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SANISAND-MPL: Toward a Unified Framework for Offshore Soil Behaviour under Undrained Loading

Junyu Zhou
Aalborg University, Aalborg, Denmark
Merita Tafili
Ruhr-University Bochum, Bochum, Germany
Amin Barari
RMIT University, Melbourne, Australia
Aalborg University, Aalborg, Denmark
Nazanin Irani
Ruhr-University Bochum, Bochum, Germany
Torsten Wichtmann
Ruhr-University Bochum, Bochum, Germany
Lars Bo Ibsen
Aalborg University, Aalborg, Denmark
junzho@build.aau.dk (corresponding author)

ABSTRACT: Offshore foundations are increasingly deployed in regions with highly variable soil conditions and are subjected to complex environmental and seismic loading. Depending on the soil's hydraulic conductivity and loading characteristics, the response can span fully drained, partially drained, and undrained regimes. To advance a unified framework for simulating offshore soil behaviour, this study introduces SANISAND-MPL, a constitutive model designed to capture state-sensitive liquefaction response with enhanced volumetric plastic flow. The new model enables realistic representation of both medium and dense sand behaviours, encompassing flow liquefaction and cyclic mobility mechanisms, thereby satisfactorily simulating the pre- to post-liquefaction responses. In this extended abstract, an undrained cyclic triaxial test on medium-dense Karlsruhe fine sand specimen was simulated to assess the model's ability to reproduce key responses. The analysis highlights the critical role of the plastic flow rule in simulating excess pore water pressure generation, critical state slopes in triaxial extension and compression, and shear strain accumulation. Results show that incorporating realistic cyclic dilatancy and contraction behaviour enables SANISAND-MPL to accurately capture both the onset of liquefaction and its subsequent effects across a range of relative densities.

1 INTRODUCTION

Offshore foundations in sandy seabed are subjected to complex (high) cyclic loadings, and seismic excitations in certain regions. Reliable performance-based design therefore requires advanced constitutive models that capture coupled stress–strain response and excess pore water pressure evolution while predicting state-dependent permanent strain accumulation under undrained cyclic shearing (Barari et al., 2017). The SANISAND-MSu model provides a strong basis for capturing undrained cyclic response, but shortcomings remain in predicting strain accumulation rates for soil specimens with various initial relative densities, particularly for medium-to-dense sands (Liu et al., 2020).

To address this limitation, this study introduces the SANISAND-MPL model, a newly developed constitutive model that extends the SANISAND-MSu model through modified volumetric plastic flow, where M stands for 'memory surface', and PL denotes the 'post-liquefaction behaviour'. It provides a more robust representation of pre- and post-liquefaction behaviour, including the enhanced stress-strain hysteresis evolution and the realistic post-liquefaction strain accumulation rate across a wide range of initial relative densities.

2 RESULTS AND DISCUSSION

The SANISAND-MSu formulation was independently implemented following the constitutive formulations stated in Liu et al., (2020). The model performance is herein examined against one undrained cyclic triaxial tests on Karlsruhe fine (KF) sand. The soil properties and the detailed experimental setup refer to Wichtmann and Triantafyllidis (2015). Figure 1 compares the experimental response with simulations from the SANISAND-MSu and the SANISAND-MPL models for a medium-dense KFS sample with initial void ratio of $e_0 = 0.832$.

