Research Proposal

Characterization of Soil and Rock for Transportation Infrastructure Using Seismic Methods in Wyoming

<u>WYDOT project Champions</u>

Kirk Hood, P.G.
Project Geologist
kirk.hood@wyo.gov

Wyoming Department of Transportation
5300 Bishop Blvd, Cheyenne, Wyoming 82009
Phone: (307) 777-4427

<u>Principal Investigator</u>

Shawn C. Griffiths, Ph.D.
Assistant Professor
Department of Civil and Architectural Engineering
University of Wyoming
Dept. 3295, 1000 E. University Ave., Laramie, Wyoming 82071
Phone: (307) 766-2184; Fax: (307) 766-2221
sgriff18@uwyo.edu

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Project Abstract

The Load Resistance and Factor Design (LRFD) method currently in use by WYDOT allows the designer to develop soil and rock specific resistance factors depending on the testing and analyses of foundation and soil elements. Currently Kam Ng has initiated testing necessary to calibrate the resistance factors for driven piles in soft rocks (RS06216). This research is in its beginning stages but may be enhanced with more detailed sub-surface data. For example, one important factor when designing pile foundations is the weathered rock / hard rock transition zone. This zone can be hard to sample and is an important layer for pile driving and foundation design.

Current design practice in Wyoming is to perform sub-surface exploration using borings, SPT analyses for soils, coring rock, and a drive point method specific to the Wyoming Department of Transportation (WYDOT). These methods have proven to work well in the past, and are still a source of vital information for today's bridge and foundation designs. The data obtained from these investigation can be enhanced using seismic techniques in sub-surface investigation which will allow designers to accurately measure the depth of the transition zone and modulus over a large area. The seismic methods proposed in this project include compression wave refraction and surface wave testing.

This project, will allow researchers at the University of Wyoming to perform refraction and surface wave testing at 9 sites in Wyoming. These 9 sites include 3 sites where advanced load and osterburg cell tests will take place. The load and osterburg tests will provide the highest quality field test data available and will be complimented by the seismic testing. It is hoped that by performing advanced seismic surveys at these 9 sites future predication and correlation information will be determined. The correlations will be a value to WYDOT, and other states building bridge foundations in similar soft rock conditions. Additionally, better subsurface investigations will yield better predictions concerning depth of competent rock which may help control costs. Long-term benefits include development of shear wave velocity information being used to help classify rock types or behavior. By performing this research WYDOT will be following recommendations from the Federal Highway Administration (FHWA) which encourages the use of different and new sub-surface investigation techniques (Rivers and Nichols, 2019)

Project Description

In Wyoming very little surficial soils are present at the ground surface. In areas were surface soils are present they are relatively shallow thicknesses. Beneath these layers, common rock types include shale or other highly weathered and weak rock. In either case there is generally a transition zone of poor quality; low strength rock above the more competent harder layers. The thickness and strength of the transition zone material is an important factor for the design and constructability of a bridge foundations.

Because of the nature of the soil/rock in this transition zone, it can be difficult to sample and test accurately. Current methods employ coring, recovery, and lab testing. However depending on the quality of the material, and fracture orientation and quantity of sample recovered coring may not produce accurate results. Even when recovery is good, laboratory based strengths may be biased towards the best samples resulting in strength properties that are greater than the rock mass.

Another factor resulting in larger and deeper foundation elements than in the past is the new LRFD design procedures being implemented by WYDOT. The LRFD procedure have very low reduction factors used in the determination of the resistance of the foundation elements. Greater reduction factors (and cost reductions) may be justified if advanced testing and calibration are performed, which is the research being performed by Dr. Kam Ng. This pool funded research is part of a larger study to perform LRFD calibration in soft rock material. Dr. Ng's research will include pile load tests at two locations and advanced pile driving analyses (PDA) at 7 other sites.

To better characterize the sub-surface profile it is proposed that seismic testing be performed at 9 sites throughout Wyoming. These 9 sites coincide with the advanced pile testing being performed by Dr. Ng and will provide a very good data set that may be used for correlations, pile drivability, pile design, drilled shaft design, rock mass designations, and ideally better rock mass behavior predictability. The generated data set will provide WYDOT with better depth to bedrock predictions, small strain material properties, transitions material thickness and rock formations at the 9 sites.

The two rock classification systems currently recommended by Loehr et. al (2017), which the FHWA manual refers to for geotechnical investigations are the Rock Mass Rating (RMR) and geological strength index (GSI). Both of these systems use a numerical designation from 0-100, where 0 is a poor rating and 100 a good rating. The ratings are based, among other things, on observations or discontinuities within the rock layer. Initially these classification systems were based on rock types more common in tunnel and excavation but have been modified for a variety of rock conditions more common in foundation design.

Using refraction and surface wave testing techniques should allow researchers to be able to determine the depths and thickness associated with the soil layers, transition zones and competent rock. Because seismic methods have a large sample size they are likely to produce results that correspond to the behavior of the entire rock mass, which is an improvement over the current sampling and testing technique when group and rock mass properties govern design. Surface wave and refraction testing use sensors that are spread over large distances (10 - 1000's ft) and rely on data recorded at the surface to determine sub-surface soil and rock properties. This allows for a sampling of the entire rock mass, albeit at small strains. Ideally this research will reveal that the rock mass properties can be correlated to deep foundation constructability and design, allowing WYDOT to better predict capacity and provide valuable design information for practitioners and other DOT's with similar soil and rock types.

Direct benefits to WYDOT include using new sub-surface techniques as recommended by FHWA (Rivers and Nichols, 2019). The collected data will provide WYDOT with more accurate sub-surface information that can be used to help with the calibration of the LRFD resistance factors and will reduce uncertainty. Improved estimates of the depth of rock and transitions zone materials may also help with future design and prediction of pile drivability and foundation design capacity included cost estimating. Figure 1. presents a schematic of all the field and laboratory testing that will be combined for this project with the potential outcomes. Although the field work for this project will be refraction and surface wave testing, all previous and future data available will be incorporated in the final analyses and correlations.

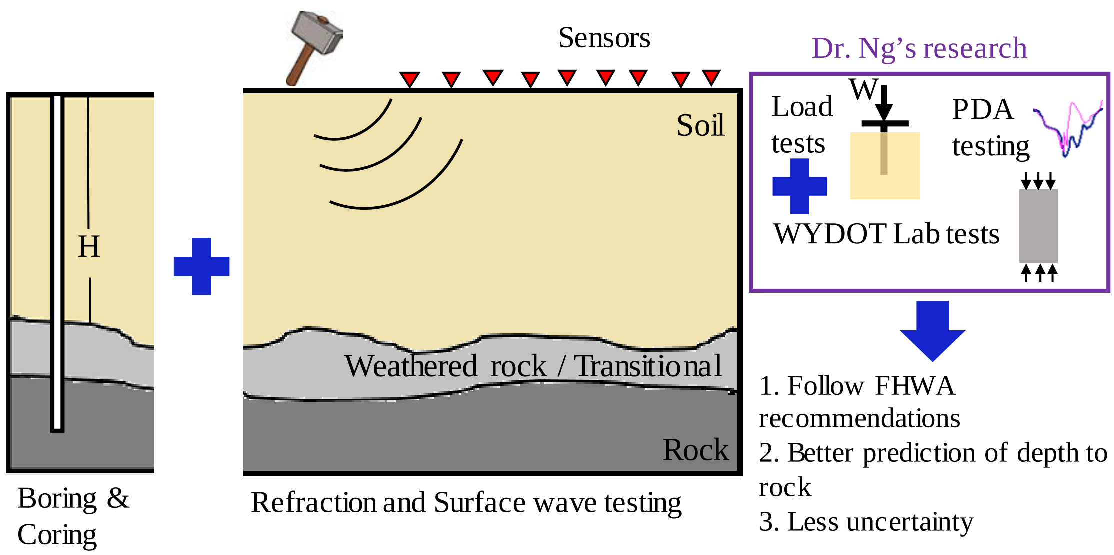

Figure 1. Schematic depicting all the sub-surface lab and field data that will be combined in this project.

