ANALYSIS OF SOIL BEARING CAPACITY PROVIDING MACADAM LAYER UNDER SPREAD FOOTING USING PLAXIS 3D

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ABSTRACT

Shallow foundations are widely constructed around the world. It is of great importance for the stability of the structure. In the design of shallow foundations, the bearing capacity of the soil is a critical parameter influencing their stability and performance. In many areas, the actual bearing capacity is not provided to the designer when designing the structure. In many remote areas or for low-rise residential building construction projects, it can be seen that a macadam layer of sand and aggregate is used under footing with a different thickness of layer, assuming that inclusion of the macadam layer in soil will increase the bearing capacity of soil by a certain amount. From that viewpoint, this study analysed the effect of the inclusion of that layer on bearing capacity using the advanced geotechnical finite element software, PLAXIS 3D. The aim of this research is to evaluate the impact of the macadam layer on the load-carrying capacity and settlement behaviour of shallow foundations. The parameters used in this study were collected from a geotechnical report. The research methodology involves the development of a representative numerical model based on soil properties and geometry. The Mohr-Coulomb soil model is used to simulate the soil behaviour, considering its shear strength parameters and stress-strain characteristics. The analysis indicated that if the macadam layer to clayey soil is taken as the ratio, the bearing capacity becomes high compared to the clayey soil. When the footing size is less by 1'x1' than the soil section (5'x5', 6'x6', 7'x7', and 8'x8') in a 3:2 ratio, the bearing capacity of the soil increases from 31% to 46.6%. The outcomes are assessed in terms of bearing capacity and the prescribed settlement of 25mm. The findings of the study provide useful information on the effectiveness of using a macadam layer to improve bearing capacity under spread footing. Which can have significant implications for the design and construction of shallow foundations.

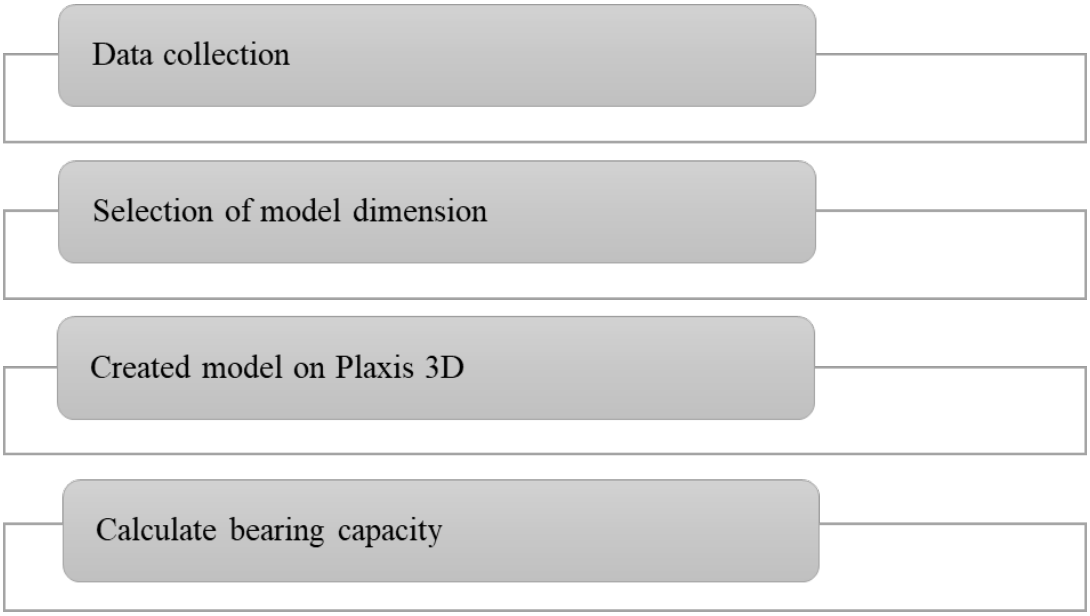
Keywords: *Bearing Capacity, PLAXIS 3D, Settlement, Macadam layer, Mohr-Coulomb*

