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Analysis of Bearing Capacity of Strip Foundation on Cohesive Soil with Soil Patch of Different Property

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Abstract

Soil in its natural form is a non-homogeneous mass, with possibilities of consisting more than one layer and pockets of heterogeneity. The pocket of heterogeneity explicitly includes the existence of void or soil of contrasting properties of buried rock mass. This study deals with the determination of bearing capacity of surface strip foundation over cohesive soil with continuous square soil patch of different consistency than that of parent soil. The analysis is made using commercially available finite element software in which the soil is modeled using Mohr Coulomb elastic perfectly plastic material model. Plane strain triangular 15-noded discrete elements is used to model the soil domain. The parametric study includes the effect of vertical and horizontal position of square shaped soil patch with respect to foundation and consistency of patch soil on the bearing capacity of surface strip foundation. The result of the study indicates that there exists a critical zone of influence under the foundation. The performance of the foundation will be significantly influenced due to existence of the soil patch in the parent soil layer only when the it is located with in this region. The size of this zone of influence depends on various factors as soil property of the parent soil and soil patch and the size of the foundation and soil patch. When the soil patch is located within the critical zone, the bearing capacity of the foundation and the deformation behaviour of the soil varies significantly with the location of the soil patch.

Keywords
Soil patch, Parent Soil, Bearing Capacity, Strip Foundation, FEM

1. Introduction

Soil deposits in nature are naturally anisotropic because of the means and method in which they are deposited. The non-homogeneity of soil formed in layers is quite common but is not always the case. Due to natural or artificial processes the formation of pocket of soil with extensively different characters can be found within a soil layer. Such pockets or patches of discontinuity in the soil may cause unfavorable and unpredictable performance of the structures build over them. The presence of these pockets or patches of heterogeneity may inflict foundation instability and resulting serious engineering problems which in turn impost severe damages to the structure built over it. When the soil patch of inconsistent property than that of the parent soil is located under the foundation, significant alterations in the bearing capacity and settlement behavior may arises which results in costly and dangerous consequences.

Over the course of time, various studies have been made to anticipate the behavior of foundation through various theories and experiments. A rational approach was developed by Terzaghi in 1943 to predict the bearing capacity of foundation of width B over a soil of unit weight γ,cohesion c and the angle of internal friction ϕ given as follows: For a square footing:

$$q_u = 1.3cN_c + \sigma_z N_q + 0.4\gamma B N_\gamma \tag{1}$$

For a strip footing:

$$q_u = cN_c + \sigma_z N_q + 0.5\gamma B N_\gamma \tag{2}$$

where, σ_z denotes the vertical stress at the level of base of foundation; and N_c, N_q and N_γ signifies non-dimensional bearing capacity factors which depends on the angle of internal friction of the soil, ϕ. The equations 1 and 2 are solely developed for homogeneous soil which is an ideal case and rare in nature. The weathering and deposition of soil by different means and modes causes soil to form in discrete layers. Hence, layered soil with indistinct zonal boundary and semi-continuous soil properties are usually found in nature. In this case, semi-empirical methods developed by Meyerhof, 1974 and Meyerhof & Hanna, 1978 are widely used. The properties of uppermost layer alone is sufficient to accurately determine the bearing capacity and settlement behavior of foundation over layered soils, if the thickness of the uppermost soil layer is remarkably greater than the width of the foundation. On the other hand, if the width of the foundation is comparable to the thickness of uppermost soil layer, the effect of lower soil layers within the zone of influence of the foundation needs to be taken into account for reliable estimation of bearing capacity [1].

In such conditions, where the thickness of uppermost layer is fairly small compared to the width of the foundation, punching shear failure generally occurs in the uppermost layer, and the lower soil layer undergo general shear failure [2], as illustrated in Figure 1.

