BEARING CAPACITY OF SURFACE STRIP FOOTINGS ON LAYERED SOILS

By

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I hereby certify that the work embodied in the thesis is my own work, conducted under normal supervision.

The thesis contains published scholarly work of which I am a co-author. For each such work a written statement, endorsed by the other authors, attesting to my contribution to the joint work has been included.

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(Signed) ____________________
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ABSTRACT

Estimating the bearing capacity of shallow foundations on layered soils is frequently required both in off-shore and onshore geotechnical engineering applications. The conventional bearing capacity theory, developed for homogeneous soils is not valid for such layered systems. Granular working platforms for tracked plant is a good example of footings on layered soils with relatively thin top layer. This problem is currently treated in practice, using a simplified method, presented in the Building Research Establishment publication BRE470-2004. Available bearing capacity solutions are mainly based on empirical models, interpreted from experimental test results that cover limited range of material parameters. While it is generally accepted that such models may be applicable to soil properties and footing geometries outside the range tested experimentally, they offer limited insights on how the assumed failure mechanism affects their range of application.

This research considers the problem of estimating the ultimate bearing capacity of rigid strip footings on layered soil profiles, comprising a finite thickness of dense sand, overlaying deep layer of different weak soils i.e. very soft to stiff clay and very loose to medium dense sand. Rigid strip footings resting on the surface of the top layer were selected for analyses, as they resemble tracked plant. The ultimate bearing capacity of the footings were estimated from the average of rigorous upper and lower limit loads on the footing, calculated using the FELA method, developed in University of Newcastle. Adaptive remeshing was employed to obtain upper and lower bounds that closely bracket the true collapse loads.

The geometry of the collapse mechanisms was interpreted from upper bound FELA analyses to gain insight into contribution of layered soils parameters in the shape of the mechanism. Detailed investigations indicated that the assumed punching shear failure mechanism of Meyerhof (1974) cannot accurately describe the geometry of the shear planes for all studied material parameters. For layered soils with cohesive subgrades, it was found that the direction of failure planes beneath the footing drift from the assumed vertical in Meyerhof’s model, as strength of the bottom layer increases relative to the top layer. As such, a more detailed investigation was undertaken that resulted in a new bearing capacity model that considers variable geometry of the failure mechanism as a function of the key parameters of the problem.

The model provides results that are in close agreement with published experimental studies, and allows treating simple problems, such as the design of working platforms, without having to resort to numerical simulations. The model is extended to clays with increasing shear strength with depth, using expressions derived for bearing capacity factor as a simple function of the dimensionless rate of increase of soil strength.
The same methodology was followed to develop a new bearing capacity model for strip footings on strong sand overlying relatively weaker sand. The inspiration behind this model was the observation that the mechanism, assumed in the classical Hanna (1981) solution, only provides acceptable estimation of the collapse loads for limited range of material parameters, where the top sand is significantly stronger than the bottom layer. A new form of failure mechanism (transitional failure mechanism) was observed via FELA analyses where the relative strength of the top layer decreases, for which Hanna’s bearing capacity model (1981) overestimates the ultimate bearing capacity of the footing. A method was developed to predict the dominant mode of failure based on the key parameters of the problem, and a new bearing capacity factor was proposed for predicting the ultimate bearing capacity of the footing, where transitional failure mechanism applies. The new method was benchmarked against published experimental data and was shown to provide accurate estimates of the bearing capacity for a wide range of the problem parameters.

The use of FELA results in this research led to the refinement of the existing bearing capacity models for footings on two layered soils. The main novelty of these models is the consideration of the failure mechanisms of variable geometry, depending on the parameters of the problem, which allows capturing the failure mode for a wide range of problem parameters. The proposed models comprise simple formulas and design charts, hence can be efficiently used in practice for the quick design of working platforms for tracked plant without having to resort to numerical analyses.
NOTATION

All variables are defined as they have been introduced into the text. However, for convenience, a list of the most commonly used variables and their definitions are presented below.

\( \alpha \)  
Angle of shear plane

B  
Footing width

B'  
Effective footing width

c_0  
Undrained shear strength of clay on top of the layer

c_u  
Undrained shear strength

\( \delta \)  
Mobilised friction angle on the assumed failure planes

\( \phi \)  
Soil internal friction angle

\( \gamma \)  
Soil unit weight

H  
Thickness of the top sand layer

H_{cr}  
Critical depth

K_p  
Coefficient of passive lateral earth pressure

K_s  
Punching shear coefficient

K_{sr}  
Coefficient of shearing resistance

N_c  
Bearing capacity factor of Cohesion

N_y  
Bearing capacity factor of Soil self-weight

N_y'  
Bearing capacity factor of layered sand

N_q  
Bearing capacity factor of Surcharge

\( \theta \)  
Angle of failure plane of the top layer to vertical direction

q_c  
Ultimate bearing capacity of the uniform clay layer

Q_L  
Lower bound ultimate bearing capacity

q_s  
Ultimate bearing capacity of the uniform sand layer

Q_U  
Upper bound ultimate bearing capacity

q_u  
Ultimate bearing capacity of shallow foundation

\( \rho \)  
Rate of increase of undrained shear strength with depth
\( P_0 \) Surcharge at the embedment depth

\( D_s \) Rate of shear power dissipation

\( P_p \) Passive thrust

\( q_t \) Ultimate bearing capacity of the top soil layer

\( q_b \) Ultimate bearing capacity of the bottom soil layer

\( q_1, q_2 \) Bearing capacity of the upper and lower layers respectively.

\( \gamma_1, \gamma_2 \) Unit weight of the upper and lower layers respectively.
The research work, presented in this thesis was conducted at the University of Newcastle in the School of Engineering during the period February 2012 through August 2018. This work was performed under the supervision of Associate Professor Andrew Abbo and George Kouretzis with the assistance of Jinsong Huang. This thesis is presented in the form of a thesis by publications, based on the five technical papers, listed below.


Salimi Eshkevari, S., Abbo, A.J. Kouretzis, G. Bearing capacity of strip footings on layered sand; Submitted and under review to be published by ASCE International Journal of Geomechanics.
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STATEMENT OF CONTRIBUTION 1

Technical papers


Authors

Salimi Eshkevari S. (Candidate)

Performed numerical simulations analysed, interpreted and compiled the results. Primary author of the four manuscripts listed above.

I hereby certify that this statement of contribution is accurate.

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Salimi Eshkevari, S., Abbo, A.J., Kouretzis, G. Bearing capacity of strip footings on layered sand; Submitted to Computers and Geomechanics.

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