Development of Load and Resistance Factor Design Procedures for Driven Piles on Soft Rocks in Wyoming

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BACKGROUND STATEMENT

Steel driven piles are typically used to support bridges due to their high driving durability on rock materials and a shallow bedrock stratigraphy in Wyoming. The total axial resistance of these piles consists of a combination of shaft resistance and end bearing. To attain the required resistance, especially in a soft overburden soil, the pile would have to rely on its end bearing on this material. Soft rock is not well defined for driven piles in the American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design Specifications (2014). However, intermediate GeoMaterial (IGM) is referred as a softer rock or stiff overly-consolidated soil materials for drilled shaft design and construction. Defined by O'Neill and Reese (1999), cohesive IGM materials are clay shales or mudstones with undrained shear strength (S_u) of 5 to 50 ksf. Cohesionless IGM materials are granular tills or granular residual soils with a corrected SPT N-value ($N1_{60}$) falls between 50 and 100 blows per ft. Due to the natural variability of soft rock or IGM materials, uncertainties in deep foundation design are exacerbated, leading to many construction challenges (Mokwa and Brooks 2008).

The AASHTO LRFD Bridge Design Specifications (2014) provide the following general recommendations for piles driven on rocks.

(1) Piles driven on soft rock shall be treated in the same manner as soil;
(2) There are no well acceptable approaches to differentiate soft from hard rocks. However, local experience with driving piles on soft rocks shall be applied to define its quality; and
(3) Piles shall be driven based on locally developed criteria to prevent pile damage. Dynamic analysis methods should be used to evaluate pile drivability, control pile driving, and detect pile damage.

Wyoming Department of Transportation (WYDOT) currently adapts the AASHTO Specifications (2014) and applies local experiences to design and construct these pile foundations. A site investigation is normally performed by the Geology Program at every bridge project to determine its subsurface profile and geomaterial properties. Standard Penetration Test (SPT) is the most commonly used in-situ field test in Wyoming. At the same location for SPT test, a drivepoint penetration test is performed by driving a 2-in diameter drivepoint into the ground using a 140-lb hammer at a drop height of 30 in. Hammer blow counts to penetrate the drivepoint 12 inches into the ground are recorded. The main purpose of the drivepoint penetration test is to determine the depth of an adequate bearing layer, such as unweathered bedrock, for the end bearing pile. When a bedrock layer is encountered, rock coring will be performed to determine the Rock Quality Designation (RQD) value, and rock samples will be tested for the uniaxial compressive strength (q_u). The Geology Program has developed a table of typical properties of soil materials for pile capacity estimation while locally calibrated unit shaft resistance and end bearing of piles on soft rocks are currently not available. Hence, it is a challenge to estimate accurate shaft resistance and end bearing of a pile driven on soft rocks. The uncertainties of pile performance in terms of resistance are high before it can be verified during construction. The current practice of WYDOT uses Wave Equation Analysis Program (WEAP) to establish pile driving criteria for all production piles. Pile Driving Analyzer (PDA) with subsequent signal matching analyses using the CAse Pile Wave Analysis Program (CAPWAP) is used as a construction control method on about 2% of the production piles in some bridge projects. PDA/CAPWAP is implemented to determine and verify the required pile capacity at bridge projects expecting high loads and soft rock bearing. Pile restrikes at 24 hours after the end of driving (EOD) are normally performed to further ensure that the desired pile resistance is achieved and pile performance is accepted.

PROBLEM STATEMENT

The aforementioned background leads to the following general design and construction challenges pertaining to piles driven on soft rocks:

Design Challenges

1) Geotechnical resistance normally governs the design of piles driven on soft rocks. However, static analysis methods are not available for pile resistance estimation. The AASHTO LRFD Bridge Design Specifications (2014) recommend that piles driven in soft rocks shall be designed in the same manner as soil while piles driven in hard rocks shall be governed by the structural limit. However, pile resistances in soft rocks are usually under-predicted, and pile-rock-soil interaction is normally not known in a structural analysis (Ng et al. 2015). Furthermore, no clear definition of soft rocks is available, and they are normally differentiated based on local experiences.
2) To satisfy the LRFD strength limit state as given by Equation (1) where γ is the load factor, Q is the applied load, φ is the resistance factor and R is the pile resistance, resistance factors were developed for piles driven in soil materials (AASHTO 2014). However, resistance factors for driven piles on soft rock materials are currently not available.

