



Behaviors of Geo-synthetic Reinforcements for Mat Foundation in Very Soft Clay

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ABSTRACT

Geo-synthetic reinforcing is the most economical ground improvement technique in very soft soils. This process is applicable for various types of foundations. Normally, earth reinforcing is used for square and continuous foundation based on past study. Several analytical and empirical formulae have been already developed for square and continuous foundations. In the present research, geo-synthetic reinforcing is used for mat foundation. Variable parameters are width to length ratio of mat, coefficient, reinforcing layers and replaced zone to foundation depth ratio. Five layers of geo-synthetic reinforcement, eight values of coefficient and several depth ratios are considered for analysis. Mild steel is used for geo-synthetic reinforcements. Minimum individual geo-synthetic reinforcing layer depth is 25mm. Prediction of critical width to depth ratio of mat and numbers of reinforcing layers are the main goal of this research. Factor of safety shows zero values for fourth and fifth layers of reinforcing. Higher thickness of replaced zone expresses zero factor of safety for some cases of fourth and fifth reinforcing layers. Lower thickness of reinforcing layers express stable condition of very soft clay. Also higher reinforcing layer expresses worst condition of very soft clay. Variations of foundation coefficients influenced bearing capacity of very soft soil. Three layers geo-synthetic reinforcing show stable condition of very soft clay for various widths to length ratios and foundation coefficients.

1. Introduction

Geo-synthetic reinforcing is one of the most popular and efficient ground improvement technologies. The basic concept of earth reinforcing is to remove a very soft layer of soil and replace it with dense sand. This method is suitable for shallow foundations. This method increases bearing capacity of very soft clay. Mild steel bar, weir meshes etc. are generally used as geo-synthetic reinforcements. Generally, sand, coarse aggregate etc. are used as filler material of geo-synthetic replaced zone [3]. Punching failure through replaced zone is critical among six potential failure modes

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[2,3,7,11] of reinforced layers. Plate load test is performed to evaluate field capacity of reinforcing zone [1,4]. Generally, two to four layers geo-synthetic reinforcements are economical for ground improvement [8]. By using earth reinforcing, increase bearing capacity of soft soil and reduce settlement [5,6,10]. Based on past studies, bearing capacity of soil is increased maximum three times from its existing value [8]. Several layers reinforcements and higher depth of replaced zone are decreased bearing capacity and increase settlement of existing soft soil. Earth reinforcement provided uplift to the existing foundation [11]. Strain in most geo-synthetic reinforcement at failure was less than 0.03% [3] when a square plate size of 457mm \times 457mm. Several analysis of earth reinforcing has been performed for square and continuous foundation. Mat foundation treated as slightly continuous foundation when its width to length ratio is very small. When using reinforcement in replaced zone then effect of settlement gradually lower. Thickness of reinforced zone varies 0.5 to 1.5 times of width of foundation [9].

In present study, geo-synthetic reinforcement is used for mat foundation. Width of mat is much larger than square as well as continuous footing. So, previous research can't specific describe the effect of mat foundation by the replacement of square or continuous foundation. Width to length ratio of mat foundation effects upon bearing capacity of soil and also geo-synthetic reinforcing layers effects on the bearing capacity of soft soil. Suitable number of reinforcing layers, replaced zone to foundation depth ratio and width to length ratio of mat are influenced on the bearing capacity of soft soil. Evaluation of critical values of these parameters is the main objectives of this research.

2. Analytical Model

Analytical model has been developed for mat foundation in very soft soil under vertical loading. Lateral effect and inclination of loading are not considered in analysis. Fixed length of mat foundation has been taken for analysis which is 40m. Width of this foundation is variable. Depth of this foundation has been considered to be 1m. Others variable parameters are replaced zone thickness and foundation coefficient. Total vertical load on this foundation has been taken as 30000kN. Location of ground water table from existing ground surface has been found to be 300mm. Maximum 5 layers geo-synthetic reinforcement have been used for analysis. Diameter, grade and spacing of mild steel reinforcing bars are 10mm, 415N/mm² and 200mm center to center. In reinforcing zone, reinforcements have been provided in both directions by using same spacing. For mat foundation, normal weight concrete has been used for analysis. Analytical model is represented by Figure. 1.

