabled real-time delivery of critical information to help inform closure actions and repairs. Further development and establishment of surface monitoring methods will also inform statewide characterization of active slides that impact ODOT infrastructure where drilling is cost prohibitive, unsafe, or impossible.

ODOT OBJECTIVES
1. Analyze monitoring data (RTK GNSS) from past landslide events to determine warning thresholds.
2. Deploy additional RTK GNSS systems, repeat unmanned aircraft system (UAS) surveys, and evaluate the utility of incorporating ODOT's interferometric synthetic aperture radar (InSAR) surface data.
3. Develop techniques to identify the shear surface and landslide features (e.g., distinct blocks).
4. Implement a systematic surface monitoring program and procedures for active ODOT landslides.

BENEFITS
The hundreds of actively moving landslides on Oregon's highways pose an ongoing threat to the connectivity of communities and economies statewide. These precarious conditions threaten the agency's mission as landslides are 1) a significant risk to user safety, 2) impose inefficiencies by delaying traffic after failure or for repair, and 3) impose economic strain as the cost of traffic delays impacts the cost of goods and services that rely on our roads. Real-time landslide surface movement data can help with emergency response by predicting the amount of material needed for repair, identifying when to close a road for safety, and determining when repairs can safely begin as the movement subsides. Further, surface monitoring is less environmentally intrusive than drilling and safer to instrument, with superior long-term monitoring potential for active slides.

SCHEDULE, BUDGET AND AGENCY SUPPORT
Estimated Project Length: <u>42 months</u>.
Estimated Project Budget: $460,000
ODOT Support: Susan Ortiz (State Geotechnical Engineer), Curran Mohney (Engineering Geology Program Lead), Rhonda Dodge (Senior Remote Sensing Surveyor)

FOR MORE INFORMATION
For additional detail, please see the complete STAGE 2 RESEARCH PROBLEM STATEMENT online at:
https://www.oregon.gov/odot/Programs/ResearchDocuments/24-37.pdf

SPR RESEARCH PROGRAM
SECOND-STAGE PROBLEM STATEMENT
FY 2024

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RESEARCH PROBLEM STATEMENT

Figure 1: *Arizona Inn landslide failure in Curry County closed Hwy 101 for nearly one week in January 2023 (ODOT, John Link)*

Landslides impede transportation in Oregon, costing the state tens of millions of dollars annually through maintenance and repair, while diminishing system reliability due to closures. Frequently, these ailments are the onset of troubling, slow movements that either simply continue to progress, or accelerate towards collapse. Conventional monitoring, site investigation and assessment of landslides for mitigation often requires drilling along with installation of piezometers and inclinometers. These tried-and-true techniques are effective for slide repair as they provide valuable information about the landslide hydrology, subsurface, and location of the shear zone. However, they are not always feasible due to the significant expense of drilling, safety concerns for working on an active landslide, and difficult site access. These restrictions result in only a small proportion of landslides having any level of characterization or monitoring. These limitations place critical infrastructure and ultimately ODOT customers at risk.

Fortunately, using alternative remotely-sensed or in-situ monitoring technologies, it is possible to develop methods and tools for ODOT that may provide (1) a velocity time history that could inform early-warning systems for the geo-professional, (2) site information when drilling for landslide investigation is cost prohibitive, (3) a first-order characterization of landslide properties when drilling is unsafe or infeasible, and (4) significantly improved spatial resolution for estimates of landside shear zone location in well-characterized landslides. ODOT could save significant time and money as well as improve safety with the development of powerful analysis tools that will augment sparse drilling and subsurface monitoring that may be unreliable for extended monitoring. This work would leverage state of the art geospatial monitoring technologies, in which ODOT has already made investments and has core capabilities. These technologies are envisioned to include (1) networks of low-cost, real-time kinematic (RTK) global navigation satellite system (GNSS) receivers installed at key landslide locations, (2) repeat surveys with change detection from terrestrial and UAS-mounted lidar, (3) digital photogrammetry (e.g., structure from motion), and (4) potentially the use of satellite-based techniques such as interferometric synthetic aperture radar (InSAR). GNSS can provide continuous real-time measurements of slide movement for alerts and be post-processed for more accurate assessment of long-term displacements. Lidar (in many forms) or digital photogrammetry can be deployed by ODOT Geometronics for refined characterization of critical slope failures. Several InSAR bands are captured repeatedly by NASA and ESA and are publicly available. When processed this method can provide high temporal resolution maps of surface change for long-term monitoring. Use of these relatively inexpensive monitoring techniques would reduce the need for and supplement conventional subsurface monitoring, providing a more comprehensive, frequent assessment of landslide surface velocities throughout the slide mass. While constraining slide kinematics with critical geotechnical data (slide surface location, piezometric conditions), we may use GNSS and UAS lidar to map surface displacements and consequently infer a three-dimensional map of the failure plane location and the dynamics of landslide – all while reducing the expense and time involved with drilling additional, expensive borings.