The PI for has performed both refraction and surface wave testing as a Ph.D. student at many locations throughout the southern U.S. and as a PI on WYDOT funded project near Jackson Wyoming. The type of soil encountered near Jackson consisted of, difficult to sample, cobbles and boulders. Although ultimately successful, surface wave testing was a challenge at the site and lessons learned from that experience will help the PI to obtain the required data at the 9 sites proposed for this project. It is also the PI's intent to continue performing surface wave testing throughout Wyoming and in other locations were soft rock is near the surface for many years to come. This material is poorly understood in regards to dynamic behavior, and engineering characteristics and this combined with the prevalence of soft rock in many intermountain west states represents an area where research can be used to benefit to society.

Brief Review of Literature

This section gives a brief review of the types of rocks and soils expected within the state and a review of the seismic methods that will be employed at the 9 testing locations. Of the 9 sites 2 will have pile-load tests, 1 will include an osterburg cell test on a drilled shaft and the remaining 6 are pile driving sites that will include advanced PDA testing.

Rock Quality in Wyoming

The surface geology of Wyoming consists mostly of rock outcrops or shallow soil over rock formations. Evidence of this geology is evident in the mean elevation of Wyoming (highest in the U.S.) and in geologic maps. Figure 2 presents a geologic map of Wyoming, the bright yellow and its muted shades represent quaternary rocks and unconsolidated deposits. Review of Figure 1 reveals that there are few quaternary rocks and unconsolidated deposits throughout the state. WYDOT bridge personal have indicated that even when soil is present the deposits are not very thick and usually terminate in weathered or poor quality rock (Kirk Hood, personal communication).

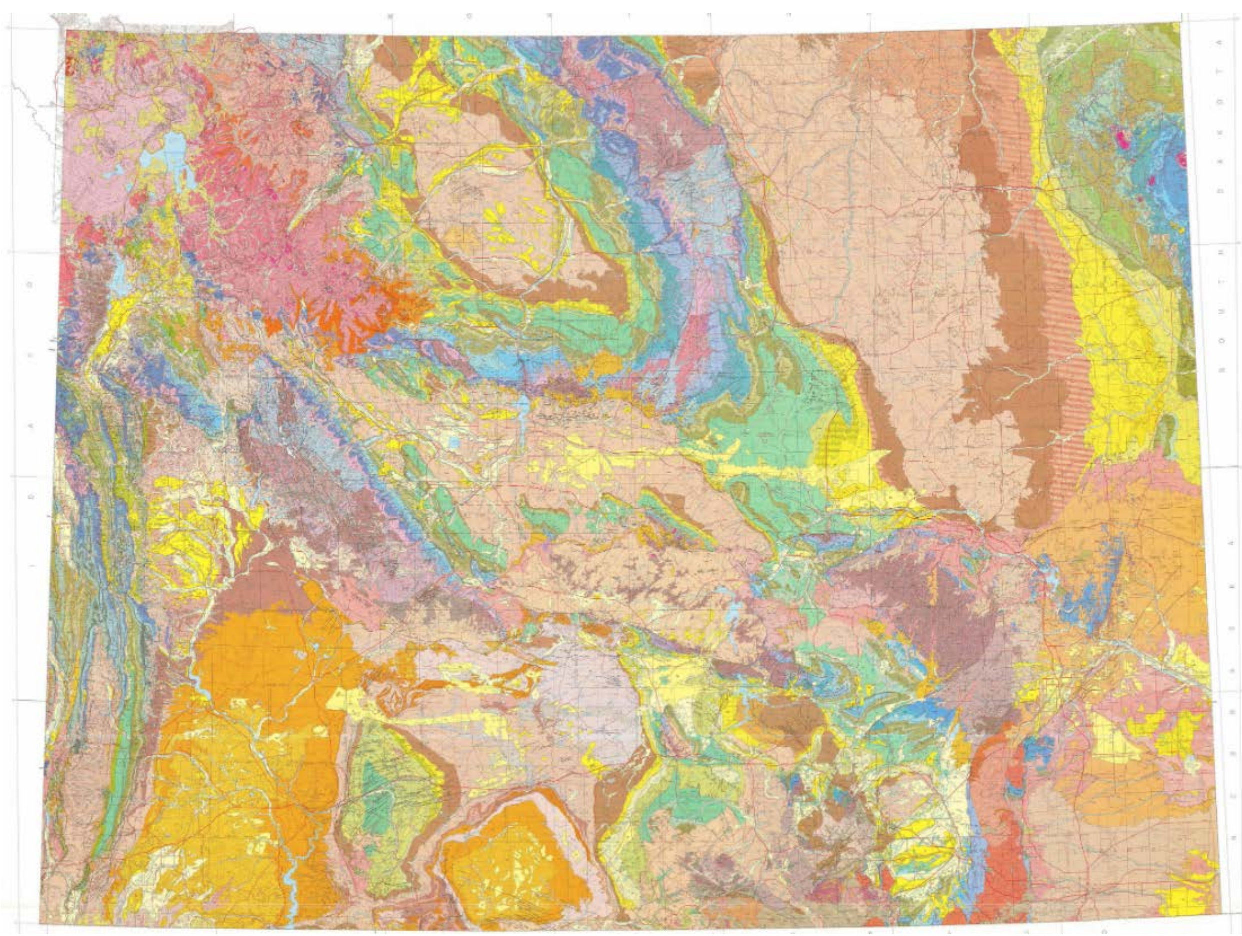

Figure 2. Geologic map of Wyoming, compiled by Love and Christiansen (1985).

The depth of the rock layer beneath the surface is an important design consideration and can be determined accurately over a large area using seismic methods. In addition the poor rock can be sampled with refraction and surface wave methods to determine velocity measurements. The collected velocity data will be compared with the sampled rock strengths which will allow for useful correlations. A brief literature review determined that characterization of rock masses using seismic methods has been performed on some projects and a variety of rock types (McCann et. al, 1990, El-Naqa, 1996, Yasar and Erdogan, 2004). The research presented in the literature included using acoustic wave testing in the lab, refraction and surface wave testing in the field, and some borehole methods. This review demonstrated that each of the previously published articles was rock type specific and clear guidance for weak rock material may be an area for future research. This indicates that the work in this project will likely be of value to others building bridges in similar rock and soil types throughout the U.S.

Seismic Testing

Seismic testing can include many forms of surface and borehole methods (Griffiths et. al, 2016). This project will use compression wave refraction and surface wave testing to characterize the subsurface. Both of these methods use the same type of equipment and require analyses of the data after it has been recorded.

Compression wave refraction surveys are common practice in the field of applied geophysics. They can produce a consistent estimate of the velocity and depth of a soft over stiff layer. Figure 3 presents a typical refraction field test. In this method, travel times for each receiver are compared with the distance from the shot location. The arrival times of the geophones nearest the shot location are compared with the arrival times of the geophones further away from the shot locations. Because the velocity of the deeper layers is greater than the surface layer some of the energy will travel through the 1st layer, be refracted across the boundary between layer 1 and 2, and then refracted again up toward the surface and recorded at a geophone before the first arrival travels across the surface in layer 1. This is because the velocity of the deeper layer is much greater than the velocity of the surface.

