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SOFT ZONE NUMERICAL MODELING APPROACH

SAVANNAH RIVER SITE • AIKEN, SOUTH CAROLINA

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1. Introduction

Numerical modeling analyses are being performed to characterize the behavior of the soil mass containing soft zones and voids. The numerical models progress from simple to complex for both the subsurface features and the constitutive and failure models. For the simplest case, soft zones and open voids are analyzed with the linear elastic-perfectly plastic constitutive model and the Mohr-Coulomb failure criterion in the effective stress state with static loading. The most complex cases incorporate overlying hard layers with the soft zones and voids. These apply the hyperbolic hardening constitutive model with small-strain stiffness and the Mohr-Coulomb failure criterion with static and dynamic loading. Other analyses use the Modified Cam Clay model and consolidation properties.

2. Objectives

The objectives of this work are aimed at quantifying and resolving issues related to the soft zones that underlie portions of the SRS. The effort will incorporate the following aspects:

1. The static and dynamic behaviors of soft zones and their effect on the surrounding ground and structures shall be evaluated using numerical modeling,
2. Characterization of the soft zones and the overlying hard layers shall be performed and shall include aspects such as geometry, spatial distribution, extent, and continuity.
3. The constitutive models and yield criteria shall be established for the varying soil types particularly for the hard layers overlying the soft zones and the soft zones,
4. Ground behavior shall be characterized for conditions in which the soft zones undergo coupled flow-deformation during static and dynamic loadings and shall include parameterization,
5. The differences between two-dimensional and three-dimensional numerical analyses shall be evaluated to determine the most realistic manner of modeling,
6. The results of the numerical modeling shall be used to produce an analytical settlement solution that can be readily used in manual calculations, and
7. The sensitivity of the model results to the various input parameters shall be evaluated.

3. Numerical Modeling Software

Three software packages have been used to numerically model the soil mass behavior with the inclusion of voids and soft zones in the subsurface. ABAQUS was used by the Georgia Institute of Technology (GIT) for two-dimensional analyses included in report K-TRT-G-00008. The modeling efforts by SRNS include the use of Sigma/W, which was developed by GeoSlope and Plaxis, which was developed by Plaxis bv. GeoSlope Sigma/W is available in a two-dimensional formulation and Plaxis is available in two-dimensional and three-dimensional formulations. Verification, example, and tutorial exercises provided by the software vendors confirmed the proper function and numerical accuracy of the Sigma/W and Plaxis software packages.

4. Basic Numerical Modeling

The basic numerical models analyzed with Sigma/W were based on the geometries, dimensions, boundary conditions, and soil strength parameters used by Georgia Institute of Technology (GIT) in the report "Comprehensive Geocharacterization of the Santee Formation and Its Implications for Engineering Behavior" (K-TRT-G-00008, Rev. 0, January 08, 2014). The effort described for basic numerical modeling was intended to replicate the results presented in the GIT report and to validate the function of Sigma/W and Plaxis.

Within the GIT report (K-TRT-G-00008), various soft zone and void conditions were considered. Those providing the most detail, information, and clarity of problem formulation and results were chosen for modeling with Sigma/W. All models were symmetrical, half-field with a width of 300 m and a height of 200 m and included five soil layers. The same foundation bearing pressure (380 kPa) and ground surface surcharge (20 kPa) were applied to all model cases. The Drucker-Prager yield criterion and the elastic-plastic constitutive model were used in the ABAQUS software by GIT. The Drucker-Prager yield criterion is not supported by Sigma/W or Plaxis. The Mohr-Coulomb yield criterion and the elastic-plastic constitutive model were used for the Sigma/W and Plaxis analyses. Descriptions of the basic modeling and the variations are given in Table 1 - Phases 1A through 1F. Soil properties and subsurface model configurations developed by GIT were used in the Sigma/W and Plaxis models.

5. Intermediate Numerical Modeling

The intermediate numerical models are analyzed using Plaxis. Although Sigma/W and Plaxis both implement the finite element method, Plaxis supports more features and capabilities. The intermediate numerical models include Phases 2A through 2E as shown in Table 1. The phases progressively investigate more complex subsurface conditions exceeding those given in the GIT report and use the hyperbolic hardening and modified Cam clay material models and include hard layers overlying the soft zones and voids. Geomechanical properties of the hard layer and soft zone materials are produced as part of this stage and include geometry, spatial distribution, extent, and continuity, which are used in the models.