1. INTRODUCTION

The geotechnical characteristics of Bangladesh's deltaic alluvial plains show a low to extremely poor foundation competence, indicating that the soil in this area has a limited bearing capacity. According to data from shear tests on Bangladeshi soils, the shear strength is often low, especially in the higher zones, which has an impact on the soil's ability to withstand shearing pressures and, as a result, its bearing capacity. When building embankments in Bangladesh, especially in regions with meandering river beds, the soft topsoil offers a significant settling issue(Mollah, 1993). All constructions are ultimately supported by the soil. The stability of the building is impacted by the behavior of the supporting earth, soil, or rock. Natural soil is quite varied and influenced by a wide range of elements. Soil characteristics must be anticipated to influence the sort of structural foundation needed for a construction(Patel, 2014). In the actual world, soil is rarely uniform. Non-homogeneity can be created by nature or by humans. Natural soil is not homogenous because of a number of processes, such as chemical bonding, erosional removal of overburden, and variations in static ground water levels. Layered soil may be the result of historical sea level changes. Horizontal soil strata from different soil types make up many earthworks, including fills and pavements(Hakro et al., 2022). Low bearing capacity of weak soils prevents them from supporting loads(Belal et al., 2015). A structure's foundation is the part that transfers the structure's load pressure to the ground(Al-Dawoodi et al., 2021). In geotechnical engineering, shallow footings are often shaped like a square, rectangle, strip, circle, or ring. They are employed to safely and efficiently transfer loads from the irregularly shaped buildings to the subsurface soils (Davarci et al., 2014) (Saha Roy & Deb, 2017). For foundation design, the monitoring of load deformation beneath the footing is crucial (Hakro et al., 2022) (Wang et al., 2018). In the discipline of foundation engineering, the foundation's bearing capability is of utmost importance. It is essential for any design that the maximum bearing capacity of a footing on layered soil may be predicted. The soil qualities of each layer and the thickness of the layer play a major role in the failure mechanism of a soil under footing and the bearing capacity value. (Belachew, n.d.) (Panwar & Dutta, 2020) (Boushehrian & Hataf, 2003). The load at which the shear failure of the soil occurs is called the ultimate bearing capacity of the foundation. (Vilas & Moniuddin, 2015)

A macadam layer with sand and gravel can support the stability of a structure in a shallow foundation base to lessen its susceptibility. This study examined the macadam layer beneath a spread footing of varied sizes to determine the footing's carrying capability.

2. METHODOLOGY



In this study, a detailed analysis was done to determine how concrete footings performed on a clayey soil and a macadam layer of sand & gravel. The research was done using the finite element software, PLAXIS 3D. The bearing capacity of the clayey soil and macadam layer was determined at different cross sections and different ratios of the macadam layer to the clayey soil.

2.1 Data Collection

For this study, data of clayey soil was collected from a soil report which was investigated and reported by BISMILLAH SOIL ENGINEERING, JAHANARA HOUSE, 35/4, MOHONA-A, SUNAMGONJ ROAD, PATHANTULA, SYLHET 3100. on February, 2023. Data of macadam layer (sand & gravel) was collected from the Mohr-Coulomb Parameters for Modelling of Structures (Plaxis Bulletin, Issue 25 / Spring 2009) and (structx.com) website.

Table 1: Material Properties

Material	Clayey Soil	Macadum layer (Sand & Gravel)	Footing (Concrete)
Model Name	Mohr-Coulomb	Mohr-Coulomb	Linear-Elastic
Drainage type	Undrained A	Drained	Non-porous
ϒunsat (kN/m3)	14.92	19.24	23.6
ϒsat (kN/m3)	19.37	22.51	-
Cohesion, c` (kPa)	35.9	0.1	-
φ°	34	34	-
E ` (kPa)	7000	40000	23X10^6
ν`	0.35	0.3	0.2

2.2 Selection of model dimension

The bearing capacity of the clayey soil and macadam layer was assessed for four different soil dimensions: 5'x5', 6'x6', 7'x7', and 8'x8'. The total depth of the soil section was taken as 5 feet for all models. For each of the soil dimensions, the footing size was taken as one foot and two feet less than the soil dimensions. For instance, while considering the soil dimensions as 7'x7', the corresponding footing sections were taken as 6'x6' [Figure: 1(c)] and 5'x5'. So, for each soil dimension, two sizes of footing were taken into consideration. For all models, the depth of footing was taken as 15 inches.

