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Determination of stresses the interface of a rigid eccentric footing, accounting for the effect of soil mechanical characteristics and footing geometrical parameters

Determination of stresses the interface of a rigid eccentric footing, accounting for the effect of soil mechanical characteristics and footing geometrical parameters

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Abstract. *As footings are the most important elements in any construction, it seems judicious to dwell on the sizes that condition these dimensions, as well as soil quality on which these footings will be constructed, especially that they often subject to eccentric loads caused by catastrophic natural phenomena (earthquakes, land pressures, wind, etc. It is therefore important to know, with the largest possible approximation, stresses distribution under the footing, and therefore to what extent the structure can remain stable. The study presented herein examines stresses distribution at soil-footing interface for different combinations of soil properties, foundation geometry and applied load eccentricity using 2D finite element modeling. The FEM evaluation is accomplished by using COMSOL software program. The results prove importance and effect of these mechanical and geometrical characteristics on stress distribution at the interface while theoretical solutions strongly ignore some of them.*

Key words: Eccentric footing, finite element method, soil behavior, soil-footing interaction, stress distribution

1. Introduction

The footings subjected to eccentric or inclined loads are frequently encountered in the case of retaining walls footings, abutments, columns, gantries, machines foundations, etc. this type of load reduces the soil ultimate bearing capacity and the stress distribution under footing will be non-uniform causing uneven distribution on both edges.

As an exhaustive presentation of literature on the problem of shallow foundations subjected to eccentric loading is practically impossible because of its huge volume, especially as a wealth of theoretical solutions has been proposed, involving various methods of elasticity or plasticity analysis, using experimental procedures, numerical techniques, analytic developments, and other procedures that still serve needs of research, which focus on aspects of foundation geometry, nature and number of applied loads applied on footing and soil as well the model describing the soil and the soil-footing interface. will be briefly presented below.

In what follows, we present a review in its majority recent of these theoretical solutions. Beginning by the experimental studies Patra et al [1], Sawwaf [2], Ehsan & al [3] conducted laboratory model tests to develop approaches and empirical relationships for footing resting on geogrid-reinforced soil under eccentric load, Singh et al [4] showed the effect of soil confinement on the behavior of an eccentric footing resting on sand, Musso and Ferlisi [5] carried experimental tests on a small physical model strip footing, resting on a saturated dense sandy soil, able to reproduce effective stress levels equivalent to those prevailing in prototype problems, thanks to the maintenance of a downward steady-state seepage in the soil.

Numerical methods have also played an active role for theoretical solutions of this problem, based on either finite difference or finite element techniques, which have been developed to overcome the defects of the conventional limit equilibrium method, among these studies, Massih et al [6] have worked on computation of the failure loads of a rough rigid strip footing subjected to a vertical, inclined or eccentric loading, Lu et al [7] have proposed a numerical procedure to create an explicit collapse mode combining a modified smeared shear band approach with a modified initial stress method. There are also researchers studied on eccentric loading as numerical and theoretical perspectives. Some of them are Nawghare et al [8], Saran et al [9], and Loukidis et al [10].

several studies describe the use of artificial neural networks (ANN), who serves as simple and reliable tool for predicting the behavior of eccentric footings, among which may be mentioned the work of Murat [11] which presented a study describing a multi-linear regression model for the prediction of ultimate loads of eccentric and eccentric inclined loaded strip footings.

Many studies have also used boundary analysis for this problem type, Prakash et al [12] used the concept of one-sided failure mechanism to prove the bearing capacity of eccentrically loaded strip footings considerably affected by the value of e/B, Michalowski and You [13] have examined and confirmed the classical solution of the changes of slip surface with increasing eccentricity and verified the reduction of ultimate bearing capacity due to load eccentricity for associative materials using the variational limit equilibrium approach apply to strip smooth footings,

This indicative list shows that the fundamental problem of the bearing capacity of an eccentric footing is not yet exhausted and will continue to offer new research topics on all its theoretical and applied aspects.