6. Advanced Numerical Modeling

Advanced numerical modeling applies information obtained from the intermediate stage in addition to seismic loading. Phases 3A through 3D are described in Table 1 and provide the most comprehensive subsurface conditions and modeling in all phases. Phases 3C and 3D are reserved for three-dimensional numerical modeling using the Plaxis software. This allows for a more accurate representation of the soft zones and their effect on ground surface settlement.

7. References

1. K-TRT-G-00008, Rev. 0, Comprehensive Geocharacterization of the Santee Formation and Its Implications for Engineering Behavior, January 2014.

Table 1: Numerical Modeling Phases and Features.

Phase		Analysis Type	Inclusion	Analysis Sequence	Software	Features
Basic Modeling	1A	Mohr-Coulomb, Elastic-Plastic, 2D	None	In Situ Stress State Surface Load	Sigma/W	Half-field and full-field model comparison.
	1B	Mohr-Coulomb, Elastic-Plastic, 2D	Void, Soft Zone	In Situ Stress State Void/Soft Zone Surface Load	Sigma/W, Plaxis	Symmetric model, one, two, and three voids/inclusions, GIT model and soil parameters.
	1C	Mohr-Coulomb, Elastic-Plastic, 2D	Void, Soft Zone	In Situ Stress State Surface Load Void/Soft Zone	Sigma/W, Plaxis	Symmetric model, one, two, and three voids/inclusions, GIT model and soil parameters.
	1D	Mohr-Coulomb, Elastic-Plastic, 2D	Void, Soft Zone	In Situ Stress State Void/Soft Zone Surface Load	Sigma/W	Symmetric model, one, two, and three voids/inclusions, GIT model and soil parameters, minimum c′.
	1E	Mohr-Coulomb, Elastic-Plastic, 2D	Void, Soft Zone	In Situ Stress State Surface Load Void/Soft Zone	Sigma/W	Symmetric model, one, two, and three voids/inclusions, GIT model and soil parameters, minimum c′.
	1F	Mohr-Coulomb, Elastic-Plastic, Groundwater, 2D	Void, Soft Zone	In Situ Stress State Surface Load Void/Soft Zone	Plaxis	Symmetric model, one, two, and three voids/inclusions, GIT model and soil parameters.
Intermediate Modeling	2A	Mohr-Coulomb, Elastic-Plastic, Groundwater, 2D	Void, Soft Zone	In Situ Stress State Soft/Void Inclusion Surface Load	Plaxis	Effects of soft zone geometries and spatial distributions.
	2B	Mohr-Coulomb, Elastic-Plastic, Groundwater, 2D	Hard Layer, Void, Soft Zone	In Situ Stress State Hard/Soft/Void Inclusion Surface Load	Plaxis	Effects of hard layers and soft zone geometries and spatial distributions.
	2C	Mohr-Coulomb, Elastic-Plastic, Groundwater, 2D	Hard Layer, Void, Soft Zone	In Situ Stress State Hard/Soft/Void Inclusion Surface Load	Plaxis	Parameter development for soft and hard inclusions.
	2D	Hyperbolic Hardening, 2D	Hard Layer, Void, Soft Zone	In Situ Stress State Hard/Soft/Void Inclusion Surface Load	Plaxis	Parameter development for hyperbolic analysis.
	2E	Modified Cam Clay, 2D	Hard Layer, Void, Soft Zone	In Situ Stress State Hard/Soft/Void Inclusion Surface Load	Plaxis	Parameter development for modified Cam clay analysis.

Phase		Analysis Type	Inclusion	Analysis Sequence	Software	Features
Advanced Modeling	3A	Hyperbolic Hardening, Modified Cam Clay, Groundwater, 2D	Hard Layer, Void, Soft Zone	In Situ Stress State Hard/Soft/Void Inclusion Surface Load	Plaxis	
	3B	Hyperbolic Hardening, Modified Cam Clay, Groundwater, Dynamic, 2D	Hard Layer, Void, Soft Zone	In Situ Stress State Hard/Soft/Void Inclusion Surface Load Dynamic Load (Seismic)	Plaxis	
	3C	Hyperbolic Hardening, Modified Cam Clay, Groundwater, **3D**	Hard Layer, Void, Soft Zone	In Situ Stress State Hard/Soft/Void Inclusion Surface Load	Plaxis	
	3D	Hyperbolic Hardening, Modified Cam Clay, Groundwater, Dynamic, **3D**	Hard Layer, Void, Soft Zone	In Situ Stress State Hard/Soft/Void Inclusion Surface Load Dynamic Load (Seismic)	Plaxis	

Table 1. Numerical Modeling Phases and Features (cont).