Research Project Work Plan

for

EFFECTS OF HIGH STRENGTH STEEL BARS AND STEEL CASING ON THE RESPONSE OF DRILLED SHAFTS

SPR-765

Submitted by

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for

Oregon Department of Transportation (ODOT)

Research Section

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1.0 Identification

1.1 Organizations Sponsoring Research

Oregon Department of Transportation (ODOT)
Research Section
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Salem, OR 97301-5192 Phone: (503)986-2700

Federal Highway Administration (FHWA)
Washington, D.C. 20590

1.2 Principal Investigator(s)

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1.3 Technical Advisory Committee (TAC) Members

Matthew Mabey, ODOT, *Chair*
Jan L. Six, ODOT
Albert Nako, ODOT
Marie Kennedy, ODOT

1.4 Project Coordinator

Matthew Mabey, ODOT Phone: (503)986-2847

1.5 Project Champions

Craig Shike, P.E., ODOT

2.0 Problem Statement

Drilled shafts offer an excellent alternative for transferring superstructure loads to the soil and/or rock stratigraphy underlying bridges. Due to seismic demands, the density of the required internal steel reinforcements has increased significantly and has led to an increase in the frequency of construction defects. Evaluating alternative steel reinforcement approaches, such as the use of high strength steel bar or permanent steel casing may reduce the occurrence of construction defects. However, the geotechnical response of such alternatively constructed drilled shafts must be evaluated in order to understand the consequences for design and performance of these shafts.

2.1 Background

Drilled shafts provide significant geotechnical resistance for support of highway bridges, and are used throughout the State of Oregon to meet its structural foundation requirements. Due to changes in construction methods and poor near-surface soils, the use of permanent steel casing for drilled shaft installation has increased. However, geotechnical design models for axial and lateral resistance of drilled shafts are largely based on soil-concrete interfaces, not soil-steel interfaces associated with large diameter steel casing. Owing to the increased understanding of our regional seismic hazards, the amount of steel reinforcement used in drilled shaft construction has increased over the past several decades, creating a new construction concern for engineers: the increased steel area results in a reduced clearance between adjacent reinforcement bars in the steel cage, such that concrete has an increased difficulty in penetrating the cage, increasing the likelihood for voids and defects within the shaft, which can lead to poor structural and geotechnical performance. The use of high-strength reinforcement steel can lead to increased clearance within the steel cage, mitigating concreting issues. The use of steel casing and the amount of steel area control the axial and lateral resistance of the shaft. Thus existing approaches need to be evaluated for modern construction methods, and new approaches developed if necessary to ensure desired performance criteria are met.

2.2 Significance of Work

Existing geotechnical design techniques for drilled shafts, such as the estimation of axial and lateral capacity, have not been evaluated for use with drilled shafts constructed with permanent steel casing, or for the latter design requirement, with high-strength steel reinforcements. This work will confirm the suitability of existing design techniques, and will develop new recommendations if existing techniques prove incapable of adequately predicting shaft performance. Oregon DOT will be able to incorporate the benefits of these alternative construction methods directly into geotechnical shaft design.

3.0 Objectives and Benefits of this Study

3.1 Objectives

The objectives of this research are to study the impact of steel casing and high-strength steel reinforcement on the axial and lateral behavior of full-scale drilled shaft foundation elements and to evaluate the appropriateness of existing ODOT design procedures. If necessary, new procedures incorporating the effect of steel casing and high-strength steel reinforcement will be developed. Specifically, identical, instrumented test shafts will be constructed in order to evaluate the behavior of un-cased conventional, cased, and high-strength steel reinforced drilled shafts at the OSU Geotechnical Engineering Field Research Site. The axial and lateral capacity of these shafts will be evaluated, including axial load transfer (e.g., t-z and q-z behavior) and lateral load transfer (p-y behavior). Existing and accepted modeling software, such as TZ-Pile, L-Pile and DFSAP, will be evaluated, as will newer 3-D finite element method approaches such OpenSees. This research will confirm the suitability of existing methods for ODOT, or suggest recommendations for changes to ODOT procedures in order to maximize the benefit of steel-cased and high-strength steel reinforced shafts.

