Bearing capacity of strip footings placed on sloping ground

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ABSTRACT: Due to the expansion practices in civil engineering, constructing strip footings near slopes has become a widespread act among engineers. Despite the fact that numerous methods have been conducted to evaluate the bearing capacity of footing adjacent to slopes, the influence of non-associated plasticity has seldom been extensively explored. In this study, a finite difference program has been used to thoroughly investigate numerically the behavior of foundations near slopes using a non-associated flow rule. The bearing capacity factor $N\gamma$ which is dependent on soil weight unit γ was calculated by varying slope angle (β), setback (b/B) and dilatancy angle (ψ) with friction angle of φ=40°. Based on the results, the current study reveals; after a specific distance from the slope's edge, the slope angle has no further impact on the bearing capacity. Additionally, the estimation of the bearing capacity is notably influenced by the dilatancy angle(ψ).

1 INTRODCUTION

From the earliest times, for isolated shallow footing lying on level ground, numerous researchers had presented the bearing capacity expression, bearing capacity factors, and failure process. Additionally, foundations built close to sloping soils are frequently used in civil engineering due to the often unavailability of horizontal ground and this type of work makes it possible to assess the ability of slopes to support large constructions and traffic. Over the course of many decades, researchers have extensively investigated the bearing capacity of shallow foundations. However, only a limited number of efforts have been dedicated to examining the bearing capacity of footing near slopes e.g.: (Huang & Kang 2008; Graham et al.1988; Mabrouki et al.2010; Castelli & Motta 2010; Chakraborty & Kumar 2013; Halder et al. 2019).
Studies of soil reinforcement by geosynthetics under the foundation revealed a substantial increase in bearing capacity. This technique for improving bearing capacity, by virtue of its ease of implementation, and its distinctly economical character compared to other methods of improving soil, has attracted the attention of a large number of scientific researchers and a considerable number of experimental and numerical studies on the effect of geosynthetics on the performance of reinforced slopes has been carried out.
In all the prior investigations, soil was assumed to follow an associated flow rule despite the fact that soils do not conform to such a rule (Tschuchnigg et al., 2015).

As a result, non-associated plasticity has garnered considerable interest from numerous scientific researchers like (Halder et al., 2019; Schmüdderich et al., 2022; Tschuchnigg et al., 2015).
The objective of this study is to conduct numerical simulations utilizing the FLAC software (Fast Lagrangian Analysis of Continua, 2011) to assess the soil bearing capacity factor $N\gamma$ for rough strip footing positioned in proximity of slopes. The typical approach to determining the bearing capacity of a shallow strip footing on level ground involves employing the Terzaghi formula:

$$qu = cNc + qNq + \frac{1}{2} B\gamma N\gamma \tag{1}$$

In the previous equation, q_u stands for the ultimate bearing capacity, B the footing's width, N_c, Nq and N_γ are the bearing capacity factors relating the effect of cohesion c, loading q and soil's weight γ, respectively.

2 NUMERICAL MODELLING PROCEDURE

This research paper focuses on conducting a numerical investigation into the bearing capacity of rough strip footing situated near slopes. The footing is resting on frictional, cohesionless soil with non-associative behavior. It is subjected to a static vertical load and is adjacent to a slope with an angle of β. In order to assess the impact of foundation's position on the bearing capacity, various setback values were taken into account. And thus, the computations were carried out for different values of the b/B ratio, namely 0, 1, 2, 3, 4, 5, 6, 7 and 8. Where B represents footing's width and b denotes the setback distance. These selected values of setback are argued by the observation that the bearing capacity tend to converge when it exceeds a setback b/B of eight.
To minimize the influence of boundaries, the study domain's top and depth are set to a dimension of 20B.Meanwhile, the model length is 20B + 12B/tanβ + 12B to accommodate the slope's foot, as illustrated in Fig. 1.
The lower boundary is considered immobile, while vertical boundaries are constrained horizontally, as shown in Fig. 1.
For the analysis, a computer code using FLAC (2011) has been employed. This program utilizes dynamic equations of motion to solve static problems, and damping terms are incorporated to gradually dissipate the system's kinetic energy.
The FLAC software employs the elastic perfectly plastic Mohr Coulomb model. Throughout the current study, soil's physical properties and mechanical characteristics are as follows: shear modulus G = 10 MPa, elastic bulk modulus K = 20 MPa, soil unit weight $\gamma = 18$ kN/m^3 and soil's internal friction angle of $\varphi = 40°$. The soil behavior is considered to be non-associated ($\varphi \neq \psi$).
To establish a reliable analysis system for subsequent computations, initial simulations were conducted to determine the appropriate domain size, grid resolution and boundary conditions.

