NHDOT SPR2 PROGRAM
RESEARCH PROGRESS REPORT

Project # SPR 26962Z		**Report Period** Year 2021 X Q1 (Jan-Mar) ☐ Q2 (Apr-Jun) ☐ Q3 (Jul-Sep) ☐ Q4 (Oct-Dec)
Project Title: Use of Smart Rocks to Improve Rock Slope Design		
Project Investigator: Jean Benoit, PhD **Phone:**		**E-mail:** jean.benoit@unh.edu
Project Start Date: April 17, 2019	**Project End Date:** June 30, 2021	**Project schedule status:** On schedule ☐ Ahead of schedule X 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.):

85 experimental rockfalls at all proposed rock cuts (9 in NH and 1 in VT) have been completed. Work during this Quarter has included analyzing the field data from the past ten sites and performing 2D modeling at equivalent slope cross-sections for each location. In addition, laboratory experiments were also carried out to evaluate coefficients of restitution obtained from instrumented and video data. The experiments were conducted in a test pit in the Geotechnical Laboratory at UNH, using a release device assembled by UNH Technical Service. Drop tests at 90 degrees and constant release heights were performed, dropping a 750g block prepared from a test rock in Warner NH. The experiments were conducted on sand and are continuing on rock (also retrieved in Warner), embedded in plaster. These results will be used to compare with previous energy assessments published in the literature.

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

We may need traffic control when doing LWD testing at the base of the rock cuts.

Anticipated research next three (3) months:

After the previously described preliminary laboratory tests, additional experiments will be conducted during the summer. These experiments will be conducted on different types of rock (from Warner, Keene, Franklin, Franconia, and Townshend), as well as other surfaces such as sand, grass, and asphalt. The effect of surface inclination and drop height will also be assessed for comparison with default coefficients published in the literature.

Additional field testing will be conducted with a light weight deflectometer (LWD). The ongoing rockfall preliminary assessment with the fourth-generation Smart Rock will be completed, evaluating test repeatability and surface characterization with LWD.

Anticipated investigation with the SR also includes analyses in the time and frequency domains using MATLAB and continuing the data analysis from past field experiments. We will also revise the Smart Rock sensor design based on our field results. We have ordered 6 more sensors which will allow for a quick response if opportunities arise for additional field experiments. They will also be used to evaluate repeatability, dispersion, and collision effect when multiple rocks are dropped at the same time from the same location.

Circumstances affecting project:

Due to the Coronavirus pandemic, UNH facilities were closed after Spring Break 2020, and the initial field tests planned for the end of March had to be postponed to early June. The laboratory work resumed in late May. With the help of an undergraduate research assistant, Hannah Miller, we were able to accelerate our work during the summer and fall. We have requested a no-cost extension so that we can use the upcoming summer and fall to complete our analyses and field testing.

Tasks (from Work Plan)	**Planned % Complete**	**Actual % Complete**
Task 1: Smart rock sensor improvements	*100*	*100*
Task 2: Laboratory testing	*80*	*70*
Task 3: Field experiments	*100*	*100*
Task 4: Analysis	*80*	*70*
Task 5: Recommendations	*70*	*50*

Barriers or constraints to implementing research results None.