3.2 Benefits

Permanent steel casing is occasionally used in the construction of drilled shafts where dictated by the soil conditions and/or contractor change orders. However, the benefit of steel casing, such as the improved flexural rigidity and increased capacity of the concrete due to confinement is not presently incorporated into drilled shaft design. By incorporating the actual shaft behavior into the design process, significant direct cost savings could be realized in addition to the avoidance of post-construction claims associated with construction defects. Likewise, the reduction in percent steel due to the use of high strength steel could result in direct cost savings. This research is proposed to evaluate the geotechnical performance of alternatively constructed shafts so that the benefit of these alternatives can be utilized directly in the design of these foundation elements.

3.3 Safety

Safety is listed first among ODOT’s values that guide our decision making and which we follow in implementing ODOT's mission and goals. We protect the safety of the traveling public, our employees and the workers who build, operate and maintain our transportation system. Workers that perform research for ODOT are also included. It is expected that those that work on this project will conform to OSU’s institutional safety policies as well as State and Federal regulations. If there is ever a question about whether some part of this project can be completed safely, the issue should be communicated to the ODOT Project Coordinator listed above.

4.0 Implementation

Meetings will be held with ODOT personnel to present research findings and progress reports. The frequency of these meetings will be determined by the ODOT TAC members, however, at a minimum, there will be one progress meeting with ODOT at 18 months following the start of the contract, and 3 months before the submission of the draft final report to accelerate the

incorporation of TAC member suggestions. The results of this research will be drafted in a formal report and be aimed towards the incorporation of steel casing and high strength steel reinforcement into typical design procedures. It is anticipated that the guidelines and design specifications presented in the final report will be referenced and/or implemented in the ODOT Geotechnical and Structural Design Manuals for use by State engineers and design consultants. Additionally, the findings of this study will be disseminated through state and national presentations, conference proceedings, and journal publications.

5.0 Research Tasks

The research tasks proposed to achieve the objectives of this study are described in the following sections. Each task provides a time frame for completing the work, the party responsible for completing the work, the estimated cost of accomplishing the task, the deliverable to be produced (if applicable), and the action required by the TAC committee (if applicable).

5.1 Task 1: Literature Review and Survey

Drilled shafts have been studied for many years. Studies relevant to drilled shaft behavior, including axial load transfer, lateral load transfer, and structural behavior relevant to the interpretation of geotechnical response will be summarized in a literature review. Because much of the research regarding concrete-filled tubes (CFTs) is new, this work will be covered in detail in order to help build the methodology for interpreting load transfer. A questionnaire/survey will be prepared for and submitted to state DOTs, consultants, and contractors to determine the nationwide state of practice regarding the use of permanent steel casing and high-strength steel reinforcement to determine what, if any benchmarks, are currently used in practice.

- Time Frame: 3 months
- Responsible Party: Principal Investigator (OSU)
- Deliverable(s): (1) Literature review; will be supplied in draft final report, and (2) Evaluation and results of survey; provided to ODOT at end of task time frame
- TAC Decision/Action: Review the results of survey, discuss impacts to research scope and amend as necessary.

5.2 Task 2: Conduct Subsurface Investigation at OSU Geotechnical Field Test Site

The general location of the test drilled shafts has already been established, being driven by the presence of shafts that were previously installed (Figure 1), but not tested, by the Association of Drilled Shaft Contractors (ADSC) in 1997. One Cone Penetration Test (CPT) has been performed in proximity to the existing shafts, conducted 13 years ago. Although other explorations on the site exist (Figure 2), they lie too far away to inform a research-quality understanding of the subsurface corresponding to the actual test area. Therefore, a new subsurface investigation will be conducted, and will consist of two CPTs with shear wave velocity testing, two mud-rotary borings with SPT and Shelby-tube sampling, and laboratory index and strength testing. A soil profile will be developed and appropriate soil parameters determined for each unit encountered. Where applicable, inherent soil variability will be

characterized in order to help interpret the soil-structure interaction observed in Task 3 (described below).

- Time Frame: 3 months
- Responsible Party: Principal Investigator (OSU)
- Deliverable: Progress reports approximately every three months.
- TAC Decision/Action: Review of progress reports and advise PI if necessary.

5.3 Task 3: Install and Test Instrumented Drilled Shafts

Task 3 forms the experimental thrust of the proposed research, with the load testing of several alternatively constructed, instrumented drilled shafts. The geotechnical test site at Oregon State University (Figure 1) presents an ideal location to perform the proposed loading tests. The native soil profile (Figure 2) consists of stiff to very stiff, cohesive upper and lower Willamette Silt (ML/MH, and locally CL/CH), separated by a thin seam of dense silty sand (SP/SM). A slightly thicker medium dense to dense sand layer separates the Willamette Silt deposits from a thick and deep deposit of cohesive, stiff to very stiff silt and clay (MH/CH). The water table varies between 3 and 7 feet below the ground surface throughout the year. Figure 2 summarizes the soil profile and results of some in-situ and laboratory tests, however, new explorations within the shaft test area will be performed to support this research as described above for Task 2.

