NHDOT SPR2 PROGRAM
RESEARCH PROGRESS REPORT

Project # SPR 26962Z	**Report Period** Year 2019 ☐Q1 (Jan-Mar) ☐Q2 (Apr-Jun) ☐Q3 (Jul-Sep) X Q4 (Oct-Dec)
Project Title: Use of Smart Rocks to Improve Rock Slope Design	
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Project Start Date:	**Project End Date:**	**Project schedule status:**
April 17, 2019	June 30, 2021	✓ On schedule ☐ Ahead of schedule ☐ Behind schedule

Brief Project Description:

Rock slopes pose a hazard to the traveling public when weathering processes dislodge portions of the slope which then fall into the road. Current ditch design practice relies on design criteria developed decades ago in different environments with different rock types. Current hazard rating practice rates the rock slopes based on semi-quantitative measures using the Rockfall Hazard Rating System (RHRS). Both the design of new rock slopes and the hazard assessment of existing rock slopes need improvement to increase safety against rockfall, construct better engineered slopes and reduce short and long-term maintenance costs.

Preliminary work performed at UNH in collaboration with the NHDOT has shown that using a smart rock sensor equipped with a 3-axis accelerometer and 3-axis gyroscope, embedded in a natural rock can provide the necessary field response data to calibrate and revise existing rockfall simulation software models. To achieve this primary goal of improving rock slope design, several objectives need to be considered during this project:

1. Improve the current smart rock (SR) sensor to include altimeter capability. The use of wi-fi technology will also be investigated as a mean to acquire data without sensor removal from the test rocks.
2. Conduct multiple experiments with the smart rock at 10 rock cuts rated A or B according to the New Hampshire RHRS.
3. Analyze smart rock accelerometer and gyroscope data coupled with video recording of each experiment to extract information and parameters as input to current rockfall software packages.
4. Develop a design evaluation protocol for new and existing slopes using smart rock technology.

Scope of Work: To improve current rock slope design to reduce hazard to motorist on NH highways, the following tasks will be undertaken:

Task 1- Smart rock sensor improvements

Improvements being considered include: altimeter data to help locate the rock elevation with time and for matching with video recordings, status test light using a transparent SR shell to ensure the SR is ready for testing between drops and, wi-fi or Bluetooth technology for data download. It is anticipated that several SR will be constructed (5 to 10) to allow cluster rock drops.

Task 2 – Laboratory testing

Experiments will be carried out in the laboratory to calibrate the smart rock sensor, by itself and embedded in a natural rock. The UNH shaking table and the machine shop lathes will be part of the tools used for this purpose. The experiments will also include a series of tests using various rock types equipped with the smart rock to evaluate the restitution coefficient between the rock and other surfaces such as concrete, asphalt, gravel, sand and turf.

Task 3 – Field experiments

Rockfall experiments will be carried out at approximately 10 rock cuts rated A or B according to the New Hampshire Rockfall Hazard Rating System. A tentative list is shown in Table 1. The sites listed in Table 1 will provide a wide spectrum of rock types, slope types as it relate to roughness (i.e. developed by various construction methods; presplit vs production, and natural conditions), slope angles, landing/ditch layout (e.g. gravel, road, grass, etc.).

Priority Rating	Route	Location	Height (ft)	Rock Formation	General Rock
A	93	AT MILE 97 NORTHBOUND - East side of I93 between MM 96.4 and 96.6 - AKA Barron Mtn Cut	140	Rangeley	Metamorphic
B	89	1.2m South of I89 SB Sutton Rest Area, at MP24.3, SW side, on curve, 2.7m S. of I89 Exit 10	25	Kinsman Granodiorite	Old Igneous

B	89 SB	0.4 MILES SOUTH OF MILE 40	36	Bethlehem Granodiorite	Old Igneous
B	125	WEST SIDE OF ROAD. ON UPHILL.	15	Eliot	Metamorphic
B	120	1m North of I89 Ext.18, CUT ON EAST AND WEST SIDES OF NH120.	35	Biotite Granite	Old Igneous
A	135	EAST SIDE of NH135, AROUND CURVE, JUST North of MONROE US POST OFFICE, 0.6m South of #335r rock cut	30	Rangeley	Metamorphic
A	10	1/4m S OF GRAFTON COUNTY COMPLEX, W side of NH10, N of mp 119.8, just North of NHDOT North Haverhill shed #204	45	Pink Biotite Granite	Old Igneous
A	112	AT KANCAMAGUS PASS before scenic overlook (on left) cut on both sides of road. LIVERMORE/LINCOLN TOWN LINE	25	Conway	Mesozoic Igneous
A	16	JUST NORTH OF EXIT 13 ON SPAULDING TURNPIKE. BOTH SIDES OF ROAD.	45	Perry Mountain	Metamorphic
B	16	0.1 MILES SOUTH OF EXIT 17. BOTH SIDES OF ROAD.	33	Rangeley	Metamorphic
B	16	EAST SIDE OF ROAD AT MILE NUMBER 25. ACROSS FROM CUT NUMBER 118R.	34	Perry Mountain	Metamorphic
B	16	WEST SIDE OF ROAD. AT MILE MARKER 25.	60	Perry Mountain	Metamorphic
B	103	SOUTH SIDE. 1 MILE EAST OF TRAFFIC CIRCLE	25	Kinsman Granodiorite	Old Igneous
B	101	101/122 INTERSECTION ON-RAMP TO 101 WEST	30	Gneiss	Gneiss
B	31	0.7 MILES N OF OLD WILTON ROAD. 0.2 S OF GREENVILLE/WILTON TOWNLINE	20	Rangeley	Metamorphic
A	12	AT KEENE SURRY TOWNLINE CUT MAKES UP BOTH SIDES OF ROAD, AROUND CORNER	32	Ordovician Dome	Old Igneous
A	103	0.1m West from I89 Exit 9 ON NH103, North side of Road	60	Kinsman Granodiorite	Old Igneous
A	103	1m EAST OF BRADFORD-WARNER T/L, Both sides of NH103, 3.0 m EAST OF NH114/NH103 Jct., 3.7m West of I89 Exit 9	30	Kinsman Granodiorite	Old Igneous
A	3A	0.6m North of NH11 & NH3A Int., Both sides of NH3A - portion of rock formation the West side of Franklin flood control dam	55	Rangeley	Metamorphic
A	93 NB	EXIT 8 NORTHBOUND EXIT/ONRAMP	65	Gneiss	Gneiss
B	11	South of cut 072r, on east bound (west side) of roadway.	35	Winnipesaukee Tonalite	Old Igneous
B	112	ROUTE 112, SOUTHERN SIDE OF ROAD, 0.7 MILES EAST OF KANCAMANGUS PASS AND LINCOLN/LIVERMORE TOWN LINE.	20	Conway	Mesozoic Igneous
B	3	E. side of US3, on a curve, @ MP 139.4, 0.25m NE of Jct. w/ NH 141 & US3 (Const. slope/berm N. end of cut, @ MPs 139.2-139.4)	31	Littleton	Metamorphic