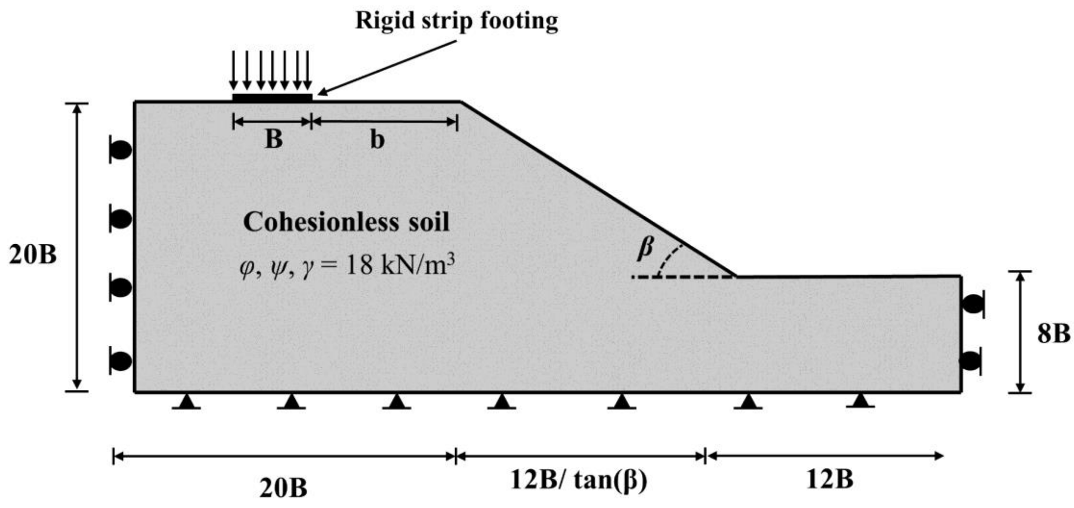

FIGURE 1. Model geometry

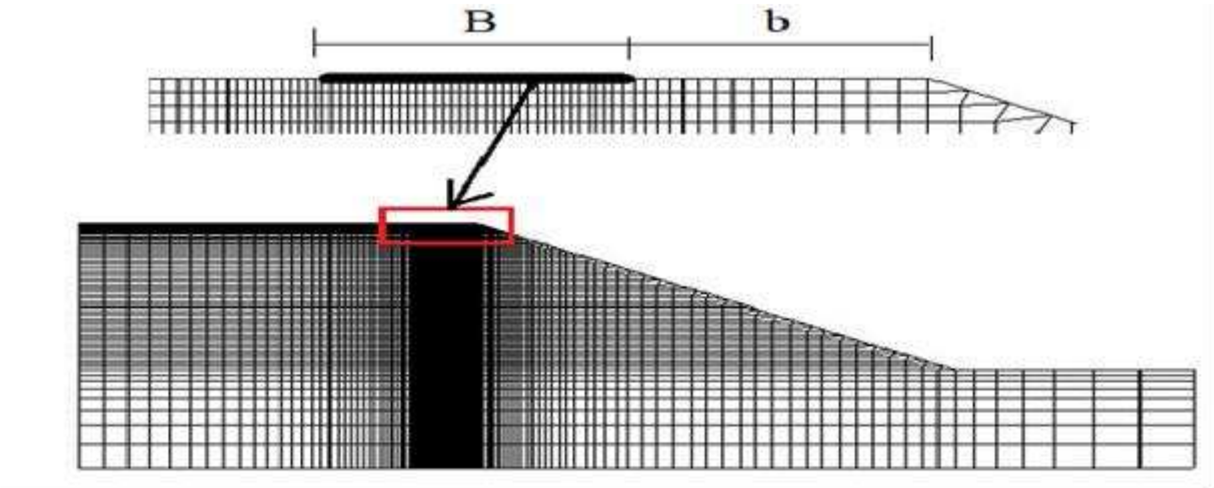

FIGURE 2. Finite difference mesh

The model domain, depicted in Fig. 2, is refined on the area near the footing to accurately capture the significant strain gradients. A detailed view of this area is shown in Fig. 2, with special attention given to the region adjacent to the foundation where the high strain gradients are expected. Hence, a very fine mesh is employed at this particular area.

The scheduled modelling procedure for calculating the bearing capacity factor involves a couple of steps. Firstly, the geostatic stresses are computed under the assumption of elastic soil behavior. During this stage, stepping is necessary to achieve equilibrium in the model. Secondly, a downward velocity of 10^{-7} meters per step is applied to the corresponding grid points of the footing. The rough footing is simulated by restricting the horizontal displacement to zero for the corresponding grid points.

3 RESULTS AND DISCUSSION

The bearing capacity factor N_γ, which is affected by soil unit weight (γ) is computed under the assumption of cohesionless soil ($c = 0$) with no load ($q = 0$). Therefore, Equation (1) can be expressed as follows:

$$qu = \frac{1}{2} B\gamma N\gamma \tag{2}$$

Here N_γ, represents strip footing's bearing capacity factor when situated in proximity to a slope. In Figures 3 and 4, the results of simulations conducted using FLAC are presented.

The figures show the variation of the bearing capacity factor N_γ as the distance of the foundation from the edge of the slope varies.