$$\sum \gamma_i Q_i \leq \varphi R \tag{1}$$

3) The natural variability of soft rocks creates a high uncertainty in the subsurface condition for pile designs. Also, knowledge on the rock quality is limited to typical properties in terms of rock quality designation (RQD) and uniaxial compressive strength (q_u). Advanced strength parameters required in the characteristic lines method proposed by Serrano and Olalla (2002) based on Hoek and Brown's non-linear failure model are not readily available for more complex pile analyses. Hannigan et al. (2006) acknowledged that pile-rock contact area, penetration depth, and rock quality are usually not available for the pile resistance estimation during the design state. However, the subsurface investigation normally performed by the Geology Program enables the estimation of pile penetration depth and basic rock properties.

Construction Challenges

1) Congruent to the design challenges, total resistance of a pile on soft rock is typically determined using dynamic analysis methods during construction. Furthermore, static load test, which is expensive and time consuming, is usually neither performed to verify the pile resistance nor calibrate the dynamic analysis methods. According to Thompson and Thompson (1985), pile load test results should be used for the pile design because strength of weathered rock could govern the pile design, and pile resistance could decrease due to rock relaxation.
2) Large discrepancies between estimated and measured pile resistances were identified by the PI while analyzing pile data provided by the Geology Program in the past three years (Ng et al. 2015). It is not unusual that these piles do not satisfy the LRFD strength limit state at the end of driving (EOD) and occasionally at the beginning of last restrike (BOR). Table 1 illustrates the pile performance acceptances for WEAP and PDA/CAPWAP used as the construction control methods. When PDA/CAPWAP was used as the governing construction control method, 14 production piles at two projects (Torrington and Owl Creek) were considered unacceptable. However, it is important to note that WEAP was used to evaluate all production piles while PDA/CAPWAP covered only about 2% of the total production piles. When the pile performance is not attained during construction, possible pile extension and/or additional piles with an enlarged pile cap will be proposed to achieve the required resistance. This could incur additional

construction duration and operational cost.

3) The high uncertainty in pile performance could incur difficulty in the construction management since foundation construction is the critical path of a bridge project. This uncertainty could result in higher construction bids, higher frequency of claims, and higher design safety for offsetting the challenge in construction management (Mokwa and Brooks 2008).
4) Conflicts between owners and contractors could occur. These conflicts could result in change-orders to the original contract for additional claims and time to achieve the required pile performance.

Table 1. Summary of pile performance acceptances in Wyoming in the past three years

Bridge Project	**No. of Piles[$]**	**Pile Performance Acceptance**			
		WEAP		**CAPWAP**	
		EOD	**BOR**	**EOD**	**BOR**
Burns South (PI3P1)	21	No (-41%)	No (-40%)	No (-7%)	Yes (0.4%)
Burns south (A1P1)	5	No (-36%)	No (-34%)	Yes (2%)	Yes (11%)
Casper (A2P1)	14	Yes (33%)	Yes (33%)	Yes (30%)	Yes (46%)
Torrington (A2P1)	9	No (-15%)	Yes (6%)	No (-28%)	No (-19%)
Owl Creek (B2P5)	5	No (-30%)	No (-27%)	No (-12%)	No (-5%)
Woods Wardell (PI2P1)	14	No (-65%)	No (-63%)	No (-3%)	Yes (10%)
Pine Bluffs-Parsons St (A1P5)	5	Yes (6%)	Yes (8%)	Yes (7%)	Yes (13%)
Pine Bluffs-Parsons St (A2P1)	5	Yes (6%)	No (-2%)	No (-4%)	Yes (2%)
Pine Bluffs-Muddy Creek (A2P1)	6	No (-7%)	n/a	Yes (22%)	n/a
Pine Bluffs-Muddy Creek (B2P1)	5	No (-31%)	n/a	Yes (0.03%)	n/a
Pine Bluffs-Muddy Creek (B3P10)	5	No (-20%)	n/a	Yes (49%)	n/a
Pine Bluffs-Beech Street (A1P1)	5	No (-9%)	Yes (5%)	Yes (0%)	Yes (9%)
Pine Bluffs-Beech Street (A1P5)		No (-6%)	Yes (24%)	Yes (8%)	Yes (28%)
Pine Bluffs-Beech Street (A2P1)	5	No (-11%)	Yes (8%)	Yes (8%)	Yes (16%)
Pine Bluffs-Beech Street (A2P3)		Yes (6%)	Yes (3%)	Yes (16%)	Yes (22%)

B−Bent No.; PI−Pier No; A−Abutment No.; P−Pile No. as the test pile; [$]−Number of production piles at the respective bent, pier or abutment location; Yes−Satisfied the LRFD strength limit state; and No−Did not satisfy the LRFD strength limit state; and (%)−Percent of measured factored resistance (φR) higher (positive) or lower (negative) than the required factored load (γQ).

