Prediction of bearing capacity of shallow strip foundation: a case study in Binh Dinh-Vietnam

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Abstract

The bearing capacity (BC) of a shallow foundation is an important parameter to design economic structures. This study aims to propose a safety factor for BC of the strip footings. By utilizing, several geologies to calculate the shallow strip footing of the mid-rise buildings in central Viet Nam. The bearing capacity of the foundation is first calculated using the different available methods such as Terzaghi, Meyerhof, Hansen, and Vesic theories. Then the three-dimensional finite element analysis of the foundation is performed using PLAXIS software. Results indicate that there is a clear difference in the bearing capacity from the theory and numerical model. Additionally, a safety factor is proposed for the design purposes of the shallow strip foundation.

Key words: *Bearing capacity, Shallow Foundation, Strip Footing, PLAXIS*

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1. Introduction

The bearing capacity (BC) of shallow foundations is one of the important parts of soil mechanics relevant to foundation design for structures (i.e., buildings, nuclear power plants) [1,2]. Many studies have been conducted to estimate the ultimate bearing capacity of the foundation soil [3-9]. For example, the BC of the liquefied sandy ground under the raft foundation was assessed by Vo and Nguyen [10]. Later, the BC of footing subjected to horizontal load, vertical load, and moment combination was calculated by Nguyen et al. [11]. Unfortunately, the load capacity of the footing under the complexity of soil conditions and loadings has not been particularly pointed in the published studies [6,9]. For instance, geology in Binh Dinh province (Viet Nam) is known as a complex site with limited research on designing the BC of the shallow foundations.

This study aims to evaluate the allowable bearing capacity of the strip footing subjected to uniform vertical loading. Finite element modeling is implemented to analyze the behavior of soil the ground under the strip footing. These results of numerical analysis are verified with existing solutions. The results are useful for engineers to reduce computational time in structural design.

2. Methodology

a. Existing theory for predicting the bearing capacity of the foundation

Ultimate bearing capacity can be expressed as the maximum pressure that a foundation soil can withstand without undergoing shear failure. For the static analysis, the shallow strip footing under vertical central loading can be calculated using different approaches.

Terzaghi's theory.

The bearing capacity equation developed by Terzaghi for the strip foundation is defined as follows [3]:

$$q_u = cN_c + qN_q + 0.5\gamma BN_\gamma \quad (1)$$

where B and D_f are the width and depth of the foundation, repectively; c, γ and q are cohesion, the weight of soil and surcharge at the ground level, respectively; N_c, N_q, N_γ are Terzaghi's bearing capacity factors for a strip foundation depend on angle of internal friction (φ) [1] and are given by equations (2 - 4)

$$N_q = \frac{e^{2\left(\frac{3\pi}{4}-\frac{\varphi}{2}\right)\tan\phi}}{2\cos^2\left(45+\frac{\varphi}{2}\right)} \quad (2)$$

$$N_c = \cot\varphi\left(N_q - 1\right) \quad (3)$$

$$N_\gamma = \frac{1}{2}K_{p\gamma}\tan^2\varphi - \frac{\tan\varphi}{2} \quad (4)$$

Meyerhof's bearing capacity theory

The superposition method is used to determine the contribution c, q and γ. The ultimate bearing capacity (q_u) of the continuous foundation is expressed as [3]:

$$q_u = cN_c + qN_q + \frac{1}{2}\gamma BN_\gamma \quad (5)$$

where N_c, N_q, and N_γ are variations of Meyerhof's bearing capacity factors, given by Eqs (6 – 8)

$$N_q = e^{\pi \tan\varphi}\left(\frac{1+\sin\varphi}{1-\sin\varphi}\right) \quad (6)$$

$$N_c = \left(N_q - 1\right)\cot\varphi \quad (7)$$

$$\frac{Q_p}{B} = cN_c + \gamma D_f N_q + 0.5\gamma BN_\gamma \quad (8)$$

Hansen's bearing capacity theory

Hansen [5] proposed the equation for the bearing capacity of strip footing as follows

$$\frac{Q_p}{B} = cN_c + \gamma D_f N_q + 0.5\gamma BN_\gamma \quad (9)$$

where Q_p is ultimate bearing capacity; the Hansen's bearing capacity factors N_c, N_q, and N_γ were presented in graphical form in Figure 1.

b. General bearing capacity

The bearing capacity formula for the soil under a shallow strip footing can be calculated by incorporating the shape factors and depth factors. It can be expressed by the following equation [3]

$$Q_u = cN_c\chi_{cs}\chi_{cd} + qN_q\chi_{qs}\chi_{qd} + 0.5\gamma BN_\gamma\chi_{\gamma s}\chi_{\gamma d} \quad (10)$$

where χ_{cs}, χ_{qs}, $\chi_{\gamma s}$ and χ_{cd}, χ_{qd}, $\chi_{\gamma d}$ are shape factors and depth factors, respectively. These factors were determined through empirical and semi-empirical studies; N_c and N_q are obtained from equations (6) and (7), respectively; white N_γ is given by equation (11)

