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Optimization of Shear Resistance at the Soil-Pile Interface through Geogrid Reinforcement – Finite Element Analysis

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Introduction

Geosynthetics are a crucial element in contemporary geotechnical engineering, providing novel solutions for ground improvement and soil stabilization. They fortify weak soils, boosting the structural robustness of roadways, embankments, and foundations, enabling dependable construction in difficult terrains. Their effectiveness in controlling deformation, enhancing load distribution, and minimizing settlement has resulted in widespread use in geotechnical infrastructure. This paper explores how geogrid reinforcement optimizes shear resistance at the soil-pile interface for single piles within soft clay, focusing on both axial and lateral loading scenarios. Utilizing the Abaqus software, a three-dimensional finite element modeling (3D-FEM) approach is employed for analysis. The study uses a semi-cylindrical finite element model to represent the pile-geogrid-soil system, taking advantage of its symmetry and employing the Mohr-Coulomb model to simulate soil behavior. The results emphasize a comparative analysis of load-displacement curves, with and without geogrid reinforcement, showcasing the impact of geogrids on the soil-pile system's mechanical response. The findings demonstrate that geogrid reinforcement enhances the performance of single piles under both axial and lateral loads by reducing pile-head settlement and displacement, attributed to increased shear resistance at the pile-soil interface.

Finite Element Modelling

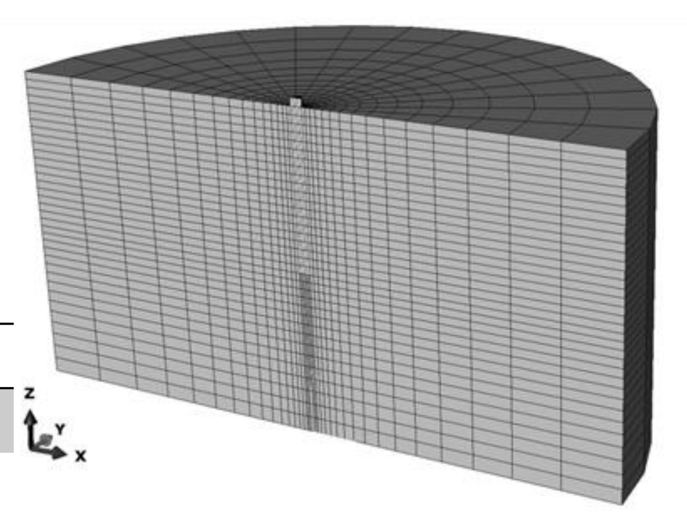
The study employs a three-dimensional semi-cylindrical finite element model in Abaqus to represent the pile-geogrid-soil system, leveraging symmetry to reduce computational cost. The soil continuum, with a diameter and height of 40 m (twice the pile's embedded length), minimizes boundary influences on analysis accuracy. The model's symmetry plane restricts y-direction displacements, while the back surface is fixed against x and y displacements, and the base is fixed in all directions.,

The Mohr-Coulomb model simulates soil behavior, with parameters for soft clay including a saturated unit weight of 17 kN/m³, an undrained friction angle of 1.0 degree, and an undrained cohesion of 20 KPa. The soil continuum is modeled using 8-node linear brick elements with reduced integration ("C3D8R"). Circular piles with varying diameters (1m, 1.5m, and 2m) are modeled as linear elastic materials, maintaining constant flexural stiffness (EI=6.56 GN.m²). Pile elements consist of C3D8R elements in the periphery and 6-node linear triangular prism elements ("C3D6") in the center.

Geogrids, designed to resist tensile forces, are modeled using a linear elastic constitutive model with no compression, an elastic modulus of 210 GPa, and a Poisson's ratio of 0.3. They are represented by 4-node membrane elements with reduced integration ("M3D4R"). Pile facings are smooth, with interfacial friction between the pile and soft clay accounted for using the "contact pairs" approach in ABAQUS, employing the "basic Coulomb friction model" with a coefficient of 0.3 for smooth piles and 0.6 for rough confined piles to represent enhanced shear resistance. The analysis involves a "geostatic" step for initial stress conditions and a "general static" step for applying axial (1MN) or lateral (0.6MN) loads.