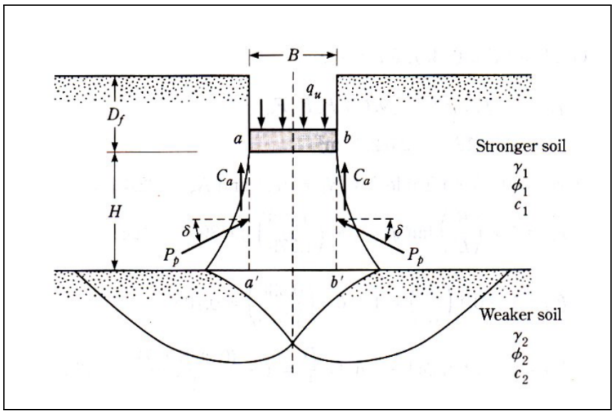

Figure 1: Punching shear models on layered soil [2]

The parametric study including the effect of strength ratio and layer thickness on bearing capacity of surface square footing over two layered clay deposit shows the strength ratio of the strong layer and weaker layer can cause significant variation in the behavior of foundation of layered cohesive soil [3].

Complex natural and artificial processes result in formation of heterogeneous soil materials whose engineering properties vary from point to point. Due to the uncertainties associated with the variability and limited information from site investigation, soil properties may be considered as random variables. Therefore, it is necessary to recognize and take into account the effect of spatial variability of geotechnical properties during the process of engineering analysis and design [4].

Investigating the effect of spatially random $c-\phi$ soil on the bearing capacity of a strip foundation using finite element analysis, when the soil properties become spatially random, the failure surface progresses through the weak zones or follows a path of low energy in the soil underneath the footing, which exhibits bearing failure [5].

[6] investigated the bearing capacity of strip footing located above silty clay with a continuous void using finite element method. The study concluded that, there exists a critical region in the soil underneath the foundation and the performance of the foundation is significantly affected by the existence of void only when it is located within this region. Also, the shape of the void has minimal effect on the settlement and bearing capacity behavior of the soil.

[7] investigated the effect of a underground buried rock on the stress and settlement of a strip foundation through a series of numerical simulation. The study investigated the effect of position and depth of a buried rock on contact stresses, under the strip footing resting on sand using finite element technique. The final results indicated that the stresses under the footing increased by up to 40% and the stresses under footing had altered when the buried rock lies away from middle footing reaching to the instability of the footing.

2. Numerical Analysis

Commercially available finite element based software was used for analyzing the bearing capacity of surface strip foundation over cohesive soil with soil patch of different property. The present study is focused to investigate the effect of presence of soil patch in the ultimate bearing capacity and deformation behavior of surface strip footing over cohesive soils using PLAXIS 2D. A soil model of 20B x 10B was adopted for the analysis where B denotes the width of the foundation. The vertical boundaries of the soil domain are normally restrained and the bottom boundary is fully restrained whereas the top boundary is free. The soil domain was discretized with 15-noded plane strain triangular elements.

A strip footoundation of 2m width was modeled as elasto-plastic, isometric, weightless plain strain model. A continuous square patch of soil of side 2m with varied properties than that of parent cohesive soil was modeled and its position were varied to investigate the performance of foundation over its presence. Figure 2 shows the geometric model of surface strip foundation of width 2m on cohesive soil with soil patch.