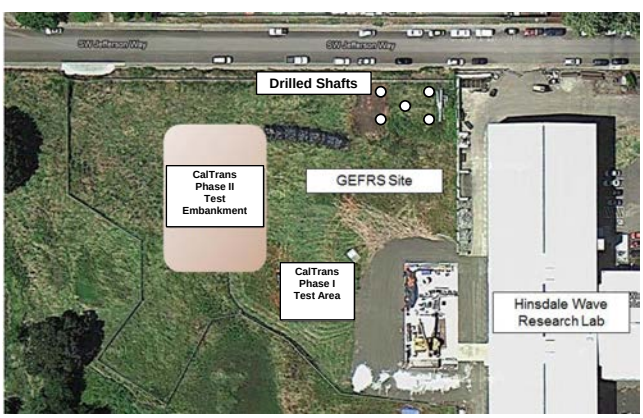

Figure 1. Aerial view of the test site, indicating location of existing drilled shafts (NOT TO SCALE).

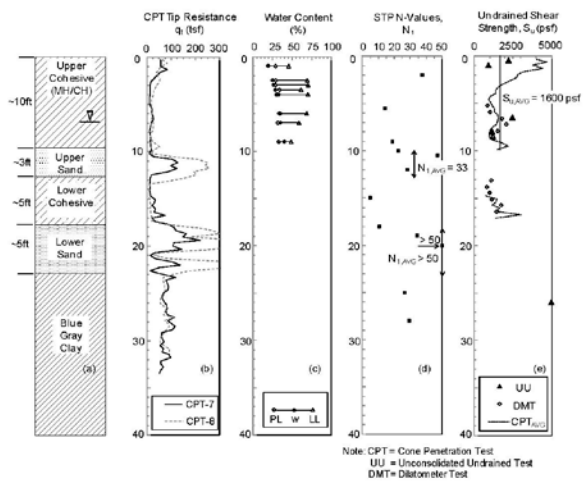

Figure 2. Typical soil profile for the test site.

The goal of Task 3 is to experimentally evaluate the alternative shaft construction techniques on geotechnical performance. The following five test shafts are proposed to be evaluated:

- Shaft A: original (1997) shaft, uncased, 36” diameter, 42’ long, 1.3% mild longitudinal steel;
- Shaft B: new shaft, uncased, 36” diameter, 60’ long, 2.0% mild longitudinal steel;

- Shaft C: new shaft, cased with 1/2” thick wall, 36” diameter, 60’ long, no mild longitudinal steel, 5.5% steel;
- Shaft D: new shaft, cased with 1/2” thick wall, 36” diameter, 60’ long, 2.0% mild longitudinal steel, 7.6% steel;
- Shaft E: new shaft, uncased, 36” diameter, 60’ long, 1.5% high strength longitudinal steel (equivalent to 2.0% mild steel).

The test program summarized above will allow original and new conventional shafts (A and B) to be compared to an identical shaft (E) with an equivalent amount of steel strength but with an increased rebar opening size. This comparison is important as it will illustrate differences in performance, if any, associated with improved constructability with regard to defect mitigation. The test program will also allow comparisons between the original and new conventional shafts (A and B) and shafts cased with steel pipes with and without internal longitudinal steel. As shown above, the unreinforced and cased shaft (C) has nearly three times the amount of steel as a conventional uncased shaft. If the steel provided by the casing can be incorporated into shaft design, significant cost savings will be realized due to labor, materials, and defect mitigation. Each of the test shafts will be instrumented to allow the observation of axial and lateral load transfer. Axial loading will occur first; lateral loading will be performed following a suitable rest period. Presently, the PI is investigating the possibility of using RIM Cells manufactured by Load Test, Inc., in a demonstration project. Should Load Test, Inc., donate the RIM Cells for this project, axial load testing will occur from the bottom of the shaft, similar to the approach Osterberg load cells. Otherwise, reaction shafts will be constructed in order to perform standard head-down axial loading tests.

