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Modeling of Linear Reinforcing Bars in 3-D real space for the use in 2-D Plane Strain Rigid Plastic FE Analysis.

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INTRODUCTION:

The soil reinforcement technique is used these days in the construction of embankments and to stabilize the natural (existing) slopes. 2-D geogrids are very popular in the former type of soil structures and the linear reinforcing bars called nails are used in the latter type structures. The stability analysis of these soil structures by FE technique is always carried out in 2-D space assuming plane strain condition where the reinforcing bars or nails are almost always modeled as an equivalent continuous reinforcing plate. Such 2-D discretization is carried out because of time and cost constraints and the plane strain assumption is valid only when the reinforcements are spaced very close in lateral direction, e.g. geogrids. In the case of linear reinforcing bars, the safety factor and axial force in the reinforcement may be overestimated. It is because the contact area of these real reinforcing bars with the surrounding soil mass is quite less than the equivalent continuous plate posses in 2-D modeling. Appropriate modeling of this problem should arrive at the same shear stress around the reinforcing bar. In fact, the real modeling of such linear reinforcing bars is possible only through the 3-D discretization. In the present study, stability of soil structures reinforced with nails is studied by 3-D and 2-D FE discretization techniques and finally a solution procedure to solve the aforementioned problem is proposed by introducing a new calibration factor where the frictional angle of the soil elements adjacent to the equivalent reinforcing plate is reduced. The variation in the safety factor and reinforcement force with respect to this factor is studied to propose an appropriate calibration factor for the future use in the design of real reinforced soil structures. The results exhibits promising features of the proposed concept.

METHODOLOGY:

The rigid plastic FEM, extended by Asaoka et al.(1994) for the stability analysis of the reinforced soil structures at limit state of soil mass, is used in this study. The reinforcing bars in soil mass are modeled by employing the *no-length change* condition(Fig. 1). The following set of algebric equations were used in the present study: $\int_V B^T s dV + L^T\lambda + C_t^T v + \mu F = \mathbf{0}$ ...(1) $L\dot{u} = \mathbf{0}$ ...(2) $C_t\dot{u} = \mathbf{0}$ ...(3) $F^T\dot{u} = 1$ ...(4).

The Eqs.(2-4) represent the no-volume change($\dot{\varepsilon}_v{}^p = 0$) condition in Mises material, the no-length change condition for the reinforcing nodes and the provisional norms of nodal velocity vectors at limit state of soil mass, respectively. The corresponding Lagrange multipliers in Equation (1) represents mean confining pressure(λ), axial force in the reinforcement(v) and the Load Factor(μ), respectively. Yield function, $f = \frac{1}{2}(s_{ij}s_{ij} - \sigma_o{}^2)$ ...(5). Stress strain rate relationships, $s_{ij} = (\sigma_o / \bar{\dot{e}})\dot{e}_{ij}{}^p$ ...(6). In this study also the Mohr Coulomb material is modeled as a Mises material just like in Asaoka et al.(1994) where the dilatancy is assumed zero and $\sigma_o = \sqrt{2}c\cos\phi + \sqrt{2}p\sin\phi$ (7).

PROPOSED CALIBRATION FACTOR:

The linear bars in 3-D FEA are modeled as they are and in 2-D FE formulation, they are modeled as continuous plates, employing the *no-length change* condition. To overcome the aforementioned over estimation in 2-D FEA, the mobilized shear stress around the reinforcing bars is proposed to be calibrated with 3-D FEA by introducing a calibration factor, $\alpha = \tau_{soil} / \tau_{moblized}$ ...(8) equivalently, the $\alpha = \sigma_{o,soil} / \sigma_{o,moblized}$ ...(9). The approximate alpha can be judged as the factor which produces the similar solutions as from the 3-D FE analysis.