2. Stress distribution

The starting point for safe constructing a footing is constituted by the good estimate of the stress's distribution induced by the acting loads on this footing at the contact interface with soil. In reality, the distribution of these stresses could never assume a linear distribution neither in the elastic region nor in the plastic region.

In this context, the classical formulas of Boussinesq for the determination of the distribution of the stresses under a rigid foundation were developed for infinite stresses at the both edges [14], which is not compatible with the real mechanical properties of soil, this elastic state corresponds to the stresses at the central part of footing Fig. 1. Prandtl [15] has given the values to the both edges so that at any distance from the axis of symmetry the other values of the stresses must be equal to that of Boussinesq, this state is called Prandtl plastic state Fig. 2.

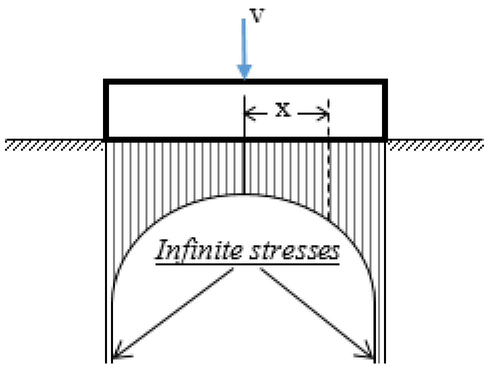

Fig. 1. Contraintes de contact sous une semelle rigide selon Boussinesq.

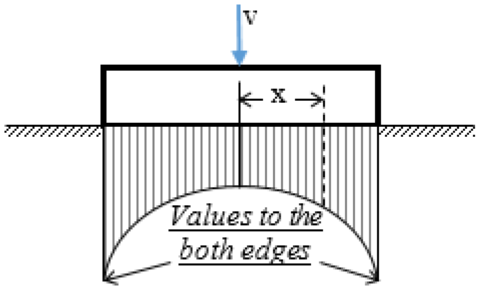

Fig. 2. Contraintes de contact sous une semelle rigide selon l'état plastique de Prandtl.

Schultze [16] developed a method predicts the contact pressure distribution with reasonable accuracy. This method was fairly evaluated by another elastoplastic method developed by Waddah [17].

For the case of footing subjected to eccentric load, most researches successfully discussed the changes of slip surface with increasing eccentricity and verified the reduction of ultimate bearing capacity due to load eccentricity. first Prandtl [15] and Reissner [18] assume that the load applied to the footing is symmetric, this useful hypothesis in which the footing width is reduced by twice the eccentricity to its "effective" size was suggested by Meyerhof [19] wich has been widely accepted in geotechnical design. Michalowski and You [13] have examined and confirmed this classical solution for associative materials using the variational limit equilibrium approach apply to strip smooth footings.

According to the literature review, none of the published studies takes into account both the effect of footing thickness and soil mechanical characteristics on footing lifting and stress distribution at the interface of an eccentric footing. Therefore, this study attempts to better understand the effect of these geometrical and mechanical characteristics to the footing behavior resting on a homogeneous soil under eccentric loads

3. Numerical modeling procedures

COMSOL software was used for two-dimensional simulation. The used model in this study represents a footing of varying width (B) and height (h) laid on a clay layer, which extends (9.5 B) from the foundation edge, and (6B) in depth. The boundary conditions are illustrated in the following Fig. 3.

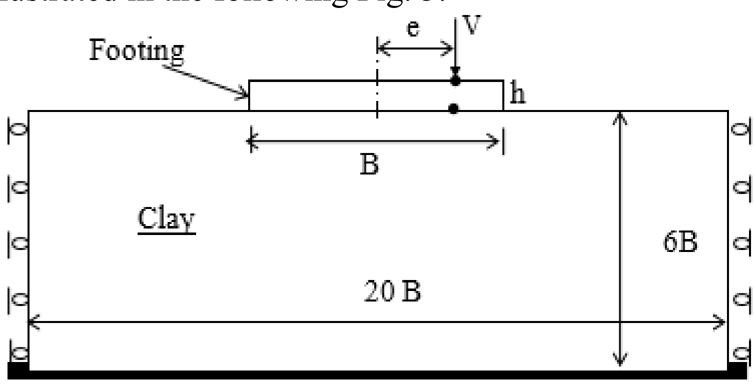

Fig. 3. Geometric characteristics and boundary conditions.

