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Research Paper

Settlement prediction for an embankment on soft clay

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ABSTRACT

A model prediction using FE modeling is performed for a trial embankment on soft clay in Ballina, Australia. The comparison between the prediction and the in situ measurement exhibits significant differences. A detailed analysis is performed to validate the model and determine necessary improvements. Sensitivity analyses elaborate upon the most dominant constitutive parameters. Based on site measurements, inverse analyses are performed to identify the optimum parameters. The inverse analysis approach is validated regarding its dependency on the objective function and data incorporated. A comparison between the prediction and the back-calculated parameters confirms the importance of engineering judgment as well as the sensitivity of the modeling strategies to the input information.

1. Introduction

In Ballina, New South Wales, Australia, a full-scale test embankment was constructed to serve as a National Field Testing Facility (NFTF). It was implemented to study the settlement behavior of soft, structured soils typically present along the east coast of Australia. Therefore, the test site was equipped with extensive and versatile in situ testing instrumentation, including that for the measurement of pore pressures, vertical and horizontal deformations and soil pressures. Moreover, high-quality soil samples were extracted and subjected to advanced laboratory testing at the Australian Research Council Centre of Excellence for Geotechnical Science and Engineering (CGSE) in Newcastle.

For the *Embankment Prediction Symposium 2016* held by CGSE in September 2016, asset owners, academic researchers and practitioners were asked to submit predictions for the embankment behavior obtained under different types of analyses, ranging from hand calculations to complex 3D finite element analyses. The predictions were performed based on field and laboratory data provided by CGSE, summarized in [1].

Section 2 introduces the 2D finite element model used within the present study, which is implemented using Plaxis 2D (version 2015). The model simulates the consolidation and creep processes underneath the embankment on soft, estuarine clay and predicts the embankment behavior in terms of transient settlements and pore water pressure dissipation. More details on the model itself and further prediction aspects, e.g., the horizontal displacements, can be found in the prediction report [2].

To minimize the computational effort, sophisticated modeling strategies are used: the geometrical conditions are reduced to an equivalent 2D model, and the installed vertical drains are modeled by a soil volume of equivalent permeability. A 2D/3D unit cell analysis validates the model regarding its dimensionality and ability to adequately simulate the drainage behavior of the vertical drains.

Since the subsoil underneath the embankment includes layers of natural, structured clay, particular focus is set on the choice of a simple but adequate constitutive model as well as on the determination of appropriate constitutive parameters [3]. A validation of the constitutive modeling strategy proves the eligibility of this approach to simulate the complex compression behavior of structured clay with a less complex constitutive law.

Section 3 validates the prediction given in [2] by comparing its results in terms of transient settlements and pore water dissipation with the observed field response provided by CGSE. The comparison reveals significant differences between the prediction and real-life behavior of the embankment.

A detailed analysis is performed to validate the prediction model and reveal necessary improvements. Within the present study, the focus is set on the constitutive modeling strategies and the determination of the constitutive parameters to obtain a better understanding of the complex behavior of soft clays.

Fig. 1 illustrates the strategic approach for the model validation and prediction improvement followed within the present study.

To improve the accuracy and reliability of a prediction, it is essential to know which parameters most strongly influence the

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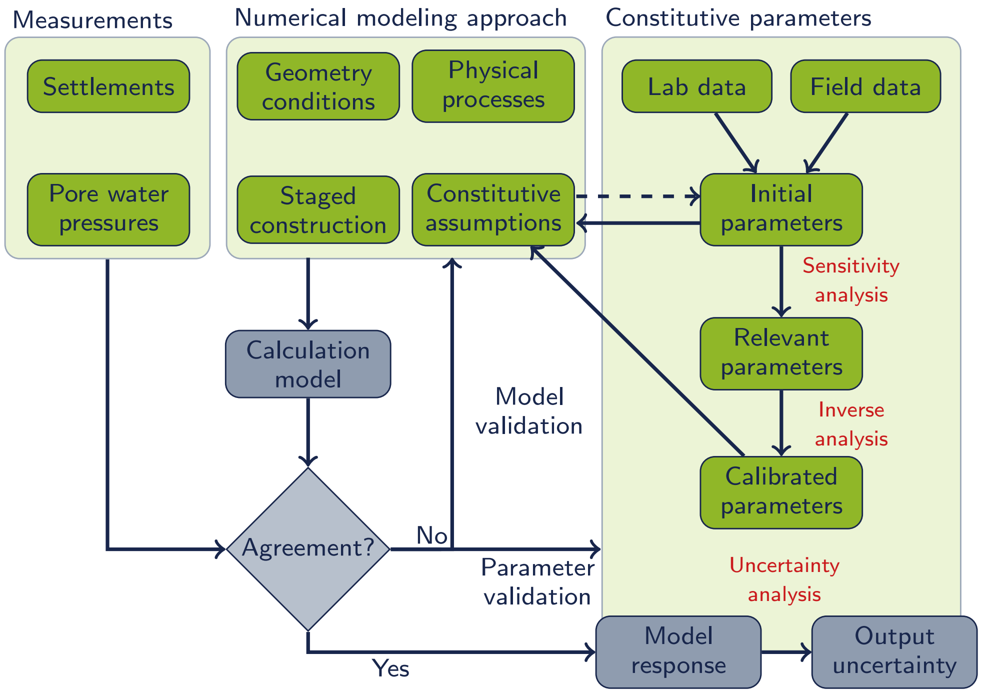