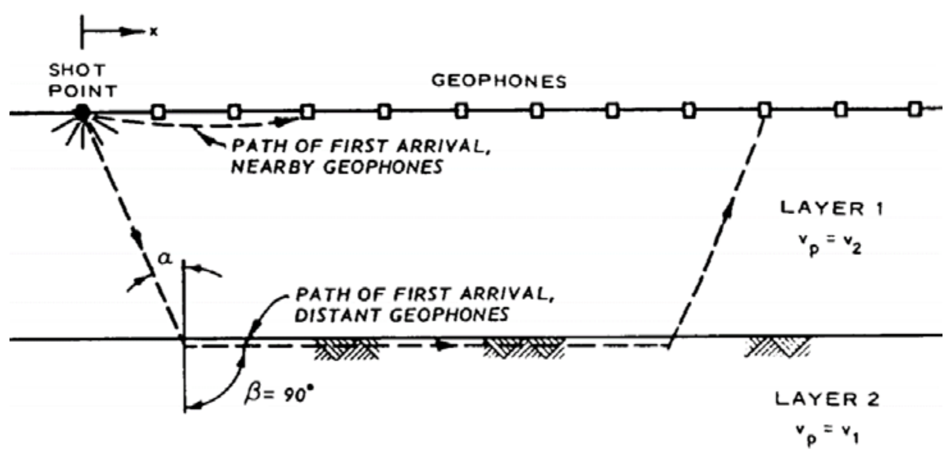

Figure 3. Typical compression wave refraction survey set up, shown with two ray paths a direct arrival and first arrival and geophones far away from the shot point (figure from U.S. Army Corp of Engineers, 1995).

Surface wave methods have been used since the 1980's (Nazarian, 1984, Nazarian et. al 1988) with the advent of the Spectral Analyses of Surface Wave (SASW) method. In this method, two sensors are placed on the ground and the relative phase difference between the sensor readings is used to determine phase velocity. This method was a pre-curser to the Mutli-Channel Analyses of Surface Waves (MASW) method developed by Park et al. (1998), which is presented as Figure 4. Both of these methods take advantage of the fact that soil and rock are dispersive materials, which means different frequency waves travel at different velocities within the same material. This allows for a determination of the phase velocity and eventual computation of the shear wave velocity of a layered earth model. Some research has shown that Love waves (horizontal polarized surface waves) produce better data quality in stiff soil conditions or in locations where there is limited soil over competent rock. Hence, for this project it is anticipated that the MASW method will include using both Rayleigh (vertical sensors) and Love waves (horizontal sensors).

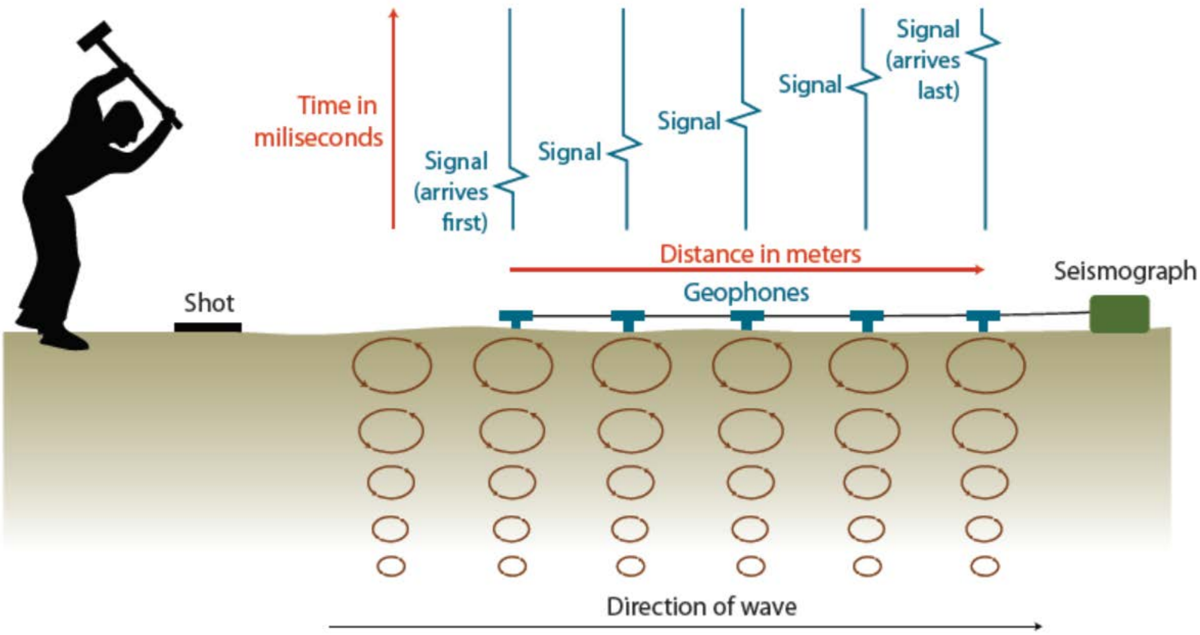

Figure 4. Typical MASW survey set up shown with wave direction, particle motion, and signal times (Ear to the Ground, 2016).

Research Plan

The research plan includes performing high quality seismic surveys at 9 locations and then comparing that data to the soil borings, drive point, pile driving records, laboratory rock strengths, and other site specific data. For some of the sites this data has been collected for other sites it will be in the near future. The data comparisons will lead to new insights and formulations for pile capacity, drivability, drill shaft capacity and hopefully rock mass classification.

The 9 sites chosen for testing include those presented in Figure 5 and in the accompanying Table 1. The sites where chosen based on availability of data, interesting sub-surface conditions, in coordination with Kam Ng's research sites, and cooperatively with the project champion at WYDOT. At each bridge site, it is anticipated that seismic surveys will be completed on both sides of the bridge in two orthogonal directions (depending on available space) and will include compression wave reflection and surface wave testing. The surface wave testing will include both Rayleigh and Love wave data collection techniques using multiple offsets for shot locations.

