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On The Behaviour Of Advanced Constitutive Soil Models In a Large Scale Experiment

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Objective

- Develop an axisymmetric finite element (FE) model of the laboratory large-scale test to simulate soil conditions below pavements in a simplified manner.
    - Calibration of advanced constitutive model parameters (Hypoplastic model with IGS and SANISAND model).
    - Development of a FE model (Model the influence of cyclic loading and friction between steel and soil).
    - Investigation of the behaviour of different advanced constitutive models.

This study contributes to the understanding of soil response under realistic cyclic load and interface conditions.

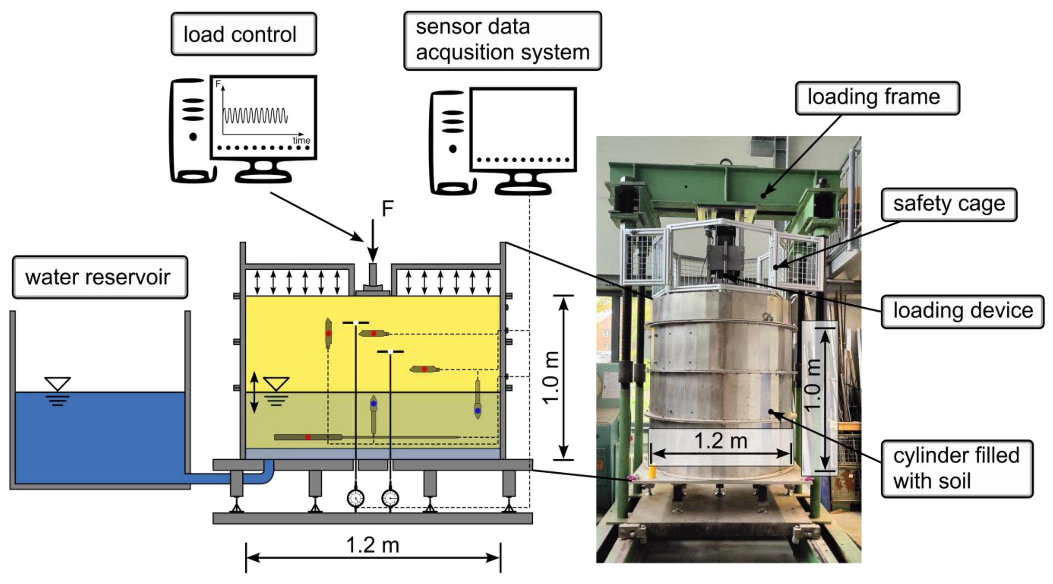

Fig. 1: Soil column as large scale Experimental test setup.

Model Setup

- **Software**: Tochnog FE is used for the simulation of basic parameters of Hypoplastic mode, while the Incremental Driver is employed to simulate cyclic loading conditions and to calibrate SANISAND model parameters (Pre- and Post- processing is performed using GID).
- **Geometry**: The total model height is 1m and radius 0.6 m. The model represents a circular steel plate resting on a cylindrical soil domain under axisymmetric conditions.
- **Boundary Conditions**: The model is symmetric about the central axis. The base is fixed with zero horizontal and vertical displacements (u_x = 0, u_y = 0) and the outer vertical boundaries are constrained horizontally (u_x = 0)
- **Loading**: Cyclic vertical loading is applied on top mid steel plate as a sinusoidal pressure to represent repeated traffic induced loads.
- **Interface**: Steel-soil interface modelled with friction coefficient of μ = 0.57