Mohr-Coulomb constitutive model parameters for the considered soft clay

Parameters	Value
Saturated unit weight γ_{sat} (kN/m3)	17
Undrained friction angle ϕ_u (deg)	1.0
Dilation angle ψ(deg)	0.1
Undrained cohesion C_u (KPa)	20
Elastic modulus E_s (MPa)	10
Poisson's ratio v_s	0.4



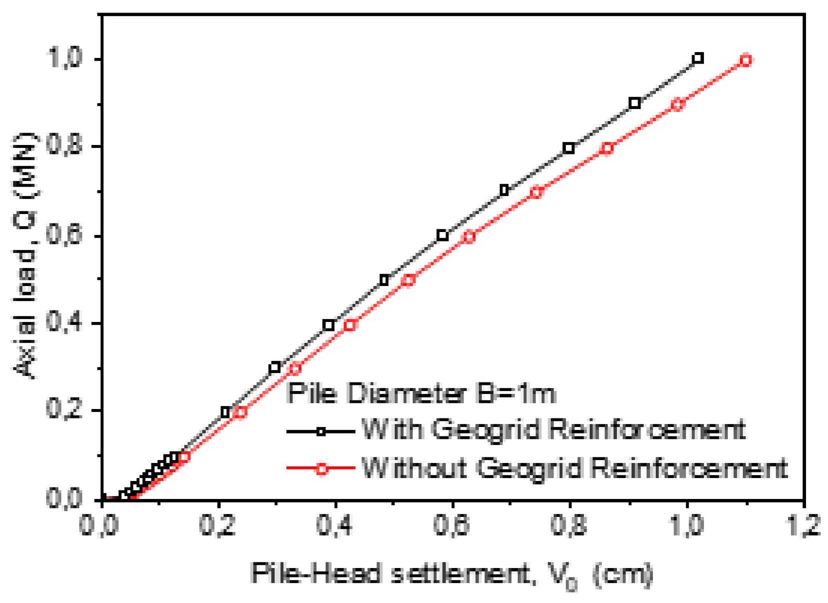
3D finite element model for the pile-geogrid-soil system

Numerical Results and Discussion

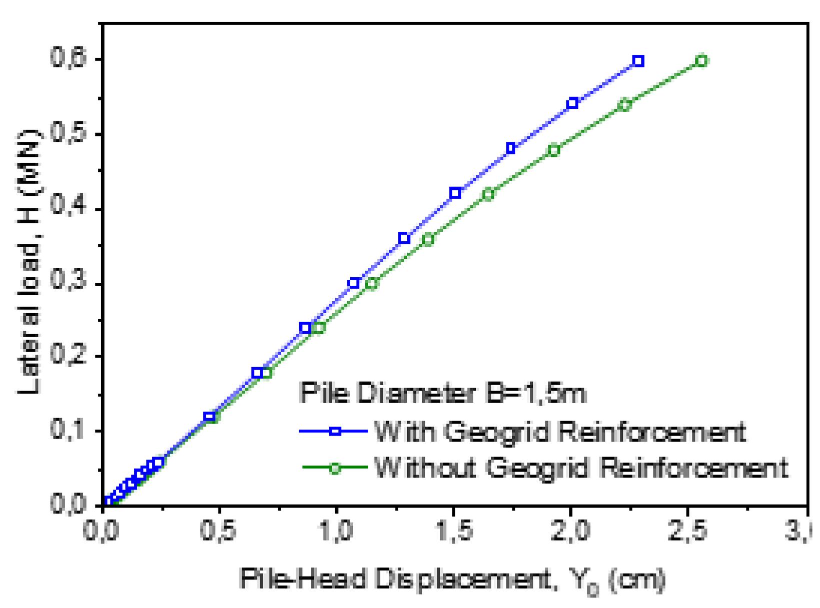
The numerical results show a comparative analysis of load-displacement curves for piles, with and without geogrid reinforcement, demonstrating the influence of geogrids on the soil-pile system's mechanical response. Pile-head settlement (V_0) decreases with geogrid-reinforced piles, regardless of the pile diameter (B). Pile-head displacement (Y_0) also diminishes in geogrid-reinforced piles across all pile diameters, showing improved pile responses to axial (Q) and lateral (H) loads due to increased shear resistance at the pile-soil interface.

The rate of decrease in pile-head settlement (ΔV_0) reduces with increasing pile diameter (B), attributed to the increased normal component of resistance (tip pressure) from the larger pile tip surface in contact with the soil. Conversely, the rate of decrease in pile-head displacement (ΔY_0) increases as the pile diameter (B) increases, interpreted as the increase in friction contact surface between the geogrid and soil, resulting in higher lateral friction stress at the pile-soil interface.

