A Comparative Review of Rippability Factors and Characteristics of Rock Cuts

WYDOT Sponsor:
Mr. Blaine A. Smith, P.G.
Engineering Geologist
WYDOT Geology Program
5300 Bishop Blvd
Cheyenne, WY 82009-3340
307-777-4785; blaine.smith@wyo.gov

Principal Investigator:
Dr. Kam Ng
Assistant Professor
Department of Civil and Architectural Engineering
University of Wyoming, Laramie, Wyoming, 82071
307-766-4388; kng1@uwyo.edu

Co-Principal Investigator:
Dr. Andrew Parsekian
Assistant Professor
Department of Geology and Geophysics
University of Wyoming, Laramie, Wyoming, 82071
650-725-8875; parsekia@stanford.edu

Submitted To:
Wyoming Department of Transportation
Programming Research Unit
5300 Bishop Blvd.
Cheyenne, WY 82009

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Problem Statement

Road construction involves the excavation of rock and unconsolidated materials. These materials can be removed either by scrapers/dozers or through blasting. The former method loosens rock using steel shank rippers attached to the rear of bulldozers as shown in Figure 1. As the bulldozer moves forward with shanks lowered into the ground, blocks of rock are ripped and displaced for ease of excavation. The rippability of rock is dependent on the geology and physical characteristics of rock materials. Accurate evaluation of rock rippability and prediction of the excavation effort through a better understanding of their properties will improve the preparation of both construction schedule and cost estimation, facilitate the selection of proper ripping equipment, and maximize production. If rock cannot be ripped, blasting will be used to remove rock. However, blasting will incur higher construction cost, affect the general configuration of the finished roadway template, and possess adverse impact on surrounding environment and safety.

Figure 1. A Caterpillar bulldozer with a single shank (Caterpillar Inc., 2000)

An ideal evaluation of rock rippability is to employ a ripper tractor on a job site and actually determine whether the rock material is rippable. However, this approach is not practical and does not align with the current construction practice in Wyoming. At current practice of the WYDOT, the rock rippability within most of the proposed road cuts is assessed by conducting on-site drilling and/or qualitative description of the physical characteristics of exposed bedrock. In many cases due to inaccessibility of the drill rig to some rock cuts, geophysical methods are conducted to indirectly predetermine the degree of rippability. Seismic refraction is the most commonly used geophysical method. Seismic refraction surveys are conducted to measure the seismic compression velocity (P-wave) and estimate the subsurface stratigraphy. However, the measured seismic velocity is influenced by many factors, such as the presence of moisture and rock fractures that cannot be identified solely by the seismic refraction without the borehole control. Additionally, the changes in velocity cannot be distinguished whether as a result of fracturing of a uniform rock type or a change in rock type with no variation in fracturing. Furthermore, the seismic refraction takes advantage of a common occurrence, whereby seismic velocities increase as a function of depth (Wightman et al., 2003). As a result of this assumption, a less competent, lower-velocity layer overlain by a thin, dense layer cannot be identified and characterized by the seismic refraction. This limitation prevents conducting the seismic surveys on frozen ground, road pavement, or any dense material overlaying a lower-velocity material (WYDOT Geology Manual-Chapter 12).

Applying the measured seismic velocity to rippability charts, such as an example shown in Figure 2 for the bulldozer D9 manufactured by the Caterpillar, Inc., the rock rippability is predicted with the best available technology. It is important to highlight that these charts were developed from field tests using various sized equipment on a variety of rock types that may not reflect the local materials inherent to Wyoming. Figure 2 shows that the rippability chart relies only on the seismic velocity and a simple material description to determine the degree of rippability while neglecting other important factors, such as rock hardness, weathering, joint spacing and continuity, and strike and dip of the bedrock. The simplicity of the rippability chart coupling with uncertainties in seismic velocity measurement leads to inconsistent rippability outcomes determined from the interpretation and actual construction. Undeniably, the current guidelines and specifications for interpreting the rock rippability are admittedly vague and prone to many uncertainties.