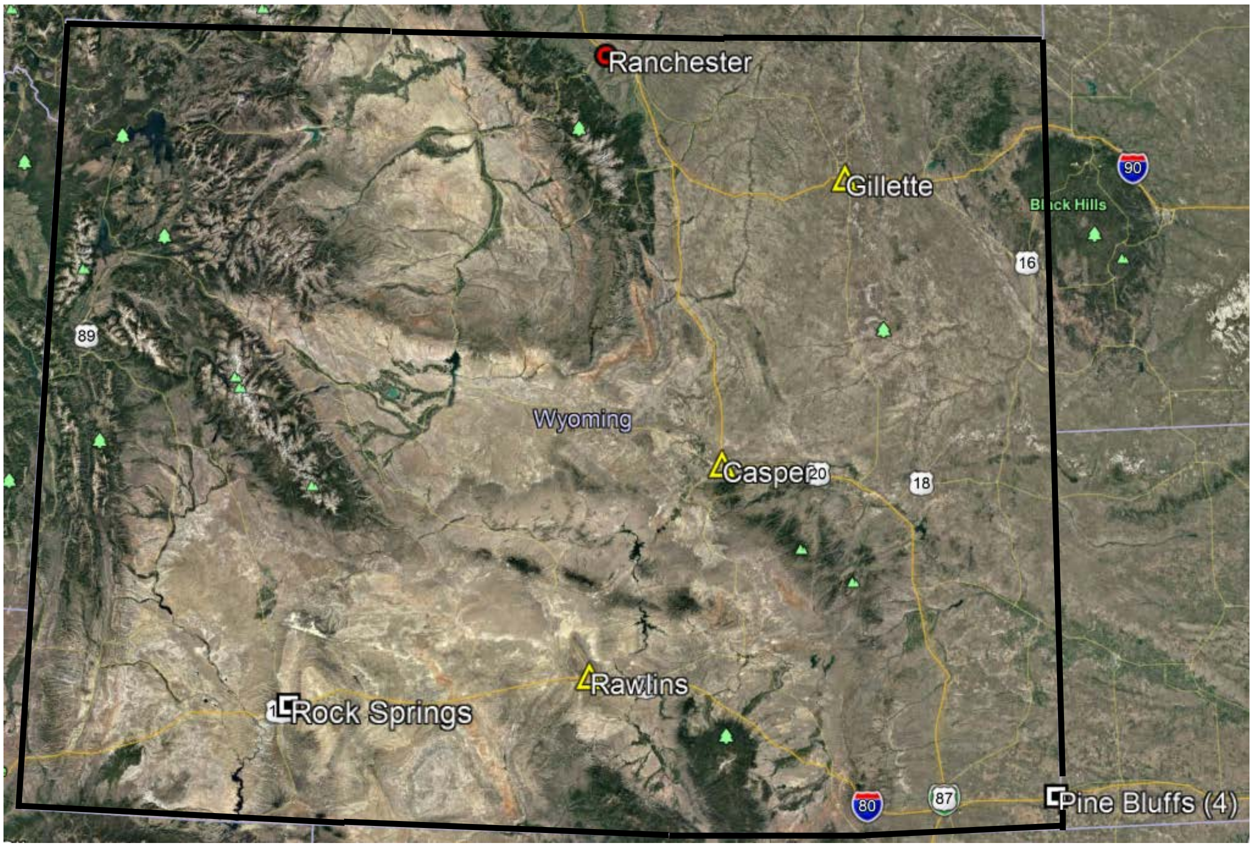

Figure 5. Nine bridge locations throughout Wyoming where compression refraction and surface wave testing will be completed.

Table 1. Nine bridge locations and competed or planned testing at each site.

Location	WYDOT No.	Crossing	Notes/Testing
Rock Springs	B123014	Interchange road	Load test planned
Pine Bluffs	1104015	Lodgepole creek	Load test planned
Ranchester	N372041	BNNR	O-cell planned
Gillette	0302089	Wildcat Creek	PDA planned
Pine Bluffs	I806198	Beech, Muddy, Parsons	3 sites/ PDA testing
Casper	0900013	Owl Creek	PDA completed
Rawlins	0804234	Cedar street	PDA completed

The project goals are to:

1) Measure the shear wave velocities of the soil, transition, and competent rock layers, including estimates of layer thickness at all nine sites.
2) Develop correlations between measured rock strength, pile drivability and pile capacity and and drilled shaft capacity for the Osterburg cell site and correlate those strengths and capacities with the shear wave velocity of the transition zone and competent rock layers.
3) Compare the shear wave velocity measurements with known methods of rock classification and determine if improvements in the classification system could result in use of the shear wave velocity data.

The proposed project will require a time commitment of two years. The project tasks are divided into four main tasks. It is expected that work on this project will begin January 1st 2019. Task 1 will be to perform an in-depth literature review of seismic testing techniques used in rock materials and begin preparations for field testing. Task 2 will include collecting surface wave data at the 9 sights. Task 3 will begin concurrently with Task 2 and will include data analyses to determine the shear wave velocity and thickness of the soil and rock layers. Task 4 will be to correlate rock strength, PDA, pile drivability, pile capacity, Osterburg cell results, and drilled shaft capacity to the measured shear wave velocity data and to prepare the final report and any publications.

Task 1

Task 1 is expected to begin January 1st 2019 and will entail an in-depth literature review. The review is expected to inform the researchers of any major pitfalls before field deployment. At the same time research trips to gather data will be planned and organized. The organization of the field work requires coordination between the PI, two graduate students, weather, and equipment availability. Prior to field deployment, proper site preparation will include a review of available land area for testing, a review of sub-surface data, and plan for sensor placement and data collection. Task 1 should be complete prior to June 1, 2020.

Task 2

Task 2 is expected to begin in the summer of 2020. Trips will be scheduled in advance and will include coordination with the WYDOT project champion to ensure site access. The site characterization will include surface wave testing using active (MASW) methods, and compression wave reflection testing. Site characterization is a major component of this research and thorough data sets will be gathered at each site so that future field deployments should not be necessary. The field deployment will include orthogonal surveys at both abutments for each bridge site, so long as there is room for access and testing. If necessary, data will be collected at night to ensure the safety of the PI and students. Most Equipment for this project will be rented from the Facility for Imaging the Near- and Sub-surface Environment (FINSE). The only exception is the permanent equipment request of 26 horizontal 4.5 Hz geophones. These are necessary for the Love wave testing and currently the FINSE facility doesn’t own this type of sensor. It is anticipated that Task 2 will be completed by October 1, 2020.

Task 3

Task 3 will be to analyze the collected data to determine the shear wave velocity and soil thicknesses for each site. Task 3 is expected to begin in the summer of 2020 as soon as data has been collected. Analyzing surface wave data is not a trivial matter. Due to the nonlinear, ill-posed and mix-determined nature of inversion, it is possible to obtain multiple shear wave velocity profiles for the same data set. Despite these and other challenges, it is possible to obtain an acceptable shear wave velocity profile using the most recent data analyses techniques (Cox and Teague, 2016). In order to help with these analyses, boring logs from each site will be used to help correlate shear wave velocity data with measured layer thicknesses. Due to the complex nature of the data analyses, and the volume of data collected it is anticipated that task 3 will take eight months to analyze. It is expected that task 3 will be completed by April 1, 2021.

Task 4

Task 4 will be to develop any correlations possible from the gathered data, and prepare final reports and publications. This has been done by others including McCann et al. (1990), but for different rock types than those common in Wyoming. Task 4 is expected to begin April 1, 2021. This work will begin as soon as records from the site and velocity data is available for each site. This task includes development of design equations, charts and useful information that could be used for future predictions. Task 4 also includes the development and writing of the final report, and any journal publications. Task 4 is expected to be complete by December 31st 2018.

In addition to these three broad goals, there are also potential long-term outcomes with this research listed below. These outcomes are not likely to occur during the two years of this project, but are a vital part of the data collection effort necessary to make these outcomes a reality.

Potential long-term outcomes:

1) Correlations between the shear wave velocity and rock strength material may reveal new ways to classify rock masses.

2) Pile load test may reveal good correlations between pile capacity and shear wave velocity data which may in turn lead to increases in reduction factors or new design equation for estimating pile capacity.

Technology Transfer

In order to ensure that the proposed analyses is implemented and used for future foundation and bridge designs it is anticipated that at least one final presentation will be scheduled with the Geology department at WYDOT. The session will be scheduled in consultation with Kirk Hood with dates and times that are compatible with the departments of interest and the project investigator. Other departments who may be interested will also be made aware and invited to participate in the session.

Implementation

Kirk Hood a principal geologist for WYDOT will be responsible for the implementation of the proposed research results within the geology department at WYDOT. It is anticipated that at the successful completion of the proposed project WYDOT geologists will have new correlations and prediction tools that can be used for future projects. In addition, future research may include implementing changes in the classification and quality designation used for transition soils and rock. The proposed project will not likely alter any of the current codes used by the bridge department, but may help determine reduction factors for use in pile driving analyses and design. By using new sub-surface investigation techniques WYDOT will be following guidance from FHWA (Rivers and Nichols, 2019).

