LOAD RESPONSE AND SOIL DISPLACEMENT FIELDS FOR SHALLOW FOUNDATIONS IN SAND USING THE DIC TECHNIQUE

by

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Shallow foundations are used to support small-to-medium size structures, and their capacity derives from the strength of strong, near-surface soils. The design of shallow foundations is done by proportioning the plan dimensions of the foundation element by considering three factors: (1) the structural stability of the foundation, (2) the allowable bearing pressure of the soil supporting the foundation to prevent ultimate bearing capacity failure, and (3) the tolerable total and differential settlements to meet serviceability requirements under normal working loads. Different theories have been developed to estimate the bearing capacity of a foundation, mostly relying on the Terzaghi (1943) form of the bearing capacity equation with the superposition of three terms. The partly theoretical and empirical methods of bearing capacity predictions rely on an assumed failure mechanism within the soil. In addition, the soil itself is considered to be a perfectly plastic material and its strength is accounted for through non-dimensional bearing capacity factors. However, the boundary-value problem of footing penetration, in reality, is quite complex and the use of the traditional bearing capacity, with use of the principle of superposition, leads to somewhat conservative results. The challenges involved in a footing penetration problem emanate not only from the difficulties in estimating soil strength parameters but also because the footing penetration problem involves large deformations and strains, which localize to form shear bands that propagate in the soil domain until the "collapse" of the sand-footing system.

The overarching aim of this research is the study of the response of shallow foundations on clean silica sands by investigating the measured bearing capacities and getting insights into the failure mechanisms that develop as a result of the soil displacements below the base of the foundation element. This was experimentally achieved using a combination of physical modelling (by performing a series of model footing 1*g* load tests inside a novel half-circular calibration chamber) and image analysis (using digital image correlation technique). The load-settlement response of the model footings is investigated by performing displacement-controlled load tests on model strip and square footings placed either on the surface or embedded in the sand samples of varying relative densities prepared inside the calibration chamber using the method of air-pluviation. A series of high-resolution images collected during model footing loading were analyzed using the digital image correlation (DIC) technique to obtain the displacement and strain fields in the sand domain. Two fully characterized silica sands, Ohio Gold Frac (OGF) and Ottawa 20-30 (OTC) are used in the research. Different testing variables that were considered in the experimental setup are: (1) sand particle morphology, (2) sand sample's relative density, (3) sand layer thickness, and (4) footing shape, size, and embedment depth. A detailed test matrix was formulated to isolate these variables and study the effects of each on both the bearing capacity and the associated failure mechanism. Accordingly, this article-based dissertation is organized to describe the results of three studies.

In the first study, the effects of relative density and particle morphology on the bearing capacity and failure mechanism of a model strip footing were investigated. This was done by using two silica sands: OGF sand and OTC sand, both the sands have comparable mineralogy, gradation, and particle sphericity; however, they have markedly different values of particle roundness. Samples of both sands were prepared at relative densities of 90%, 65%, and 30%. The evolution of the footing's collapse mechanism was considered by selecting relevant points on the load-settlement curves. A novel methodology was adapted to record the thickness of the shear band that developed in the sand domain. In the second study, the effects of the presence of a stiff layer below the strip footing were investigated. This was achieved by load testing the model strip footing on OTC sand layer of limited thickness. To simulate the sand-bedrock system, a half-circular steel plate supported by a stack of hollow concrete blocks was used. Load tests on model strip footing were performed on OTC sand samples without the presence of a stiff base and on the sand samples underlain by a stiff base located at depths equal to 0.5*B* and 1*B* below the base of the footing. The effect of the presence of the stiff base on the unit bearing capacity of the footing and stiffness of the sand-footing system were investigated. In addition, the contours of the cumulative maximum shear strains, horizontal displacements, and vertical displacements that develop in the sand layer are presented for both cases of with and without the presence of the stiff base. In the third study, the effects of footing geometry and embedment on the bearing capacity and failure mechanism were investigated. Load tests were performed on surface and embedded model strip and square footings on dense, medium dense, and loose OTC sand samples. The effects of choice of flow rule (associative versus non-associative) on the bearing capacity calculation and the increase in bearing capacity due to footing embedment (bearing capacity ratio) were determined. In addition, a framework is proposed to experimentally determine the shape and depth factors using strip and square footings of equal widths considering the flow rule non-associativity, conditions of low confinement, and different loading paths.

The results of the experimental program presented in this research on bearing capacity, displacement fields, strain fields, and failure mechanisms for different footing sizes and shapes under different testing conditions show that that the footing's collapse mechanism depends on the relative density of the sand sample, sand particle morphology, and the footing geometry. Significant differences in the bearing capacity of model footings due to sand particle morphology and sand sample density were observed. The shear band thickness is also shown to be dependent on the shape of the sand particles. It was also observed that the scale effects in model footing tests are closely related to sand dilatancy. For a sand layer of finite thickness underlain by a stiff base it is shown that the critical depth of the stiff base is greater for stiffness calculation than that for the bearing capacity calculation. DIC analysis results provided valuable insights to the footing penetration problem and corroborated the theoretical knowledge about the failure modes in sandy soils. It is shown that the failure mechanism extend deeper and wider for sands with angular particles as compared to the sand with rounded particles. DIC analysis also revealed that as the distance between the footing base and stiff layer reduces, the shear bands are more readily formed but their lateral extents are reduced considerably. The high-quality experimental data provided in this dissertation is aimed to be useful to researchers working on the validation of numerical simulations of footing penetration in sands.

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