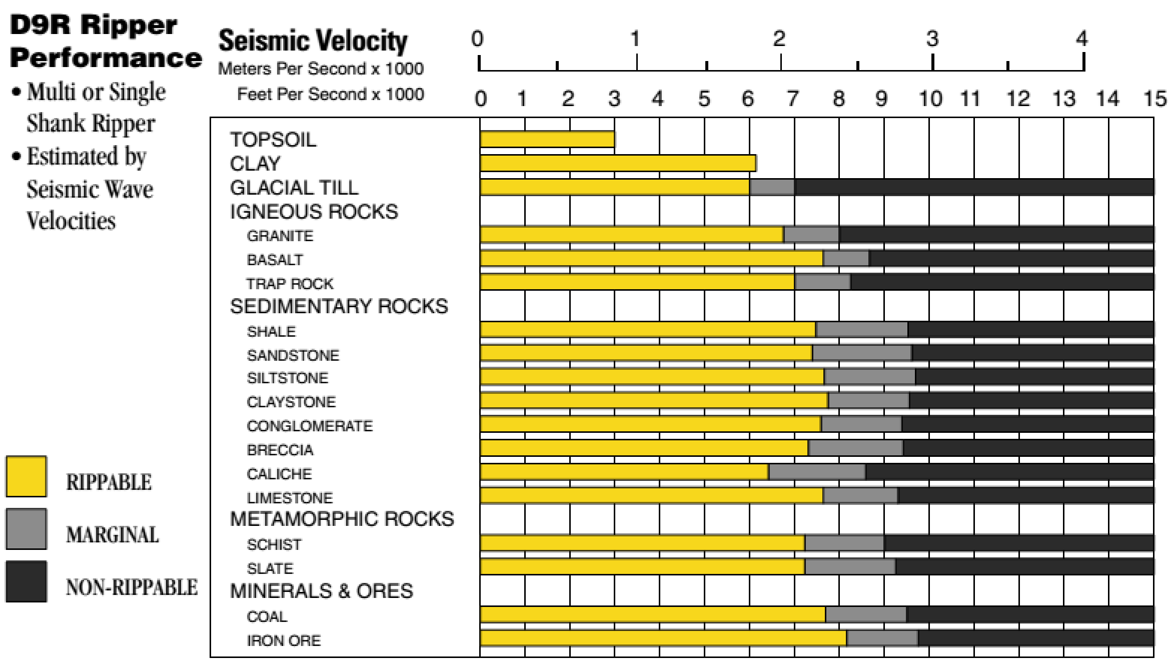

Figure 2. Example of a Caterpillar rippability chart (Caterpillar Inc., 2000)

The inconsistent outcomes and lack of accurate and reliable methods for evaluating the rock rippability often cause conflict between WYDOT and excavating contractors. These conflicts usually result in delays in project construction and change-orders to the contracts for additional money to offset the difficulties in rock excavation and removal. Furthermore, this problem increases the operational cost of WYDOT, especially the Geology Program due to the repeated trips back to the field during excavation in order to verify the measured seismic velocity and re-evaluate the rippability of the rock. Unfortunately, these return trips typically result with a similar seismic velocity as in the original survey data provided to the excavating contractor, provide no solutions to resolve the conflict, and unable to prevent additional claims. This problem will persist unless better knowledge and methods pertinent to the rippability of rock can be determined to improve the current WYDOT's guidelines and specifications. This problem is not restricted to a particular construction project or location in Wyoming. In fact, the number of additional claims submitted by contractors to WYDOT has increased in recent years, and they were from construction sites across the state of Wyoming.

Problem Background

Historically, WYDOT conducted seismic investigations in locations where the drill rigs could not gain access. More recently, seismic lines are run at sites where borrow drill holes have been conducted in an effort to correlate drilling characteristics and seismic velocities to the rippability of the rock. The comparison to the drilling has been made more difficult recently by the increased torque and horsepower generated by larger drills used by WYDOT. Other problems associated with the cuts also include the variation of the physical properties of the rock within the same cut, in some cases separated by tens of feet. Also, it has been previously hypothesized the arid climate native to much of Wyoming results in lower rock velocities for otherwise hard, unweathered bedrock. Thus, the comparative literature review will provide useful knowledge to the state of practice utilized by other state Departments of Transportation (DOTs).

To illustrate the significance of this problem, a cost analysis was performed on three recently completed road projects in Wyoming with issues of rock rippability as summarized in Table 1. These three projects were selected, because the cost data were readily available for analysis. In fact, many more projects had this problem over the two-year period. Table 1 shows the original contract amount, additional claim incurred by engaging rock blasting and its associated mobilization cost, and the percent increase in cost of each project. Regardless of its original contract amount, additional claims of at least $90,000 were estimated on projects with the issue of rock rippability. Particularly for the Flying V Slide project, the additional cost increased by as high as 41.5% or $354,240.

