Fuller Mossbarger Scott & May

FMSM ENGINEERS

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Influence of Grout Confinement on Micro Pile Axial Load Capacity

Micro Pile Research Proposal
Association of Drilled Shaft Contractors
Dallas, Texas 75243

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Influence of Grout Confinement on Micro Pile Axial Load Capacity

Micro Pile Research Proposal

1. Introduction

This proposal describes research on the influence of grout confinement on the axial load capacity of micro piles. The proposal is written assuming the reader is familiar with micro pile terminology and design issues. The proposed project includes three components:

1) A review of literature on grout stress–strain behavior and design code requirements for strain compatibility between concrete and steel,

2) Laboratory testing of confined grout and small–scale micro pile elements, and

3) Development of a simplified model for predicting the ultimate axial load capacity of micro piles not considering end conditions.

The project would require about three months to complete with a budget between $21,900 and $27,400.

2. Research Needs

2.1. Deep Foundations Institute and Association of Drilled Shaft Contractors Micro Pile Committee Research Topics

The Association of Drilled Shaft Contractors (ADSC) and Deep Foundations Institute (DFI) Micro Pile Committee has identified the following micro pile research needs:

1) Strain Compatibility of Grout and Steel Bars.

2) Influence of Confinement in Rock on Axial Load Capacity

3) Elastic Properties of Grout

The fundamental issue identified by the ADSC-DFI Committee is that the maximum concrete strain used in design is 0.003 inches/inch. At this strain, the stress in steel reinforcing elements is 87 ksi for uniaxial loading conditions. Therefore, the maximum yield stress in compression of the reinforcing steel used in micro pile design is typically limited to 80 ksi or 87 ksi per the ACI 318 code or the FHWA Micro Pile Design and Construction Guidelines Manual. However, the experience of several ADSC-DFI committee members is that higher steel yield stresses and strains have been successfully used in practice.

2.2. Previous Research

A brief review of the literature reveals that the influence of confinement on the stress–strain behavior of concrete has been examined by researchers. One of the earliest and most significant studies was by Richart et al. (1928). Richart and his co-workers studied the influence of confinement on concrete and showed that stiffness, peak stress, and strain at peak stress increase as confinement increases. Figure 2.1 is based on data from the Richart et al. study. This effect can be attributed to the dilation characteristics of concrete.

Richart et al. proposed the following relationship for predicting the axial strength of confined concrete as a function of uniaxial compressive strength and confinement:

$$f_{cc} = f_c' + k\sigma_3$$

where f_{cc} is the axial compressive strength of concrete confined by the lateral stress σ_3, f_c' is the uniaxial compressive strength of the concrete, and k is the triaxial factor. Richart et al. also proposed the following predictive relationship for the axial strain at peak stress:

$$\varepsilon_{cc} = \varepsilon_c \beta_1 \left(\frac{f_{cc}}{f_c'} - \beta_2 \right)$$

where ε_c is axial compressive strain at peak uniaxial stress, and β_1 and β_2 are material parameters. They determined k =4.1, β_1 = 5 and β_2 = 0.8 to be appropriate values for concrete. The work on the stress–strain characteristics of concrete under compressive loads by Richart et al. and subsequent researchers (e.g. Grassl, 2002; Johansson and Åkesson, 2001; and Mander et al., 1989) provides a framework for characterizing the behavior of grout for triaxial loads.

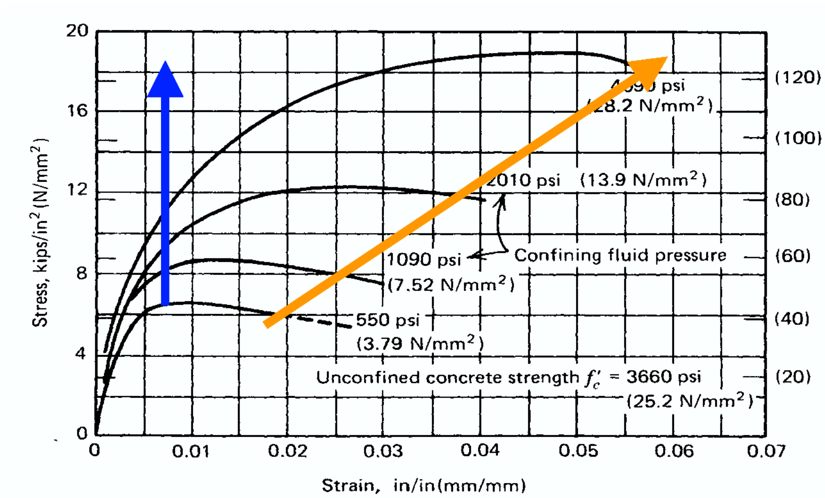


Figure 2.1. Influence of Confinement on Stress–Strain Characteristics of Concrete *(from http://overlord.eng.buffalo.edu/ClassHomePages/cie525/Lectures/Lecture03.pdf)*