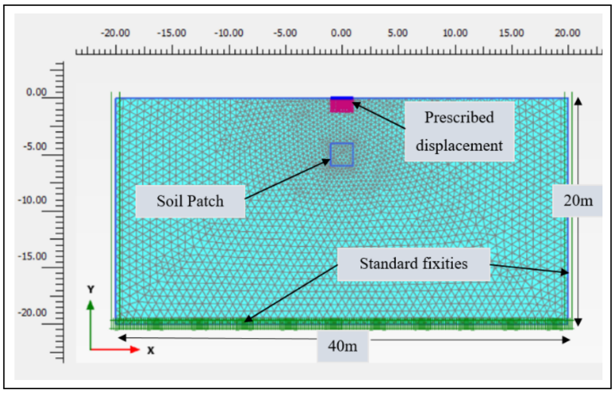

Figure 2: Geometrical model of strip footing resting on cohesive soil

The soil is modeled as elastic-perfectly plastic Mohr Coulomb constitutive model under undrained material model. Parent cohesive soil of medium to soft consistency and soil patch of very soft to soft consistency were chosen for the study. For saturated soils under undrained conditions, the angle of internal friction should be taken as zero whereas the poisons ratio as 0.4-0.5 [8]. The values of unit weight and undrained shear strength of the parent soil were chosen as an upper limit of the range for soft cohesive soils and Young's Modulus were chosen as in a range correlated to the undrained shear strength as given by [8, 9]. For patch soil, the unit weight was taken same and the undrained shear strength was chosen to vary from 20% to 100% of that of the parent soil.

The material properties of footing and soil used in the analysis are shown in Table 1 and Table 2 respectively. The various factors chosen for parametric study are revealed in Table 3.

Table 1: Footing properties

Parameter	Values
Width of footing, m	2
Normal Stiffness (EA) kN/m	$1.5*10^7$
Flexural Rigidity (EI) kN/m^2/m	$3.13*10^5$
Equivalent Thickness, m	0.5
Poisson's Ratio	0.15

Table 2: Soil properties

Parameters	Parent Soil	Soil Patch
Unsaturated unit weight of soil (kN/m^3)	18 kN/m^3	18 kN/m^3
Saturated unit weight of soil (kN/m^3)	19 kN/m^3	19 kN/m^3
Friction angle of soil	0 °	0 °
Undrained shear strength of soil (kN/m^2)	25 (c1)	5, 10, 15, 20, 25 (c2)
Young's modulus of elasticity (kN/m^2)	1000*c1	1000*c2
Poisson's ratio	0.5	0.5
Failure criteria	Mohr-Coulomb	Mohr-Coulomb
Type of material model	Undrained condition	Undrained condition

Table 3: Factors for parametric study

Case	Parameters
Undrained shear strength of soil patch (kN/m^2)	5, 10, 15, 20, 25
Horizontal position of soil patch, x (m)	0, 0.5, 1.0, 1.5, 2.0, 4.0, 6.0
Vertical position of soil patch, y (m)	0, 0.5, 1.0, 1.5, 2.0, 4.0, 6.0
Size of soil patch, w (m)	2

3. Results and Discussion

Output results are analyzed and load settlement-curves are generated. From the load-settlement curves, the bearing capacity is computed as shown in Figure 3.

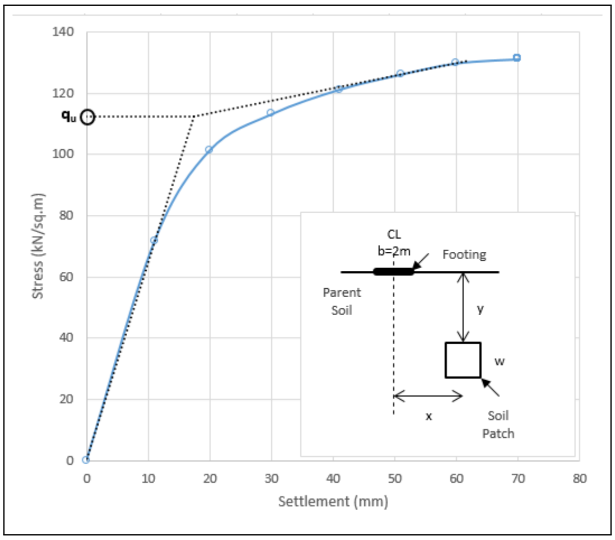

Figure 3: Load-Settlement Curve

The deformation of soil under the foundation is observed from the result of FE simulation showing the settlement and displacement characteristics of soil and the shear straining of soil caused by the application of load.