Table 1: Summary of recent construction projects in Wyoming with issues of rock rippability

Year	Project Description	Original Contract Amount	Additional Claim	Percent Increase in Cost
2011	N255040 Flying V Slide	$ 852,800	$ 354,240	41.5
2011	N301015 Rosie's Ridge Section	$ 5,020,141	$ 97,700	2.00
2012	N Sybille Creek Section	$ 2,398,968	$ 91,038	3.80

Study Objectives

The rippability of rock has been a continuous problem for the WYDOT, especially the Geology and Construction Programs. This problem is primarily attributed to the inadequacy of current guidelines and specifications in assessing the degree of rock rippability. The objectives of this study are to:

1) determine methods/procedures to better correlate rock properties obtained from both geophysical and laboratory test methods with its rippability;
2) determine a more comprehensive and/or industry accepted rippability prediction system; and
3) improve the assessment of the rippability of rock cuts.

Study Benefits

The research project described in this proposal has several direct benefits to WYDOT, particularly to road design and construction in Wyoming. These anticipated benefits are described as follows:

1) eliminate the ambiguity of current system for evaluating the rock rippability;
2) provide a more reliable prediction system for rock rippability;
3) improve construction efficiency in rock excavation;
4) avoid construction delay;
5) reduce and possibly eliminate additional claims submitted by excavating contractors pertaining to the excavation of rock cuts in the future;
6) reduce or avoid unnecessary operational cost and time of various WYDOT programs, especially Geology Program; and
7) improve work relationship between WYDOT and excavating contractors.

Work Plan/Scope

The work plan was established based on the aforementioned problem and study objectives. It is envisioned that the research objectives will be achieved by completing five major tasks described below. A time schedule to complete these tasks within the projected 18-month period is also provided in this proposal.

<u>Task A: Literature Review</u>

This task will focus on conducting a comprehensive literature review pertinent to the rippability factors and characteristics of rock cuts. The literature review will include the following activities:

1) conduct a comprehensive literature search for documents, papers, reports, catalogs, manuals, notes, and presentation slides pertinent to the rippability of rock cuts (refer to Appendix on literature found by the principal investigators);
2) document and review current state of knowledge and the current state of practice relating to the rippability of rock cuts;
3) study current specifications and guidelines adopted by various state DOTs, mining companies, and consultants pertinent to the excavation and removal of rock cuts;
4) identify potential application and adaptation through literature review; and

5) identify gaps in the body of knowledge necessary to develop a nationwide survey in Task B.

The literature review will be facilitated by the excellent libraries, high speed internet, and extensive interlibrary loan capabilities at the University of Wyoming (UW). The research team will utilize many useful sources in conducting this task, including the link to federal and state libraries and databases given on the WYDOT's Research Center website (http://www.dot.state.wy.us/home/planning_projects/research-center/links-to-federal-and-state-libraries-and-databases.html).

Task B: Nationwide Survey

Upon completing Task A, gaps in the body knowledge will be identified and formulated in a series of questions for the development of a nationwide and/or western state district survey conducted in this task. The survey questions will be reviewed by WYDOT prior to sending it out to the relevant national, state and local agencies (e.g., Transportation Research Board's Geotechnology Committees and DOTs). Survey data will be collected, analyzed and reported to fill in missing knowledge, in order that a preliminary recommendation to rock rippability can be evaluated in Task C. To improve data collection and enhance security, the survey will be developed using commercial online survey software, such as SurveyMonkey®.

Task C: Pilot Project

A pilot project will be conducted to verify the preliminary recommendations determined from Tasks A and B and to further evaluate the rippability factors and characteristics of rock cuts in Wyoming. Working closely with the Geology Program, a project location will be selected at either a past project site or an upcoming construction site, at which rock excavation and removal will be anticipated. Furthermore, the selected site shall be accessible to drill rigs or heavy equipment for this study. Rock sampling, on-site reconnaissance, laboratory rock tests, geophysical investigations, rock ripping test, and data analysis will be performed in this task.

