SPR RESEARCH PROGRAM
SECOND-STAGE PROPOSAL SUMMARY

PROBLEM NUMBER AND TITLE

26-30: Phase III Wickiup Junction: Diatomaceous Soil Numerical Modeling to Support Design, Performance, and Feasibility

PROBLEM SUMMARY

Diatomaceous soils exist at many ODOT projects in Oregon, including the Wickiup Junction overpass site. Construction challenges have been encountered for ODOT projects on and in diatomaceous soils, including pile freeze, overlength piles, and excessive settlement. Ongoing Wickiup Junction embankment monitoring indicates that these embankments are undergoing continuous settlement at about 1.75 inches per year. Recently, a consultant's feasibility study estimated that settlement mitigation for future overpass construction will cost $47M to $63M. This high mitigation cost is attributable to extensive deposits of soft and compressible diatomaceous soils that underlay the site. Considering that diatomaceous soils are non-standard geomaterials, limited literature, standards, or case histories exist to guide design and construction in these materials. However, this Wickiup Junction location may provide a prime translational research opportunity to improve engineering practice through development of a case history report with associated design charts for diatomaceous soils.

ODOT OBJECTIVES

This highly applied research proposal will investigate the recently released design options at Wickiup Junction using advanced soil numerical modeling as a case study for design in diatomaceous material. This work will build on previous ODOT diatomaceous soil research to develop design tools that can be applied for construction in and on these deposits. Specific objectives include: 1) develop settlement model of the Wickiup Junction Overpass, and 2) develop design charts for diatomaceous soils.

BENEFITS

Diatomaceous soils exist at many ODOT sites in southern and southeastern Oregon. Past projects on diatomaceous soil sites have experienced unexpected conditions and soil properties that led to costly project delays, design changes, or abandonment. The information and numerical model of this project will provide economic benefits to ODOT by enabling investigation into the cost and performance of various design approaches at the Wickiup Junction site, allowing engineers to explore and select cost-effective design measures. This research project represents the next step in ODOT-sponsored research into diatomaceous soils. SPR820 explored basic diatomaceous soil properties and behavior by testing diatomaceous soil samples from four sites in Oregon. An outcome of SPR820 was an understanding of how to sample, test, characterize, and interpret engineering properties for diatomaceous soils. SPR879 represents applied research through a pile load test in diatomaceous soils to test how characterized diatomaceous soil properties relate to the design performance of a pipe pile foundation. This highly applied research proposal will build upon the results of SPR820 and SPR879 to bridge knowledge of diatomaceous soils directly to ODOT engineering practice.

SCHEDULE, BUDGET AND AGENCY SUPPORT

Estimated Project Length: 30 months.
Estimated Project Budget: $325,000
ODOT Support: Susan Ortiz (State Geotechnical Engineer), Russ Frost (Region 4 Geo/Environmental Manager), Tom Grummon (Senior Bridge Geotechnical Engineer)

FOR MORE INFORMATION

For additional detail, please see the complete STAGE 2 RESEARCH PROBLEM STATEMENT online at:
https://www.oregon.gov/odot/Programs/ResearchDocuments/26-30

SPR RESEARCH PROGRAM
SECOND-STAGE PROBLEM STATEMENT
FY 2026

PROBLEM NUMBER AND TITLE

<u>26-30:</u> Diatomaceous Soil Numerical Modeling to Support Design, Performance, and Feasibility

RESEARCH PROBLEM STATEMENT

Oregon has at least twenty-five lake-bed basins with diatomaceous silts at engineering depths of interest to ODOT (Figure 1). Roughly 167 National Bridge Inventory (NBI) Bridges (40 NBI ODOT Bridges) cross these deposits. 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.