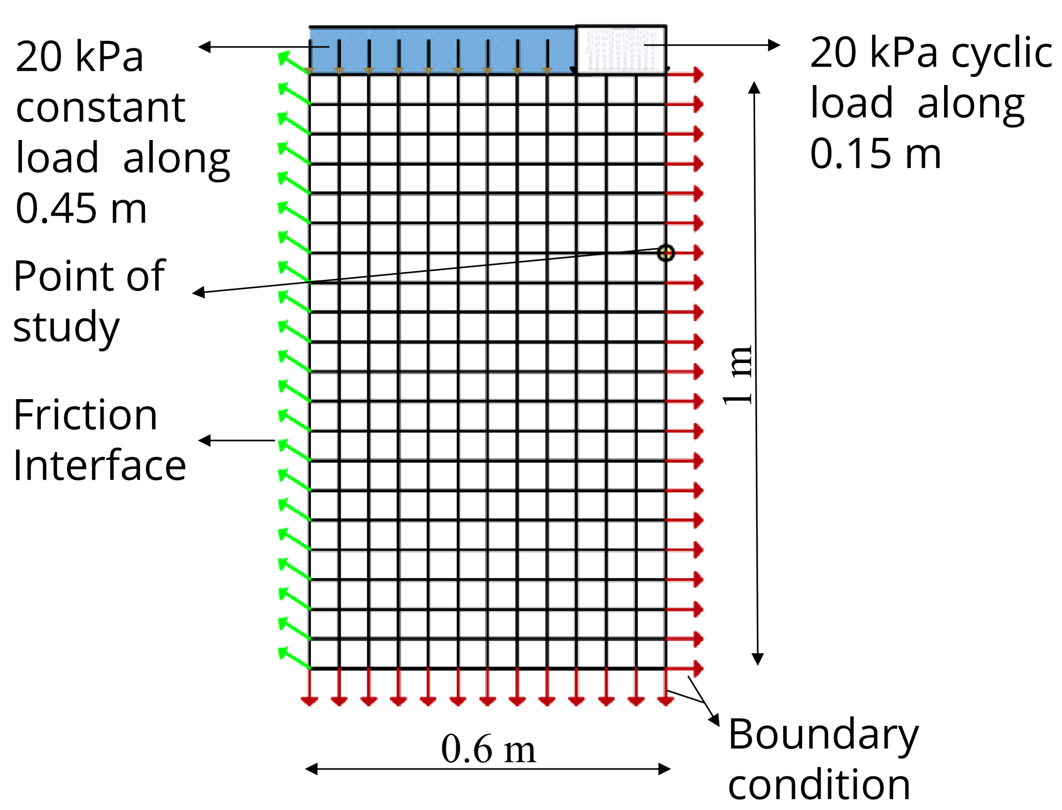

Fig. 2: Geometry of FE half axisymmetric model with uniform mesh (0.05m) generated in GiD.

Calibration : Hypoplastic model with Intergranular Strain concept (IGS)

- Combines elastic and plastic behaviour into single constitutive law without yield surface, capturing history-dependent stiffness of sandy soil.
- The Intergranular Strain Concept (Niemunis & Herle, 1997) adds reversible micro-strain, modelling small-strain stiffness and predicting hysteresis and cyclic stiffness degradation.
- Model parameters, calibrated from triaxial and oedometer tests reproduce nonlinear stress-strain response and cyclic behaviour.
- Accurately captured small-strain stiffness, stress response and compressibility for lower/moderate stresses.
- Good prediction of cyclic deformation for recoverable strain, though long term ratcheting slightly underestimated.