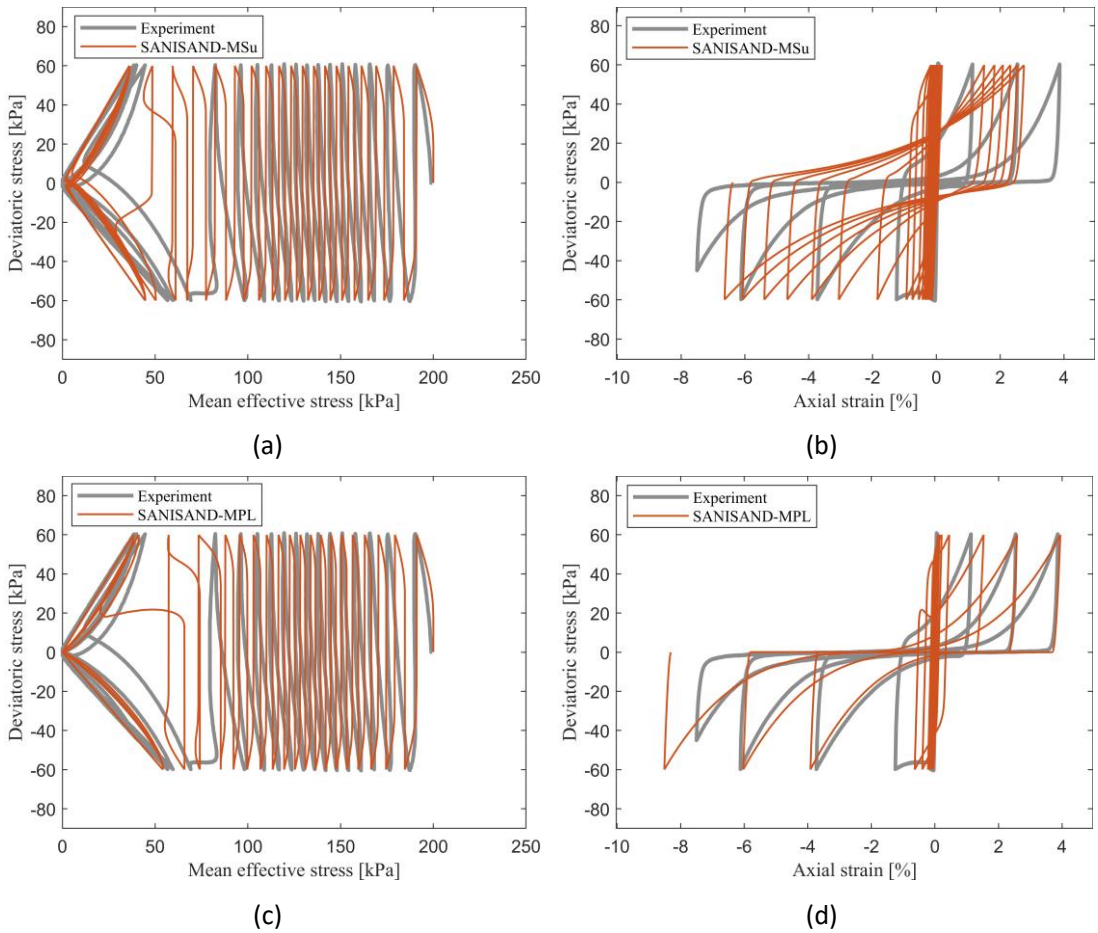

Figure 1. Comparison of experimental and simulation results for an undrained cyclic triaxial test on KF sand with $e_0 = 0.832$, using the SANISAND-MSu model (a-b) and the proposed SANISAND-MPL model (c-d).

Both models successfully reproduce the main pre-liquefaction trends and capture the influence of loading history on EPWP buildup. However, in the post-liquefaction stage, the SANISAND-MPL model more accurately captures the critical state slopes for triaxial extension and the liquefaction stress attractor ($p = q = 0$). Furthermore, benefitted by more realistic predictions of the in-cycle stiffness degradation and recovery during cyclic mobility, the SANISAND-MPL model produces more realistic stress-strain hysteresis details, and subsequently yields more pronounced strain accumulation and strain amplitude generation, that aligns closely with the experimental observations.

3 CONCLUSIONS

This study proposes the SANISAND-MPL model, which enhances the SANISAND-MSu model with an updated plastic flow rule. The comparative analysis proves that the proposed SANISAND-MPL model better predicts the butterfly-shaped stress loops, liquefaction-induced stiffness degradation, and the permanent strain accumulation as well as the strain amplitude evolution during cyclic mobility.

These advances strengthen the basis for incorporating implicit numerical simulations for offshore foundation design under complex seismic and cyclic loading conditions.

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