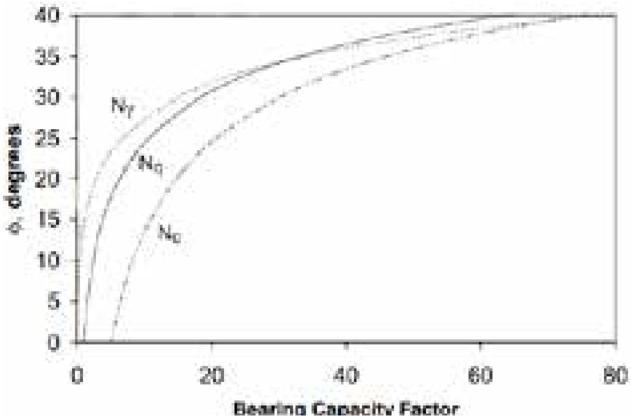

Figure 1: Hansen's bearing capacity factors [3]

$$N_\gamma = 2\left(N_q + 1\right)\tan\phi \quad (11)$$

Gross allowable bearing capacity

Gross allowable bearing capacity (q_{all}) is fomulated to consider both shear failure and settlement of the soil, and it is defined as [5]

$$q_{all} = \frac{q_{ull}}{FS} \quad (12)$$

where (q_{all}) is the ultimate bearing capacity, FS is the safety factor ranging from 3 to 4. [5]

2.2. Finite element modeling

PLAXIS 2D is a well-known software for geotechnical engineering projects, which is used to accomplish the deformation and flow analysis of soil behavior. The 2D analysis can be modeled by a plain stain or symmetrical model.

In this study, Plaxis software is used to analyze the BC of the ground under the continuous foundation. Modeling of

Table 1: Geotechnical input data for the bearing capacity calculations

Site	Soil type	Description	γ(kN/m³)	γ_{sat}(kN/m³)	φ(⁰)	c(kN/m²)	E(kN/m²)
1	Clayey sand	Soft	20.2	20.6	17.25	17.1	3021.6
2	Fine-grained sand	Medium dense	-	17.5	32	-	6300
3	Medium-grained sand	Medium dense	-	18.4	34.28	-	13200

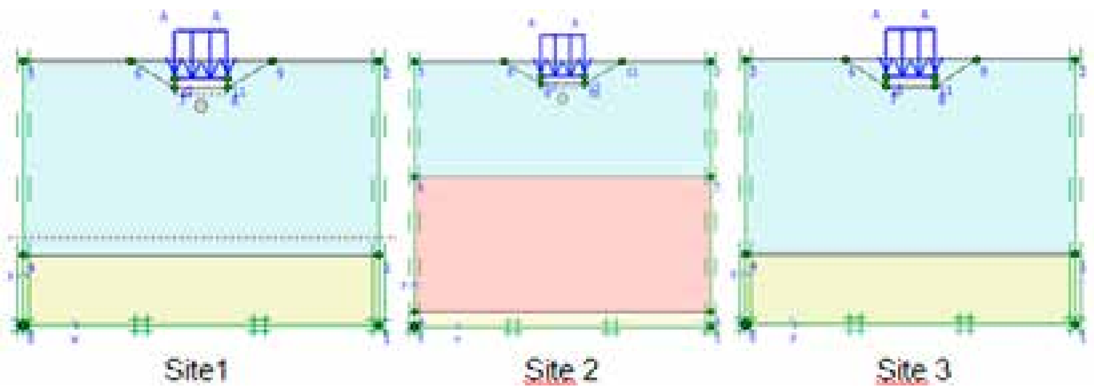

Figure 2: Geometry model in Plaxis 2D. (Site 1) BIDV Bank, (Site 2) Quy Nhon University, and (Site 3) Quy Hoa National leprosy dermatology hospital

Figure 3: Site Location. (Site 1) BIDV Bank, (Site 2) Quy Nhon University, and (Site 3) Quy Hoa National leprosy dermatology hospital

the shallow strip footing under loading is shown in Figure 2. It is noted that the Mohr-Coulomb model is used for soil, and elastic model behavior is assigned for strip footing. The foundation was divided by a strip footing subjected to vertical and uniform load. The groundwater level is at the ground surface.

3. Numerical example

Binh Dinh is a coastal province of South Central Vietnam, and it is known as a zone of coastal creeks and lagoons. The earth structures were developed by beaches associated with sand deposition. The surface geology was made up of the fine sand or medium sand.

We only mentioned the geological conditions in 3 buildings in Binh Dinh province to analyze the BC of the shallow foundation in this study were illustrated in Figure 3, including Quy Hoa National leprosy dermatology hospital, Quy Nhon University, and BIDV bank. The geotechnical parameters of the investigated sites are listed in Table I. These sites are utilized for designing the mid-rise buildings. The foundation dimensions corresponding to values of 3m, 1.5m, and 0.5m for width, depth, and thickness were selected for this purpose. An analysis is performed for the applied foundation pressure of 50kN/m^2.