RELATIONSHIP TO WYDOT STRATEGIC GOALS

The project outcomes will address the following WYDOT strategic goals.

1) *State of Good Repair* – Since pile foundation is a critical element of our highway infrastructure, it is essential to properly design, construct, and maintain these pile foundations to maximize its productivity and performance and minimize full life cycle costs.
2) *Safety* – It is a good practice and responsibility of a pile design engineer to ensure the LRFD strength limit state described in Eq. (1) is satisfied and a target safety margin is achieved.
3) *Economic Competiveness* – Advancing the current knowledge of piles on rocks will minimize the existing design and construction challenges, which will lead to an efficient and economic pile foundation system.
4) *Environmental Sustainability* – The research outcomes will indirectly reduce unnecessary pile materials and driving efforts that use non-renewable natural resources, such as fossil fuels, during construction.

GOAL AND OBJECTIVES

The overall goal of the proposed research project is to develop locally calibrated LRFD procedures (i.e., design methodologies and resistance factors) for driven piles on soft rocks in Wyoming. Recognizing the design and construction challenges of piles driven on soft rocks, the research project is proposed to accomplish the following objectives:

1) To advance the knowledge of design and construction of piles driven on soft rocks;
2) To alleviate the aforementioned design and construction challenges; and
3) To advance the current state of practice pertaining to the design and construction of piles on soft rocks in Wyoming.

STATEMENT OF WORK

The research program was established based on the aforementioned research goal and objectives. The research objectives will be achieved by completing eight major tasks.

<u>Task 1: Literature Review</u>

This task will focus on conducting a literature review pertinent to the design and construction of piles driven on rocks, especially soft rocks. This task will provide the necessary references and data for completing the subsequent tasks. The literature review will include the following activities:

1) Conduct a literature search for documents, papers, reports, catalogs, manuals, notes, and presentation slides pertinent to the design and construction of driven piles on rocks;
2) Document and review the current state of knowledge and the current state of practice relating to driven piles on rocks;
3) Study current specifications and guidelines adopted by various Departments of Transportation (DOTs), AASHTO, and other agencies pertinent to driven piles on rocks;
4) Identify criteria adopted by state DOTs and agencies to differentiate soft and hard rocks;
5) Identify usable driven pile data for subsequent tasks; and
6) Identify gaps in the body of knowledge.

<u>Task 2: Usable Data Collection and Electronic Database Development</u>

High quality and usable data containing subsurface, pile, hammer, installation, and load test information will be identified and collected while conducting Task 1. The PI has collected at least fifteen usable pile data from the WYDOT Geology Program as summarized in Table 2. The PI will work closely with the Geology Program to gather more historical and new pile data. The PI has the full access to the driven pile database PILOT developed for the Iowa DOT (Roling et al. 2010), pile data records contained in the database PD/LT2000 used to develop resistance factors summarized in the NCHRP Report 507 (Paikowsky et al. 2004), and the Federal Highway Administration (FHWA) pile database DFLTD (Abu-Hejleh et al. 2015; Kalavar and Ealy 2000). Particularly, the PD/LT2000 database has 22 piles driven on rocks. Among these 22 piles, 13 are steel H-piles ranging from HP10×42 to HP12×74. The DELTD database contains 685 pile load tests from 15 states, and about 600 piles were driven in rock. Other pile data records for the Minnesota DOT (Paikowsky et al. 2014), Oregon DOT (Smith et al. 2010), Florida DOT (McVay et al. 1998), Caltrans (Smith et al. 2010), Illinois DOT (Long et al. 2009), Montana DOT (Mokwa and Brooks 2008), and Louisiana DOT (Yong et al. 2008) will be examined to identify and collect usable pile data pertaining to this research. All usable pile data will be stored in an electronic database developed using a commercial program, such as Microsoft Office Access, that has the capability of performing efficient filtering, sorting, and querying procedures on the amassed pile data set.