3.1 Effect of position of soil patch

In order to perform parametric analysis, various models has been simulated with varying the position of soil patch in the soil domain below the foundation. These models has been analyzed and bearing capacity has been determined from output.

3.2 Effect of patch depth

In order to observe the extent of influence of vertical position of soil patch in the performance of foundation, the soil patch is modeled from the base of footing to greater depths. Further, the bearing capacity as perceived from the load-settlement curve for different depths of the soil patch keeping other parameter constant are shown in Figure 4. The result indicates that, ultimate bearing capacity decreases with a decrease in the depth of soil patch and maximum reduction of bearing capacity is obtained when the crest of soil patch lies just at the base of the footing. Further when the soil patch is moved away to greater depths, the effect of soil patch diminishes.

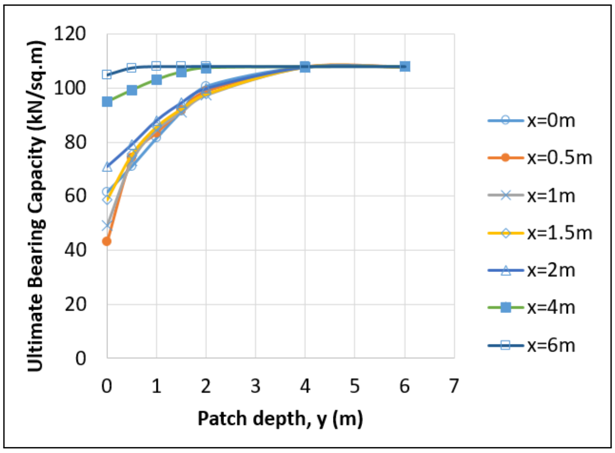

Figure 4: Bearing capacity of foundation with variation of soil patch depth (y) for different eccentricity of soil patch (x)

This occurs at a depth greater than 2 times the width of the foundation (i.e. from y=4m) which may be due to the reason that the failure surface propagates only up to the effective depth below the foundation. Below which there is minimal influence of the soil characteristics on the performance of the foundation. Hence, the result signifies the presence of critical zone of influence under the foundation. The performance of the foundation will be significantly influenced due to existence of the soil patch in the parent soil layer only when the it is located at a depth with in this region.

3.3 Effect of eccentricity of patch

In order to observe the extent of influence of horizontal position of soil patch in the performance of foundation, the soil patch is modeled from below the center of the foundation to greater distance away in the models. Further, the bearing capacity as perceived from the load-settlement curve for different eccentricity of the soil patch keeping other parameter constant are shown in Figure 5. The results indicates that, ultimate bearing capacity decreases with a decrease in the distance of footing from soil patch and maximum reduction of bearing capacity is obtained when the soil patch is near the vicinity of the footing. Precisely, the greatest influence if the soil patch on the performance of the footing is observed when the center of soil patch coincides with the edge of the footing. This is due to non-uniform distribution of load under the footing and stress concentration in the soil patch below one of the edge of the footing causing reduction in the bearing capacity. Further when the soil patch is moved away to greater distance

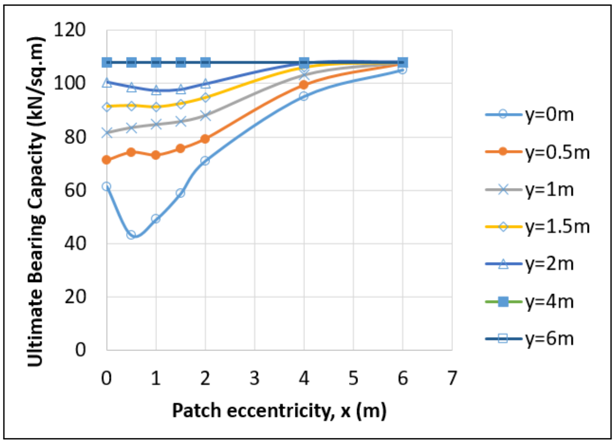

Figure 5: Bearing capacity of foundation with variation of eccentricity of soil patch (x) for different soil patch depth (y)

from the center of the foundation, the effect of soil patch diminishes. This occurs at a clear distance between the foundation and the soil patch greater than 2 times the width of the foundation which may be due to the reason that the failure surface progresses outward in the horizontal direction up to the edge of Rankine's passive zone.