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RESULTS AND DISCUSSIONS:

The Figs.2 , 3 and 4 show the typical FE discretization for 3-D, 2-D analyses and mesh around reinforcement for the proposed calibration method, respectively. The computations in the first two cases have been carried assuming homogeneous soil mass. The plane strain matching is assumed in relating the 3-D soil properties for Drucker Prager material with the Mohr-Coloumb material (c-ϕ). In the 3rd FE mesh, the shear stress of soil elements adjacent to the reinforcement is reduced by the factor mentioned earlier. In the present study, the thickness of such FE elements around reinforcements is kept constant of 5cm for all analyses in order to avoid the possible influence of the element thickness on the computed factor of safety, velocity vectors and reinforcement force, so that, a fixed value of alpha for a particular FE configuration can be established. The alpha is varied from 1, 1.5, 2, 2.5, 3, 5, and 10 to see its influence on the results in a wide spectrum. The alpha equal to 1 means the shear stress around the reinforcement is not reduced, which is equivalent to Asaoka et al.(1994). The soil mass has c=10kPa and varies ϕ=0 to 25 deg. The most appropriate alpha for the given mesh configuration was calibrated by comparing the axial force and safety factor from the proposed method with the 3-D analysis results under similar conditions. In the present case it was 2.0. The computed safety factors for alpha equal to 1 and 2 are compared with the 3-D analysis in Fig. 5.The computed axial force distributions in the reinforcements are illustrated in Fig.6.

CONCLUSIONS:

The method presented in this study seems promising. The calibration factor decided based on the procedure presented in the present study can be used in the design of real reinforced soil structures with the advantage of the reduced cost and time of computations.

References: Asaoka et al.(1994), *Stability Analysis of reinforced soils.....*, Soils and Found. V34(1).

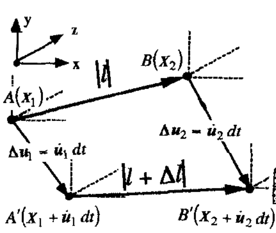

Fig. 1 "*no-length change*"

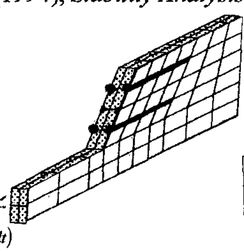

Fig. 2 3-D Mesh

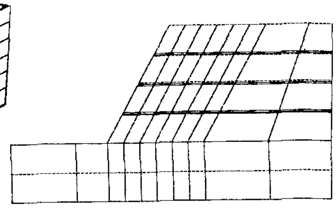

Fig. 3 2-D Mesh

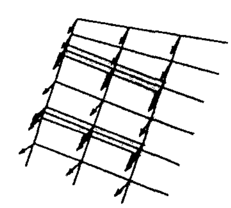

Fig. 4 Proposed Mesh around Reinf.

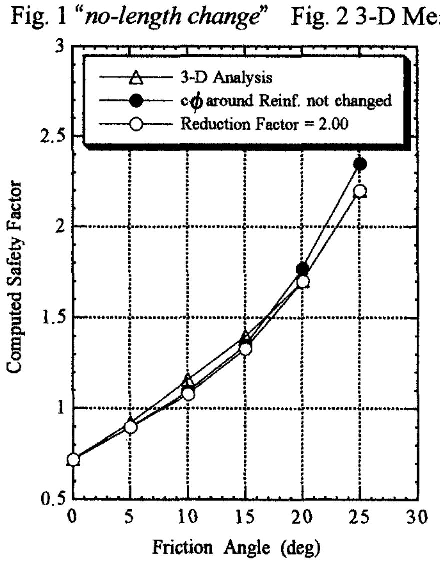

Fig.5 Computed Fs vs Calibration factor

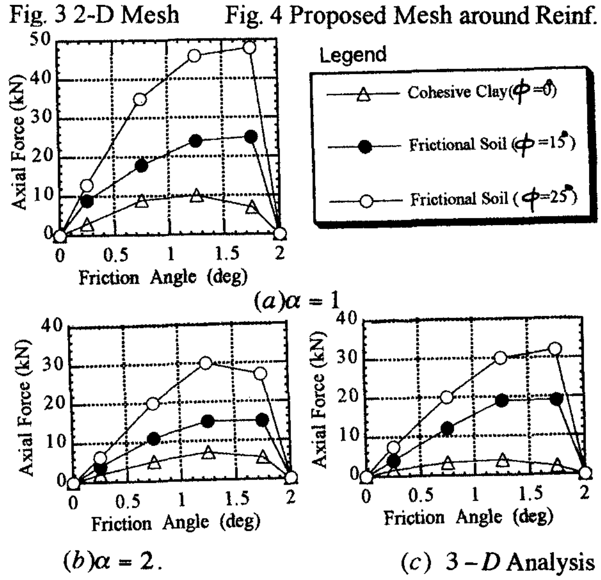

Fig.6 Axial force along the reinforcement