Outcomes

Benefits to WYDOT

By using new sub-surface investigation techniques WYDOT will be following guidance from FHWA (Rivers and Nichols, 2019). The seismic methods will also serve as a trial proof-of-concept for better evaluation of transition zone and competent rock properties. The results may include an improved prediction tool that will allow WYDOT to assess rock strength and help with pile and drilled shaft design and construction. The data may also help reduce risk and uncertainty in foundation design.

Broader Impacts

Wyoming is a rock state, with few alluvial soil deposits. Often rock is at or near the surface with only thin layers of soil above rock. In addition much of the rock is weathered or consists of poor quality shale and similar rock types. These soils are hard to sample and test and the current sampling techniques may not represent the characteristics of the entire rock mass. By obtaining more information concerning the rock mass properties through seismic testing it may be possible to better predict pile and drilled shaft behavior during construction and design. The efforts made in this work will be a valuable asset for states throughout the mountain west. Performing seismic testing for these rock sites in a rural state like Wyoming may provide insights and guidance to other rural states, especially concerning the potential cost-effectiveness of performing advanced site characterization for bridge foundations.

Findings from this project will also be incorporated into courses at the University of Wyoming (CE 4630 Ground Improvement and CE 3600 Soil Mechanics). Due to the expected soil conditions throughout Wyoming, use of seismic methods to sample the transitional materials and determine correlations will be of interest to many others throughout the nation. Graduate students participating in this project will gain valuable communication and technical problem solving skills, which will carry the benefits of this project to other locations and into the future. Additionally, hiring an undergraduate student will result in a valuable introduction to earthquake engineering for the younger student and mentoring opportunity for both the undergraduate and graduate student.

Budget
Tabulated budget information is included as Tables 2 and 3 for each year of the project. The budget for the proposed project is $107,090 for year one and $64,578 for year two. This sums to a total of $171,168 (sum of line L in Tables 2 and 3) for the total cost over two years. The budget justification for each year is included below.

1st Year
The Costs associated with the first year of the proposed project are included below and in Table 2.

Personal
Budget for personal is a major component of the overall budget. Two months of summer salary for the principal investigator is included for the supervision of a graduate student and travel associated with data collection. During the other months of the year the salary for the principal investigator is covered by the University of Wyoming. The support of one graduate Ph.D. student for one year (12 months) is also included. Both the PI's summer and graduate student stipend include an adjustment of 3% over current costs for inflation. Also included is $2000 to support an undergraduate student, who will be identified and hired hourly to help collect and possible analyze surface wave data. This results in a total personal cost of $43,808 (A+B in Table 2).

Fringe Benefits
In accordance with University regulations fringe benefits are charged to supplemental (summer) salary of 34.8% for faculty and 2.9% for students. This results in a total cost of fringe benefits of $7,334 (C in Table 2).

Permanent Equipment
Based on experience from the PI, it is known that some sites yield higher quality data when subjected to Love wave instead of the more common Rayleigh waves. In order to sample Love waves horizontal geophones are necessary. While the FINSE facility at the University of Wyoming can provide most of the necessary equipment for the proposed project they do not own the required 4.5 Hz horizontal geophones that the PI would like to use. The cost of shipping and renting this equipment may be less than the cost to buy however, these instruments are an important part of the data collection and have been added to the permanent equipment in case proper equipment cannot be rented at the time the work needs to be performed. The expected cost of the sensors $93 each, with a total of 26 geophones purchased this results in a total of $2418 (which does not include tax or shipping). Accordingly $2500 has been included in the budget for permanent equipment.

Travel
Travel cost for the proposed project for the 1st year includes the costs associated with travel, lodging and meals to the proposed bridge sites with the necessary equipment and personal (principal investigator, one graduate student and one undergraduate student) to perform the seismic testing. The trips associated with the data collection include 1 day each for travel to and from the site, with 1 day budgeted for the field work. The travel expenses also include monies for the principal investigator to attend one national conference to present findings associated

Table 2. Budget information for year one of the propose WYDOT project.

	WyDOT Budget		SUMMARY			
		PROPOSAL BUDGET			FOR WYDOT USE ONLY	
	Organization		FY	2017	Proposal No.	DURATION (24 mo)
	UNIVERSITY OF WYOMING					Proposed Awarded
	Principal Investigator				Award No.	
	Dr. Shawn C. Griffiths					
A.	Senior Personnel: PI/PD Co-PI's,	WyDot Funded | Person-mo			Funds	Funds
	Faculty and other Senior Associates	CAL	ACAD	SUMR	Requested	Granted
1	Dr. Shawn C. Griffiths			2	19008	
2					0	
3					0	
4					0	
5					0	
6					0	
7	Total Senior Personnel (1-6)	0	0	2	19008	
B.	Other Personnel					
1	Post-doctoral Assoc.					
2	Other Professionals					
3	Graduate Student		9	3	22800	
4	Undergraduate Students				2000	
5	Secretarial/Clerical				0	
6	Shop/Tech.				0	
	TOTAL SALARY AND WAGES (A+B)				43808	
C.	Fringe Benefits: 34.8% faculty, 2.9% students	0.35	0.029		7334	
D.	PERMANENT EQUIPMENT				2500	
	Total Permanent Equipment				2500	
E.	Travel 1. domestic				20000	
	2. foreign				0	
F.	PARTICIPANT COSTS.					
1	Stipend					
2	Travel					
3	Subsidence					
4	Other					
	TOTAL PARTICIPANT COSTS				0	
G.	OTHER DIRECT COSTS					
1	Materials and Supplies				2000	
2	Publication costs				100	
3	Consultant Services				1000	
4	Computer Services				2500	
5	Subcontracts					
6	Tuition and fees	Sem	2		10000	
7	Other					
	TOTAL OTHER DIRECT COSTS				15600	
H.	TOTAL DIRECT COSTS (A-G)				89242	
I.	INDIRECT COSTS					
	General Overhead for Wyoming agency's of 20%					
		0.2			17848	
J.	TOTAL direct and Indirect (H+I)				107090	
K.	Residual Funds					
L.	AMOUNT OF THIS REQUEST for year 1				107090	
PI/PD TYPED NAME AND SIGNATURE		DATE			FOR WyDot USE ONLY	
Shawn C. Griffiths				INDIRECT COST RATE VERIFICATION		

with the proposed research and collaborate with other researchers with expertise in seismic testing. It is expected that the total travel expenses will be $20,000 for the 1st year of the project (E in Table 2).

Other Direct Costs

Other direct costs are included in section G of Table 1. These costs include materials and supplies which covers cost associated with field testing (gloves, safety equipment, shovels, PPE, cones, ect...). Also included is the cost to rent the equipment needed to perform field testing. Publication costs include printing posters or developing specialty graphics. Consultant fees are included to hire a consultant to review the data analyses which will ensure quality interpretation of the seismic data. Computer services, which will be used to purchase the hardware and software necessary to record, analyze and store seismic data. Tuition and fees for the support of one Ph.D. student for a full year (two semesters plus summer). Total direct costs for year one are $15,600 (G in Table 2).

Total Direct Costs

Total direct costs for year one of this project are $89,242 (H in Table 2).

Indirect Costs

In accordance with University of Wyoming policy, state of Wyoming agencies are charged a rate of 20% of the total direct costs. This cost does not include the any cost associated with the permanent equipment. This results in an indirect cost amount of $17,348 (I in Table 2), and a total cost for year one of $106,590.

2nd Year

The Costs associated with the second year of the proposed project are included below and in Table 3.