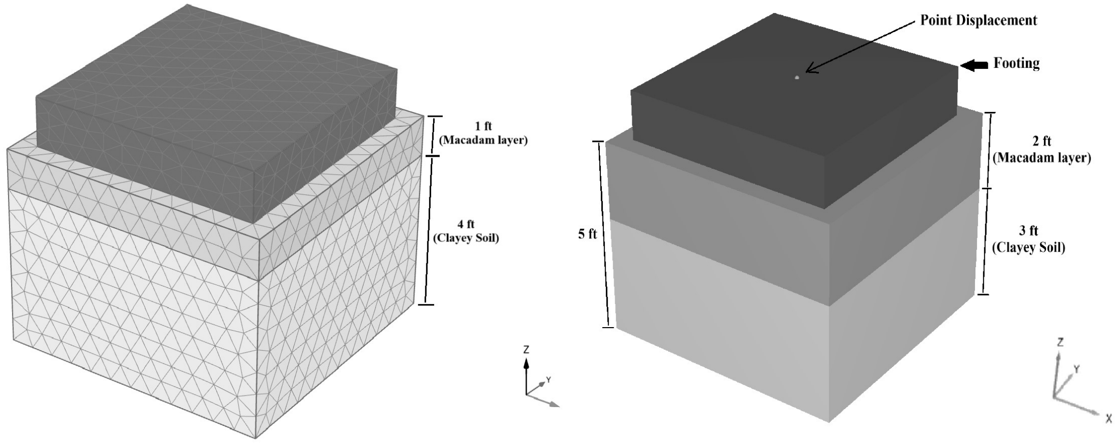
The ratios of the macadam layer to clayey soil were considered for each footing dimension. The ratios of the macadam layer to clayey soil were selected as 1:1, 1:4, 2:3, and 3:2. Since the depth of the soil section was taken as 5 feet, here 1:1 ratio signifies that, in the overall depth of 5 feet, 2.5 feet is clayey soil and 2.5 feet is the macadam layer [Figure: 1(c)]. In the same manner, a 3:2 ratio signifies 3 feet of macadam layer and 2 feet of clayey soil [Figure: 1(d)]. In this procedure, other ratios were taken into consideration. In each case, the macadam layer was placed above the clayey soil.

For each footing size, four models were created for four different ratios and one model was created assuming the full soil section as clayey soil. So, a total of forty models were created for the four soil dimensions (5'x5', 6'x6', 7'x7', and 8'x8').

2.3 Creating model in PLAXIS 3D

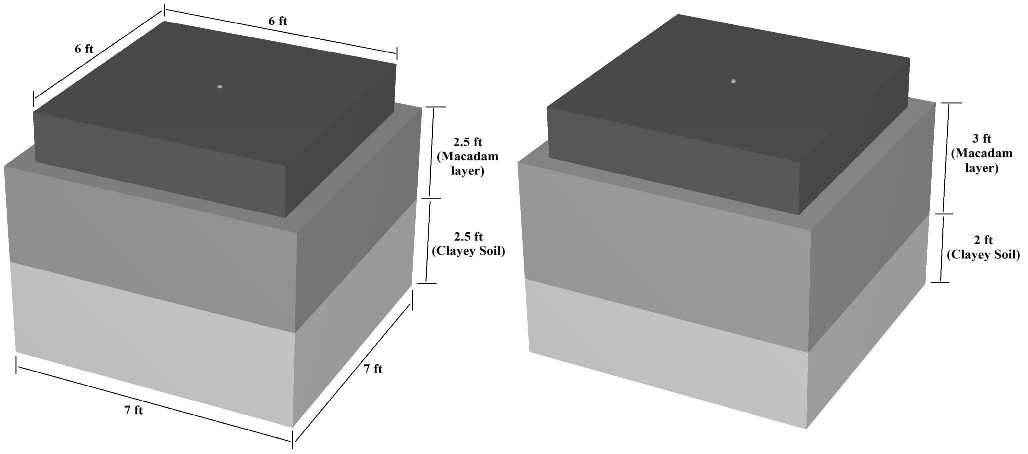
The project properties were set to the metric system. The water table was excluded from this model to prevent complexities. The point displacement was positioned at the midpoint directly above the footing [Figure 1(b)]. The prescribed displacement for the specified position was established as 25mm. In PLAXIS 3D, the medium option was selected for meshing. A coarseness factor of 1 was taken to refine the point prescribed displacement. The K0 procedure was used in the initial phase and no initial stresses were generated in this phase. Footing was activated in the second phase. In the third phase, the point prescribed displacement was activated. The node was selected at the base of the footing under the point displacement. The calculation type was set to Plastic analysis and the loading type was selected as Staged construction. Max steps parameter was set to 1000 and Tolerated error was defined as 0.01.