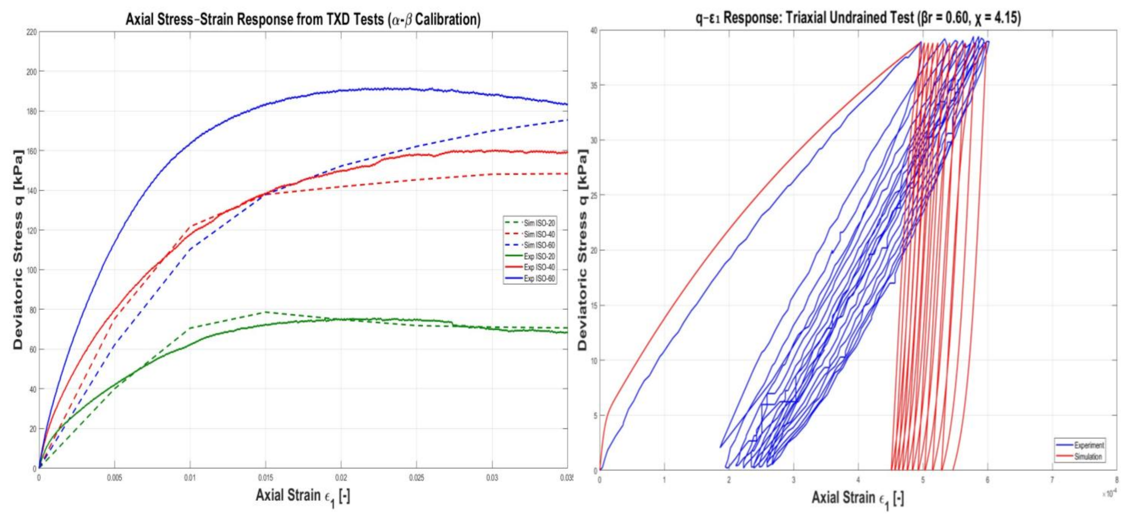

Fig. 3: Calibration of Hypoplastic Model – Comparison between experimental and simulated triaxial test results.

Calibration : SANISAND model

- Simple Anisotropic Sand model captures elasto-plastic behaviour of sand based on Critical State Soil Mechanics and Bounding Surface Plasticity.
- Employs narrow wedge shaped yield surface to capture anisotropy.
- Models loose/dense sands, high pressure states, cyclic and reverse loading.
- Calibration done with triaxial test data.
- Captured realistic trends of dilatancy behaviour and stress response.
- Good prediction of cyclic deformation for permanent strain.
- Require more precise calibration.

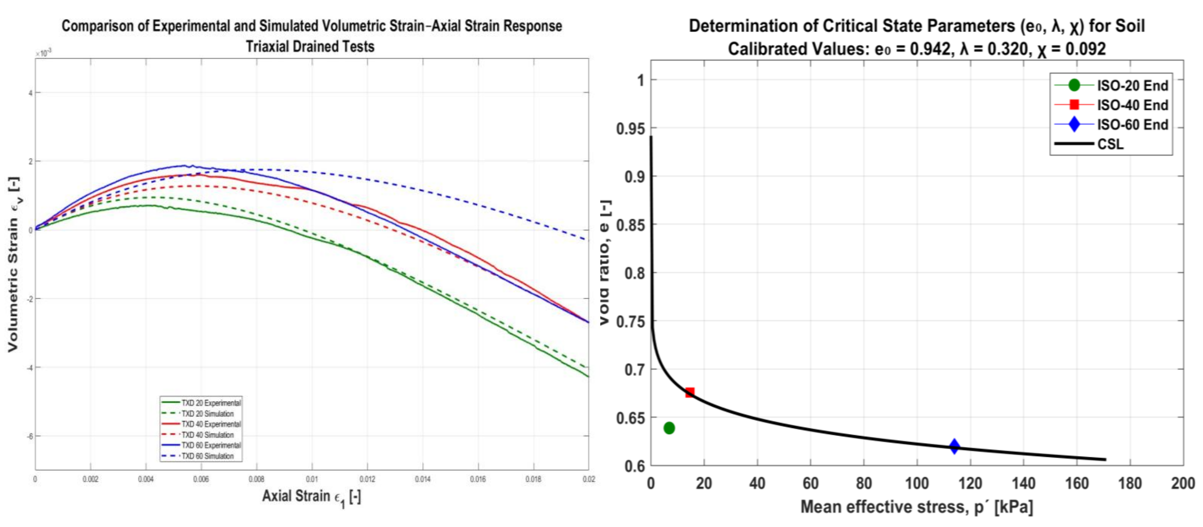

Fig. 4: Calibration of SANISAND Model – Experimental and predicted triaxial test responses with fitted Critical State Line.