Personal

The second year of the project includes 1.0 month of summer salary for the principal investigator for the supervision of a graduate student. During the others months of the year the salary for the principal investigator is covered by the University of Wyoming. The support of one graduate Ph.D. student for year two (12 months) is also included with an adjustment of 3% cost increase included. Additional funds of $2000 are included to hire an undergraduate student who will help analyze data and prepare the final report. This results in a total personal cost of $34,589 (A+B in Table 3).

Fringe Benefits

In accordance with University regulations fringe benefits are charged to supplemental (summer) salary of 34.8% for faculty and 2.9% for students. This results in a total cost of fringe benefits of $4,126 (C in Table 2).

Table 3. Budget information for year two of the propose WYDOT project.

	WyDOT Budget		SUMMARY			
		PROPOSAL BUDGET			FOR WYDOT USE ONLY	
	Organization		FY	2017	Proposal No.	DURATION (24 mo)
	UNIVERSITY OF WYOMING					Proposed Awarded
	Principal Investigator				Award No.	
	Dr. Shawn C. Griffiths					
A.	Senior Personnel: PI/PD Co-PI's,	WyDot Funded	Person-mo		Funds	Funds
	Faculty and other Senior Associates	CAL	ACAD	SUMR	Requested	Granted
1	Dr. Shawn C. Griffiths			1	9789	
2					0	
3					0	
4					0	
5					0	
6					0	
7	Total Senior Personnel (1-6)	0	0	1	9789	
B.	Other Personnel					
1	Post-doctoral Assoc.					
2	Other Professionals					
3	Graduate Student		9	3	22800	
4	Undergraduate Students				2000	
5	Secretarial/Clerical				0	
6	Shop/Tech.				0	
	TOTAL SALARY AND WAGES (A+B)				34589	
C.	Fringe Benefits: 34.8% faculty, 2.9% students	0.35	0.029		4126	
D.	PERMANENT EQUIPMENT					
	Total Permanent Equipment				0	
E.	Travel 1. domestic				5000	
	2. foreign				0	
F.	PARTICIPANT COSTS.					
1	Stipend					
2	Travel					
3	Subsidence					
4	Other					
	TOTAL PARTICIPANT COSTS				0	
G.	OTHER DIRECT COSTS					
1	Materials and Supplies				0	
2	Publication costs				100	
3	Consultant Services				0	
4	Computer Services				0	
5	Subcontracts					
6	Tuition and fees	Sem	2		10000	
7	Other					
	TOTAL OTHER DIRECT COSTS				10100	
H.	TOTAL DIRECT COSTS (A-G)				53815	
I.	INDIRECT COSTS					
	General Overhead for Wyoming agency's of 20%					
		0.2			10763	
J.	TOTAL direct and Indirect (H+I)				64578	
K.	Residual Funds					
L.	AMOUNT OF THIS REQUEST for year 2				64578	
	PI/PD TYPED NAME AND SIGNATURE	DATE			FOR WyDot USE ONLY	
	Shawn C. Griffiths			INDIRECT COST RATE VERIFICATION		

Travel
Travel costs or year two of the proposed project includes costs associated with travel, lodging and meals for the principal investigator and one graduate student to attend one national conference to present findings associated with the proposed research. It is expected that the total travel expenses will be $5,000 (E in Table 3).

Other Direct Costs
Other direct costs are included in section G of Table 3. These include tuition and fees for the support of one Ph.D. student for two semesters (summer tuition and fees are included). Also included in the publication cost of $100 which may cover the cost of poster printing. Total other direct costs are $10,100 (G in Table 3).

Total Direct Costs
Total direct costs for year two of this project are $53,815 (H in Table 3).

Indirect Costs
In accordance with University of Wyoming policy, state of Wyoming agencies are charged a rate of 20% of the total direct costs. This results in an indirect cost amount of $10,763 (I in Table 2), and a total cost for year two of $64,578.

Data management Plan
Various forms of data will be generated as part of the proposed project. Including; sensor recordings from field measurements, data analyses files for the determination of the shear wave velocity profile, data files used to perform the analyses, and program specific files of the completed analyses. The data can be categorized as pre-processed (raw data), post-processed (i.e. engineering units) and analyses files and final figures. Appendix A includes the data management plan form that is required for InterAgency Agreement between the Wyoming Department of Transportation and the University of Wyoming.

<u>Data Form and Format</u>
Depending on the sensor used the raw file format of the recorded data will be miniSEED or SEG-2. It is anticipated that these files will be converted into text or Matlab files for use in the analyses. It is also anticipated that Matlab scripts to process and manage the data will also be developed and stored. Figures will be developed to help visualize the results and other important data (shear wave velocity data, dynamic soil properties, correlated strengths), these files will be stored as *.jpg or Matlab *.fig files.

<u>Storage and Dissemination</u>
It is anticipated that all the data generated for both the pre- and post-processing will occupy 1-3 terabytes of storage space. Long-term storage and backup of the data will be handled at the University of Wyoming using desktop storage devices. Access to the raw data will be available to engineers at WYDOT upon request. It is not anticipated that the pre-processed or post-processed data will be published or accessible to the broad research community. However,

it is anticipated that research findings, figures and some tabulated data will be published in a comprehensive reports, articles, and journals.

References

Cox, B.R., and Teague, D. P. (2016). “Layering ratios: a systematic approach to the inversion of surface wave data in the absence of a priori information.” Geophysical Journal International, Volume 211, Issue 1, October 2017, Page 378, https://doi.org/10.1093/gji/ggx319

Ear to the Ground (2016). “Peering Into The Earth: Geophysical Techniques Can Find Rock For Forest Roads”. <https://washingtondnr.wordpress.com/2016/08/07/peering-into-the-earth-geophysical-techniques-can-find-rock-for-forest-roads/>, 9/27/19.

El-Naqa, A. (1996). “Assessment of geomechanical characterization of a rock mass using a seismic geophysical technique.” Geotechnical and Geological Engineering, 1996, 14, pp. 291-305.

Griffiths, S.C., Cox, B.R., Rathje, E.M., and Teague, D.P. (2016). “A Surface Wave Dispersion Approach for Evaluating Statistical Models that Account for Shear Wave Velocity Uncertainty”. Journal of Geotechnical and Geoenvironmental Engineering., Vol. 142, 11. http://dx.doi.org/10.1061/(ASCE)GT.1943-5606.0001552.

Loehr, E., Lutenegger, A., Rosenblad, B., and Boechmann, A. (2017). “Geotechnical Site Characterization, Geotechnical Circular No. 5.” National Highway Institute, U.S. Department of Transportation, Federal Highway Administration, Washington D.C., pp. 688.

Love, J.D., and Christiansen, A.C. (1985). “Geologic Map of Wyoming”. Department of the Interior, U.S. Geologic Survey in cooperation with the Geological Survey of Wyoming.

McCann., D.M., Culshaw, M.G., and Northmore, K.J. (1990). “Rock Mass Assessment from Seismic Measurements.” From Bell, G.G., Clushaw, M.G., Cripps, J.C. and Coffey, J.R. (eds). Feild Testing in Engineering Geology. Geological Society Engineering Geology special Publication No 6, pp 257-266

Nazarian, S. (1984). “In Situ Determination of Elastic Moduli of Soil Deposits and Pavement Systems by Spectal-Analysis-of-Sruface-Waves Method.” Ph.D. dissertation. The University of Texas at Austin, 1984.

Nazarian, S., Stokoe, K.H., Briggs, R.C., and Rogers, R., (1988). “Determination of Pavement Layer Thicknesses and Moduli by SASW Method.” Transportation Research Record No. 1196. Official Journal of the Transportation Research Board. pp. 133-150.