4. Results and discussions

The bearing capacity failures for strip footing were calculated by finite element analyses and existing approaches. Note that the effect of shape and depth factors for variations of allowable bearing capacity to each soil group is skipped in this study. The comparison of the permissible bearing capacity for strip footing at a shallow depth of 1.5m for all sites is shown in Figure 4 and Figure 5. In each figure, the obtained results from the existing solutions are compared with those from the numerical modeling. As seen, the allowable bearing capacity of the shallow strip foundation varies from 80 to 300kN/m^2. While, for medium dense sands, these values range from 200 to 300kN/m^2.

Another finding is that outcomes for all cases vary slightly. The variations between theoretical and numerical modelling values range from 6 to 10%, depending on soil types. It is seen that the variation obtained from the Meyerhof method is less than 6% (FS = 4) [5], indicating the best estimations of allowable bearing pressure of the strip footing.

Through the analysis results, the safety factor of 4 for the gross allowable bearing capacity of the strip foundation is recommended for the investigated sites.

5. Conclusions

In this study, a finite element model was made to calculate the BC of shallow strip footing. The Mohr-Coulomb model with drained behavior was used to analyze soil behavior. Material parameters were obtained based on the results from field tests and laboratory tests. A comparison of the numerical and theoretical outcomes are introduced. The following conclusions are drawn:

- The Meyerhof method was the most promising one since it gave only an approximation to the numerical modeling.

- A safety factor of 4 for the allowable footing pressures of the strip footing is recommended for mid-rise buildings.

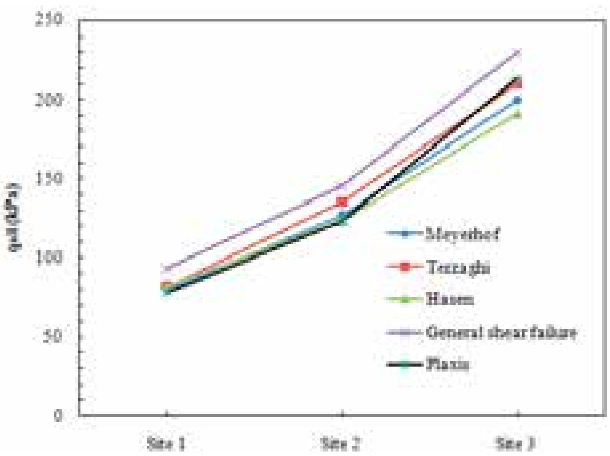

Figure 4: Allowable bearing capacity FS = 4 [5]

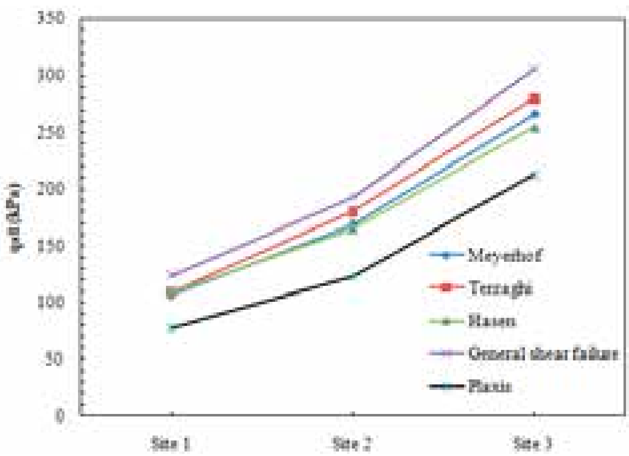

Figure 5: Allowable bearing capacity FS = 3 [5]

The effects of foundation depth and footing geometry are known as significant parameters, which are ignored in this study. Therefore, it is recommended that these effects will be considered for further investigation./.

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The effect of aging and slurry density on triaxial shear properties...

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with shear stress, and an increase in the elastic component of strain by aging in in-situ specimens. This property is similar to that of cement-treated gravelly soil[5]).

4. Conclusions

Base on the results of a series of undrained triaxial compression tests on LSS mixed with fibered materials and LSS, the following conclusions were obtained.

1) The slurry density had a considerable effect on the strength of LSS. When slurry density is increased, the strength increases by about 40% for both indoor and in-situ curing, whereas reducing slurry density decreases the strength by about 30% and 14% for indoor and in-situ curing, respectively.

2) The influence of shear stress level on the degree of damage appears to be independent of slurry density in case of in-situ curing. This result has practical implications for the application of LSS to increase seismic resistance.

3) By both logarithms, the relationship between qmax and the curing time t of LSS is linear. The effect of curing time on the increasing rate of strength is small in compared to indoor specimens of LSS.

4) By adding fiber into in-situ cured LSS, the effect of curing time on the degree of damage is found to be largely due to a decrease in viscous deformation and an increase in the elastic component of strain.

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