Task C.1: Sampling and Field Reconnaissance

A drill rig will be mobilized by the Geology Program to the selected project location for rock boring and sampling. Standard rock cores with a diameter of about 2.16-in. (NX-size) will be collected for laboratory tests and to check for any possible favorable properties, such as cavities, cracks, and other deterioration, that could facilitate the rippability of the rock cuts. At least a 5-ft "core-run" segment is needed for each rock type and at each location, where geophysical investigations will be performed later. These rock core samples will be used in the laboratory rock tests. Rock Quality Designation (RQD) will be determined at each rock core segment for a subsequent rock mass classification.

Field reconnaissance will be conducted jointly by UW's research team and the Geology Program on any exposed bedrock at the selected site in accordance with the standard practice of the Geology Program. During the reconnaissance observation, structural features, such as fault, fracture, or discontinuities, and properties will be identified and documented.

Task C.2: Laboratory Test

Laboratory tests will be performed jointly by UW's research team and the Geology Program to characterize the rock properties. The rock core samples collected in Task C.1 will be used for strength tests. Uniaxial rock tests will be performed by the Geology Program to yield uniaxial compressive strength, which is a typical rock property used to correlate with the seismic velocities obtained from geophysical investigations. Triaxial strength tests will be performed by UW in accordance with the ASTM D7012 (2010) using the newly purchased servo-controlled testing system. This testing system has a maximum compressive load of 337 kips and is currently placed at the UW's Engineering Building as shown in Figure 3(a). The triaxial rock test will yield important mechanical properties, such as Young's modulus (E) and Poisson's ratio (μ), and Mohr's Coulomb parameters: friction angle and cohesion. An example of the triaxial test result of a Wyoming's sedimentary rock is shown in Figure 3(b). The slope of the solid line is the Young's modulus and the ratio of the radial to axial strains is the Poisson's ratio.

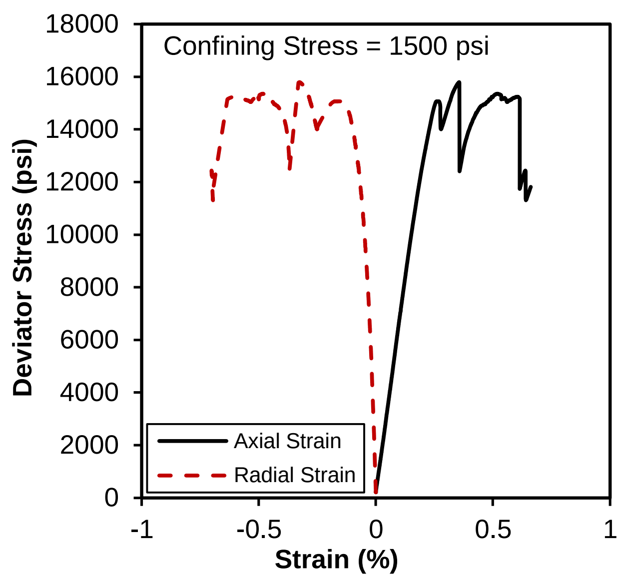

Figure 3. (a) Servo-controlled rock testing system; and (b) Example of triaxial test result

Task C.3: Geophysical Investigations

Field geophysical investigations to be performed include seismic and electrical methods at locations coincident with extracted cores (Task C.1). First, P-wave measurements and analysis will be conducted using seismic refraction in accordance with the standard practices of WYDOT to serve as a baseline dataset. The result will be an estimate of P-wave velocity (V_p) for the study site. Next, S-wave datasets will be acquired along the same line as P-wave data using low frequency 4.5 Hz geophones and seismic source optimized for generating shearing ground motion. The S-wave data will be processed using commercially available multichannel analysis of surface waves (MASW) software. This will result in S-wave velocity (V_s) for the study site. Finally, electrical resistivity tomography (ERT) geophysical measurements will be conducted along the same line as the seismic surveys. This will result in a 2D distribution of subsurface electrical properties that is an independent measurement from the seismic results. The field geophysical measurements aim to answer three questions: 1) is an alternative geophysical measurement capable of providing data to improve rippability estimates?; 2) is the combination of two or more geophysical measurements able to improve the rippability estimates?; and 3) is the V_p and V_s estimate obtained in the field comparable to estimates of velocity made on laboratory samples?

