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Bearing capacity of foundations on soft clays with granular column and trench

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Abstract

The bearing capacity of foundations on soft clays under undrained conditions has been computed with inclusion of (i) a single vertical granular trench below a strip footing and (ii) a granular column placed below a circular footing. A lower bound plane strain and axisymmetric limit analysis, in conjunction with finite elements and an optimization procedure, has been used. The efficiency factor (ξ) has been determined by varying B_t/B_f; where (i) B_t = diameter of the column (width of the trench) and (ii) B_f = diameter of the circular footing (width of the strip footing). The effect of (i) the depth (D) of the column (trench) and (ii) the angle of internal friction (ϕ) of the column (trench) material has been explored for a wide range of $c_u/(\gamma B_f)$; c_u and γ imply undrained cohesion and the unit weight of the clay mass, respectively. Factor ξ increased quite significantly with increases in B_t/B_f and D/B_f. Factor ξ improved further with (i) increases in ϕ and (ii) decreases in $c_u/(\gamma B_f)$.

Keywords: Bearing capacity; Clays, Finite elements; Foundations; Limit analysis; Optimization; Plasticity; Stone columns

1. Introduction

A number of investigations, that examined the improvement in the bearing capacity of foundations by the insertion of granular trenches and columns, have been reported in literature. The studies are based on (i) analytical approaches (Madhav and Vitkar, 1978; Bouassida and Hadhri, 1995; Bouassida et al., 1995), (ii) elasto-plastic finite element analyses (Schweiger and Pande, 1986; Mitchell, 1985), and (iii) numerical lower and upper bound finite element limit analyses (Bouassida et al., 2015).

Series of small-scale model experiments (Hamed, 1986; Nazir and Azzam, 2010; Bouassida and Porbaha, 2004) and full-scale field tests (Mitchell, 1981, 1985; Stuedlein and Holtz, 2012) have been carried out by a few researchers. These different model and field tests revealed that the bearing capacity of foundations can be increased quite significantly with an increase in the depth of the granular trench.

In the present paper, the aim is to determine the bearing capacity of both strip and circular footings, placed on soft to medium soft clays reinforced with a single granular trench and column, respectively, by using the lower bound limit analysis with finite elements and the optimization principle.

2. Problem statement

A strip footing with width B_f and a circular footing with diameter B_f are placed over a soft clay deposit with $\phi = 0$.

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The strip footing is provided with a vertical granular trench of width B_t and the circular footing is reinforced with a vertical column of diameter B_t. The depth of the column (trench) is D. The undrained shear strength of the clayey deposit is c_u and the internal friction angle of the granular trench/column material is ϕ. The clayey deposit and granular soil media are assumed to follow the Tresca and Mohr-Coulomb yield criteria, respectively. The internal friction angle of ϕ of the clay is taken as being equal to 0. The associated flow rule is assumed to be applicable for granular material as well as for clay. It is to determine the magnitude of P_u for different values of B_t/B_f, D/B_f, $c_u/(\gamma B_f)$, and ϕ. The interface between the footing and the underlying soil mass is assumed to be perfectly rough. The unit weights of both clay and granular materials are chosen to be the same. Computations for a number of cases, however, have also been exclusively carried out by varying the ratio of the unit weights of these two different materials.

3. Problem domain and boundary conditions and finite element mesh

A rectangular domain KLST, shown in Fig. 1(a), has been considered for solving the problem. The entire problem domain remains symmetric about the vertical axis MN passing through the centre of the footing. Accordingly, zone MNST has been chosen for the analysis. The horizontal distance (L_r) from the right edge of the footing to the vertical boundary, ST, is varied from $5B_f$ to $15B_f$ for different values of ϕ. Depending upon D/B_f and ϕ, the vertical extent (L_d) of the domain is chosen to be between $6B_f$ and $15B_f$. The values for L_r and L_d are selected in a manner such that (i) the yielded elements do not approach any of the chosen domain boundaries (ST and NS) and (ii) increments in the size of the domain do not affect the magnitude of the collapse load.

The stress boundary conditions, applicable along different boundaries of the domain, are illustrated in Fig. 1(a).