Figure 1(a) shows the mesh generation process and Figure 1(b), (c) and (d) illustrates the stage construction steps for different ratios of the macadam layer and the clayey soil. Figure 1(e) displays the output model of total deformation that results from the prescribed point displacement in a 1:1 ratio of the macadam layer to the clayey soil.



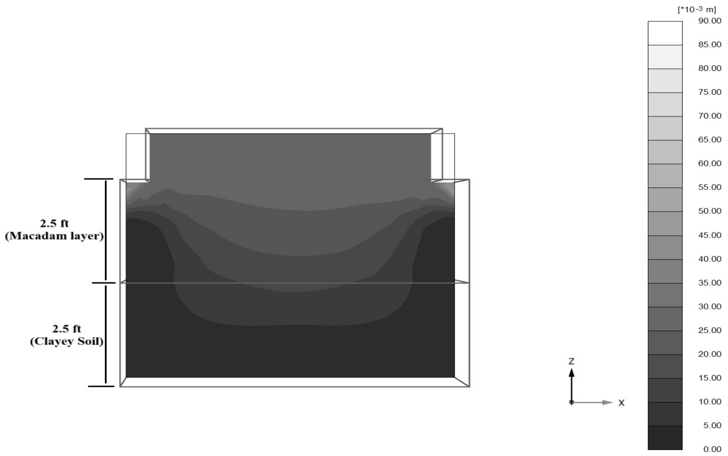
(a): Mesh generation (1:4)

(b): Stage Construction of soil model (2:3)



(c): Stage Construction of soil model (1:1)

(d): Stage Construction of soil model (3:2)



(e): Total Deformation (1:1)

Figure 1: Visual representations of different soil models (1'x1' less footing section than the soil section)

2.4 Bearing Capacity Calculation

The utmost load that a footing can support without encountering excessive settling of soil or failure is indicated by the bearing capacity. Each model's bearing capacity was calculated using the PLAXIS 3D output data. Since the point displacement is set to 25mm, the load will be imposed as long as the soil does not reach 25mm settlement. This directly calculates the allowable bearing capacity of the soil. After calculation of all soil models, the findings for varied ratios of the macadam layer to the clayey soil were compared with the results of the clayey soil when regarded as a whole.

3. RESULT AND DISCUSSION

This section will go through the outcomes of the investigation after looking at some of the characteristics that influence soil behaviour and their bearing capacity. The bearing capacity of each soil section for different ratios of the macadam layer to the clayey soil (CS) is shown in Tables 2–5. For each soil section, two footings of different dimensions were considered and the data were tabulated accordingly.