2.3. Summary of Research Needs

The discussion of Richart et al.'s work shows that the first two research topics identified by the DFI Micro Pile committee are related to the behavior of grout under confinement. A cursory review of the literature reveals that the influence of confinement on the stress–strain behavior of concrete is fairly well understood. However, it does not appear that analogous work on grout has been performed. Although it is anticipated that the behavior of grout under confinement is similar to concrete, the concrete models are not directly transferable to grout. Dilation is the mechanism by which confinement influences stress–strain characteristics, therefore the presence and characteristics of the aggregate in a concrete mix has a significant effect on stress–strain characteristics for triaxial loading. It is reasonable to assume that concrete stress–strain models can be extended to grout given a limited database of laboratory grout triaxial compression data. The work on concrete's behavior under compressive loads by Richart and subsequent researchers suggests that enhanced understanding of grout stress–strain behavior for triaxial compression will shed light on many aspects of micro pile performance. Therefore, this proposal partially focuses on developing a model for the stress–strain characteristics of grout. This work will provide a fundamental framework for addressing issues such as strain compatibility between the grout and reinforcing bar and the influence of rock confinement.

3. Project Description

3.1. Goals and Objectives

There are two primary goals of the proposed research. The first goal is to develop predictive relationships for the stress–strain behavior of cement grout for generalized loading conditions. The second is to develop a simplified design method for axial load capacity which incorporates the effects of grout confinement.

3.2. Proposed Methods

3.2.1. Literature Review

A literature review will be conducted to achieve two objectives. The first objective is to document code requirements and current design practice pertaining to the strain compatibility between the reinforcing steel bar and cement grout in axially loaded micro piles. The second objective is to identify literature on the behavior of confined grout or concrete and select candidate stress–strain models for concrete that can be extended to neat cement grout. The findings of the literature review will be summarized in the project report.

3.2.2. Experimental Work

Two different test methods will be used to examine the influence of confinement on the stress–strain characteristics of grout. A neat cement and water grout mixed in a high shear colloidal mixer with a water cement ratio of 0.40 will be used in both methods. The test methods include triaxial compression tests on the grout and axial load tests of grout columns in various casings. The two methods are described in greater detail in the following paragraphs.

3.2.2.1. Triaxial Compression Tests of Grout

Nine triaxial compression tests will be performed on grout over a range of confining stresses. The grout specimens will be cast in three–inch diameter, six–inch high cylindrical molds from the same grout batch used to cast the micro–pile specimens. Two specimens will be tested using the ASTM D3148 "Elastic Moduli of Intact Rock Core Specimens in Uniaxial Compression" test procedure at FMSM's Lexington Testing Laboratory. The remaining seven specimens will be tested using the ASTM D-5407 "Elastic Moduli of Undrained Intact Rock Core Specimens in Triaxial Compression" test procedure at Advanced Terra Testing's Lakewood, Colorado Testing Laboratory. Confining pressures of 0, 50, 100, 200, 500, 1000, and 2000 pounds per square inch (psi) will be used for the ASTM D-5407 specimens. The tests will include measurements of axial and lateral strains, axial load, and confining stress. The data from the tests will be compared to the models for confined concrete to derive model parameters specific to grout. These tests are necessary in order to understand if "confined" grout can achieve the strain level required to fully mobilize the capacity of Grade 150 reinforcing bars.