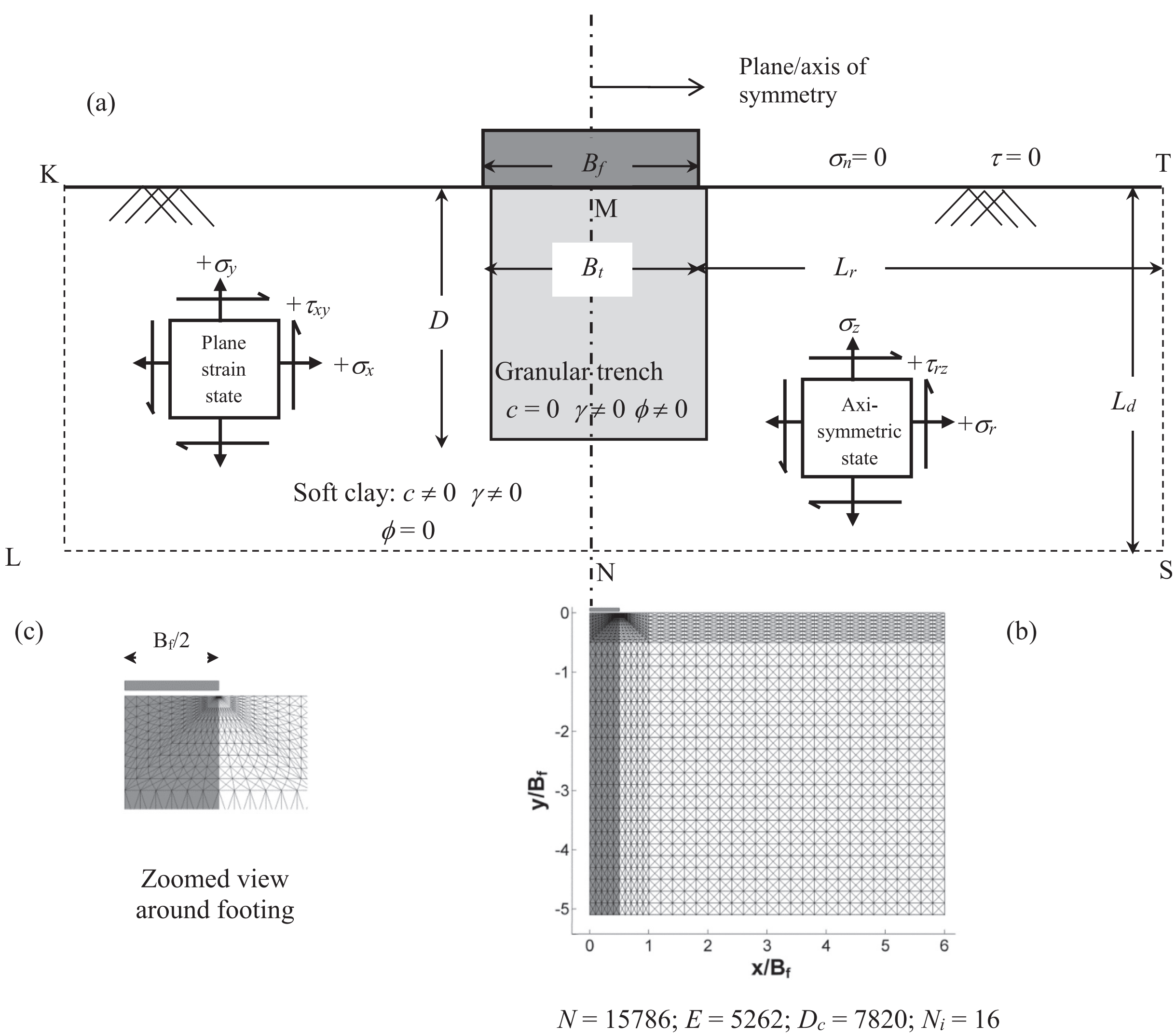

Fig. 1. (a) Schematic diagram of the problem, (b) typical finite element mesh for a strip/circular footing with a granular trench, (c) zoomed view of mesh around footing.