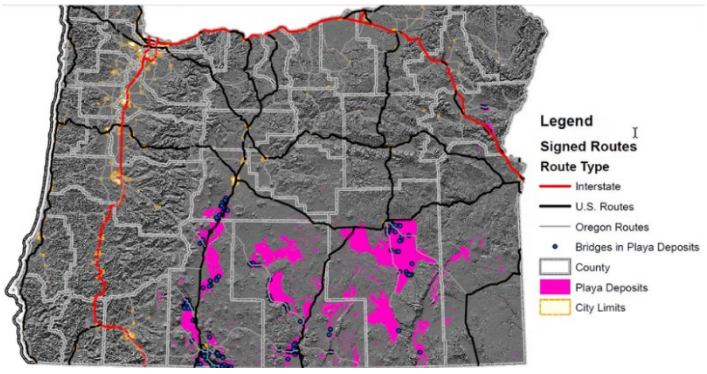

Figure 1: Predicted diatomaceous deposits in Oregon and impact to road network including 167 NBI bridges (40 NBI ODOT Bridges).

Numerous ODOT bridges have been constructed in diatomaceous soils, including the unfinished Wickiup Junction bridge in La Pine, OR. Associated construction problems encountered by ODOT engineers during these projects have included over-length piles, piles meeting refusal prior to minimum design lengths, excessive settlements beneath spread footings, slope and embankment instability, and installation difficulties with drilled shafts. Wickiup Junction bridge started in 2016, however, before construction was completed in spring 2017, large and unexpected settlements of the approach embankments and bridge abutments were measured. Construction of the overpass was abandoned in response to these settlements. Ongoing monitoring indicates that the embankments are undergoing continuous settlement at about 1.75 inches per year. Recently, a consultant's feasibility study estimated that settlement mitigation for future overpass construction will cost $47M to $63M. This high mitigation cost is attributable to extensive deposits of soft and compressible diatomaceous soils that underlay the site. Since diatomaceous soils are non-standard geomaterials, there exists scant published literature, standards, or case histories to guide design and construction in these materials. ODOT engineers would benefit from: (i) a tool to explore settlement mitigation, design, and other remedial options and their cost savings at the Wickiup Junction site, and (ii) design charts that are developed specifically for construction in diatomaceous soils.

RESEARCH OBJECTIVES

This work will build on previous ODOT diatomaceous soil research to develop design tools that can be applied for construction in and on these deposits. The two specific objectives are described below.

<u>Objective 1</u>: *Settlement model of the Wickiup Junction overpass.* We will develop a numerical model for exploring feasibility options for the Wickiup Junction overpass. The goal is a numerical model calibrated to the soils and conditions at Wickiup Junction and validated with settlement monitoring data. This model can be used by ODOT in conjunction with the Cornforth feasibility study options to study likely performance, explore alternative mitigation options, and investigate cost-effective changes to the design and/or construction process. Additionally, the model can be used for future investigations and construction at other diatomaceous deposits.

<u>Objective 2</u>: *Develop design charts for diatomaceous soils.* We seek to develop design charts construction on and in diatomaceous soils, such as for design of piles and shallow foundations (Figure 2). The complex

behavior of diatomaceous soils means that published and standard design charts cannot be relied upon for construction in and on diatomaceous soils. We will use advanced numerical models to simulate various design scenarios and loadings on diatomaceous soils. Simulation results will be used to develop diatomaceous-specific design charts that can be used to inform ODOT engineers and provide a basis for design decisions.

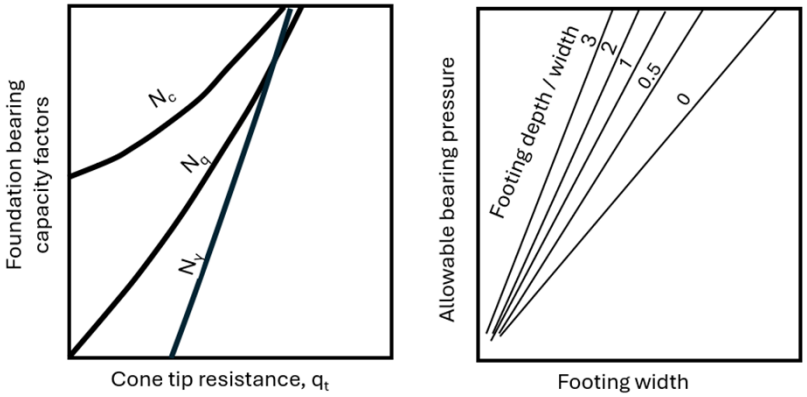

Figure 2: Representation of envisioned design charts. Estimated foundation bearing capacity factors by cone tip resistance (left), and allowable bearing pressure by footing width (right).