Park, C., Xia, J., and Miller, R. (1998). “Imaging dispersion curves of surface waves on multi-channel record.” 68th Annual Int. Meeting of the Society of Exploration Geophysicists, Society of Exploration Geophysicists, Tulsa, OK, 1377–1380.

Rivers, B., and Nichols, S. (2019). “EDC-5: Advanced Geotechnical Methods in Exploration (A-GaME).” Center for Accelerating Innovation, U.S. Department of Transportation Federal Highway Administration. < https://www.fhwa.dot.gov/innovation/every-daycounts/edc_5/geotech_methods.cfm>, 9/30/19.

U.S. Army Corp of Engineers (1995). “Geophysical Exploration For Engineering and Environmental Investigations.” Department of the Army, Engineer Manual No. 1110-1-1802.

Yasar, E., and Erdogan, Y. (2004). “Correlating sound velocity with density, compressive strength and Young’ modulus of carbonate rocks.” International Journal of Rock Mechanics and Mining Sciences, 41, pp 871-875.

Appendix A

Data Management Plan

Name of Contractor	**Shawn Griffiths**
Name of project	**Characterization of Soil and Rock for Transportation Infrastructure Using Seismic Methods in Wyoming**
Project Duration	**Start date : January 2020** **End: December 2022**
DMP Version	**One**
Date Amended, if any	
Name of all authors, and ORCID number for each author	Shawn C. Griffiths, Ph.D., 0000-0003-0694-4769
WYDOT Project Number	
Any Digital Object Identifier (DOI), including any CROSSREF number, which has been assigned to any peer reviewed publication or data generated by this project	
Name of all peer reviewed publications which have been generated using data from this project	
URLs for all peer reviewed publications which have been generated using data from this project	
RiP RH Display ID Number	
Dataset URL, if available	

What constitutes such data will be determined by the Principle Investigator, Project Champion, and the Research Manager. In general, your plan should address final research data. This includes recorded factual material commonly accepted in the scientific community as necessary to validate research findings. Final research data do not include laboratory notebooks, partial datasets, preliminary analyses, drafts of scientific papers, plans for future research, peer review reports, communications with colleagues, or physical objects, such as gels or laboratory specimens. As part of your research, you may also generate unique data, which are data that cannot be readily replicated. Your DMP should also address unique data that may arise from your research.

WYDOT expects the timely release and sharing of data to be no later than the acceptance for publication of the main findings from the final dataset, unless the Principle Investigator will be embargoing the data. In such a case, the data cannot be embargoed for a period longer than twelve (12) months.

1. Introduction

The purpose of this research project is to:

Perform seismic testing at 9 sites throughout Wyoming and attempt to correlate seismic data with pile driving records, rock strength, and depth of transitional material.

2. Definitions

a. Code or scripts include code used in the collection, manipulation, processing, analysis or visualization of data, but may also include software developed for other purposes.

b. Copyright is a set of legal rights extended to copyright owners that govern such activities as reproducing, distributing, adapting, or exhibiting original works fixed in tangible forms.

c. Data means the recorded factual material commonly accepted in the scientific community as necessary to validate research findings, but not any of the following: preliminary analyses, drafts of scientific papers, plans for future research, peer reviews, communications with colleagues. Recorded material excludes physical objects (e.g. laboratory samples). Research data also does not include trade secrets, commercial information, materials necessary to be held confidential; and personnel and medical information and similar information the disclosure of which would constitute a clearly unwarranted invasion of personal privacy.

d. Data Archive is a site where machine readable materials are stored, preserved or possibly redistributed to individuals interested in the materials.

e. Data Management Plan is a document that specifies your plans for managing your data and files for a research project.

f. Dataset means collection of data.

g. Metadata refers to structured data about data which helps define administrative, technical, or structural characteristics of the digital content.

3. Data Types and Storage

The types of data and/or datasets generated and/or used in this project include …

The recorded data will be miniSEED or SEG-2. Data collection will be documented using field notebooks and datasheets, which will be scanned and stored with the raw data. The raw collected data is not reproducible and the loss of this data will require field investigations to be repeated. The analyzed data is reproducible and can be produced from the raw data by performing new analyses. If the analyzed data is lost or corrupted new analyses can be performed. It is anticipated that many of the raw files will be converted into text or Matlab files for use in the analyses. It is also anticipated that Matlab scripts to process and manage the data will also be developed and stored. Figures will be developed to help visualize the results and other important data (shear wave velocity profiles, dynamic soil properties, ect…), these files will be stored as *.jpg or Matlab *.fig files.

The growth rate of the data depends on the depth and number of analyses performed. Which is unknown until the analyses are complete. However it is anticipated that all the data will occupy no more than 1-3 terabytes of storage space for this project. Long-term storage and backup of the data will be handled at the University of Wyoming using local storage devices. Access to the raw data will be available to engineers at WYDOT upon request. It is not anticipated that the pre-processed or post-processed data will be published or accessible to the broad research community. However, it is anticipated that research findings, figures and some tabulated data will be published in a comprehensive reports, articles, and journals.

Pre-existing data includes "as-built" bridge plans from 1958 which are stored and accessible by bridge engineers at WYDOT, these plans may be used to help plan future site investigations. Other data collected includes PDA, field borings, rock strengths and pile driving records. WYDOT stores all this data and will make it available to the PI during the project as needed.

Provide a description of the data that you will be gathering in the course of your project. You should address the nature, scope, and scale of the data that will be collected. Describe the characteristics of the data, their relationship to other data, and provide sufficient detail so that reviewers will understand any disclosure risks that may apply. Discuss value of the data over the long-term. Please provide the name of all repositories where the data will be housed during the lifetime of the project.

Checklist
- o What type of data will be produced?
- o How will data be collected? In what formats?
- o How will the data collection be documented?
- o Will it be reproducible? What would happen if it got lost or became unusable later?
- o How much data will it be, and at what growth rate? How often will it change?
- o Are there tools or software needed to create/process/visualize the data?
- o Will you use pre-existing data? From where?
- o Storage and backup strategy?

3. Data Organization, Documentation and Metadata

The plan for organizing, documenting, and using descriptive metadata to assure quality control and reproducibility of these data include …

Raw data formats include SEG-2 and miniSEED files which are common files types for the collection of data in seismic testing. From these raw files text and data analyses files will be generated. The organization of these generated files will be determined as the files are generated and will be consistent throughout the project. Likely data will be organized based on the project, site, and test number. This structure of folders and subfolders will allow for future identification of the tests performed and data collected can be easily identified if needed. Documentation of how the files structure is made and used will be determined between the graduate assistant and the principal investigator. Data will be generated in formats inluding; txt, jpeg, bmp, matlab fig files. Geopsy, a free inversion and wave analyses software will be used to develop multiple files for analyses and includes many file types.

There is currently no one single community sharing standard for storing and sharing this type of data however, the SEG-2 and miniSEED file formats are standard and can be shared with others (WYDOT) upon request.

Your DMP should describe the anticipated formats that your data and related files will use. To the maximum extent practicable, and in accordance with generally accepted practices in your field, your DMP should address how you will use platform-independent and non-proprietary formats to ensure maximum utility of the data in the future. If you are unable to use platform-independent and non-proprietary formats, you should specify the standards and formats that will be used and the rationale for using those standards and formats.

NOTE: Attach the Metadata transmittal form or URL for data generated or peer reviewed publications from this project.

Checklist

o What standards will be used for documentation and metadata?
o Is there good project and data documentation format/standard?
o What directory and file naming convention will be used?
o What project and data identifiers will be assigned?
o Is there a community standard for metadata sharing/integration?