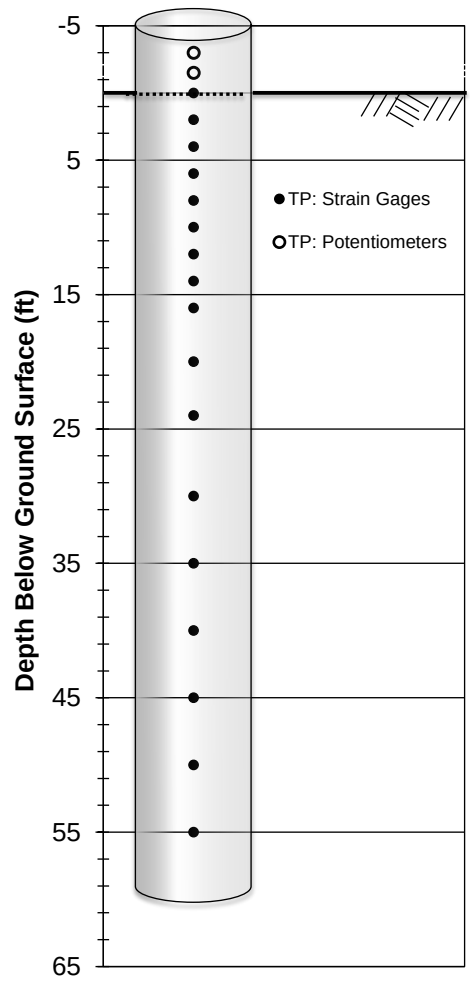

Figure 3. Proposed instrumentation plan for the test shafts.

Figure 3 illustrates the typical instrumentation program to be implemented for each test shaft. As shown in Figure 3, the shaft head will be instrumented with two string potentiometers to verify actuator-imposed displacements. Strain gages will be placed below the ground surface in pairs and at diametric locations parallel to the direction of loading in order to provide redundancy for the estimation of axial and lateral load transfer. Resistance gages will be used for the cased shafts by epoxying the gages directly to the casing; concrete embedment gages will be used for internally reinforced uncased shafts. The existing/original shaft will need to be cored and fitted with new embedment gages in order to obtain accurate load transfer observations. Shaft head loads will be measured using high resolution load cells for laterally

loaded shafts, and RIM Cells or load cells for axial transfer, depending on whether the shafts will be loaded in a head-down or toe-up manner.

The ADSC will construct the shafts, and therefore the budget presented below does not include the equipment, labor, and material costs associated with the shaft construction. The PI and student researchers will instrument the shafts during construction in order to allow the observation of axial and lateral load transfer; note, the budget *does* include the cost of the instrumentation required.

- *Time Frame:* 6 months
- *Responsible Party:* Principal Investigator (OSU)
- *Deliverable(s):* Progress reports approximately every three months
- *TAC Decision/Action:* Review of progress reports and advise PI if necessary

5.4 Task 4: Evaluate Axial and Lateral Load Transfer

The goal of Task 4 is to study the axial and lateral load transfer exhibited by the test shafts. Several actions will be pursued in Task 4, ranging from the prediction of capacity, the determination of the experimental load transfer, and the determination of experimental differences between conventional and the alternative shaft construction techniques. Class A predictions of axial and lateral capacity using common design software (DFSAP, LPile, etc.) and calibrated using subsurface information available to the PI *prior* to the completion of Task 2 will be performed to evaluate the accuracy of existing methods when used with incomplete information. Class B1 capacity predictions will also be made, the distinction being that the new subsurface information obtained from Task 2 will be used. This information will guide the design of the experimental work in Task 3. Following the completion of Task 3, experimental *t-z*, *q-z*, and *p-y* curves will be determined (forming the major effort of Task 4), and compared to *t-z*, *q-z*, and *p-y* curves assumed in commercially available software. Additionally, comparisons will be made to previously reported experimental load transfer curves, in order to determine if significant differences in behavior exist given differences in the engineering composition of the drilled shafts (e.g., steel casing vs. uncased; high-strength-steel vs. mild steel, etc.). If necessary, new generic load transfer curves will be proposed for use with the kinds of shafts evaluated. The work required to complete this task includes the structural section analysis of the various shafts in order to appropriately model the flexural rigidity of the drilled shafts, and therefore includes Senior Personnel, Dr. Andre Barbosa (of OSU), in the budget.