Task 3: Subsurface and Geo-Material (Soil and Rock) Assessment

Using the database developed in Task 2, piles driven on a similar rock type will be sorted and grouped. Likewise, grouping can be efficiently conducted based on pile type, location, hammer, and load test methods. Geotechnical reports and subsurface profiles will be assessed to determine properties of overburden soils and underlying soft rock materials necessary for pile resistances estimation in Task 4. Correlation studies to determine the geomaterial parameters, such as Geological Strength Index (GSI), elastic modulus, and Poisson's ratio, will be presented. The stratigraphy, geologic formation, and discontinuity of rocks will be described. These characteristics and properties will be summarized for subsequent studies.

Table 2. Summary of fifteen usable pile data collected in Wyoming in the past three years

Project	Structure	Steel H-Pile	Emb. Pile Length (ft)	Hammer	Overburden Soil	Soft Rock
Burns South	Pier 3	14×73	39	Delmag D16-32	Silty Sand	Sandstone
	A1	14×73	72	Delmag D16-32	Silty Sand	Sandstone
Casper St.	A2	14×73	33	MVE M-19	Silty Sand/Gravel	Sandstone
Torrington Street	A2	14×73	100	MVE M-19	Well to Poorly Graded Sand	Claystone
Owl Creek	Bent 2	14×73	34	ICE-42S	Silty Sand/Gravel	Shale
Woods Wardell	Pier 2	12×53	23	APE D19-42	Silty Sand/Gravel	Siltstone to Claystone
PB-Parsons St	A1	12×53	88	Delmag D16-32	Sandy Silt	Siltstone
	A2	12×53	75	Delmag D16-32	Sandy Silt	Siltstone
PB-Muddy Creek	A2	12×53	54	Delmag D16-32	Sandy Silt	Siltstone
	Bent 2	12×53	35	Delmag D16-32	Sandy Silt	Siltstone
	Bent 3	12×53	38	Delmag D16-32	Sandy Silt	Siltstone
PB-Beech Street	A1-P1	12×53	47	Delmag D16-32	Sandy Silt	Siltstone
	A1-P5	12×53	47	Delmag D16-32	Sandy Silt	Siltstone
	A2-P1	12×53	45	Delmag D16-32	Sandy Silt	Siltstone
	A2-P3	12×53	47	Delmag D16-32	Sandy Silt	Siltstone

PB−Pine Bluffs; A−Abutment; P−Test Pile; Emb.−Embedded; MVE−Mississippi Valley Equipment Company; and ICE−International Construction Equipment.

Task 4: Pile Resistance Estimation and Statistical Analysis

Using the data collected from previous tasks, the geotechnical resistances of driven piles identified as usable data records will be estimated using static analysis methods specified in the AASHTO LRFD Bridge Design Specifications (2014). These static analysis methods are 1) α-method by Tomlinson (1987), 2) β-method by Esrig and Kirby (1979), 3) λ-method by Vijayvergiya and Focht (1972), 4) SPT method by Meyerhof (1976), and 5) Nordlund (1979) method. Also, the static analysis method by the Canadian Geotechnical Society (1985) for end bearing in rock materials described in the AASHTO (2014) will be evaluated. Also, pile resistances will be estimated using dynamic analysis methods (e.g., wave equation analysis method). Estimated resistances will be compared with resistances measured by static load tests. If the static load test results are not available, the comparison will be performed using the next best available resistance estimated by the dynamic testing based on a signal matching technique (i.e., CAPWAP). To account for potential pile setup, a more accurate nominal shaft resistance at the BOR and end bearing at the EOD will be considered in this study. This comparison will evaluate the appropriateness of the static analysis methods and the dynamic analysis methods. The comparison will be performed by determining the statistical distribution of a ratio of measured to estimated geotechnical resistances and its associated statistical parameters (i.e., resistance bias and coefficient of variation). These statistical parameters will be applied in Task 6 for the development of locally calibrated LRFD resistance factors (φ) using probability-based methods, specifically for driven piles on soft rocks in Wyoming. This study will provide the basis for the calibration of static analysis methods conducted in Task 5. Recommendations on the application of static analysis methods will be provided in Task 8.

