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Simulation of complex triaxial tests with HySand, a new multisurface constitutive model in the hyperplastic framework

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Offshore wind has a key role to play in the energy transition. The majority of offshore wind turbines (OWTs) are bottom-founded with monopiles [1]. Monopiles account for up to 35% of the installation cost of the OWT [2, 3]. Optimising the design of monopiles can thus lead to significant savings and increased competitiveness of OWTs in the energy market.

The PISA project [4] has led to the optimisation of the design under monotonic lateral loading of monopiles founded in sands, clays, and layered profiles [5 ,6, 7]. Because of this optimisation, along with the increasing size of OWTs, and the deeper waters where they are installed, design under cyclic loading is becoming crucial. There are, however, significant shortcomings in current design methods to predict the effects of cyclic loading on a monopile: accumulated rotation, changes in stiffness, energy dissipation and strength.

The PICASO project, a joint research project between the University of Oxford and Ørsted, seeks to develop a new design method for monopiles under cyclic loading in sands and clays. Similarly to PISA [8,9], this design method will use the finite element method to simulate the behaviour of monopiles. For PICASO, such simulation requires constitutive models able to capture the behaviour of soil under cyclic loading. However, available advanced constitutive models for sand face severe limitations [10, 11] and are not satisfactory for the simulation of cyclic loading.

HySand [12, 13], a family of models developed in the hyperplastic framework, fills this gap. HySand_base is a 14 parameter multisurface plasticity model with non-linear elasticity, shear plasticity and hardening, and two plastic volumetric mechanisms resulting in non-associative plasticity: one dilation mechanism which value depends on the evolving density and anisotropy of the sample, and one density dependent consolidation mechanism.

This document presents comparisons between the database on Karlsruhe fine sand by Wichtmann [14] and results of simulations with HySand_base. The focus will be on complex tests that other models fail to simulate adequately, such as undrained strain-controlled cyclic tests. Data and simulation with HySand_base of such test on medium dense sand are presented in Figure 1.

HySand_base performs well across densities and types of triaxial tests. This gives confidence in its existing three-dimensional implementation in finite element codes, and demonstrates its value to future design processes.

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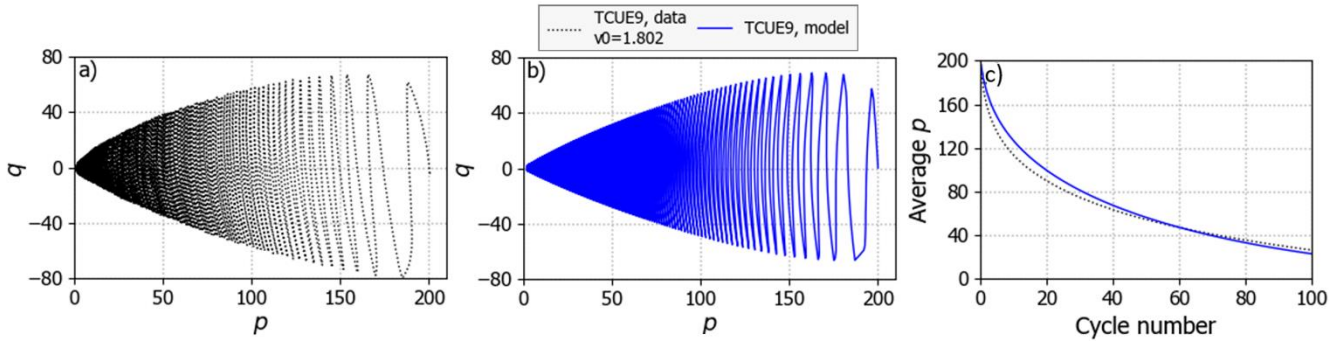

Figure 1: Test TCUE9 by Wichtmann [14] (strain amplitude 0.06%). a) Stress path, data; b) Stress path, simulation with HySand_base; c) Comparison of mean effective stress relaxation with number of cycles during the test.

Data Availability Statement

Further simulations with HySand_base can be found in Simonin [13].

Contributor statement

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