The soil behavior is governed by an elastic-perfectly plastic law and the friction criterion adopted corresponds to that of Mohr-Coulomb. The values of the calculation parameters (E, v, γ, and φ) mentioned in Table I were determined experimentally by the West Public Works Laboratory (WPWL) of Algeria. They correspond to the clay of Abadla city, the region of Bechar, Algeria.

The footing is subjected to an eccentric load, its material is supposed to be a concrete, as for him, to follow a behavior of an isotropic linear elastic type. Its high rigidity compared to that of clay makes it possible to assimilate the kinematics of the footing to that of a rigid body, so the loading is modeled by the application of an imposed displacement instead of a load. This imposed displacement can be specified by the maximum stability value of the footing so that it does not tip over, without creating resistance to rotation and maintained vertical as the footing has rotated. The imposed displacement value is variable, related to the footing geometrical parameters and the soil mechanical characteristics.

Table I

Materials Constitutive parameters

Parameters	Name	Soil type - Clay	Concrete	Unit
Model type	Model	Mohr-coulomb	Elastic	-
Weight	ρ	1700	2200	Kg/m^3
Young’s modulus	E	$2{,}06\times10^6$	20×10^9	Pa
Poisson Coefficient	ν	0,3	0,23	-
Cohesion	c	19,4	-	KN/m^3
Friction Angle	φ	24,73	-	°
Angle of dilatation	ψ	10	-	°

The model has no geometric symmetry because of the load eccentricity, it has been discretized in its entirety by quadratic isoparametric finite elements type with 8 nodes. The same type of elements has been adopted for the footing mesh, in order to ensure a correct assembly. Local mesh refinement was carried out in the suspected zones with strong stress gradients: in the footing vicinity, under its base.

For the treatment of the contact problem, the penalty method is used with a Coulomb's friction coefficient equal to 0.3.

The parametric study targeted four parameters: the first two are of geometrical natures corresponding to the footing thickness and width, while the other two are of mechanical natures related to the cohesion and internal friction angle of clay..

4. Results analysis

4.1 Effect of footing thickness

The effect of footing thickness on its uplift (δ) (Fig. 4) was studied by making numerical simulations on footings with different thickness-width ratios (h / B = 0.125, 0.25, 0.375, 0.5, 0.625, 0.75, 0.875, 0.1, 1.125, 1.25, 1.375, 1.5, 1.625, 1.75, 1.875 and 2) and for each ratio (h / B) the eccentricity value (e) is varied. All the footings rested on the soil surface without embedding.

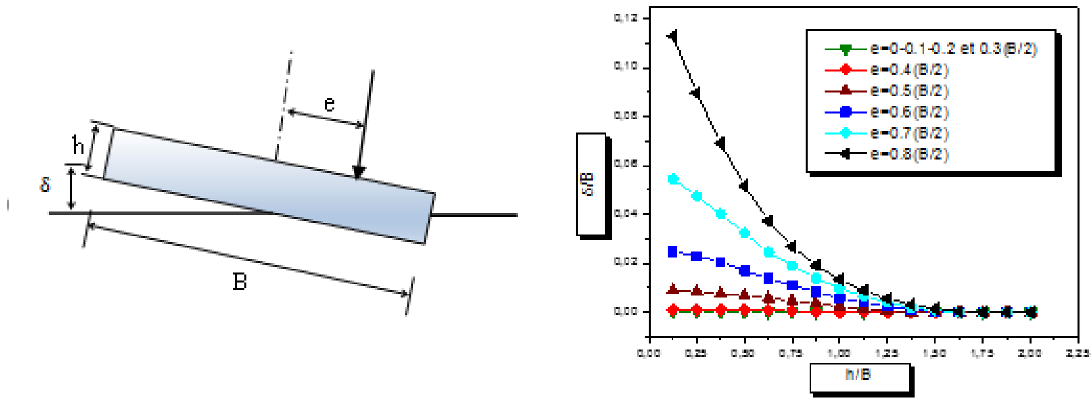

Fig. 4. Contraintes de contact sous une semelle rigide selon Boussinesq.

