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FINE ELEMENT ELASTOPLASTIC ANALYSIS OF A PILED RAFT FOUNDATION BASED ON THE USE OF A MULTIPHASE MODEL

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Summary. *A multiphase model for the analysis of soil structures reinforced by stiff inclusions is proposed in the context of an elastoplastic behavior for both the soil and the reinforcements. A finite element numerical tool incorporating a plasticity algorithm adapted to this multiphase model, where the effects of shear and bending are taken into account, is developed and illustrated on the example of a piled raft foundation.*

1 INTRODUCTION

A multiphase model for the analysis of soil reinforced structures has recently been proposed, which makes it possible to overcome computational difficulties due to the strong heterogeneity of such structures, by providing a macroscopic description of the composite reinforced soil [1,2]. This contribution is devoted to the extension of the model to the context of elastoplasticity, where the matrix phase is given the same yield criterion as the soil, while the reinforcement phase is characterized by a yield condition involving both the bending moment and the axial effort densities. A finite element computational tool allowing to deal with two-dimensional problems has been developed and used to simulate the behavior of a piled raft foundation under a combined loading.

The general features of this model applied to reinforced soils, a detailed description of which is to be found in [1,2] including in the context of an elastoplastic behaviour [3], may be briefly outlined as follows. According to this model, a region of soil reinforced by an array of densely and regularly distributed inclusions, such as piles, is described as the superposition of two continuous media, called matrix and reinforcement phases, respectively. The matrix phase is endowed with the same properties as the soil, while the reinforcement phase is modelled as a micropolar continuum, involving axial and shear forces, as well as bending moment densities, thus capturing the beam-like characteristics of the reinforcing linear inclusions. Elastic as well as plastic properties may then be assigned to each phase separately.

2 AN ILLUSTRATIVE APPLICATION

The above-described two-phase model of reinforced soils, and related numerical tool, are now used to simulate the global response of a piled raft foundation represented in Figure 1. A strip footing of width B is acting upon a two layered soil mass of thickness $H = H_1 + H_2$ and total horizontal extension equal to B'. Both layers are made of purely cohesive materials (clays) of elastoplastic characteristics (E_1,ν_1,C_1) for the upper layer and (E_2,ν_2,C_2) for the lower one.

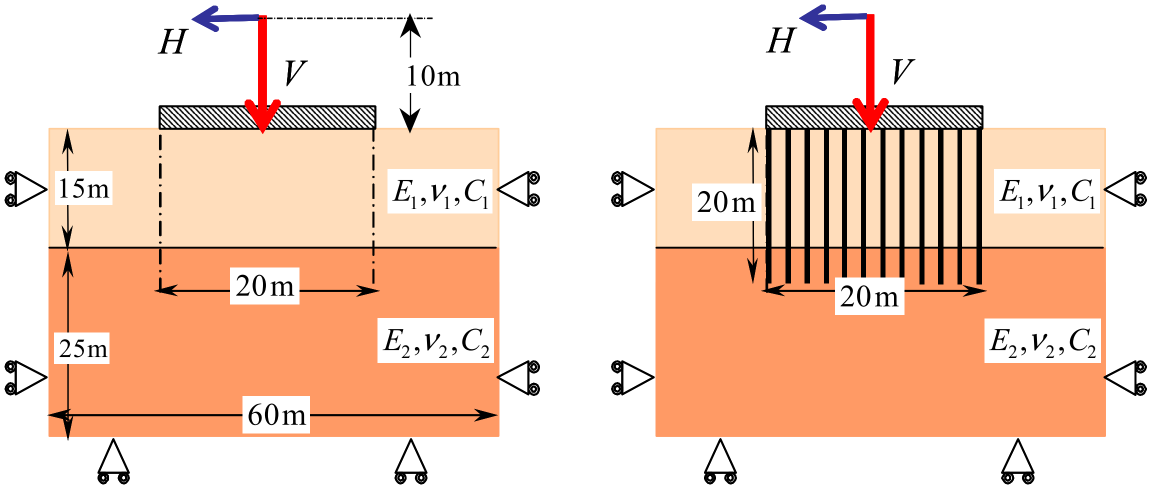


FIG. 1 – (a) Non-reinforced and (b) reinforced foundation.