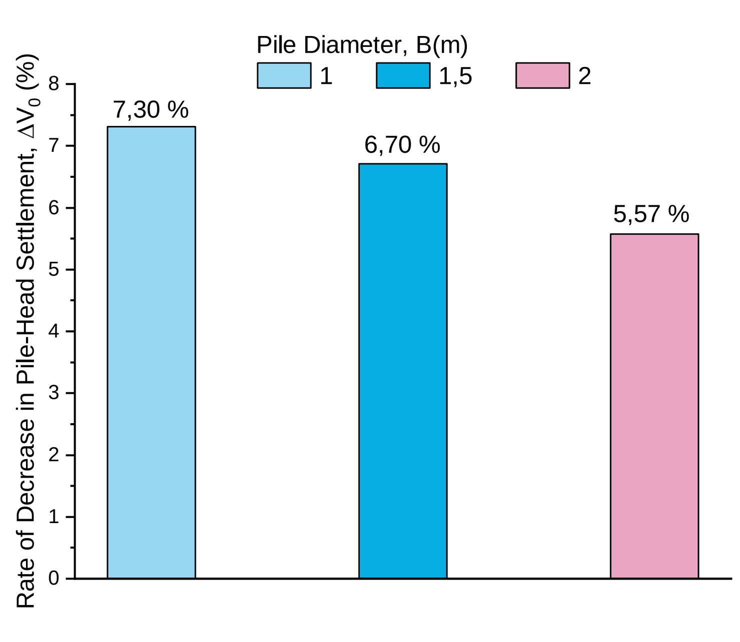
In conclusion, geogrid reinforcement improves single pile performance under axial and lateral loads by reducing pile-head settlement (V_0) and displacement (Y_0), thanks to increased shear resistance at the pile-soil interface. Increasing the pile diameter (B) increases the rate of decrease in pile-head displacement (ΔY_0) but lowers the rate of decrease in pile-head settlement (ΔV_0).



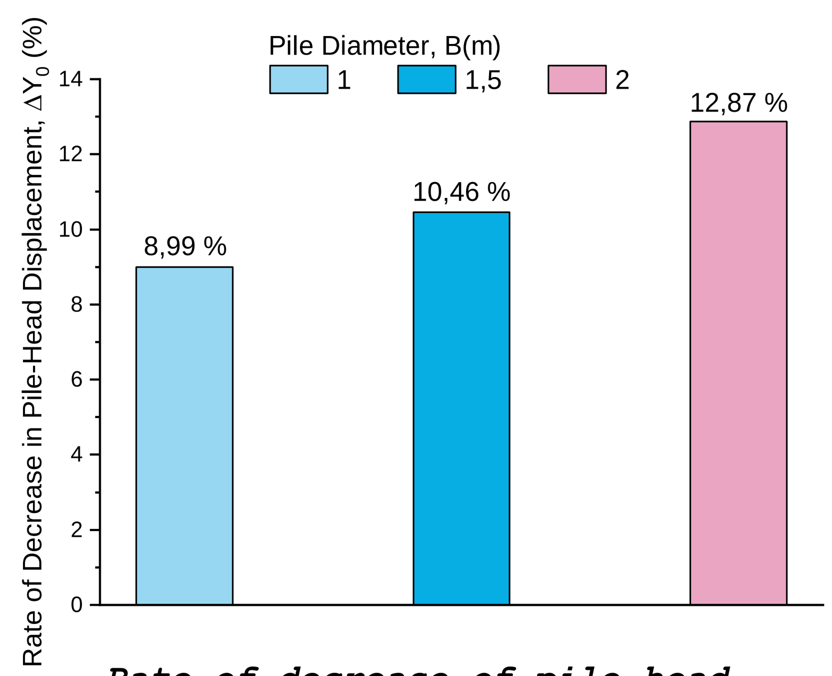
Geogrid reinforcement influence on pile-head settlement V_0 under axial load Q



Geogrid reinforcement influence on pile-head displacement Y_0 under lateral load H



Rate of decrease of pile-head settlement ΔV_0 under axial load Q



Rate of decrease of pile-head displacement ΔY_0 under lateral load H

Conclusions

A three-dimensional finite-element analysis using ABAQUS software of geogrid-reinforced single piles embedded in soft clay, under axial and lateral loads, leads to the following conclusions:

- Geogrid reinforcement improves single piles responses under both axial and lateral loads by reducing pile-head settlement V_0 and pile-head displacement Y_0, respectively.

- These improvements are attributed to the increase of the shear resistance at the pile-soil interface due to the Geogrid Reinforcement.

- Increasing the friction contact surface between the geogrid and the surrounding soil by increasing the pile diameter B, leads to: Increase the rate of decrease of pile-head displacement ΔY_0. This increase can be logically interpreted by the increase in the friction contact surface between the geogrid and the soil, resulting in an increase in lateral friction stress at the pile-soil interface.

- Decrease the rate of decrease of pile-head settlement ΔV_0. This can be attributed to the increase in the normal component of resistance (tip pressure) due to the increase of the pile tip surface in contact with the soil beneath.