RESEARCH OBJECTIVES

This research will develop a versatile set of tools that will:

1. Analyze monitoring data (RTK GNSS) from past landslide events to determine warning thresholds.
2. Deploy additional RTK GNSS systems, repeat unmanned aircraft system (UAS) surveys, and evaluate the utility of incorporating ODOT's interferometric synthetic aperture radar (InSAR) surface data for monitoring.
3. Develop techniques to identify the shear surface and landslide features (e.g., distinct blocks) that can provide an estimate of shear surface geometry given detected changes in landslide surface topography and estimated landslide extent as well as simple forensics tool that will estimate either shear strength or groundwater depth based on observed landslide movements and estimated geometry,
4. Implement a systematic surface monitoring program and procedures for active landslides that can provide guidance for establishing a framework to assess early warning of landslide activity (e.g., determine closure based on observed landslide accelerations, repair plans based on observed landslide velocities).

This research would result in guidance to effectively use supplementary monitoring techniques. As a starting point, the OSU team has developed and successfully deployed a system of RTK-GNSS units with a base station to monitor slope movements using low-cost, rapidly deployable units. An initial prototype system was developed and is currently installed at two large coastal landslides that traverse Highway 101 (Arizona Inn and Hooskanaden), where data is processed and sent back every half hour to the cloud for online viewing. These data proved critical to help engineering geologists make decisions regarding repairs associated with the January 2023 surge at Arizona Inn. The proposed work would expand on using this data to develop early warning detection algorithms to identify when the slide is rapidly accelerating or showing heightened movement. Such systems will significantly reduce drilling expenses associated with conventional monitoring, as well as provide a data-driven means of evaluating potential catastrophic landslide movements. This RTK-GNSS system, repeat collection of UAS lidar, and potentially InSAR surface data will be used with site-specific geotechnical data to corroborate slide movements and create a three-dimensional profile of the inferred slide surface, which will be compared with the boring log data.

WORK TASKS, COST ESTIMATE AND DURATION

The following tasks are envisioned for this research, which will leverage existing monitoring data of slope failures and erosion from SPR807, SPR808, and SPR843 to corroborate RTK GNSS, lidar change detection measurements, and potentially InSAR data:

1. Review current approaches for monitoring landslide movements using inclinometers, lidar/photogrammetric change detection, InSAR, and GNSS systems. Provide guidance to ODOT on the appropriate types of slides to utilize each technology, including combinations of the technologies for effective, low-cost site monitoring. Evaluate approaches for analyzing monitoring data as a precursor to failure for early warning systems for region geologists and geotechnical engineers.

2. Install rapidly deployable RTK GNSS units at additional well-instrumented, monitored landslides. Connect instruments with ODOT Geometronics GNSS network. (Note that a small number of units have been installed in a pilot proof of concept study for SPR807). Develop algorithms to process these data automatically and establish warning thresholds. When available, use InSAR time series data to corroborate and/or infill GNSS surface displacement time series.

3. Perform 2-3 UAS lidar surveys and analyze data for change detection using image correlation/computer vision techniques (e.g., SlideSim (Senogles, 2022)) that can provide vectors of displacement across the landslide based on digital image correlation techniques between epochs. Baseline surveys have been collected at two slides as part of SPR807 and will be leveraged for this work.