Task 5: Calibration of Static Analysis Methods

The existing static analysis methods were developed based on piles driven in soil materials. They tend to underestimate the side resistance and end bearing of piles driven on soft rocks. Using the measured pile resistances obtained from static load tests or the resistance distribution estimated by CAPWAP, static analysis methods will be calibrated by modifying respective empirical coefficients (e.g., adhesion factor (α) defined in the α-method) and incorporating soft rock properties (e.g., uniaxial compressive strength). Calibration of each static analysis method will be performed using a regression analysis technique to reestablish the relationship of empirical coefficients specifically for piles driven on soft rock materials. Furthermore, an independent set of usable pile data that are not used in the calibration will be established for the verification of calibrated static analysis methods by statistically comparing the estimated and measured resistances. However, it is important to note that calibration and verification of static analysis methods can only be successfully performed if adequate usable pile data sets are available.

Task 6: Development of Resistance Factors

Using the statistical results from Tasks 4 and 5, LRFD resistance factors will be determined using probability-based reliability methods, such as First-Order Reliability Method (FORM), First-Order Second Moment (FOSM) method, and/or Monte-Carlo simulation. The reliability methods will ensure that the regionally calibrated resistance factors would satisfy the LRFD framework as required by AASHTO (2014). These reliability methods will account for different uncertainties induced by parameters, such as variability of soft rocks and deficiency of a design method, that influence the accuracy of resistance estimations while maintaining a common target reliability index to ensure a prescribed margin of safety. The regional LRFD resistance factors specific to the State of Wyoming will be developed based on the assumptions made in the reliability methods, recommended numerical values for probabilistic characteristics of loads as documented by Paikowsky et al. (2004) and Allen (2005), and AASHTO (2014) suggested reliability index of 2.33 for commonly used redundant pile groups (i.e., a group of five or more piles). For a non-redundant pile group, a higher reliability index of 3.00 will be used to account for the lower redundancy. The reliability indexes of 2.33 and 3.00 are corresponded to approximate failure probabilities of 1 in 100 and 1 in 1000, respectively. To increase the efficiency of LRFD and to provide better recommendations, resistance factors using different reliability methods will be developed and compared for existing and/or calibrated static analysis methods as well as the WEAP method. If static load test results are available for the statistical analysis, the resistance factor for PDA/CAPWAP will be calibrated. The calibrated resistance factors will be adjusted if necessary to maintain consistency and resolve any anomalies observed among the factors. Finally, a set of resistance factors for both design and construction control methods will be recommended.

Task 7: Criteria Assessment for Soft and Hard Rocks

Current WYDOT criteria to differentiate soft and hard rocks will be documented and assessed. The assessment will be performed by reviewing and comparing the historical and current pile design and driving data on both soft and hard rocks. Relevant WYDOT guidelines, specifications, and subsurface investigation reports will be reviewed. WYDOT practice will be compared with criteria adapted by other state DOTs and agencies gathered from the literature review in Task 1. Recommendations to current WYDOT criteria will be established to facilitate the differentiation of soft and hard rocks for pile design and construction.

Task 8: Outcomes and Recommendations

Upon completion of Tasks 1 through 7, research outcomes will be determined and recommendations will be established to facilitate the design and construction of driven piles on soft rocks in Wyoming. The anticipated research outcomes and recommendations are summarized as follows:

1) A collection of usable pile data.
2) An electronic pile database for pile analyses, LRFD resistance factor development, and future pile data collection.
3) A catalog of soft rock properties for pile designs.
4) Calibrated static analysis methods for the estimation of shaft resistance and end bearing of piles driven on soft rocks.
5) A set of recommended resistance factors for design and construction control methods.
6) Recommendations on current WYDOT criteria for the differentiation of soft and hard rocks.
7) Recommendations of pile design and construction best practices.
8) Recommendations for the revision of existing WYDOT pile design and construction specifications and guidelines.

The research outcomes and recommendations will provide WYDOT the basis for the establishment of revised guidelines and specifications pertaining to piles driven on soft rocks. It is envisioned that the recommendations will satisfy the study objectives and bring benefits to WYDOT and relevant stakeholders.

Schedule

The projected duration for the research presented in this proposal is 30 months or 10 quarters, tentatively beginning July 2016 through December 2018. A time schedule is shown in Table 3.

