SPR RESEARCH PROGRAM
SECOND-STAGE PROPOSAL SUMMARY

PROBLEM NUMBER AND TITLE

24-66: Phase II: Method Development for Construction Design in Diatomaceous Soils

PROBLEM SUMMARY

Diatomaceous soils, which contain silica frustules from ancient algae blooms, are prevalent in eastern and central Oregon, including in areas of ODOT right-of-way. For engineering projects built on top of or in these deposits, problems such as excessive settlement of embankments, slope instability, and construction difficulties with drilled shafts and driven piles have been observed (ex. Wickiup Junction, Buck Creek Bridge). Lack of a robust understanding of the behavior of diatomaceous soils is often cited as the reason for this poor design performance. Complicating matters further, relatively little is documented in the literature regarding the performance of piles in diatomaceous soils. To begin to understand the behavior of diatomaceous soils, ODOT recently invested in a research program (SPR820) to develop predictive estimating models for geotechnical properties of Oregon's diatomaceous silt, leveraging available data from existing ODOT diatomaceous projects together with targeted field-directed geotechnical testing including an array of in-situ tests at select sites in diatomaceous deposits. These materials have been further characterized through an extensive laboratory testing program. A full-scale field test is now required to develop and validate necessary empirical design methods for deep foundations in diatomaceous silt.

ODOT OBJECTIVES

A full-scale, field-testing program to develop empirical design methods using ODOT's new diatomaceous soil models developed from SPR820 is proposed. This work will leverage existing geotechnical investigation(s) within ODOT right-of-way. The envisioned work products include development of an empirical design methodology for deep foundations in diatomaceous silts, spreadsheet tools for design, and a short-course reviewing the results of this research project.

BENEFITS

The rich dataset that will be produced in an actual operational environment through this well-instrumented and robust full-scale pile test program will provide ODOT geologists and engineers with actionable data that can be applied directly to future ODOT design and construction projects in diatomaceous deposits. The field program, as envisioned, will result in the following new, actionable data and tools: (1) quantitative (rather than anecdotal) information about the difficulties encountered during pile driving, how these difficulties may be anticipated based on site investigation data, and the potential mechanisms underlying them, thereby informing potential mitigation measures; (2) field-data-informed methods to predict static bearing capacity of a driven pile in diatomaceous deposits; and (3) approaches to estimate the stresses and excess pore water pressures developed during pile driving based on documented data. Further, this proposed project will support ODOT's Strategic Action Plan and Mission by enabling ODOT to reliably design transportation infrastructure in diatomaceous soils, thereby improving transportation reliability within our rural communities and supporting these resource dependent economies where ODOT service is essential.

SCHEDULE, BUDGET AND AGENCY SUPPORT

Estimated Project Length: 42 months
Estimated Project Budget: $515,000
ODOT Support: Susan Ortiz (State Geotechnical Engr.), Curran Mohney (Engineering Geology Program Lead)

FOR MORE INFORMATION

For additional detail, please see the complete STAGE 2 RESEARCH PROBLEM STATEMENT online at:
https://www.oregon.gov/odot/Programs/ResearchDocuments/24-66.pdf

SPR RESEARCH PROGRAM
SECOND-STAGE PROBLEM STATEMENT
FY 2024

PROBLEM NUMBER AND TITLE

24-66: Phase II: Method Development for Construction Design in Diatomaceous Soils

RESEARCH PROBLEM STATEMENT

Current design methodology for deep foundations in diatomaceous soils is often judgment-based rather than founded in analytical, numerical, or empirical design methods. Costly project delays and change orders are common for ODOT projects constructed within diatomaceous deposits due to the lack of reliable geotechnical engineering methods and standards of practice for building in these unique subsurface conditions. Oregon has at least twenty-five lake-bed basins with diatomaceous silts at engineering depths of interest to ODOT (Figure 1). Notably, these diatomaceous soils are prevalent across large areas of ODOT and local agency right-of-way in central and eastern Oregon, where these rural communities are directly impacted by ODOT infrastructure performance.

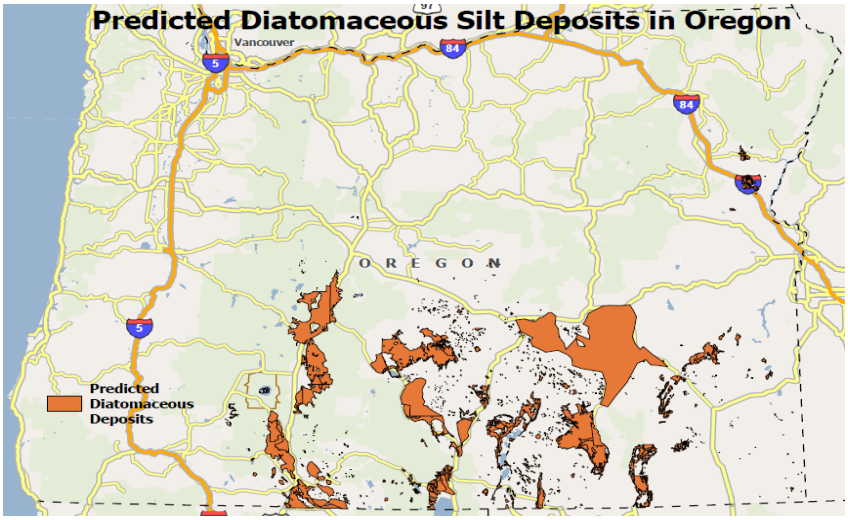

Figure 1: Predicted Diatomaceous Silt Deposits.