4. Data and/or Database Access and Intellectual Property

What access and ownership concerns are there…

Because the raw data will not be shared with the broad research community and no business or participants are sharing confidential information there are no concerns about database access. However, password protection will be used on short- and long-term storage devices. Long term data storage will be controlled on-site and controlled by the principal investigator.

Protecting research participants and guarding against the disclosure of identities and/or confidential business information is an essential norm in scientific research. Your DMP should address these issues and outline the efforts you will take to provide informed consent statements to participants, the steps you will take the protect privacy and confidentiality prior to archiving your data, and any additional concerns. If necessary, describe any division of responsibilities for stewarding and protecting the data among Principal Investigators.

If you will not be able to deidentify the data in a manner that protects privacy and confidentiality while maintaining the utility of the dataset, you should describe the necessary restrictions on access and use. In general, in matters of human subject research, your DMP should describe how your informed consent forms will permit sharing with the research community and whether additional steps, such as an Institutional Review Board (IRB), may be used to protect privacy and confidentiality.

Checklist

o What steps will be taken to protect privacy, security, confidentiality, intellectual property or other rights?
o Does your data have any access concerns? Describe the process someone would take to access your data.
o Who controls it (e.g., PI, student, lab, University, funder) ?
o Any special privacy or security requirements (e.g., personal data, high-security data) ?
o Any embargo periods to uphold?

5. Data Sharing and Reuse

The data will be released for sharing in the following way …

The raw data and processed data will not be shared with others except under written consent from the Wyoming Department of Transportation, and those hired to review the data as outlined in the project proposal. Published data from this project will include figures, tables and descriptions of the collected data. The data is likely to be published after the project is complete and in a yet unidentified journal. It is also likely that conference publications may be used to disseminate these results.

Describe who will hold the intellectual property rights for the data created by your project. Describe whether you will transfer those rights to a data archive, if appropriate. Identify whether any copyrights apply to the data, as might be the case when using copyrighted instruments. If you will be enforcing terms of use or a requirement for data citation through a license, indicate as much in your DMP. Describe any other legal requirements that might need to be addressed.

Checklist

o If you allow others to reuse your data, how will the data be discovered and shared?
o Any sharing requirements (e.g., funder data sharing policy) ?
o Audience for reuse? Who will use it now? Who will use it later?
o When will I publish it and where?
o Tools/software needed to work with data?

6. Data Preservation and Archiving

The data will be preserved and archived in the following ways …

Long-term storage of the data will be accomplished using a non-portable storage device. This will reside at the University of Wyoming and will be a backup for the data that is collected in the field as well as the analyzed data. Because much of the data can be reproduced from analyses, long term storage will be backed up to the cloud or a similar on-line tool for the SEG-2 and miniSEED data. This raw data represents a large expense and is the only data that will be stored on the cloud. All other data can be generated from this data and will not be stored in cloud based archive. The file structure and long-term storage will be maintained by the principal investigator. While the use of an institutional repository to back up all data generated from the project is acceptable, the long term cost associated with monthly/yearly subscriptions make the use of a non-portable storage device much more affordable for most of the generated data.

The dissemination of the research results will also include publications that include persistent identifiers that are maintained by the publishers. Often digital object identifiers are used to reference and find that information. Although a journal has not been identified for publication, it is anticipated that the publisher will maintain a persistent identifier.

Describe how you intend to archive your data and why you have chosen that particular option. You may select from a variety of options including, but not limited to:

- Use of an institutional repository
- Use of an archive or other community-accepted data storage facility
- Self-dissemination

You must describe the dataset that is being archived with a minimum amount of metadata that ensures its discoverability. Whatever archive option you choose, that archive must support the capture and provision of the US Federal Government "Common Core" metadata. In addition, the archive you choose must support the creation and maintenance of persistent identifiers and must provide for maintenance of those identifiers throughout the preservation lifecycle of the data. Your plan should address how your archiving and preservation choices meet these requirements.

Checklist

o How will the data be archived for preservation and long-term access?
o How long should it be retained (e.g., 3-5 years, 10-20 years, permanently) ?
o What file formats? Are they long-lived?
o Are there data archives that my data is appropriate for (subject-based? Or institutional)?

o Who will maintain my data for the long-term?

NOTE:

Researchers evaluating data repositories as the option(s) for storing and preserving their data should examine evidence demonstrating that the repository:

a. Promotes an explicit mission of digital data archiving;

b. Ensures compliance with legal regulations, and maintains all applicable licenses covering data access and use, including, if applicable, mechanisms to protect privacy rights and maintain the confidentiality of respondents;

c. Has a documented plan for long-term preservation of its holdings;

d. Applies documented processes and procedures in managing data storage;

e. Performs archiving according to explicit work flows across the data life cycle;

f. Enables the users to discover and use the data, and refer to them in a persistent way through proper citation;

g. Enables reuse of data, ensuring appropriate formats and application of metadata;

h. Ensures the integrity and authenticity of the data;

i. Is adequately funded and staffed, and has a system of governance in place to support its mission; and

j. Possesses a technical infrastructure that explicitly supports the tasks and functions described in internationally accepted archival standards like Open Archival Information System (OAIS).

**These guidelines are based on the Data Seal of Approval.

METADATA TRANSMITTAL SCHEMA

Title[1]	Human-readable name of the asset. Should be in plain English and include sufficient detail to facilitate search and discovery. A name given to the publication or data element. **All substitute or alternative titles must have a different Metadata Transmittal Schema**
Creator/contact point	An entity/person(s) primarily responsible for making the content of the resource. Contact person's name and email for the asset.
Publication Date(s)	The date associated with the final report/dataset.
Description/Abstract	Human-readable description (e.g., an abstract) with sufficient detail to enable a user to quickly understand whether the asset is of interest. May include abstract, table of contents, reference to a graphical representation of content or a free text account of the content.
Subject and Keywords	The topic of the content of the resource. Tags (or keywords) help users discover your dataset; please include terms that would be used by technical and non-technical users.
Identifier[2] and/or source	A unique identifier for the dataset/publication. Examples: URI, URL, DOI, ISNB, ISSN.
Edition	Most recent date on which the dataset was changed, updated or modified.
Coverage	Spatial location, temporal period, jurisdiction.
Language	The language of the dataset/publication.
Publisher/Distributor	**FHWA and Wyoming Department of Transportation**

[1] *To include alternate title; conference title; and journal title if they are different.*
[2] *To include record numbers; report numbers; NTIS number; TRIS Accession Number; OCLC Number; ISBN; ISSN; contract number; and DOI if available.*
Red Text indicates NTL Required information.

	List all other publishing companies that this publication has been sent to.
Funding agency	**FHWA and Wyoming Department of Transportation**
Access Restrictions	The degree to which this dataset **could** be made publicly-available, *regardless of whether it has been made available*. Choices: public (Data asset is or could be made publicly available to all without restrictions), restricted public (Data asset is available under certain use restrictions), or non-public (Data asset is not available to members of the public).
Intellectual Property and Other Rights	This may include information regarding access or restrictions based on privacy, security, or other policies. This should also serve as an explanation for the selected “accessLevel” including instructions for how to access a restricted file, if applicable, or explanation for why a “non-public” or “restricted public” data asset is not “public,” if applicable.
License	The license or non-license (i.e. Public Domain) status with which the dataset or API has been published.
Format	The machine-readable file format. May include media type or dimensions. Used to determine the software, hardware or other equipment needed to display or operate the resources.
Collection	The collection of which the dataset is a subset. Include all identifiers and/or sources.
Related Documents	Related documents such as technical information about a dataset, developer documentation, etc.
Data Organization	
Size of file	