WORK TASKS, COST ESTIMATE AND DURATION

Task 1: *Data and literature review.* We will review existing literature and ODOT design reports from diatomaceous soil sites for relevant soil properties, loading conditions, and modeling approaches. We will synthesize construction data, monitoring data, subsurface investigation data, and laboratory test data from Wickiup Junction and other diatomaceous soil sites. The monitoring data from Wickiup Junction was collected by Cornforth Consultants from June 2017 to April 2023 and includes vibrating wire piezometers, inclinometers, tiltmeters, and survey hubs.

Task 2: *Site investigation at the Wickiup Junction.* Cone penetration testing (CPT) at Wickiup Junction will target locations immediately adjacent to and through the embankment and close to instrumentation locations. CPT profiles will characterize the subsurface stratigraphy to define model geometry. CPT data was collected as part of SPR820 and the Cornforth feasibility study, however the profile locations were about 50' from the embankments, introducing uncertainty into the subsurface conditions at the embankments. Collection of the additional data at the embankments is necessary to capture the conditions, including depth, thickness, and continuity of diatomaceous soils, underneath the embankments.

Task 3: *Selection and calibration of material model.* This task will use single element simulations of common laboratory tests (e.g., one-dimensional consolidation, direct simple shear, triaxial compression) to examine how various constitutive models capture diatomaceous soil behavior, and to calibrate soil model properties to diatomaceous soil behavior. The simulated behavior will be compared to lab-measured results under the same loading conditions to evaluate an appropriate soil model and set of model parameters for the subsequent simulation tasks.

Numerical modeling in this study, including Tasks 3-5, will be performed using FLAC (Fast Lagrangian Analysis of Continua; Itasca Consulting Group). FLAC is an explicit finite difference modeling software optimized for simulation of large deformations and widely used throughout geotechnical engineering practice and research. The software package includes built-in soil constitutive models (e.g., soft soil model, NorSand, MIT-S1) that will be explored to assess their abilities to capture diatomaceous soil behavior. If none of these models are appropriate for diatomaceous soils, user-defined models can be programmed into FLAC. FLAC has been used to investigate complex geotechnical engineering projects, such as excess settlement of the Millenium Tower in San Francisco (Stewart et al. 2023) and the San Fernando Dam failure in Los Angeles (Boulanger & Montgomery 2016). The project personnel from Portland State University and Oregon State University have experience modeling various geotechnical problems in FLAC and have existing drivers for single-element simulations.

Task 4: *Numerical modeling of the Wickiup Junction site.* We will build and validate a numerical model to simulate the overpass and settlement at the Wickiup Junction site. This task will require building the site model with subsurface data and construction data and using the calibrated soil model from Task 3. Validation will be facilitated by monitoring data collected by Cornforth Consultants. Subsurface soil

properties will come from explorations by ODOT for original construction at Wickiup Junction, Cornforth Consultants, and SPR820.

After calibration and validation of the Wickiup Junction model, the three options proposed in the Cornforth feasibility study will be simulated. These simulations will provide advanced insight into their performance, and opportunities for design changes and cost savings. Additionally, this model can be used to explore the performance of other options and construction alternatives, also potentially leading to cost-saving measures.

Task 5: *Numerical modeling to support design in/on diatomaceous soils and development of design chart(s).* In this task, we will adapt the computational model in Task 4 to simulate design cases such as shallow foundations on diatomaceous soils, and pile foundations in diatomaceous soils. Foundation response (i.e., settlement) and capacity will be evaluated for a range of soil properties, as determined in Task 1, and loading conditions to develop design charts for ODOT engineers' use.

