Assessment of static and seismic bearing capacity factors of shallow strip foundations using the discontinuity layout optimization procedure

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Abstract. This paper presents and analyzes the main results of a series of calculations of the static and seismic bearing capacity factors for shallow strip foundations. The calculations were performed using the Discontinuity Layout Optimization numerical analysis procedure based on the upper bound limit analysis theory on a strip footing embedded in a dry homogeneous soil mass which is subjected to different horizontal seismic coefficients. Calculations results obtained show that the values of the surface, depth and cohesion static factors are in good agreement with those provided by known benchmark solutions of the bearing capacity calculation for shallow strip foundations. They also highlight the influence of seismic action on the values of these parameters which seem to decrease rapidly as the seismic acceleration increases. They also justify the importance of choosing the adequate calculation parameters.

Keywords: Strip footing, Horizontal seismic coefficient, Upper bound limit analysis theory, Pseudo-static approach, DLO procedure.

1 Introduction

Terzaghi's classical bearing capacity theory [1] and its derivatives are used for the design and justification of shallow foundations under static or seismic loadings. The soil static bearing capacity factors (static surface factor $N_{\gamma S}$, static depth factor N_{qS} and static cohesion factor N_{cS}; where the subscript S refers to static loading) have been defined by some well-known conventional mathematical expressions in soil mechanics [2,3]. The soil seismic bearing capacity factors (seismic surface factor $N_{\gamma E}$, seismic depth factor N_{qE}, and seismic cohesion factor N_{cE}; where the subscript E refers to earthquake) have also been the subject of some analytical and numerical studies, by considering pseudo-static seismic forces [3].

This paper aims to compare the soil bearing capacity factors values evaluated by means of some of these above mentioned conventional methods with results of a numerical simulation carried out using the Discontinuity Layout Optimization numerical analysis procedure (DLO procedure) implemented in the LimitState:GEO geotechnical software [4]. Adopted calculation model treats the case of a strip footing embedded in a dry horizontal homogeneous soil mass.

2 Materials and methods

Considered calculation model simulates a rigid strip footing embedded in a dry homogenous soil mass. The massif's borders are chosen sufficiently far from the footing so that the boundary conditions have no influence on its behavior. The soil-footing interface is assumed to be smooth or rough according to the foundation's construction mode and especially for concrete foundations. Table 1 gives the calculation parameters used in order to compute the soil static and seismic bearing capacity factors.

Table 1. Calculation parameters used.

Bearing capacity factor	$\mathbf{N_\gamma = 2q_u/\gamma B}$	$\mathbf{N_q = q_u/q}$	$\mathbf{N_c = q_u/c}$
Soil unit weight, γ	$\gamma \neq 0$	$\gamma=0$	$\gamma=0$
Soil cohesion, c	c=0	c=0	$c \neq 0$
Surcharge, q	q=0	$q \neq 0$	q=0
Soil friction angle, φ	It ranges from 0 to 45° in 1° increment		
Soil-footing interface, δ/φ	Smooth: $\delta=0$, Rough: $\delta=\varphi$, Concrete: $\delta=2\varphi/3$		
Horizontal seismic coefficient, k_h	It ranges from 0 (static loading) to 1 in 0.1 increment		

$q_u = \frac{1}{2}\gamma B N_\gamma + qN_q + cN_c$ *(ultimate bearing capacity)*
B: footing width
δ: soil-footing interface friction angle

Calculations were performed using the LimitState:GEO software. Seismic loading is modelled using the pseudo-static approach by specifying the applied horizontal and vertical seismic coefficients. The ultimate limit state of the structure is determined by the minimum value of the upper bound limit analysis using the DLO procedure. Detailed descriptions of the limit analysis theory and the DLO procedure are given in [5] and [6], respectively.

3 Results and discussion

Figs. 1 and 2 show the soil static and seismic bearing capacity factors values, respectively. It can be noted that:

- The soil static bearing capacity factors greatly increase with the soil internal friction angle for smooth and rough footings, as well as for concrete footings.
- Unlike the surface factor, depth and cohesion factors do not depend on the roughness of the soil-footing interface.
- Unlike plasticity calculations, the DLO procedure based on the upper bound limit analysis theory does not detect the non-associativity effect of the soil behavior law, nor the evolution of the corresponding strains.
- The calculation results obtained using the DLO procedure are in good agreement with known benchmark solutions and with others analytical or numerical solutions [1,5,7-12]. However, the gap is significant only for the surface factor.