It can be perceive from the results that the vertical position of the soil patch in the soil domain plays prime role in the performance in the foundation along with its horizontal position. When the soil patch is at the surface or at the level of base of footing (i.e. at y=0m), greatest influence of its presence can be seen on the bearing capacity. This may be due to the reason that the soil around the foundation is responsible to provide passive earth pressure and the failure surface extends to greater distance at the surface and tends to lie inside or just at the edge of the soil patch causing greater shear in the weaker soil patch which in turn lowers the ultimate bearing capacity. This effect is seen to have nominal effect when the soil patch lies at greater depths (i.e. at y>0 m). Hence, the result signifies the presence of critical zone of influence around the foundation. The performance of the foundation will be significantly influenced due to existence of the soil patch in the parent soil layer only when the it is located at a distance with in this region.

3.4 Effect of shear strength of soil patch

In this study, the effect of stiffness property of the soil patch on the performance of the foundation has been investigated. In order to investigate extent of influence of the strength of the soil patch in the performance of foundation, the soil patch of varying undrained shear strength from 20% to 100% of that of the parent soil has been taken into consideration in the models. Further, ultimate bearing capacity as perceived from the load settlement curve for different undrained shear strength soil patch keeping other parameter constant are shown in Figure 6 and Figure 7.

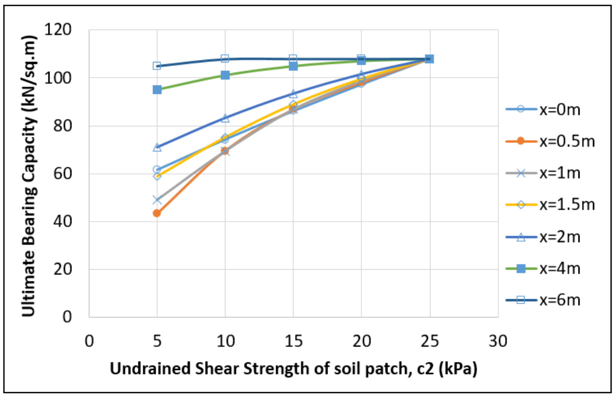

Figure 6: Bearing capacity of foundation with variation of undrained shear strength property of soil patch (c2) for different eccentricity of soil patch (x)

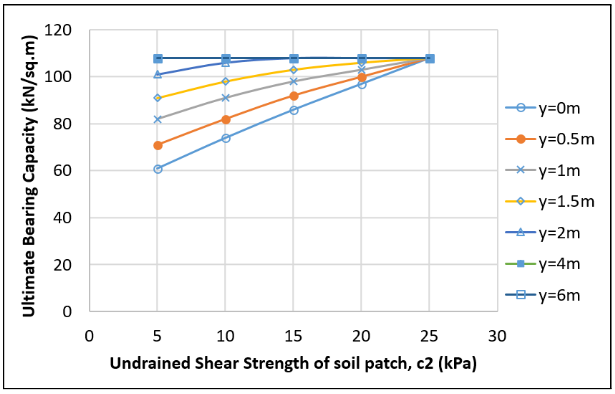

Figure 7: Bearing capacity of foundation with variation of undrained shear strength property of soil patch (c2) for different depth of soil patch (y)

The result indicates that, the ultimate bearing capacity decreases with decrease in the shear strength of the soil patch. This may be due to the reason that the failure surface progresses through the weaker zone in the soil under the foundation. This effect in performance of the foundation diminishes as the shear strength of soil patch is near the shear strength of the parent soil. It can be observed that the shear strength property of the soil patch plays primary role in lowering the ultimate bearing capacity of the foundation. This may be due to the incapability of the weaker soil patch with lower shear strength than that of the parent soil to withstand the shear stresses developed by the foundation.