3.2.2.2. Axial Load Tests of Micro Pile Specimens

Seven axial load tests of six–inch diameter and fifteen–inch high cylindrical micro pile specimens will be performed. The influence of rock confinement will be investigated by testing grout columns encased in Schedule 10 steel pipe, Schedule 40 steel pipe, and Schedule 40 plastic pipe[1]. Each confinement case will be tested with and without a one and three-quarter inch diameter Grade 150 steel bar centered in the grout column. One unconfined specimen will be tested as a control specimen. The specimens will be loaded to an axial strain of 0.006 inches/inch, which is twice the strain currently allowed in micro-pile design and slightly higher than the 0.005 inches/inch axial strain required for an axial stress of 150 kips per square inch (ksi) in Grade 150 steel. Figure 3.1 is a sketch of the planned specimen configuration. Electrical resistance strain gages will be mounted on the casing and the steel bar during specimen preparation. The axial strain in the steel reinforcing bar, and the axial and circumferential strains in the casing will be recorded during specimen loading. A bond breaker will be applied to the interior of the specimen casings to limit direct transfer of axial load to the casing.

The axial load tests will be conducted at the United States Bureau of Reclamation's (USBR) Materials Engineering and Research Laboratory (MERL) in Denver, Colorado. MERL has a five million pound load frame that can be utilized for testing. It is anticipated that the axial load during testing of many of the specimens will exceed one million pounds. We are unaware, as is the USBR, of any commercial laboratory with a load frame capacity in excess of one million pounds.