4. Create a framework as well as guidance to reconstruct potential landslide shear zone geometry, possible

groundwater depth and/or shear strength based on surface movement trajectories. This will include criteria for selecting the appropriate suite of technologies based on the landslide characteristics to minimize cost.

5. Provide documentation for field application of supplementary surface monitoring techniques along with potential cost savings and limitations in comparison to drilling.

6. Host a hands-on training course for ODOT professionals for the tools including sensor installation, monitoring, maintenance, and data analysis.

Key Deliverables:
This project will provide many deliverables including (1) installed GNSS sensors, (2) UAS orthophoto data, (3) analysis tools, (4) a final report summarizing the findings of the research including the framework, (5) workshop, and (6) guidance and training materials from the workshop.

Estimated Project Length: 42 months.
Estimated Project Budget: $460,000

IMPLEMENTATION
Geoengineering staff will have access to methods and training to incorporate surface monitoring methods for evaluation and monitoring of active landslides. These anticipated deliverables will assist with landslide characterization, emergency response and repair needs including timing for repair, and provide longevity to the investment for landslide monitoring. Implementation plans including potential incorporation into the Geotechnical Design Manual will be developed by the Geotechnical Engineering, Engineering Geology, and Hazmat Section together with Engineering Automation. The Research Coordinator will assist with coordination of training sessions and development of training materials.

POTENTIAL BENEFITS
The hundreds of actively moving landslides on Oregon's highways pose an ongoing threat to the connectivity of communities and economies statewide. These precarious conditions threaten the agency's mission as landslides are 1) a significant risk to user safety, 2) impose inefficiencies by delaying traffic after failure or for repair, and 3) impose economic strain as the cost of traffic delays impacts the cost of goods and services that rely on our roads. Currently, continual monitoring of these numerous slides is too expensive; thus, we must rely on qualitative data (maintenance reports, driver reports) to prioritize the limited resources allotted towards repair of these slides. By using a suite of surficial monitoring data, we may leverage real-time data to monitor movements on a much larger network of landslides, possibly providing failure alerts to ODOT professionals. Through change detection using high-resolution lidar or photogrammetric techniques, we may corroborate slide movement vectors between GNSS units. Finally, through reducing the costs associated with possibly tens of borings and inclinometer installations per landslide, we may use this surface data to inexpensively interpolate critical geotechnical data relevant to landslide repair, resulting in significant cost saving. In sum, real-time landslide surface movement data can help with emergency response by predicting the amount of material needed for repair, identifying when to close a road for safety, and determining when repairs can safely begin as the movement subsides. Further, surface monitoring is less environmentally intrusive than drilling and safer to instrument, with superior long-term monitoring potential for active slides.

As a proof-of-concept, these techniques will be deployed on select, highly active landslides that are currently being monitored with state-of-the-art geotechnical instrumentation installed as part of research projects SPR807 and SPR808 in conjunction with past STIC funds.

PEOPLE
ODOT champion(s): Susan Ortiz (State Geotechnical Engineer), Curran Mohney (Engineering Geology Program Lead), Rhonda Dodge (Senior Remote Sensing Surveyor)
Problem Statement Contributors: Ben Leshchinsky (OSU), Michael Olsen (OSU), Curran Mohney (ODOT), Rhonda Dodge (ODOT), Kira Glover-Cutter (ODOT)

REFERENCES

Senogles, A., Olsen, M.J., and Leshchinsky, B.A. (2022). "SlideSim: 3D Landslide Displacement Monitoring through a Physics-Based Simulation Approach to Self-Supervised Learning" Remote Sensing 14, no. 11: 2644. https://doi.org/10.3390/rs14112644

STAFF REVIEW PAGE

Literature Check

TRID&RIP

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

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 in order to realize the full potential of this research.

Cross-agency stakeholders

- Geotechnical Engineering, Engineering Geology, and Hazmat Section
- Region Geos
- Engineering Automation