Table 3. Detailed schedule proposed for the research tasks

Task		2016		2017				2018			
		Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Literature Review	■	■	■							
2	Data Collection and Electronic Database Development		■	■	■	■	■	■	■	■	
3	Subsurface and Geo-material Assessment			■	■	■					
4	Pile Resistance Estimation and Statistical Analysis				■	■	■	■			
5	Calibration of Static Analysis Methods						■	■	■		
6	Development of Resistance Factors							■	■	■	
7	Criteria Assessment for Soft and Hard Rocks	■	■	■	■	■				■	
8	Outcomes and Recommendations										■

BENEFITS

The proposed research project will have several direct benefits to WYDOT, deep foundations industry and other relevant stakeholders. These anticipated benefits to design and construction of driven piles on soft rocks are described as follows:

Benefits to Design:

1) An electronic pile database for pile analyses and future pile data collection.
2) A catalog of representative soft rock properties.

3) Recommendations of locally calibrated static analysis methods for estimating geotechnical resistances of piles driven on soft rocks prior to construction.
4) Incorporation of local experiences into criteria to differentiate soft and hard rocks.
5) Better estimation of geotechnical resistances of driven piles on soft rocks.
6) Facilitation of pile designs using locally calibrated resistance factors.
7) Avoidance of conservative pile designs.
8) Improvements to existing LRFD pile design practices, specifications, and guides.

Benefits to Construction:

1) Reduction of the discrepancy between estimated and measured pile capacities.
2) Attainable target pile capacity during construction verified using dynamic analysis methods or static load test method.
3) A set of locally calibrated resistance factors for construction control methods.
4) Lower uncertainty in pile performance.
5) Facilitation of pile construction management: yielding lower construction bids, avoiding construction delays, minimizing additional operational costs, and reducing the possibility of additional claims.
6) Avoidance of unnecessary conflicts between foundation contractors and WYDOT.
7) Improvements to existing LRFD pile construction practices, specifications, and guides.

DELIVERABLES

To update the progress of the research project, short quarterly reports will be submitted to WYDOT Research and Geology Programs. Also, a yearly interim report will be submitted to WYDOT at the end of 2016 and 2017 to report the research progress. 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.

BUDGET

The detailed budget estimate requested from WYDOT is presented in Table 4. Funds are requested to support wages covering 2 months for the PI, 24 months for a PhD graduate research assistant, 18 months for a MS graduate research assistant, and 300 hours for an undergraduate research assistant. The fringe benefits for each employee are charged individually as direct costs in accordance with the current rates: 1) 49.863% for PI, and 2) 0.606% for the undergraduate and graduate research assistants. A domestic travel cost of $2,500 is included to cover all travelling expenses required to perform Tasks 2 and 7 involving historical pile data collection, present research results and final report to WYDOT, and disseminate research outcomes at one national conference. A budget of $200 for supplies and materials is included to cover the rental fee of statistical software, such as Minitab 17, required in Tasks 4, 5 and 6. Tuition and health insurance of the two graduate students are included under the other direct cost with a total amount of $31,063. The indirect cost with a rate of 20% is charged on all direct costs except the tuition and health insurance. The total cost estimate for this research project is $160,372. This total cost will be spread over in three years with $16,647 for year 2016, $87,249 for year 2017, and the remaining $56,475 for year 2018.

Table 4. Detailed budget estimate for the proposed research

Development of Load and Resistance Factor Design Procedures for Driven Piles on Soft Rocks in Wyoming