Cyclic Load Modelling

- Applied 8 cycles of half-sinusoidal wave cyclic load on steel plate to evaluate settlement.
- Both models exhibited increasing settlement with load cycles, followed by stabilization.
- SANISAND showed more pronounced cyclic accumulation, while the Hypoplastic model predicted higher initial stiffness.
- Results validated both models ability to simulate cyclic densification effects.

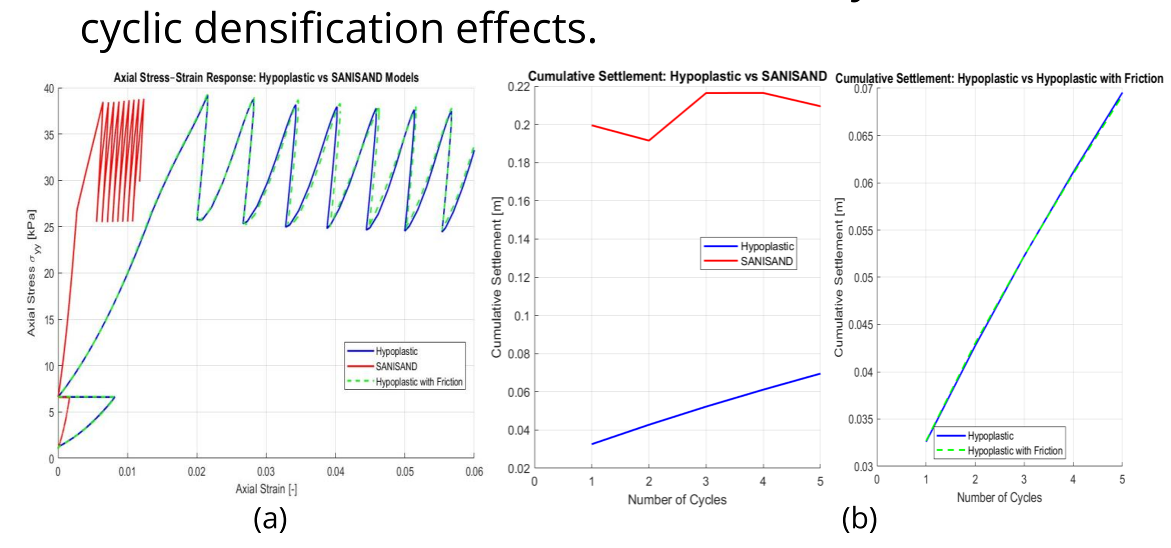

Fig. 5: (a) Vertical Stress-strain response (b) Settlement response under cyclic load for Hypoplastic model, SANISAND model and Hypoplastic model with friction.

Friction Modelling

- The steel-soil interface was modelled using Coulomb friction law: τ = μ . σ_n.
- A single friction coefficient (μ = 0.57) based on friction angle of soil, was applied to reproduce realistic settlement.
- The friction interface enhances structural performance, by reducing peak stresses, minimizing settlement and increasing overall system stability without significantly altering long- term deformation.