The strip footing is first subject to an increasing vertical loading up to $N = 2.5\text{MN/m}$, then an additional horizontal (seismic) loading equal to V=0.15*N is* progressively applied at a distance H_3 of the footing. The following set of geometrical and mechanical characteristics of the structure has been selected:

$$H_1 = 15 \text{ m}, H_2 = 25 \text{ m}, H_3 = 10 \text{ m}, B' = 60 \text{ m}, \ B = 20 \text{ m} \tag{1}$$

$$E_1 = 5 \text{ MPa}, E_2 = 200 \text{ MPa}, \nu_1 = \nu_2 = 0.3, \ C_1 = 5 \text{ kPa}, \ C_2 = 100 \text{ kPa} \tag{2}$$

A finite element computational tool allowing to deal with two-dimensional problems has been developed, first in the context of elasticity [2], then extended to the case of elastoplasticity by using an iterative procedure, which combines an elastic calculation with prescribed non-elastic strains defined in both phases, with a local projection of the trial states of stress in each phase on the corresponding yield strength domain.

3 RESULTS AND COMMENTS

A preliminary finite element calculation is carried out on the non-reinforced structure subject to a purely vertical loading path, showing that the ultimate load (0.5MN/m) remains lower than the prescribed vertical load N (lower curve of Figure 2). In order to enhance the carrying capacity of the structure by making it capable to support the vertical as well as the subsequent lateral loading, the following reinforcement scheme is then proposed. A group of vertical hollow circular pipes of radius $R = 1\text{m}$, thickness t=0.02m and length L=20m are placed into the soil mass following a regular square mesh of side d=5m. It is made of a steel having the following characteristics:

$$E^s = 200\,\text{G Pa}\,,\ \nu^s = 0.3\,,\ \sigma_0^s = 200\,\text{MPa} \qquad (3)$$