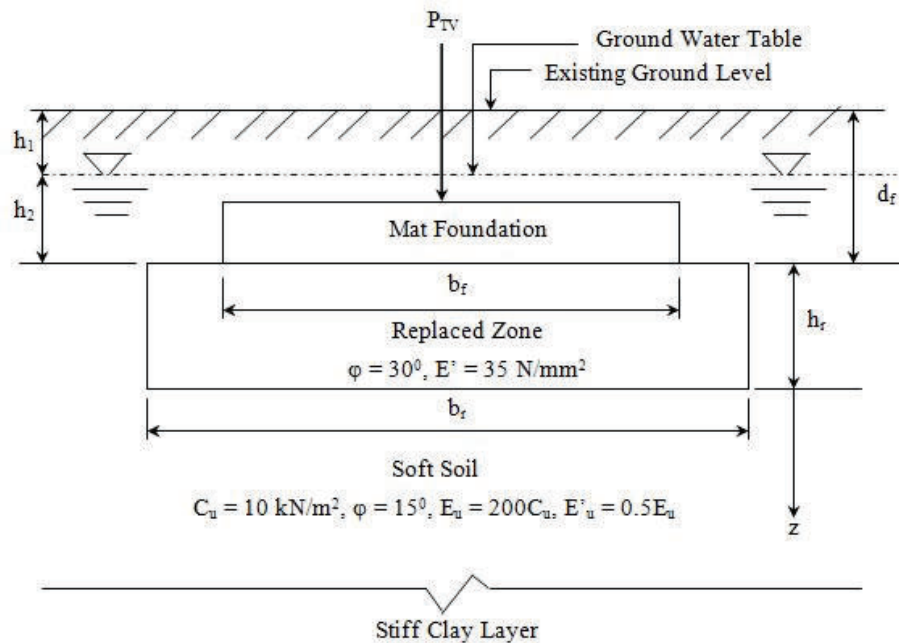


Figure 1: Analytical model of mat foundation in very soft clay.

3. Experimental Data and Analytical Formulae

Various types of laboratory test has been performed of very soft clay such as unconsolidated un-drained test, direct shear test, moisture content, specific gravity, grain size analysis etc. Several analytical formulae have been developed by closed formed solution. Some analytical formulae are listed here which influenced bearing capacity of very soft soil.

3.1 Experimental Study

Experiment is important before start analysis of soil. In reality, soil expresses very complex behaviors such as anisotropic, non-linearity and high damping capacity. It has not possible to find out actual behavior of soil in laboratory but some concept earn from laboratory test for analyze of soil. Various properties of very soft clay are represented in Table 1.

Table 1: Material properties of very soft clay

<i>Materials Identity</i>	<i>Laboratory Test Results</i>	<i>Unit</i>
Unit weight of soft soil above ground water table	17.5	kN/m ³
Unit weight of geo-synthetic reinforcing zone and below ground water table	19.5	kN/m ³
Un-drained cohesion of very soft clay	10	kN/m ²
Friction angle of geo-synthetic reinforcing zone	30	degree
Friction angle of soft soil	15	degree
Effective modulus of elasticity of replaced zone	35000	kN/m ²

Others properties are come from mathematical relations. Modulus of elasticity of very soft soil is two hundred times of un-drained cohesion and effective modulus is half of elastic modulus. Depth factor, shape factor, inclination factor are comes from empirical relations. Cohesion is very low which represents soil is very soft.

3.2 Analytical Formulae

Analytical formulae were developed by several researchers' from their research. Several types of analytical formulae have been developed by considering six failure modes. Such types of analytical formulae [8] have been represented in present study. Punching failure through reinforced zone is critical among six modes of failure. Generally, ultimate bearing capacity of soil due to punching failure through replaced zone is expressed by Eq. (1).

$$q_{ult,r} = q_b + \frac{2C_1c_r h_r}{B_f} + C_1\gamma'_r h_r^2 \left(1 + \frac{2D_f}{h_r}\right) \frac{K_s \tan\phi_r}{B_f} + \frac{2C_1 T_a \tan\delta}{B_f} - \gamma'_r h_r \quad (1)$$

Where,

q_b = ultimate bearing capacity of the foundation with a width of B_f at a depth of $D_f + h_r$.

T_a = total allowable tensile strength of all reinforcement layers in one side of footing.