Table 2: 5'x5' Soil Section

Footing Section	3'x3'					4'x4'				
Macadam layer : Clayey soil	CS	1:1	2:3	3:2	1:4	CS	1:1	2:3	3:2	1:4
Allowable bearing capacity, kip	92.1	71.8	62.8	70.2	51.3	194.2	261.9	213.9	265.9	123.2

Table 3: 6'x6' Soil Section

Footing Section	4'x4'					5'x5'				
Macadam layer : Clayey soil	CS	1:1	2:3	3:2	1:4	CS	1:1	2:3	3:2	1:4
Allowable bearing capacity, kip	157.6	143.4	127.4	155.3	99.6	310.2	400.8	361.3	406.5	219.6

Table 4: 7'x7' Soil Section

Footing Section	5'x5'					6'x6'				
Macadam layer : Clayey soil	CS	1:1	2:3	3:2	1:4	CS	1:1	2:3	3:2	1:4

Allowable bearing capacity, kip	243.7	221.7	216.3	267.1	198.6	422.6	600.7	549.7	607.7	345.8

Table 5: 8'x8' Soil Section

Footing Section			6'x6'					7'x7'		
Macadam layer : Clayey soil	CS	1:1	2:3	3:2	1:4	CS	1:1	2:3	3:2	1:4
Allowable bearing capacity, kip	357.7	372.1	304.2	418.8	156.1	588.1	835.4	763	861.9	481.1

From Figure 2, it can be seen that, for soil section 5'x5' and footing section 3'x3', the bearing capacity of the clayey soil is 92.1 kips. When the Macadam layer was placed over the clayey soil in a 1:4, 2:3, 3:2, and 1:1 ratio, the bearing capacity reached 51.3 kips, 62.8 kips, 70.2 kips, and 71.8 kips, respectively, which are less than the bearing capacity of the clayey soil. Again, when the footing section was taken 1'x1' smaller than the soil section as 4'x4', the bearing capacity of clayey soil was found to be 194.2 kips (Table 2). After placing the macadam layer over the clayey soil in a 1:4, 2:3, 3:2, and 1:1 ratio, the bearing capacity reached 123.2 kips, 213.9 kips, 265.9 kips, and 261.9 kips, respectively (Figure 3). From this result, it can be seen that the bearing capacity increased with respect to the clayey soil in the 1:1, 2:3, and 3:2 ratios and decreased in the 1:4 ratio. The percentage of bearing capacity increased in the 1:1, 2:3, and 3:2 ratios are 34.9%, 10.19%, and 36.97%, respectively.

Again, Figure 2 demonstrates that, for soil section 6'x6' and footing section 4'x4', the bearing capacity of clayey soil is 157.6 kips. When the Macadam layer was placed over the clayey soil in a 1:4, 2:3, 3:2, and 1:1 ratio, the bearing capacity reached 99.6 kips, 127.4 kips, 155.3 kips, and 143.4 kips, respectively, which are less than the bearing capacity of the clayey soil (Table 3). Again, when the footing section was taken as 5'x5', the bearing capacity of the clayey soil was determined to be 310.2 kips. After putting the macadam layer over the clayey soil in a 1:4, 2:3, 3:2, and 1:1 ratio, the bearing capacity reached 219.6 kips, 361.3 kips, 406.5 kips, and 400.8 kips, respectively (Figure 3). The percentage of bearing capacity increased in the 1:1, 2:3, and 3:2 ratios are 29.21%, 16.47%, and 31.04%, respectively.