Task C.4: Rock Ripping Test

After completing the previous Tasks C.1 to C.3, a rippability rock test will be conducted at the same project site and location where investigations are conducted. A typical Caterpillar ripper or equivalent, such as Caterpillar D9, will be mobilized to actually rip the rock. The ripping shall be performed in accordance with the manufacturer's specifications and guidelines. If the ripping tractor fails to rip the rock material, a larger capacity tractor subjected to its availability will be tried to repeat the ripping test.

Task C.5: Data Analysis

Collected data will be analyzed to assess the rippability of the rock and compared with the outcome of the ripping test. The data analyses include, but are not limited to the following:

1) Based on the collected data and the outcome of the field reconnaissance, rock mass classification will be performed to determine the relationship between rock quality and its rippability;
2) The uniaxial compressive strength obtained from uniaxial strength test will be correlated with the seismic velocities obtained from geophysical investigations;
3) The measured elastic modulus obtained from the triaxial test will be compared with the modulus values estimated using the field-estimated seismic velocities. This comparison will validate the accuracy of the seismic refraction and the S-wave methods;
4) Velocity information will be used in conjunction with 2D electrical resistivity results to evaluate heterogeneity of material to be ripped at the site.

<u>Task D: Recommendations</u>

Based on the outcomes obtained from Tasks A, B, and C, recommendations will be established. The recommendations will suggest improvement to current WYDOT's specifications and guidelines for evaluating the rock rippability. It is envisioned that the recommendations will satisfy the study objectives and bring benefits to the WYDOT in the future.

<u>Task E: Reporting</u>

To update the progress of the research project, short quarterly reports will be submitted to WYDOT. Integrating all the outcomes obtained from previous tasks as well as comments given by WYDOT representatives, a draft final report will be prepared. A final report, containing all aspects of the proposed research, an executive summary and a plan for any future works, will be prepared and submitted to the WYDOT. A technical presentation on the completed project will be given to the WYDOT Research Advisory Committee (RAC). To further disseminate the research outcomes, at least one journal/conference paper will be published and technical presentations will be given at regional and/or national conferences.

Work Schedule

The projected duration for the research presented in this proposal is 18 months, tentatively beginning July, 2014 through December, 2015. A detailed schedule per task is shown in Table 2.

Table 2: Detailed schedule proposed for the research tasks

Task		2014						2015											
		Q3			Q4			Q1			Q2			Q3			Q4		
A	Literature Review	■	■	■	■	■	■	■											
B	Nationwide Survey					■	■	■	■	■	■								
C	Pilot Project									■	■	■	■	■	■				
D	Recommendations														■	■	■		
E	Reporting			■			■			■			■			■	■	■	■

Cost Estimate

The detailed budget estimate is presented in Table 3. Funds are requested to support wages covering 1 month for Kam Ng as the PI, 1 month for Andrew Parsekian as the Co-PI, 18 months for a graduate student researcher, and 120 hours for an undergraduate research assistant. The fringe benefits for each employee are as specified and are charged individually as direct costs in accordance with the current rates: 1) 45.56% for PI and Co-PI; and 2) 0.7% for a graduate student research and an undergraduate research assistant. An undergraduate resistance assistant will be hired to assist with the literature search, survey, and field investigations. A domestic travel cost of $2,792 is included to cover all travelling expenses required to perform Task C involving field works, present research results and final report to WYDOT, and disseminate research outcomes at one to two national conferences, such as TRB meeting, in the United States. Although the cost of laboratory and geophysical equipment will be contributed by the investigators, a cost of $1,500 is included under suppliers/materials to cover expendable items needed to conduct Task C. Other direct cost includes 1) $200 for acquiring a commercial survey software/license needed in Task B; and 2) $1,000 for reporting, which includes editing, preparing, publishing, and disseminating of research results. The indirect cost with a rate of 20% is charged on all direct costs except student's tuition, fees and health insurance. The total cost estimate for this research project is $77,011.00. This total cost will be spread over two years with $28,585.00 in 2014 and the remaining $48,426.00 in 2015. It is important to highlight that the proposed budget does not include the cost for mobilizing, operating and demobilizing tractor rippers, paying for tractor's operator man hours, and any other construction expenses required to perform the rock ripping test described in Task C.4.