- *Time Frame:* 18 months
- *Responsible Party:* Principal Investigator (OSU)
- *Deliverable:* Progress reports approximately every three months
- *TAC Decision/Action:* Review of progress reports and advise PI if necessary

5.5 Task 5: Develop Design Guidance and Document Findings in Final Report

Task 5 includes the synthesis of information developed in Tasks 1 through 4 in an accessible report for use by design professionals. The report will summarize the literature review and survey of industry and DOT practice, detail the test program, and present the experimental load

transfer determined from the test program. Comparisons of the observed and predicted *t-z*, *q-z*, and *p-y* curves and modifications to the load transfer curves will be summarized, as appropriate. To the extent possible, design guidance will be consistent with LRFD. The experimental work and design guidance will also be provided in conference proceedings and journal papers.

- *Time Frame:* 6 months
- *Responsible Party:* Principal Investigator (OSU)
- *Deliverable(s):* Progress reports approximately every three months
- *TAC Decision/Action:* Review of progress reports and advise PI if necessary

6.0 Time Schedule

The thirty-six month schedule for the proposed research program is provided in the tables below, and provides the tasks and monthly time blocks for which each task will be accomplished. The schedule is requested to begin on January 1st, 2014, midway through the 2014 Fiscal Year, and be completed by December 31st, 2016. This schedule has been proposed based on the goal of maximizing the impact of the PacTrans portion of the funds.

The schedule shows the full-scale testing occurring in the summer and fall of FY 2015; this portion of the schedule is subject to the timing/scheduling dictated by the drilled shaft contractor that will be donating their services. Therefore, some variation in the proposed schedule should be anticipated.

Task	Research Task Topic	Year 1: FY 2014						Year 2: FY 2015											
		J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
1	Literature Review and Survey	X	X	X	x	x													
2	Subsurface Characterization			x	X	X	X	x	x										
3	Install and Test Instrumented Drilled Shafts					x	x	X	X	X	X	X	X	x	x				
4	Evaluate Axial and Lateral Load Transfer													X	X	X	X	X	X
5	Final Report																		
	Quarterly reports:			O			O			O			O			O			O

Task	Research Task Topic	Year 3: FY 2016												Year 4: FY 2017					
		J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
1	Literature Review and Survey																		
2	Subsurface Characterization																		
3	Install and Test Instrumented Drilled Shafts																		
4	Evaluate Axial and Lateral Load Transfer	X	X	X	X	X	X	X	X	X	X	X	X	x	x				
5	Final Report											x	x	X	X	X	X	X	X
	Quarterly reports:			O			O			O			O			O			O

X – Indicates major task work under way;
x – Indicates possible preparatory or minor polishing of task products.

7.0 Budget Estimate

An itemized budget for the project is included here, showing expenditures for each item by fiscal year and in total. An indirect (i.e., overhead) rate of 26 percent was assumed for all years for the purposes of budget estimation. As shown below, no personnel costs are planned for Fiscal Year 2014; rather, most of the personnel expenditures (students and PI) for FY 2014 and the first six months of FY 2015 will be billed to the parallel PacTrans budget. The only costs in FY 2014 planned for this budget (i.e., the ODOT budget) are related to experimental expenditures such as instrumentation, maintenance items to the lateral loading actuator, and subsurface explorations, which will be required to be purchased or completed prior to the begin of Task 3. Significant personnel costs for technicians are budgeted in FY 2015, and required to accomplish the experimental program.

	FY 2014	FY 2015	FY 2016	FY 2017	TOTAL
Personnel					
Professor	$0	$2,364	$9,672	$5,029	$17,065
Technicians	$0	$33,156	$0	$0	$33,156
Students	$0	$17,792	$27,108	$13,374	$58,273
Total Salaries	**$0**	**$53,312**	**$36,780**	**$18,403**	**$108,495**
Fringe Benefits					
Professor	$0	$946	$3,192	$1,660	$5,797
Technicians	$0	$15,008	$0	$0	$15,008
Students	$0	$2,303	$3,901	$1,855	$8,060
Total Fringe Benefits	**$0**	**$18,257**	**$7,092**	**$3,515**	**$28,864**
Tuition	$0	9,716	19,909	5,306	$34,931
Total Personnel Costs	**$0**	**$81,285**	**$63,781**	**$27,224**	**$172,290**
Travel	$0	1,500	3,500	3,500	$8,500
Services and Supplies	82,240	$0	$0	$0	$82,240
Total Direct Costs	$ 88,240	$ 82,785	$ 67,281	$ 30,724	$269,030
Total Indirect Costs	$ 22,942	$ 18,998	$ 12,317	$ 6,609	$60,866
Total Project Costs	**$111,182**	**$101,782**	**$ 79,598**	**$ 37,333**	**$329,896**