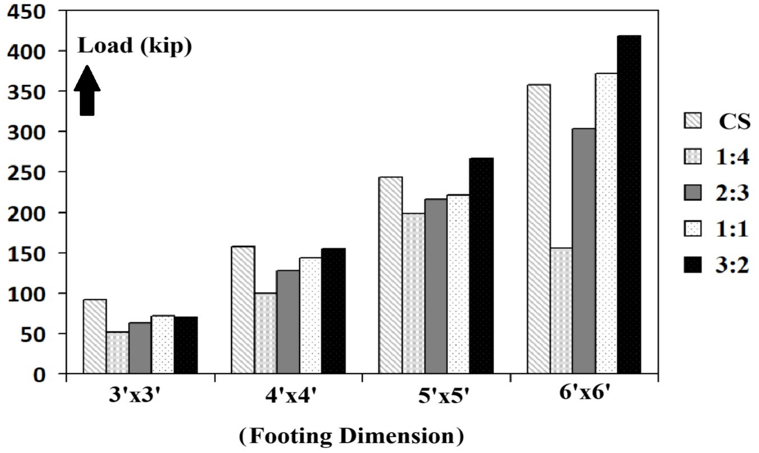


Figure 2: Bearing capacity on 2'x2' less footing sections than the soil section

Also, from Figure 2, for the 5'x5' footing and 7'x7' soil section, the bearing capacity of clayey soil is 243.7 kips. When the Macadam layer was set over the clayey soil in a 1:4, 2:3, 3:2, and 1:1 ratio, the bearing capacity reached 198.6 kips, 216.3 kips, 267.1 kips, and 212.7 kips, respectively (Table 4), which are less than the bearing capacity of the clayey soil. Again, when the footing section was taken 1'x1' smaller than the soil section as 6'x6', the bearing capacity of the clayey soil was determined to be

422.6 kips. After putting the macadam layer over the clayey soil in a 1:4, 2:3, 3:2, and 1:1 ratio, the bearing capacity achieved 345.8 kips, 549.7 kips, 607.7 kips, and 600.7 kips, respectively (Figure 3). It shows the increase of bearing capacity in the 1:1, 2:3, and 3:2 ratios by 42.14%, 30.08%, and 43.8%, respectively.

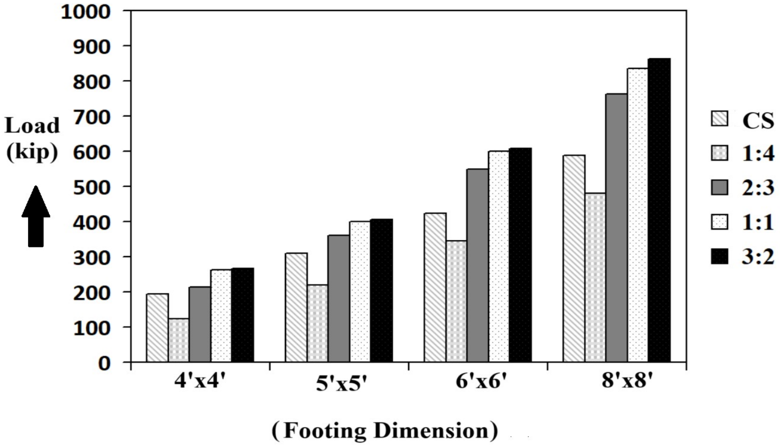


Figure 3: Bearing capacity on 1'x1' less footing section than the soil section

Figure 2 further demonstrates that for footing section 6'x6' and soil section 8'x8', the bearing capacity of the clayey soil is 357.7 kips. When the Macadam layer was laid over the clayey soil in a 1:4, 2:3, 3:2, and 1:1 ratio, the bearing capacity reached 156.1 kips, 304.2 kips, 418.8 kips, and 372.1 kips, respectively (Table 5), which are lesser compared to the bearing capacity of the clayey soil. Again, when the footing section was taken as 7'x7', the bearing capacity of clayey soil was determined to be 588.1 kips. After placing the macadam layer over the clayey soil in a 1:4, 2:3, 3:2, and 1:1 ratio, the bearing capacity reached 481.1 kips, 763 kips, 861.9 kips, and 835.1 kips, respectively (Figure 3). The bearing capacity in the 1:1, 2:3, and 3:2 ratios increased by 42.05%, 29.74%, and 46.6%, respectively.

Finally, Figure 2 presents that, when the footing dimension is less by 2'x2' than the soil dimension, the bearing capacity does not increase with respect to the bearing capacity of the clayey soil. But according to Figure 3, when the footing dimension is less by 1'x1' than the soil dimension, the bearing capacity increases in the 1:1, 2:3, and 3:2 ratios and decreases only in the 1:4 ratio with respect to the bearing capacity of the clayey soil. Figure 3 also demonstrates the highest increase of bearing capacity in percentage in the 3:2 ratio of the macadam layer to the clayey soil for all footing dimensions, which are less by 1'x1' than their respective soil dimensions. The second highest increase in percentage is in the 1:1 ratio for all footing dimensions, which are less by 1'x1' than the soil dimension.