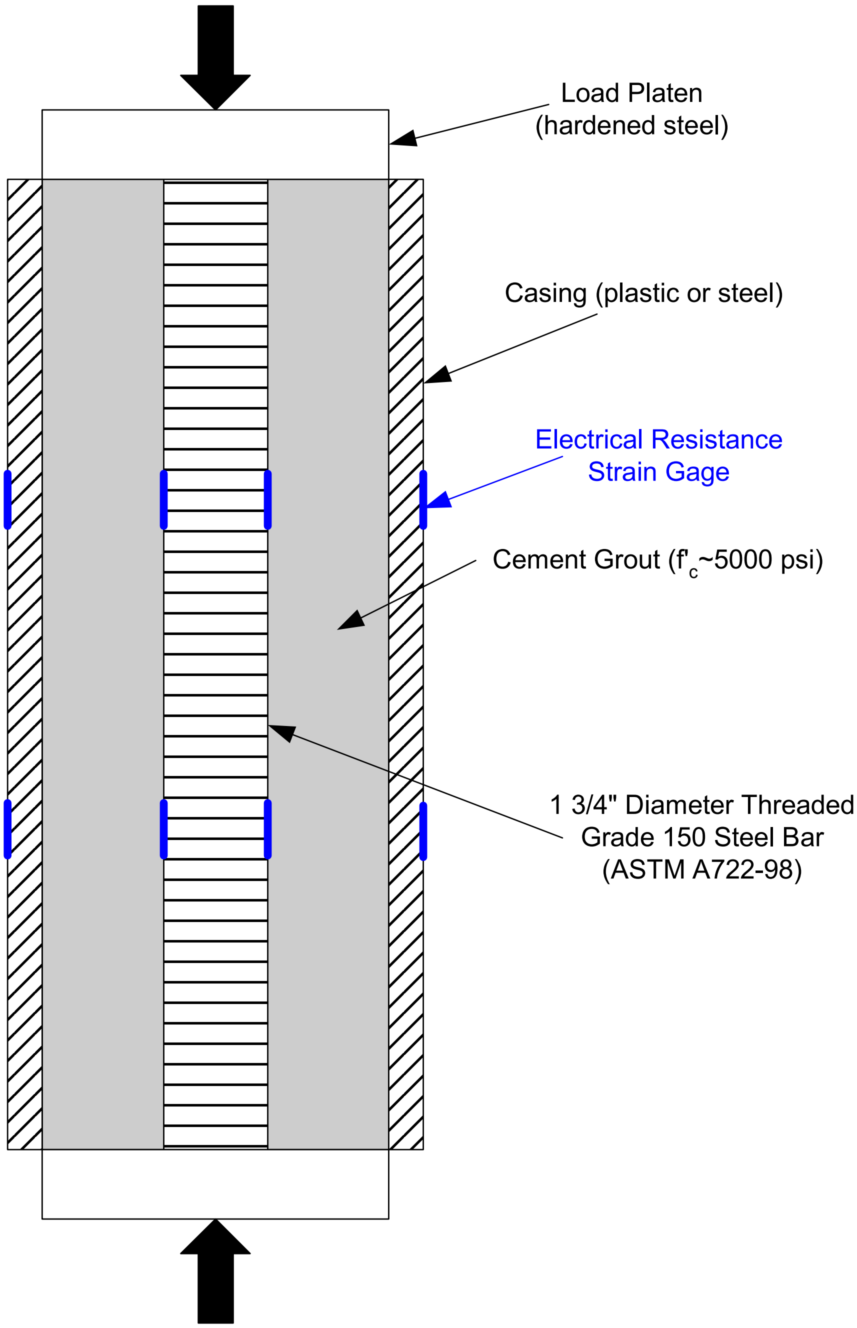
3.2.3. Model Development

Following completion of the experimental program, work will begin on developing a simplified model for the axial capacity of a micro pile. The framework for this work is the extension of a confined concrete stress–strain model to grout using the experimental program results and use of basic engineering mechanics and elastic theory to derive closed-form solutions. The scope of this model development effort is limited because of the ADSC-DFI Micro Pile Committee's desire to keep the project budget near $20,000.

3.3. Project Report

At the completion of the project, a report will be submitted to the DFI Micro Pile Committee. The report will document the goals and objectives, methodology, results, and conclusions of the project.

[1] Actual pipe materials used for the tests will be submitted to ADSC-DFI point of contact for approval prior to sample fabrication.



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Checked by:	gy

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Figure 3.1. Micro Pile Axial Load Specimen

4. Assumptions, Schedule, and Budget

4.1. Significant Assumptions

The following assumptions were made in the derivation of the budget for this proposal:

1) The samples will be formed at Denver Grouting Company's facility.

2) The ADSC–DFI Micro Pile Committee will provide steel and plastic casing for micro-pile axial load testing specimens.

3) The ADSC–DFI Micro Pile Committee will provide machined 1 ¾–inch Williams Grade 150 steel threaded rod. Six 15.00 inch long pieces will be required with ends machined flat and strain gage locations machined flat.

4) Strain gages will be installed on steel rod and confining pipe for micro pile specimens by FMSM Engineers. Instrumented rod and pipe pieces will be shipped to Denver.

5) Samples will be shipped by FMSM via Fed-Ex Ground service to Advanced Terra Testing's Lakewood, Colorado Laboratory and the United States Bureau of Reclaimation's Denver Materials Engineering and Research Laboratory (MERL) in Denver. The replacement cost of the samples is uninsurable by Fed-Ex. There is no allowance for lost samples in the budget.

6) MERL can complete testing of the micro-pile specimens in two days of testing. There is a $1,500 per day charge for use of the USBR's high-capacity load frames and data-acquisition system.

7) The MERL machine shop can prepare suitable load platens at a cost of $1,000.

8) Only one set of load platens will be required.

9) The project schedule is flexible and air-fares can be purchased with sufficient notice to obtain reasonable prices.

4.2. Proposed Project Budget and Schedule

Table 4.1 summarizes the proposed project budget. It is anticipated that approximately three months will be required to complete the project. The project budget was derived assuming that a senior geotechnical engineer would be responsible for the literature review, model development, and project report. It was also assumed that a day and a half of a laboratory technician's time would be required per micro pile specimen to mount electrical strain gages. The proposed budget includes two optional items: 1) FMSM attendance at sample preparation and 2) FMSM attendance at micro-pile specimen testing at MERL.

Table 4.1 Proposed Project Budget

Item	Duration	Cost
Literature Review (24 hours @ $100/hr)	1 week	$2,400
Triaxial tests on Grout (2 tests @ $400/test and 7 tests @ $516/test)	3 weeks	$4,410
Option 1. FMSM trip to Denver Grouting Company	2 ½ days	$2,500
Laboratory Axial Load Tests of Micro Piles (7 tests @ $1060/test)	4 weeks	$7,820
Option 2. FMSM trip to USBR Denver MERL Facility	3 days	$3,000
Model Development (40 hours @ $100/hr)	1 week	$4,000
Report	1 week	$3,270
	Total Cost:	$27,400

5. Conclusions

A proposal to develop a stress–strain model for grout under confinement and a simplified axial load model for micro piles was presented. The understanding of the stress–strain characteristics of grout under confinement is key to understanding the axial load capacity of micro piles. The proposed research will provide a framework for understanding and investigating the axial load capacity of micro piles with high capacity steel reinforcing bars. The budget for the proposed project including two optional trips by FMSM to Denver is $27,400 with an estimated project duration of three months. The terms of the project contract will be time and materials with a not-to-exceed cost based on the proposal options selected.

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