Table 3: Detailed budget estimate for the research

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Budget Estimate

	YEAR 2014		YEAR 2015				
	Q3	*Q4*	*Q1*	*Q2*	*Q3*	*Q4*	Subtotal
Salary							
Principal Investigator (1 month)	$ 4,150	$ -	$ -	$ -	$ 4,150	$ -	**$ 8,300**
Co-Principal Investigator (1 month)	$ 4,000	$ -	$ -	$ -	$ 4,000	$ -	**$ 8,000**
Graduate Student Researcher (18 months)	$ 4,218	$ 4,218	$ 4,218	$ 4,218	$ 4,218	$ 4,218	**$ 25,308**
Undergraduate Research Assistant (120 hours)	$ 180	$ 180	$ 180	$ 180	$ 360	$ -	**$ 1,080**
Fringe							**$ -**
Principal Investigator (1 month)	$ 1,890.7	$ -	$ -	$ -	$ 1,890.7	$ -	**$ 3,781**
Co-Principal Investigator (1 month)	$ 1,822.4	$ -	$ -	$ -	$ 1,822.4	$ -	**$ 3,645**
Graduate Student (18 months)	$ 29.5	$ 29.5	$ 29.5	$ 29.5	$ 29.5	$ 29.5	**$ 177**
Undergraduate Research Assistant (120 hours)	$ 1.3	$ 1.3	$ 1.3	$ 1.3	$ 2.5	$ -	**$ 8**
Travel-Domestic	$ -	$ -	$ -	$ 1,292	$ 750	$ 750	**$ 2,792**
Graduate Student Tuition and Health Insurace	$ 378	$ 3,102	$ 3,102	$ -	$ 378	$ 3,102	**$ 10,062**
Supplies/Materials	$ -	$ -	$ -	$ 1,500	$ -	$ -	**$ 1,500**
Other Direct Costs							
Survey Software/License	$ -	$ 200	$ -	$ -	$ -	$ -	**$ 200**
Reporting (Editing/Printing/Copying)	$ -	$ -	$ -	$ -	$ 300	$ 700	**$ 1,000**
Total Direct Cost:	$ 16,670	$ 7,731	$ 7,531	$ 7,221	$ 17,901	$ 8,800	**$ 65,853**
UW Indirect Costs (20%)	$ 3,258	$ 926	$ 886	$ 1,444	$ 3,505	$ 1,140	**$ 11,158**
Total Costs Per Quarter	$ 19,928	$ 8,657	$ 8,417	$ 8,665	$ 21,406	$ 9,939	
Total Costs Per Year	$	28,585	$			48,426	
TOTAL ALL COSTS	**$ 77,011**						

Staffing

The project team will be comprised of an academic group consisting of faculties, staff, and students from the University of Wyoming (UW), who specialize in geotechnical engineering and geophysics. Kam Ng, assistant professor of geotechnical engineering, will serve as the Principal Investigator (PI). Kam Ng has 10 years of industry experience in civil engineering design and construction. He has completed several research projects relating to geotechnical engineering for the Iowa DOT. His research outcomes have led to the design recommendations and revision of the Iowa DOT Bridge Design Manual Section 6. Andrew Parsekian, assistant professor of hydrogeophysics, will serve as the co-principal investigator (Co-PI). He brings 6 years of academic research experience in geophysics to the project, including a track-record of peer-reviewed research utilizing various near-surface geophysical measurement methods.

Facilities

The Department of Civil and Architectural Engineering at UW has computer, structural and geotechnical/material laboratories, especially the uniaxial and triaxial rock equipment, that are adequate for this research project. The Geology and Geophysics Department “Facility for imaging the Near- and Sub-surface Environment (FINSE)” owns the seismic and electrical imaging field geophysical equipment required to complete the proposed research. The UW high-speed computing network supports services for instruction and research. The libraries at UW offer facilities and services that aid in research, teaching and studying. The UW libraries have extensive interlibrary loan capabilities that further enhance research activities.

Deliverables

To update the research progress, accomplishments and any problems encountered, short quarterly progress reports will be prepared and submitted to the WYDOT. All of these documents with appropriate changes based on the review comments received from WYDOT representatives will be integrated to form a draft final project report documenting the entire project effort. The research work will conclude with a final report and a technology transfer sheet. The final report will include results of each task presented and an executive summary. The research team will review the report for accuracy and consistency prior to submission to WYDOT. Particularly, a more comprehensive and/or industry accepted rippability prediction system will be recommended to alleviate the problems associated with the rippability of rock in Wyoming.

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