Hessisches Kompetenzzentrum
für Hochleistungsrechnen

Automatic Parameter Calibration of Advanced Soil Constitutive Models



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Project Term
2025 - 2026

Clusters
Lichtenberg II Cluster Darmstadt

Additional Software
numgeo-ACT

Institute
Institute for Geotechnics

University
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Introduction

Understanding soil behaviour is essential for safe engineering design. Many engineering structures such as buildings, bridges, and embankments depend on reliable predictions of how soils respond to different loading conditions. In many practical situations, especially in coastal areas and river valleys, these structures are founded on sandy soils. The mechanical response of sands can be complex and depends strongly on the applied loading conditions. During earthquakes, foundations and earth structures are subjected to repeated loading cycles that can significantly influence the mechanical response of sands. Under undrained cyclic loading, sands may experience large deformations and stiffness changes, which can affect the stability and safety of structures. Therefore, understanding and accurately modelling the behaviour of sands under earthquake loading conditions is an important task in geotechnical engineering. To simulate this complex behaviour, advanced soil constitutive models are required. These models contain several parameters that are to be calibrated so that the simulated soil response matches the results from laboratory tests. Traditionally, this calibration is performed manually by experts, which requires considerable experience and can be very time-consuming. Automatic parameter calibration provides a more efficient alternative. By using optimization algorithms, the calibration process can be performed systematically and with reduced user influence. However, this approach requires a very large number of numerical simulations. To make this process feasible within reasonable time, the simulations are performed on a High-Performance Computer, where many simulations can run in parallel. The performance of the calibrated parameters is subsequently evaluated in the numerical simulation of an earthquake-prone embankment to assess their performance in a realistic engineering application.

Methods

The project focuses on the automatic parameter calibration of advanced soil constitutive models, which describe the behaviour of sands under monotonic and cyclic loading conditions. The calibration is based on laboratory element tests that represent the mechanical response of sands under different loading paths. To determine suitable model parameters, an automatic calibration framework is used. In this approach, many possible parameter sets are generated and evaluated systematically over successive iterations. For each parameter set, a numerical simulation of the soil response is performed and compared with the corresponding laboratory measurements. The difference between simulated and measured behaviour is then used to assess the quality of the parameter set. Several laboratory element tests are used in each calibration run to determine suitable model parameters. Cyclic laboratory tests used for calibration can contain up to several hundred loading cycles. Each cycle must be calculated step by step in the numerical simulation, which makes these analyses computationally intensive and time-consuming. As the calibration requires evaluating a large number of parameter sets, thousands of such

simulations must be performed. In addition, the applied optimization approach includes random elements and therefore may lead to slightly different parameter sets in different runs. To evaluate the reproducibility of the calibration results, the procedure is repeated several times and the resulting simulation responses and error measures are compared. Different parameter sets may lead to similar predictions of the soil behaviour. This is considered acceptable as long as the calibrated parameters lead to comparable predictions in the simulation of the element tests and the investigated earthquake-prone embankment. Because of the large number of simulations required, the computations are performed on a High-Performance Computer, where many simulations can run simultaneously and the total computation time can be significantly reduced.

Results

The automatic parameter calibration was applied to investigate the behaviour of sands relevant for an earthquake-prone embankment. For this purpose, a soil constitutive model was calibrated using laboratory element tests representing both monotonic and cyclic loading conditions. The calibrated parameters were later used to simulate the response of the investigated embankment in a boundary value problem. To assess the reliability of the obtained parameters, several independent calibration runs were performed. The results show that the optimization procedure consistently reduces the difference between simulations and laboratory observations over successive iterations. The calibration error decreases consistently over successive iterations for all independent calibration runs. The simulations reproduce the responses of the laboratory element tests for all independent calibration runs. The results demonstrate that the automatically calibrated parameter sets produce similar model responses, indicating a reproducible calibration procedure. The calibrated parameter sets were subsequently used in the numerical simulation of the investigated embankment to evaluate their performance in a boundary value problem. The calibrated parameter sets were further evaluated in the simulation of the investigated embankment. The predicted settlements obtained from ten independent calibration runs show only minor variations.

Discussion

The results show that automatic parameter calibration is a promising approach for determining parameters of advanced soil constitutive models. Compared with traditional manual calibration, the automated procedure allows a systematic and reproducible evaluation of many parameter combinations. The results from several independent calibration runs indicate that similar model responses can be obtained for both monotonic and cyclic loading conditions. The performance of the calibrated parameter sets was further evaluated in a boundary value problem representing an earthquake-prone embankment subjected to earthquake loading. This allowed the performance of the automatically calibrated parameters to be assessed in a

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realistic engineering application. A major challenge of the automatic parameter calibration is the large computational effort required. The use of a High-Performance Computer therefore plays a key role in making the calibration process feasible within a reasonable time.

Publications

Brosz F., Machaček J., Zachert H.: Automatic Parameter Calibration of Advanced Constitutive Soil Models and Application to a Boundary Value Problem, Geotechnical Engineering Challenges to Meet Current and Emerging Needs of Society, S. 369-374, London, CRC Press/Balkema, XVIII European Conference on Soil Mechanics and Geotechnical Engineering (ECSMGE 2024), Lisbon, Portugal, 26.08.2024- 30.08.2024

Brosz F., Machaček J., Zachert H.: Automatic Parameter Calibration of Two Sophisticated Soil Models Based on Monotonic and Cyclic Tests on Sand, Proceedings 10th NUMGE 2023, London, 10th European Conference on Numerical Methods in Geotechnical Engineering, Imperial College, London, 26.06.2023-28.06.2023

Last Update: 2026-06-16 14:33