Budget Estimate

	YEAR 2016		YEAR 2017				YEAR 2018				
	Q3	*Q4*	*Q1*	*Q2*	*Q3*	*Q4*	*Q1*	*Q2*	*Q3*	*Q4*	Subtotal
Salary											
Principal Investigator (2 months)	$ -	$ -	$ -	$ -	$ 9,272	$ -	$ -	$ -	$ 9,272	$ -	$ 18,545
PhD Graduate Research Assistant (24 months)	$ -	$ -	$ 5,850	$ 5,850	$ 5,850	$ 5,850	$ 5,850	$ 5,850	$ 5,850	$ 5,850	$ 46,800
MS Graduate Research Assistant (18 months)	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ 4,500	$ -	$ -	$ -	$ -	$ 27,000
Undergraduate Research Assistant (300 hours)	$ 600	$ 600	$ 600	$ 600	$ 600	$ -	$ -	$ -	$ -	$ -	$ 3,000
Fringe											
Principal Investigator (2 months)	$ -	$ -	$ -	$ -	$ 4,624	$ -	$ -	$ -	$ 4,624	$ -	$ 9,247
PhD Graduate Research Assistant (24 months)	$ -	$ -	$ 35	$ 35	$ 35	$ 35	$ 35	$ 35	$ 35	$ 35	$ 284
MS Graduate Research Assistant (18 months)	$ 27	$ 27	$ 27	$ 27	$ 27	$ 27	$ -	$ -	$ -	$ -	$ 164
Undergraduate Research Assistant (300 hours)	$ 4	$ 4	$ 4	$ 4	$ 4	$ -	$ -	$ -	$ -	$ -	$ 18
Travel-Domestic	$ -	$ 150	$ 150	$ 150	$ -	$ -	$ -	$ -	$ -	$ 2,050	$ 2,500
Supplies/Materials	$ -	$ -	$ -	$ 100	$ -	$ -	$ -	$ 100	$ -	$ -	$ 200
Other Direct Costs											
Graduate Student Tuition and Health Insurace	$ 4,153	$ -	$ 8,986	$ 648	$ 8,306	$ -	$ 4,493	$ 324	$ 4,153	$ -	$ 31,063
Total Direct Cost:	$ 9,284	$ 5,281	$ 20,152	$ 11,914	$ 33,218	$ 10,413	$ 10,378	$ 6,309	$ 23,934	$ 7,935	$ 138,820
UW Indirect Costs (20%)	$ 1,026	$ 1,056	$ 2,233	$ 2,253	$ 4,982	$ 2,083	$ 1,177	$ 1,197	$ 3,956	$ 1,587	$ 21,551
Total Costs Per Quarter	$ 10,310	$ 6,337	$ 22,386	$ 14,168	$ 38,201	$ 12,495	$ 11,556	$ 7,507	$ 27,891	$ 9,523	
Total Costs Per Year	$	16,647	$			87,249	$			56,475	
TOTAL ALL COSTS	**$ 160,372**										

FACILITIES

The PI has the required software programs to perform the static and dynamic analyses described in Task 4. The Department of Civil and Architectural Engineering at UW has computer, structural, and geotechnical/material laboratories, which are adequate for this research project. 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.

IMPLEMENTATION

The aforementioned research outcomes and recommendations will directly benefit WYDOT, especially the Geology and Bridge Programs or other programs that involve in the design and construction of bridge pile foundations. The research project will provide improvement to the existing WYDOT design and construction practices, specifications and guidelines pertaining to bridge pile foundations installed on soft rocks. This implementation plan will be performed in close coordination with the WYDOT representatives in the Geology and Bridge Programs. The final report will include a section specifically highlighting the research outcomes for WYDOT implementation. Recommendations established from this research study shall be evaluated on several future pilot bridge projects before a full implementation. Lessons learned from these future pilot projects will help the WYDOT to adjust and revise their existing design and construction practices, specifications and guidelines.

TECHNOLOGY TRANSFER

Technology transfer will be performed in close coordination with WYDOT, especially the Geology Program, throughout the entire project. The final report will provide recommendations for potential revisions to exiting WYDOT design and construction specifications and guidelines. Research activities and outcomes will be summarized in the final report. They will be disseminated through peer-reviewed publications and technical presentations at state conferences, such as the annual Wyoming Engineering Society meeting, and national conferences, such as the TRB annual meeting.

DATA MANAGEMENT PLAN

The usable pile data obtained in Task 2 will consist of hammer, pile, geomaterial, driving, and load test information. These usable pile data sets will be collected in an electronic database. The usable pile data can be filtered and queried according to the specified location, hammer, pile, geomaterial, driving, and load test information. Also, all relevant documents, such as geotechnical reports, construction plans and test reports, will attached in a pdf format that can be easily extracted from the database. While developing the pile database, all pile data contained in folders under a research directory will be stored in an online file hosting service that offers cloud storage (e.g., Dropbox) as well as in the existing, multiple PI's RAID hard drive storage. The online file storage service allows the research team to access data remotely and share the data with WTDOT. All original data will be secured by the PI at UW. Furthermore, research findings and results will be disseminated in the forms of reports, journal papers, conference papers and technical presentations that can be widely shared with other researchers and the public as well as permanently documented by publishers and in conference proceedings. The data acquired and preserved in the context of this proposal will be further governed by the UW's policies pertaining to intellectual property, record retention, and data management.

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