Task 6: *Transfer models, design charts, and results to ODOT.* This task will transfer the design charts and numerical models to ODOT engineers for their own use. The models will be transferred as model scripts for implementation, and as simulated model states for specific loading conditions. Documentation and training materials will also be provided to run and alter the models, and to use the design charts.

Key Deliverables: Numerical model that explores three feasibility scenarios for Wickiup Junction with assessments of cost savings by design change; design charts for diatomaceous soils; recommendations for pile driving in diatomaceous materials; workshop; final report; published case study in peer review journal if research successful.

Estimated Project Length: 30 months.
Estimated Project Budget: $325,000

IMPLEMENTATION

ODOT Geoengineering staff, consultants, and project teams will use the results of this research to efficiently design and construct under conditions where diatomaceous soils influence engineering behavior. Based on the outcome of this research implementation plans include edits to ODOT's GDM and a short course for ODOT describing the findings, significance, and limitations of this research.

POTENTIAL BENEFITS

Diatomaceous soils exist at many ODOT sites in southern and southeastern Oregon. Past projects on diatomaceous soil sites have experienced unexpected conditions and soil properties that led to costly project delays, design changes, or abandonment. A better understanding of design and construction in diatomaceous soils will enable ODOT to take on construction projects at these sites without relying on overconservative designs. At the Wickiup site settlement mitigation for overpass construction are estimated to be $43M to $57M. The information and numerical model of this project will provide economic benefit to ODOT by enabling investigation into the cost and performance of various design approaches at the Wickiup Junction site, allowing engineers to explore and select cost-effective design measures.

This research project represents the next step in ODOT-sponsored research into diatomaceous soils. SPR820 explored basic diatomaceous soil properties and behavior by testing diatomaceous soil samples from four sites in Oregon. An outcome of SPR820 was an understanding of how to sample, test, characterize, and interpret engineering properties for diatomaceous soils. SPR879 represents applied research through a pile load test in diatomaceous soils to test how characterized diatomaceous soil properties relate to the design performance of a pipe pile foundation. This highly applied research proposal will build upon the results of SPR820 and SPR879 to bridge knowledge of diatomaceous soils directly to ODOT engineering practice.

PEOPLE

ODOT champion(s): Susan Ortiz (State Geotechnical Engineer), Tom Grummon (Senior Bridge Geotechnical Engineer), Russ Frost (Region 4 Geo/Environmental Manager)

Problem Statement Contributors: Diane Moug (Portland State University), Matt Evans (Oregon State University), Kira Glover-Cutter (ODOT)

REFERENCES

Cornforth Consultants Report. “Updated Feasibility Study US97 at Wickiup Junction La Pine, Oregon”. September 17, 2024.

SPR820 Final Project Report.

Stewart, J. P., Wagner, D., Murphy, D., Butkovich, J., Largent, M., Nouri, H., Curran, H., Maffioli, D. and J. A. Egan. "Foundation Settlement and Tilt of Millennium Tower in San Francisco, California." *Journal of Geotechnical and Geoenvironmental Engineering* 149, no. 6 (2023): 05023002.

Boulanger, R.W. and Montgomery, J., 2016. Nonlinear deformation analyses of an embankment dam on a spatially variable liquefiable deposit. *Soil Dynamics and Earthquake Engineering*, *91*, pp.222-233.

STAFF REVIEW PAGE

LITERATURE CHECK

TRID&RIP

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

ODOT DECISION LENSES

Climate: This research is not focused on climate and will not include analysis of climate.

Equity: This research is not focused on climate and will not include analysis of equity.

Safety: This research will support improving safety by identifying optimized design strategies for building in unpredictable diatomaceous soils.

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 IMPACTS

List ODOT partners or impacted units. Susan Ortiz (State Geotechnical Engineer), Russ Frost (Region 4 Geo/Hydro/Environmental Manager)