By examining the curves of this previous Fig. 4. it appears from these graphs that for eccentricities (e=0.1(B/2),0.2(B/2),0.3(B/2)) there is no uplift of the other footing extremity (δ=0), beyond the eccentricity e=0.3(B/2) the lifting (δ) increases by the decreasing of the footing thickness (h) and vice versa.

In uplift case, a part of the footing base does not participate in the transmission of pressure at the soil. This phenomenon is admissible for footings under columns solicited by moments due to the variable load.

4.2 Effect of cohesion and internal friction angle

The influence of the clay mechanical properties (φ and C) on the distribution of the contact stresses at the interface was studied by analyzing a footing with fixed geometry (h=0.25m, B=2m), subjected to an imposed eccentric displacement equal to 0.67m, the used eccentricities are (e=0, 0.3 and 0.7m) and for each eccentricity we have varied (φ) then (C). In reality, the eccentricities over than (B/6) (out of the central third) are rare because the pressure becomes equal to zero at one of the edges of the footing. The effect of the variation of these characteristics is illustrated by the figures below:

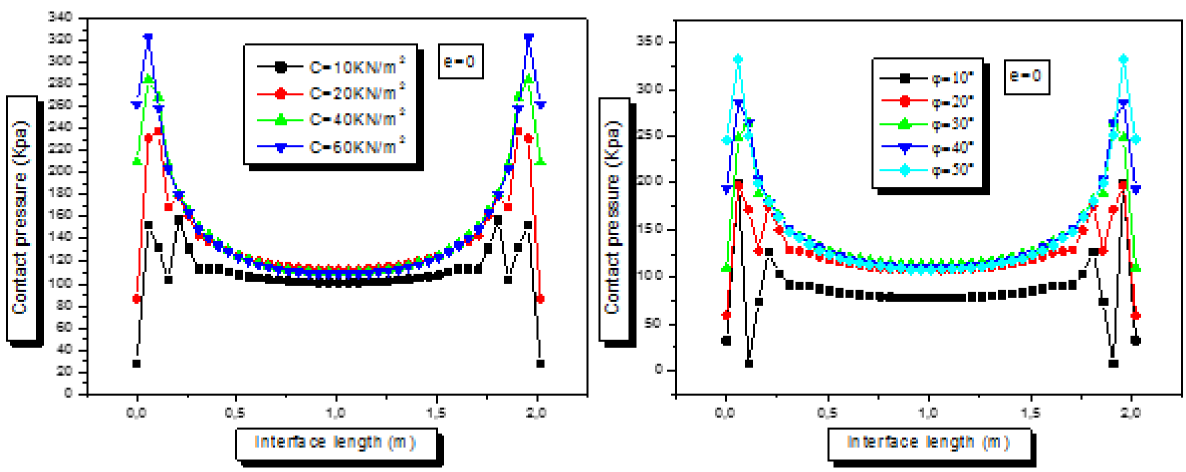

Fig. 5. Contact pressure at the interface (C and φ are variable, e = 0.0m).