The figures clearly demonstrate that the bearing capacity factor experiences an increase as the foundation moves away from the slope's crest up to a critical distance, beyond which the slope's effect on the bearing capacity vanishes. This critical distance for which the effect of the slope on the bearing capacity cancelled out is of the order of 2B to 6B varying with the slope angles; it is smaller for low slope angles, and greater for steeper ones. Moreover, the magnitude of the bearing capacity is notably influenced by the dilatancy angle (ψ). For low dilatancy ratio ψ/φ, the bearing capacity is comparatively smaller, while for higher dilatancy ratios, it becomes greater. Similar findings have been reported in (Tschuchnigg et al. 2019).

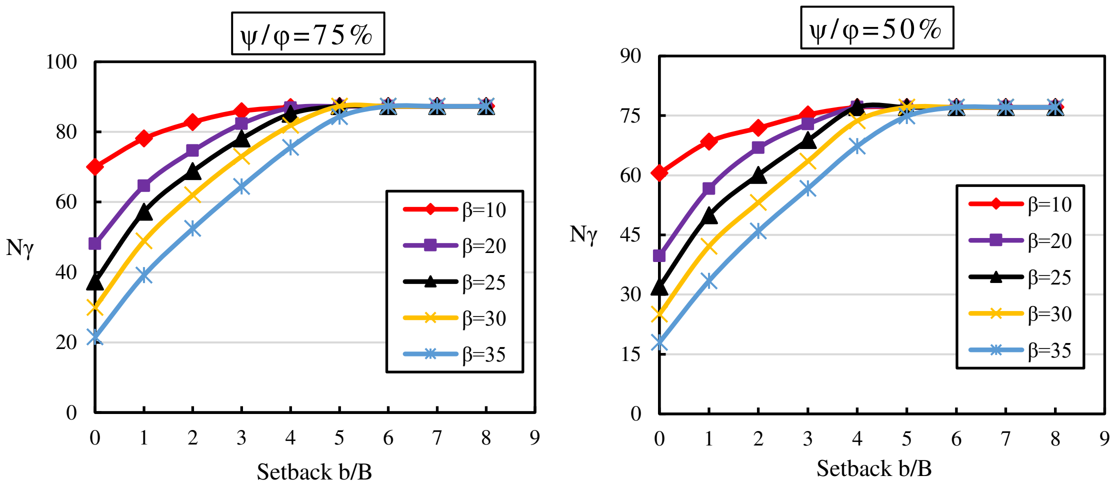

FIGURE 3. Variation of bearing capacity factor N_γ and setback from the edge for different dilatancy ratios (ψ/φ), with $\varphi = 40°$

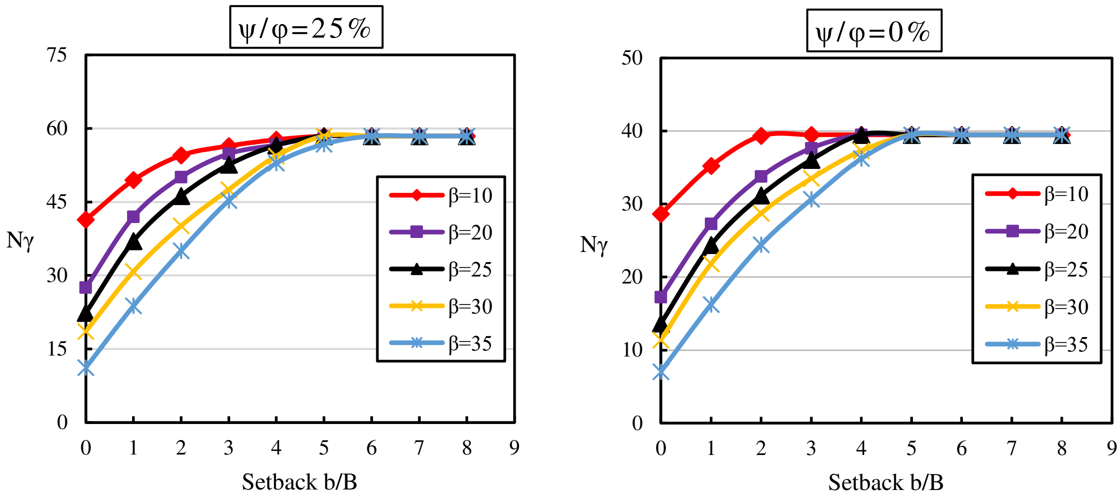

FIGURE 4. Variation of bearing capacity factor N_γ and setback from the edge for different dilatancy ratios (ψ/φ), with φ= 40°

4 CONCLUSIONS

The FLAC finite difference software was employed to assess soil bearing capacity factor N_γ for rough rigid strip footing located near a slope. Based on this study and the resultant findings, the following observations can be made:

- The bearing capacity of foundations located near slopes escalates as the footing's setback increases.
- At a critical distance, ranging approximately from 2B to 6B the impact of the slope upon bearing capacity vanishes. The distance depends on the slope angles (β) and the dilatancy angle (ψ).
- The present study focusing on non-associated plasticity clearly shows the effect of the dilation on the bearing capacity factor N_γ which increases when the dilatancy angle (ψ) increases and vice versa.
- As a perspective, it must be said that more detailed studies have shown that the introduction of a single layer or several layers of geosynthetic can considerably improve the bearing capacity and reduce settlements and therefore proves to be a cost-effective solution compared to a deep foundation.

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