- All bearing capacity factors seem to be greatly affected by seismic action; this result being confirmed by other works [13-17].
- Except the surface factor, these results show that depth and cohesion factors do not appear to be affected by the inertia effect of the foundation massif. In any case, recent works show that the inertia effect of foundations massif does not seem excessive [13].
- Note that when $\tan(\varphi) > k_h$, the adequate soil bearing capacity factor cannot be calculated. This appears to be explained by the fluidization phenomenon of cohesionless dry soils which behave like a viscous flow [17]. Also note that beyond $k_h > 0.6$ (corresponding to catastrophic earthquakes), only coherent soils can have some bearing capacity.

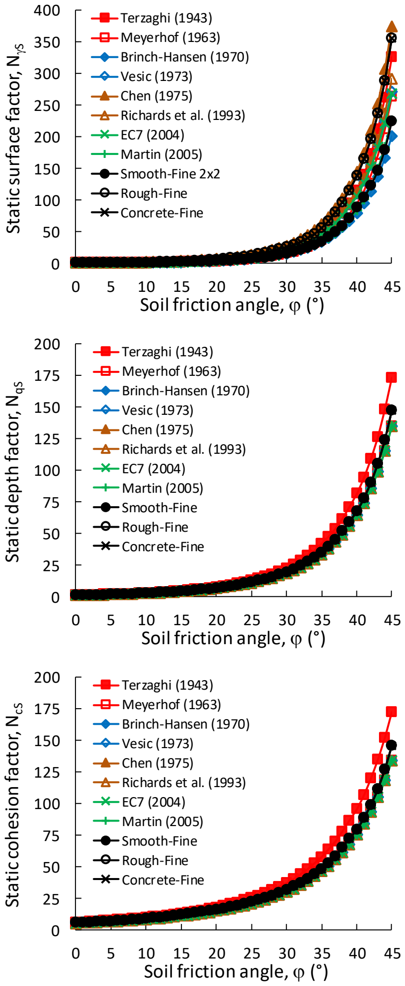

Fig. 1. Soil static bearing capacity factors.

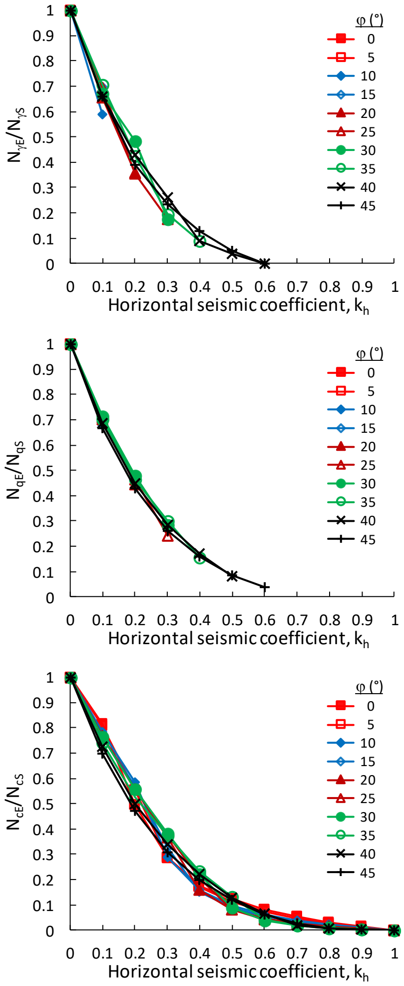

Fig. 2. Soil seismic bearing capacity factors.

4 Conclusion

The computed results presented in this paper provide the following main conclusions:

- The predicted values of static bearing capacity factors confirm those obtained by other calculation methods such as the limit equilibrium method and the limit analysis theory using other calculation procedures such as the finite elements method or the finite differences method.
- The seismic action seems to affect substantially these bearing capacity factors, consequently, the bearing capacity of shallow strip foundations.
- Both soil static and seismic bearing capacity factors show that the Terzaghi’s superposition formula is not satisfied.

These results also show that the DLO procedure can be a fairly satisfactory alternative in evaluating the bearing capacity of shallow strip foundations. This procedure can therefore be the long-awaited solution of both practitioners and researchers.

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