Diatomaceous silt (e.g., Figure 2) contains diatom microfossils that exhibit substantial intra-particle porosity and are highly abrasive. These unique properties of diatom microfossils strongly impact the engineering properties of the material relative to "textbook" soils. Many common geotechnical design methods use typical assumptions of "sand-like" or "clay-like" soil behavior and are empirically developed from experience with sand and clay soils. These empirically based equations are not suitable for estimating the behavior or engineering properties of diatomaceous soils. Numerous ODOT bridges have been constructed in diatomaceous soils, including the partially built – *and recently demolished* – Wickiup Junction bridge in La Pine, OR. Therefore, the lack of design methodology for foundations in diatomaceous soils has a direct impact on ODOT. Design of deep foundations by engineers often involves judgment, back-analysis, and personal experience rather than analytical-empirical methods supported by fundamental science. This approach to deep foundation design combined with a lack of understanding of this type of soil, has led to problems during projects, including over-length piles, piles meeting refusal prior to achieving minimum design lengths, excessive settlements beneath spread footings, slope and embankment instability, and installation difficulties with drilled shafts. At a minimum, a standard of practice

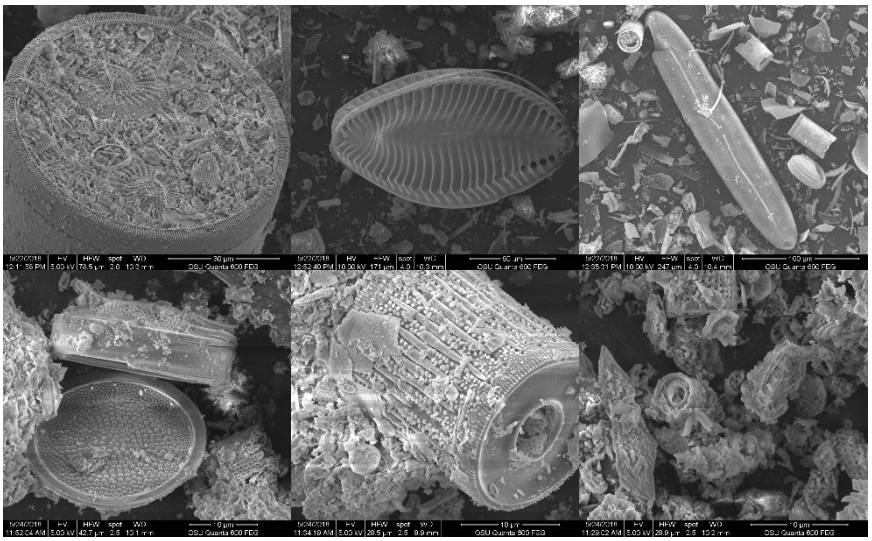

Figure 2: Scanning electron microscope (SEM) images showing examples of diatomaceous soils found in Oregon.

for deep foundation design in diatomaceous soil is needed.

To begin to understand the behavior of diatomaceous soils, ODOT recently invested in a research program (SPR820) to develop predictive estimating models for geotechnical properties of Oregon's diatomaceous silt, leveraging available data from existing ODOT diatomaceous projects together with targeted field-directed geotechnical testing including an array of in-situ (field) tests at select sites in diatomaceous deposits. These materials have been further characterized through an extensive laboratory testing program. A full-scale field test is now required to develop the necessary empirical design methods for deep foundations in diatomaceous silt.

RESEARCH OBJECTIVES

A full-scale, field-test program to develop empirical design methods using ODOT's new diatomaceous soil models developed from SPR820 is proposed. This work will leverage existing geotechnical investigation(s) within ODOT right-of-way. The envisioned work products include development of an empirical design methodology for deep foundations in diatomaceous silts, spreadsheet tools for design, and a short course reviewing the results of this research project.

WORK TASKS, COST ESTIMATE AND DURATION

Task 1: Review of Existing Data and Site Selection: A study location within ODOT right-of-way with site characterization will be chosen. The site characterization will be used to inform a preliminary numerical investigation, test instrumentation, and load test programs.