Fig. 1. Flowchart of the conceptual approach followed in this research.

model response. Therefore, in a first step, a parametric study using metamodeling strategies to perform global sensitivity analyses is used to elaborate upon the most relevant constitutive parameters. However, it has to be considered that the predominance of certain model parameters might be caused by model assumptions. A close evaluation of this enables the assessment of the method and highlights what has to be considered when conducting this type of analysis.

With the knowledge of the relevant model parameters, inverse analyses using a Generic Algorithm (GA) for parameter identification can be performed. The aim of this inverse analysis is to identify an optimum parameter set to achieve a good fit between the predicted and measured values. This can be particularly useful when only limited experimental data on the soil properties are available and/or a sophisticated constitutive model requiring advanced laboratory tests is applied. Of course, the inverse analysis itself and its output are strongly dependent on the input information provided for the parameter optimization. Here, particularly, the influence of the chosen objective function for the optimization in terms of type, amount and quality of data incorporated needs to be evaluated. Thus, a step-wise inverse analysis approach considering different objective functions is preferred and executed in the present study. This strategy allows for the assessment of the tool of inverse analysis regarding its dependency on the choice of objective function and data incorporated. Consequently, the importance of engineering judgment and the sensitivity of the method to input information can be illustrated.

After identifying an optimum parameter set, a critical examination of the identified parameter values needs to be conducted. Through a comparison of the initial and optimum parameter values, a physical justification needs to be achieved.

Moreover, the initial as well as final predictions are based on parameter values that are not precisely known but that are mean values with ranges estimated by engineering judgment. To observe the impact of parameter uncertainty and identify the most dominant parameter ranges on the model output, an uncertainty analysis needs to be executed. A comparison of the model response uncertainty between the initial and optimum parameters will help provide a better understanding and assessment of the performed improvement strategy.

2. Finite element model for embankment prediction

The test embankment is simulated by both a 2D plane strain model and a 3D Finite-Element (FE) model. Plaxis 2D (version 2015) and Plaxis 3D (version AE) are used for conducting the 2D and 3D simulations, respectively.

2.1. 2D FE model

The geometry and mesh discretization of the 2D FE-model are shown in Fig. 2. The soil deposit present prior to embankment construction is simplified into 6 horizontal layers. The working platform and horizontal drainage layers are installed prior to the embankment construction. A total of 22 wick drains with a spacing of 1.2 m are used in this test embankment, and the drains are installed up to 15 m beneath the ground surface. According to the in situ investigation, the ground water level is assumed to be 0.72 m below the ground surface.

Based on the trial analysis, the mesh discretization is determined such that model responses are mesh independent. Specifically, Fig. 3 shows the relation between the model response and the number of elements. The point that is located at the center of the 2D model and 4 m below the surface is chosen to check the excess pore pressure after the embankment construction is completed. The model responses using 14,100 elements are taken as the reference value (42 kPa excess pore pressure) to calculate the normalized value of the other cases. As seen, when the number of elements increases from 14,100 to 18,200, the variation in the model response is less than 1%; hence, models with 14,100 elements are used in this research, and the total number of nodes is approximately 114,000.

The bottom of the model is assumed to be fixed, with no deformation allowed. At the left and right boundaries, the horizontal displacements are fixed, whereas vertical displacements are