It can be clearly observe that the reduction in bearing capacity is not uniform with respect to the shear strength of the soil patch. It can be perceive from the results that, the position of the soil patch with respect to the foundation in the soil domain plays secondary role in the performance of the foundation, as closer the soil patch is located to the foundation, greater will be its influence. When the soil patch is at greater distance than the critical zone around the foundation, the effect of its presence is negligible. As from Figure 7, when the soil patch is at a depth greater than the critical depth (i.e. y$\geq$4m), no influence of its presence can be seen on the bearing capacity for any shear strength and position of soil patch. This may be due to the reason that the failure surface and stress only extends to a certain region around the foundation beyond which the presence of soil patch has no influence in the performance of the foundation. It can be observed that the effect of strength property of soil patch is negligible as the patch of soil moves out of the critical zone of influence even when the shear strength of soil patch is very low.

4. Conclusions

The present study concludes that for a surface strip foundation resting on cohesive soil with square continuous soil patch with different property:

- There exists a critical zone of influence under the foundation. The performance of the foundation will be significantly influenced due to existence of the soil patch in the parent soil layer only when the it is located with in this region. The size of this zone of influence depends on various factors as soil property of the parent soil and soil patch and the size of the foundation and soil patch.
- Based on the results of the FEA the presence of the soil patch has negligible effect when the patch is located at a depth equal to twice the width of the foundation and at a clear horizontal distance between the foundation and the soil patch equal to twice the width of the foundation.
- Remarkable decrease in the bearing capacity of soil can be observed for a soil patch with weaker strength characteristics than that for soil patch with stronger strength characteristics. The influence of soil patch on the performance of the foundation is directly proportional to the variance of shear strength characteristics of the soil patch and the parent soil.
- The results of a series of numerical model analysis have shown that the bearing capacity of the soil vary according to the closeness of the soil patch to the foundation. The settlement and deformation of soil is greater in the presence of soil patch than the homogeneous case but causes turbulence when it lies away from middle footing reaching to the instability of the footing and greater reduction in bearing capacity.

References

[1] HG Poulos, JP Carter, and JC Small. Foundations and retaining structures-research and practice. In *Proceedings of the International Conference on Soil Mechanics and Geotechnical Engineering*, volume 4, pages 2527–2606. AA Balkema Publishers, 2002.

[2] GG Meyerhof. Ultimate bearing capacity of footings on sand layer overlying clay. *Canadian Geotechnical Journal*, 11(2):223–229, 1974.

[3] Sunil S Pusadkar and Sheetal M Baral. Behaviour of square footing resting on two layered clay deposits. *Studies*, 2(3):142–149, 2013.

[4] DV Griffiths and Gordon A Fenton. Bearing capacity of spatially random soil: the undrained clay prandtl problem revisited. *Geotechnique*, 51(4):351–359, 2001.

[5] Gordon A Fenton and DV Griffiths. Bearing-capacity prediction of spatially random c φ soils. *Canadian geotechnical journal*, 40(1):54–65, 2003.

[6] RL Baus and MC Wang. Bearing capacity of strip footing above void. *Journal of Geotechnical Engineering*, 109(1):1–14, 1983.

[7] Abdelmegeed Kabasy Mohamed. Numerical study for the behavior of strip footing on sand in the existence of a buried rock. *JES. Journal of Engineering Sciences*, 40(6):1611–1624, 2012.

[8] JE Bowles. Foundation analysis and design, -1997, mcgraw-hill book companies, inc. 1997.

[9] Donald P Coduto, William A Kitch, and Man-chu Ronald Yeung. *Foundation design: principles and practices*, volume 2. Prentice Hall USA, 2001.