Table 1: NH Rock Cuts A and B Rated

Experiments with the smart rocks will include natural rocks of various sizes and shapes. Experiments using multiple rocks dropped at the same time and at the same location will be conducted to evaluate repeatability, dispersion and the effect of collision. For each rock cut, a minimum of 3 experiments at the same location and using the same drop technique will be carried out for statistical evaluation of trajectories and runout.

Each experiment with the SR will include video recording of the drop, measurement of lateral dispersion, estimates of rock bounce, measurements of runout, full acceleration and rotation spectra in 3-axes.

Task 4 – Analysis

For the 10 rock cuts selected for testing, a concurrent funded project using the STIC grant program will develop highly detailed 3D point clouds for these rock cuts. The results of the STIC work will serve as input for the smart rock models.

For each rockfall experiments, the acceleration and rotation data will be analyzed using Matlab in terms of time domain and frequency domain to assess which approach will yield the most useful information for design. The SR data coupled with the 3D point clouds will be used in software packages such as Rockfall, RAMMS, CRSP and others. The results from the software analyses will be compared to field observations. The reliability of these methods will be tested, and a documented approach will be proposed to improve their prediction capability.

Using the accelerations and rotation rates, the kinetic energy for each drop will be assessed and documented for future possible use in barrier design. All data will undergo a statistical analysis and present maximum, minimum and average values of runout and expected forces.

Task 5 – Recommendations

The work conducted as part of Tasks 1 – 4 will be used to develop the following:

a) Design evaluation protocol for new and existing rock slopes

b) Design charts – major revision of Ritchie's model
c) Develop parameters for rock analysis
d) Collaborate with other research groups and populate existing databases

Progress this Quarter (include meetings, installations, equipment purchases, significant progress, etc.):

The initial TAG meeting was scheduled at the NHDOT on May 23, 2019 at 10:00 am.

Since this initial meeting we have made significant progress on Task 1 which involves constructing new smart rock sensors with improvements for altitude and performance check before testing. A total of 6 new SRs were assembled by Artur Apostolov and are currently being evaluated. However, after an initial evaluation of the SRs in September 2019, additional maintenance regarding altitude measurements and battery life were necessary. These issues have been fixed and the SRs are now fully operational. As a result of these issues, the field testing expected late fall needed to be delayed to early 2020.

Using UNH departmental funds we have purchased a portable drill corer which will facilitate drilling into our rocks, in the laboratory and in the field. A GoPro system was also set to video the field experiments with cameras readily available in our department.

Items needed from NHDOT (i.e., Concurrence, Sub-contract, Assignments, Samples, Testing, etc...):

We will need additional rocks after our initial testing in Keene. Our testing this winter will be weather and field conditions dependent for both safety and accessibility.

Anticipated research next three (3) months:

We anticipate testing and evaluating all new 6 SRs in the laboratory. We are in the process of designing an experiment to evaluate the coefficient of restitution for realistic comparisons in computational rockfall models.

We are planning to perform rockfall in Keene as soon as possible, depending on weather and field conditions. Snow and ice accumulation along the rock slope may impede some of the tests and make the process unsafe. While field testing at further locations is still not possible, we intend to perform rockfall testing at a rock slope near the University of New Hampshire to assess the data gathered from the new sensors and calibrate the video recording system. A potential high hazard slope was recently blasted in Dover/NH which we will use for these preliminary tests.

Circumstances affecting project:

The technical issues with the Smart Rocks delayed the initial field testing, but it should not affect the overall project delivery schedule.

Tasks (from Work Plan)	Planned % Complete	Actual % Complete
Task 1: Smart rock sensor improvements	*50*	*30*
Task 2: Laboratory testing	*10*	*0*
Task 3: Field experiments	*0*	*0*
Task 4: Analysis	*0*	*0*
Task 5: Recommendations	*0*	*0*

Barriers or constraints to implementing research results

None