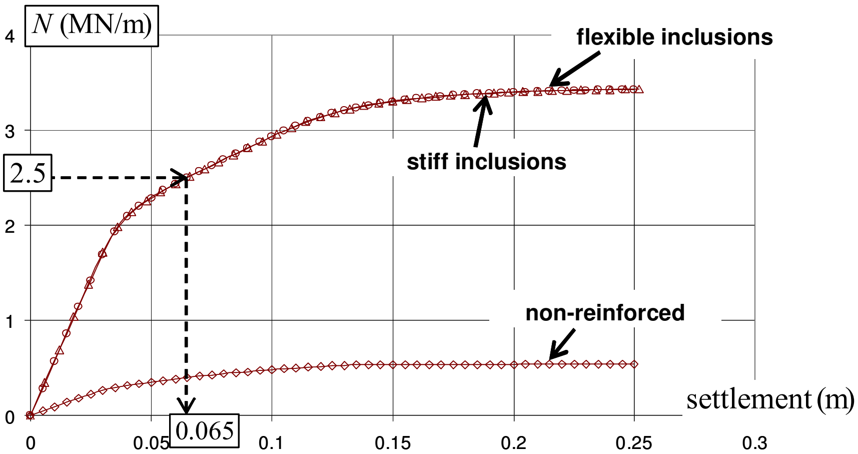
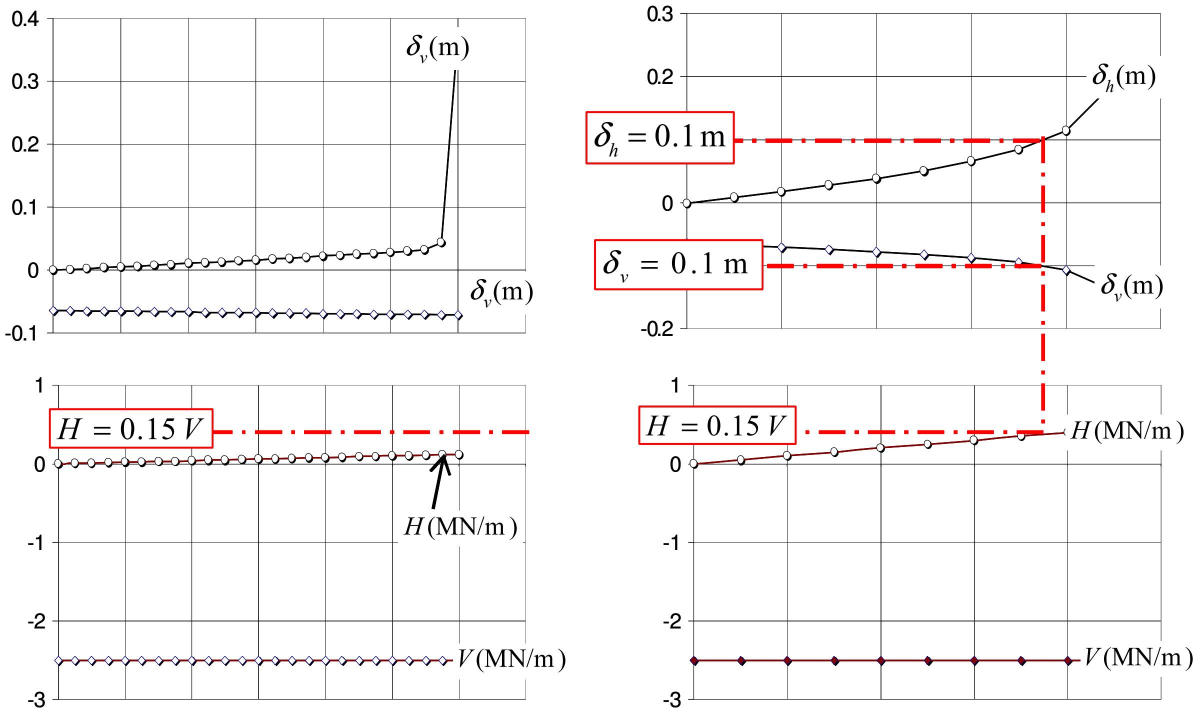


FIG. 2 – Load-settlement curves under vertical loading of the foundation

The elastoplastic characteristics of the matrix and reinforcement phases, to be used in the finite element simulations, are derived as follows. The matrix phase is given the same characteristics as those of the soil. As regards the reinforcement phase, the axial, shear and flexural stiffness densities are obtained by dividing the corresponding rigidities of each individual inclusion, regarded as a structural beam, by the cross sectional area of the representative elementary volume of reinforced soil. Likewise, the yield condition assigned to this phase, expressed as a function of both the axial force and bending moment densities, involves a combination between the resistances of the inclusions under pure axial and flexural loadings.

The upper curves of Figure 2 clearly demonstrates that the use of the proposed reinforcement scheme quite considerably increases the foundation bearing capacity, leading to a vertical settlement of 6.5 cm for the prescribed value of vertical loading. It is to be noted in particular that the fact to account (“stiff” inclusions) or not (“flexible” inclusions) for the shear and bending behavior of the reinforcement has no significant influence on the structure response.

Starting from this preloaded initial state, the horizontal loading is then progressively increased from zero to V=0.15N, as shown in Figure 3. The results are reported in terms of loading history at the bottom of the figure and corresponding response of the foundation in terms of vertical as well as horizontal displacements at the center of the footing, at the top of the same figure. Furthermore, the numerical simulations have been carried out under the assumption of negligible (Figure 3a) or not (Figure 3b) shear and bending effects. It is worth noting that, while in the first case the ultimate bearing capacity of the foundation remains well below the prescribed level of loading, in the second situation the foundation is actually able to support such a combined loading, the corresponding horizontal and vertical displacements being equal to approximately 10 cm. This points to the crucial importance of using stiff and not flexible inclusions in the design of laterally loaded foundations.



(a) (b)

FIG. 3 – Response of the structure in the case when the effects of bending and shear are neglected (a) or not (b).

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