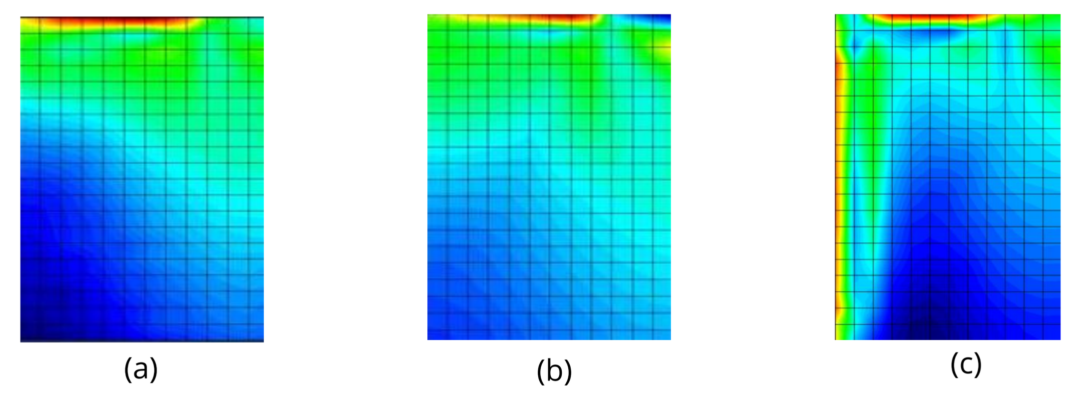

Fig. 6: Stress distribution of maximum vertical stress over all 8 cycles for (a) Hypoplastic model, (b) SANISAND model and (c) Hypoplastic model with friction.

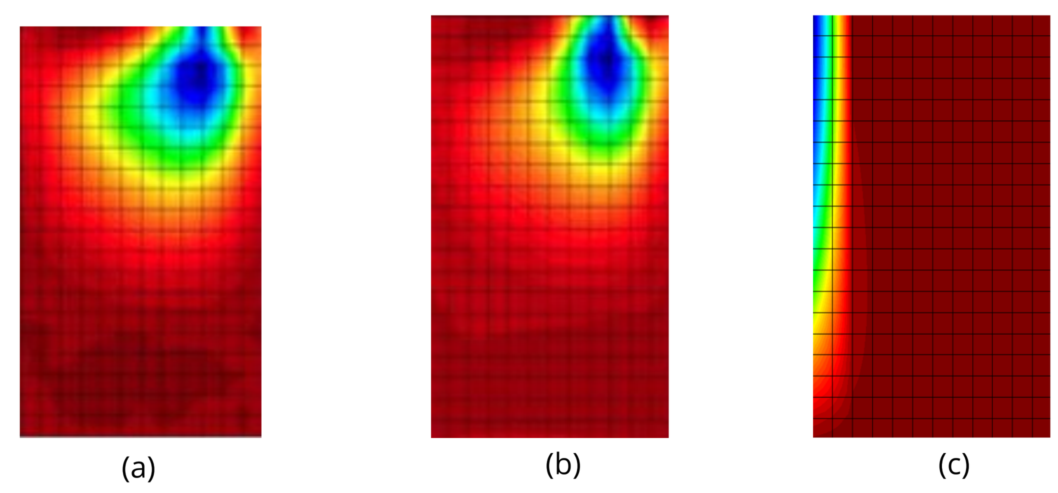

Fig. 7: Shear strain distribution over all 8 cycles for (a) Hypoplastic model, (b) SANISAND model and (c) Hypoplastic model with friction.

Conclusion

- The study evaluated the predictive capabilities of two advanced constitutive models : Hypoplastic with Intergranular Strain (IGS) and SANISAND.
- Hypoplastic model with IGS concept
    - Captured realistic small-strain stiffness and reversible cyclic response in element level.
    - Effectively predicted realistic settlement in system level.
    - Showed limitation in reproducing volumetric strain and long term ratcheting effects under repeated loading.
    - Inclusion of friction reduces total settlement by ~ 15%, increases strength response by ~ 0.7%, and showed negligible ~ 0.03% on permanent deformation under cyclic loading, while also improving interface stiffness, limiting relative movement and reduces peak stress by 7.7 %.
- SANISAND model
    - Accurately simulated realistic dilatancy trends in small scale.
    - Effectively captured stress response, along with better numerical stability and computational efficiency in large scale.
    - Demonstrated high sensitivity to parameter calibration.

Overall, neither model fully capture complex soil behaviour under cyclic loading. However, both model were found to be internally consistent.

Project
Project Thesis

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Submission
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