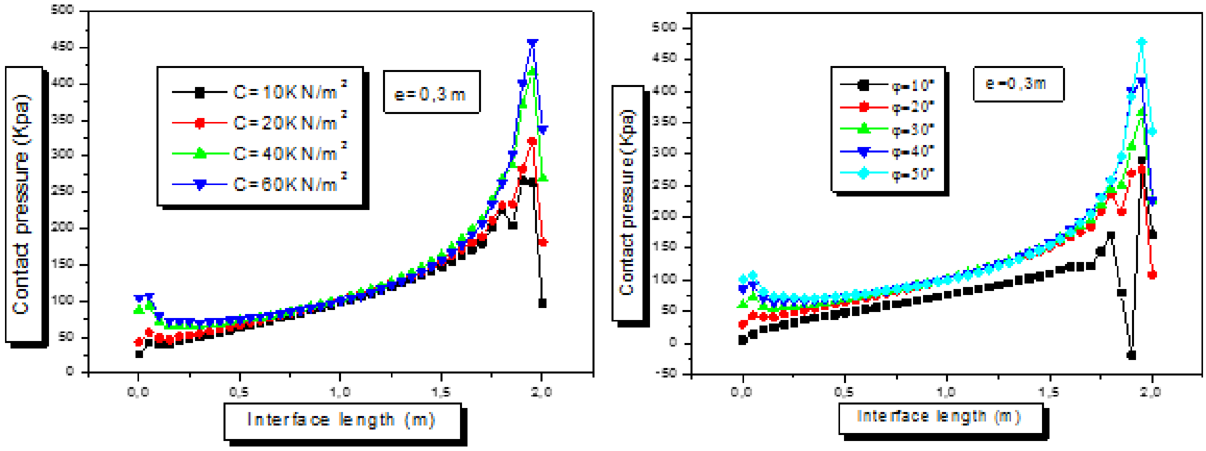

Fig. 6. Contact pressure at the interface (C and φ are variable, e = 0.3m).

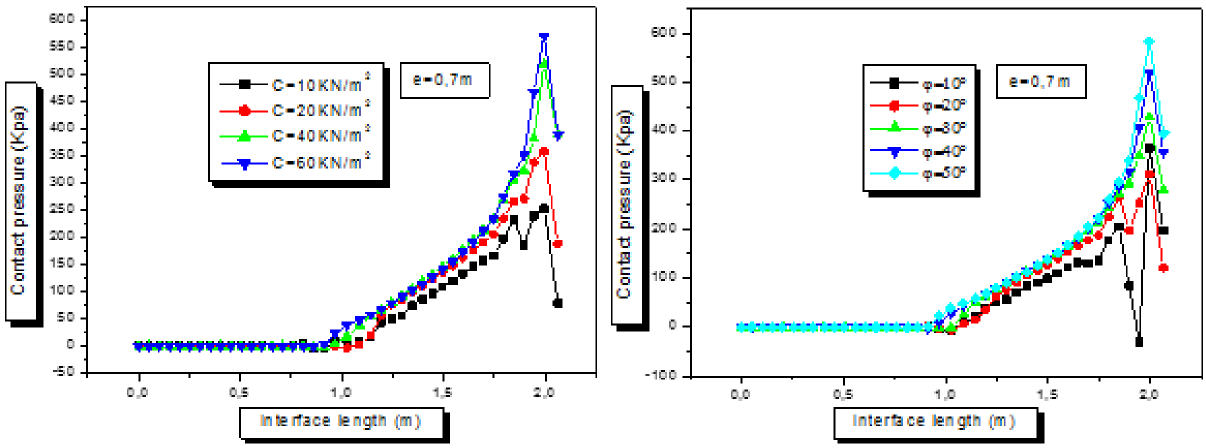

Fig. 7. Contact pressure at the interface (C and φ are variable, e = 0.7m).

From the figures (Fig. 5, 6 and 7) above, it can be observed that the increase of the mechanical characteristics C and φ causes the increase of the contact pressure. It is also clear that the stresses are much greater at the edges than the centre. As one might expect, the footing edge closest to the load sinks deeper than the center. It can be seen that eccentricity has little influence on the settlement at the center but much more on the edge.

These results are significantly different with several analytical formulas, they indicate that the stress distribution does not depend only on the eccentricity, the footing width and the applied load, but also on the footing thickness, as well as the mechanical characteristics of the soil (Cohesion and internal friction angle). They showed the importance of these characteristics (geometric and mechanical) on the influence of this distribution, especially at the edges.

5. Conclusion

This numerical study has shown the influence of the thickness of an eccentric footing on its uplift, while all theoretical solutions ignore the effect of this parameter. As well as the influence of the soil mechanical characteristics on the stress distribution at the soil-footing interface, especially at the edges. The results obtained make it possible to envisage a better understanding of the fact that the behaviour of the interface of an eccentric footing with the soil is influenced by the geometrical characteristics of this footing and the soil mechanical characteristics.

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