4. CONCLUSIONS

The stability of a structure relies significantly on the soil displacement, which, in turn, is influenced by the soil's bearing capacity. Analysis indicates that the bearing capacity of a mixture comprising three parts macadam layer (sand & gravel) and two parts clayey soil surpasses that of mixtures with ratios of 1:1, 1:4, 2:3, and 3:2. Notably, the 3:2 ratio demonstrates superior performance, particularly when the foundation's dimensions are reduced by 1 foot from the soils. When designing shallow foundations, it is crucial to consider the bearing capacity of the soil to ensure its structural strength. Consequently, for optimal structural strength, it is recommended to design shallow foundations with a 3:2 ratio of the macadam layer (sand & gravel) to the clayey soil and take the footing dimension 1 foot less from both sides of the soil dimension. A 1:1 ratio of the macadam layer to the clayey soil can also be used since it provides outcomes that are most similar to a 3:2 ratio.

REFERENCES

Al-Dawoodi, A. B., Rahil, F. H., & Waheed, M. Q. (2021). Numerical simulation of shallow foundation behavior rested on sandy soil. *IOP Conference Series: Earth and Environmental Science*, *856*(1), 012042.

Belachew, H. (n.d.). *EVALUATING BEARING CAPACITY OF LAYERED SOILS USING FINITE ELEMENT ANALYSIS SOFTWARE ADDIS ABABA INSTITUTE OF TECHNOLOGY SCHOOL OF CIVILAND ENVIRONMENTAL ENGINEERING SCHOOL OF GRADUATE STUDIES*.

Belal, A., Nagy, N., & Elshesheny, A. (2015). Numerical evaluation of bearing capacity of square footing on geosynthetic reinforced sand. *Proceedings of the International Conference on Civil, Structural and Transportation Engineering*, 1–9.

Boushehrian, J. H., & Hataf, N. (2003). Experimental and numerical investigation of the bearing capacity of model circular and ring footings on reinforced sand. *Geotextiles and Geomembranes*, *21*(4), 241–256.

Davarci, B., Ornek, M., & Turedi, Y. (2014). Analyses of multi-edge footings rested on loose and dense sand. *Periodica Polytechnica Civil Engineering*, *58*(4), 355–370.

Hakro, M. R., Kumar, A., Almani, Z., & Shah, S. R. A. (2022). Numerical Modelling of Shallow Foundation on Multi-Layer Soil with varying Stiffness. *Jurnal Kejuruteraan*, *34*(6), 1053–1062.

Mohr-Coulomb Parameters for Modelling of Structures. (n.d.).

Mollah, M. A. (1993). Geotechnical conditions of the deltaic alluvial plains of Bangladesh and associated problems. *Engineering Geology*, *36*(1–2), 125–140.

Panwar, V., & Dutta, R. K. (2020). Numerical study of ultimate bearing capacity of rectangular footing on layered sand. *Journal of Achievements in Materials and Manufacturing Engineering*, *101*(1).

Patel, V. (2014). Software for design of shallow foundation using Matlab. *Int. J. Eng. Sci. Res. Technol*, *3*(4), 1912–1919.

Saha Roy, S., & Deb, K. (2017). Bearing capacity of rectangular footings on multilayer geosynthetic-reinforced granular fill over soft soil. *International Journal of Geomechanics*, *17*(9), 04017069.

Vilas, M. K., & Moniuddin, K. (2015). Finite element analysis of soil bearing capacity using plaxis. *International Journal of Engineering Research and Technology*, *4*(6).

Wang, J.-Q., Zhang, L.-L., Xue, J.-F., & Tang, Y. (2018). Load-settlement response of shallow square footings on geogrid-reinforced sand under cyclic loading. *Geotextiles and Geomembranes*, *46*(5), 586–596.

Wout Broere, R. B. E. B. andArny L. (2009). *Crane Monopile Foundation Analysis Mohr-Coulomb Parameters for Modelling of Concrete Structures Simulation of Soil Nail Structures using PLAXIS 2D Plaxis Bulletin*. www.plaxis.nl

StructX, n.d.

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