Task 2: Pile Instrumentation Design: Using data from the site identified in Task 1, a preliminary numerical investigation of pile drivability and capacity in diatomaceous soils will be performed to inform the pile installation, instrumentation, and testing activities, thereby maximizing the efficacy of the subsequent field program. Existing numerical models calibrated with site investigation data will be used to optimize sensor location, number, and type. A predictive empirical model will be developed, tested, compared to existing empirical models, and then modified after dynamic and static load testing.

Task 3: Pile Instrumentation and Installation: Using SPR 820 data, site characterization from Task 1, and numerical analyses described in Task 2, a test pile will be instrumented, as well as at least four reaction piles to form a reaction frame and driven into a diatomaceous deposit with guidance from ODOT. Sacrificial vibrating wire piezometers will be installed using direct push methods (i.e., a cone penetrometer).

Task 4: Dynamic Pile Load and Integrity Tests: Wave-based measurements will be used to infer the capacity of the driven test pile. Wave equation analyses will be performed both during installation and on the as-installed pile. Results from dynamic capacity analyses will be related to drivability data to facilitate future capacity predictions during installation of piles in diatomaceous soils.

Task 5: Static Load Testing: The reaction piles will be used to test the axial capacity of the instrumented pile. The measured pile load-displacement curve will be interpreted using a selection of hyperbolae from the literature to determine initial tangent stiffness and ultimate load. The timeline for static load testing will be determined with guidance from ODOT engineers and pore water pressure instrumentation data to evaluate how the pile capacity changes over time.

Task 6: Data Synthesis and Tool Development: The results of pile driving analysis, pile static load testing, and the SPR 820 dataset will be synthesized to develop and calibrate an empirical design method for deep foundations in diatomaceous soil. Because diatomaceous soils have been shown to exhibit a combination of sand-like and clay-like behaviors, both "alpha type" and "beta type" design approaches will be considered for side resistance. The procedure adopted for toe bearing will be selected based on excess pore water pressure measurements collected during installation and testing. Static $t - z$ and $q - z$ curves will be developed using the load test results.

Task 7: Deliver Final Report, Recommendations, and Analysis Tools: This work will be summarized in a final report,

including an empirical design methodology for diatomaceous soil, refined recommended procedures for field-based testing, sampling, and lab testing protocols for pile design in diatomaceous silt. Upon approval of the final report, the findings of this work will be presented as an ODOT short course.

Key Deliverables: *Design methods and tools to estimate (1) static resistance of driven piles; and (2) stresses and excess pore water pressures developed during pile driving. Quantitative case study for future application within ODOT's Geotechnical practice. Short course.*

Estimated Project Length: 42 months.
Estimated Project Budget: $515,000

IMPLEMENTATION

Based on the outcome of this research, implementation plans include recommendations for modifying design guidance for ODOT's Geotechnical Design Manual and Bridge Design Manual and providing a short course for practitioners describing the findings, significance, and limitations of this research. This research will provide critical guidance for the engineering behavior of pile design in diatomaceous silts, and the appropriate selection of design parameters. ODOT engineers, consultants, and project teams will use the results of this research to efficiently design in diatomaceous soils.

POTENTIAL BENEFITS

The rich dataset that will be produced in an actual operational environment through this well-instrumented and robust full-scale pile test program will provide ODOT geologists and engineers with practical data that can be applied directly to future ODOT design and construction projects in diatomaceous deposits. The field program, as envisioned, will result in the following new data and tools: (1) quantitative (rather than anecdotal) information about the difficulties encountered during pile driving, how these difficulties may be anticipated based on site investigation data, and the potential mechanisms underlying them, thereby informing potential mitigation measures; (2) field-data-informed methods to predict static bearing capacity of a driven pile in diatomaceous deposits; and (3) approaches to estimate the stresses and excess pore water pressures developed during pile driving based on documented data. Further, this proposed project will support ODOT's Strategic Action Plan and Mission by enabling ODOT to reliably design transportation infrastructure in diatomaceous soils, thereby improving transportation reliability within our rural communities and supporting these resource dependent economies where ODOT service is essential.

PEOPLE

ODOT champion(s): Susan Ortiz (State Geotechnical Engineer), Curran Mohney (Engineering Geology Program Lead)

Problem Statement Contributors: Matt Evans (OSU), Diane Moug (PSU), Jiayao Wang (OSU), Susan Ortiz (ODOT), Curran Mohney (ODOT), Kira Glover-Cutter (ODOT)

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STAFF REVIEW PAGE

Literature Check

TRID&RIP

☒ A review of TRID & RIP databases found no existing research that answers the research question

Technology & Data assessment

☒ No Identified T&D output

☒ At the end of this project, the implementing unit(s) within ODOT will need to coordinate the adoption of new technology or data in order to realize the full potential of this research.

Cross-agency stakeholders

- Geotechnical Engineering, Engineering Geology, and Hazmat Section
- Region Geos