C_1 = constant (2 for square footing, 1 for continuous footing and variable for mat foundation)

c_r = cohesion of replaced zone ($c_r = 0$, if the replaced zone is fill by sand)

h_r = Thickness of replaced zone

B_f = width of mat foundation

γ'_r = effective unit weight of replaced zone

D_f = depth of mat foundation

K_s = factor depends on angle of internal friction of reinforcing zone and bearing capacity of soil

$$\delta = \frac{2}{3} \varphi_r$$

φ_r = angle of internal friction of reinforcing zone

Geo-synthetic reinforcement pullout capacity on each side of mat foundation is expressed by Eq. (2). Extended length of reinforcement from edge of mat for geo-synthetic layers is considered to be 1m.

$$T_a = \sum T_{po} = 2C_i L_a \sum [c_r + \gamma'_r (D_f + h_r) \tan \varphi_r] \quad (2)$$

Where,

C_i = factor, usually it is taken as 0.9

L_a = extended length of mat foundation.

Ultimate bearing capacity at beneath of reinforcing zone is the function of several factors. This bearing capacity and its corresponding relations are expressed by Eq. (3), Eq. (4), Eq. (5), Eq. (6), Eq. (7), Eq. (8), and Eq. (9).

$$q_b = c_u N_{c2} s_c d_c + \sigma'_{z0} N_{q2} s_q d_q \quad (3)$$

$$d_q = 1 + 0.1 \sqrt{K_p} \frac{D_f + h_r}{B_f} \quad (4)$$

$$d_c = 1 + 0.2 \sqrt{K_p} \frac{D_f + h_r}{B_f} \quad (5)$$

$$s_c = 1 + 0.2 K_p \frac{B_f}{L_f} \quad (6)$$

$$s_q = 1 + 0.1 K_p \frac{B_f}{L_f} \quad (7)$$

$$q_1 = 0.5 \gamma'_r B_f \left[\left(\left(\tan^2 \left(45^\circ + \frac{\varphi_r}{2} \right) e^{\pi \tan \varphi'_r} \right) - 1 \right) \tan (1.4 \varphi'_r) \right] \quad (8)$$

$$q_2 = c_u N_{c2} \quad (9)$$

Where,

c_u = un-drained cohesion

N_{c2} = bearing capacity factor, 5.14 for soft clay

N_{q2} = bearing capacity factor, 1 for soft clay

s_c, s_q = shape factor

d_c, d_q = depth factor

K_p = earth pressure coefficient factor

L_f = length of mat foundation

q_1 = bearing capacity of a mat foundation on the surface of the replaced zone

q_2 = bearing capacity of a mat foundation on the surface of the soft soil

σ'_{z0} = effective overburden pressure at the beneath of replaced zone

Applied pressure at the base of the mat foundation and factor of safety are represented by Eq. (10) and Eq. (11).

$$q = \frac{P + W_f}{A_f} - u_D \quad (10)$$

$$FS = \frac{q_{ult,r}}{q} \quad (11)$$

Where,

P = total vertical load on mat foundation

W_f = self weight of mat foundation

A_f = cross – sectional area of mat foundation

u_D = water pressure

Above mentioned equations are influenced behaviors of reinforcing layers and bearing capacity of mat foundation. These behaviors depends various factors.

4. Results and Interpretations

There are four variables parameters are used in this research such as width to length ratio of mat, thickness of reinforcing zone to foundation depth ratio, reinforcing layers and coefficient of foundation. Width to length ratio of mat varies from 0.1 to 0.8 with 0.1 increments. These ratios are 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7 and 0.8. For single layer reinforcement, replaced zone to foundation depth ratio varies from 25mm to 1000mm with 25mm increment. Similarly, two, three, four and five layer reinforcements, this ratio varies from 50mm to 2000mm, 75mm to 3000mm, 100mm to 4000mm and 125mm to 5000mm. For two layer reinforcement, minimum thickness of double layer is 50mm and individual layer thickness is 25mm. For all case, one reinforcing layer is placed within 25mm. First reinforcing layer must be placed on the very soft soil body. Another variable is foundation coefficient which is varies from 0.25 to 2 with 0.25 intervals.

4.1 Single Layer (Layer = 1) Reinforcement within Thickness of Reinforcing Zone

Factor of safety is gradually decreasing with the increment of thickness of reinforcing zone and decreasing of foundation coefficient. Uniform variations are observed for all cases. This variations show like as spectrum. Difference of factor of safety for various foundation coefficients is maximums at 1.0, replaced zone to foundation depth ratio when width to length ratio of mat is 0.3. For single layer reinforcing, foundation coefficient not largely effect on the factor of safety. Increment of reinforcing layer thickness expresses failure of very soft soil and it also expresses occurrence of lager settlement. For single layer reinforcement, factor of safety value is very low for all case. However, uniformities of graphs indicate accuracy of analysis and its corresponding results. Figure 2 expresses the behavior of single layer reinforcement of mat foundation.

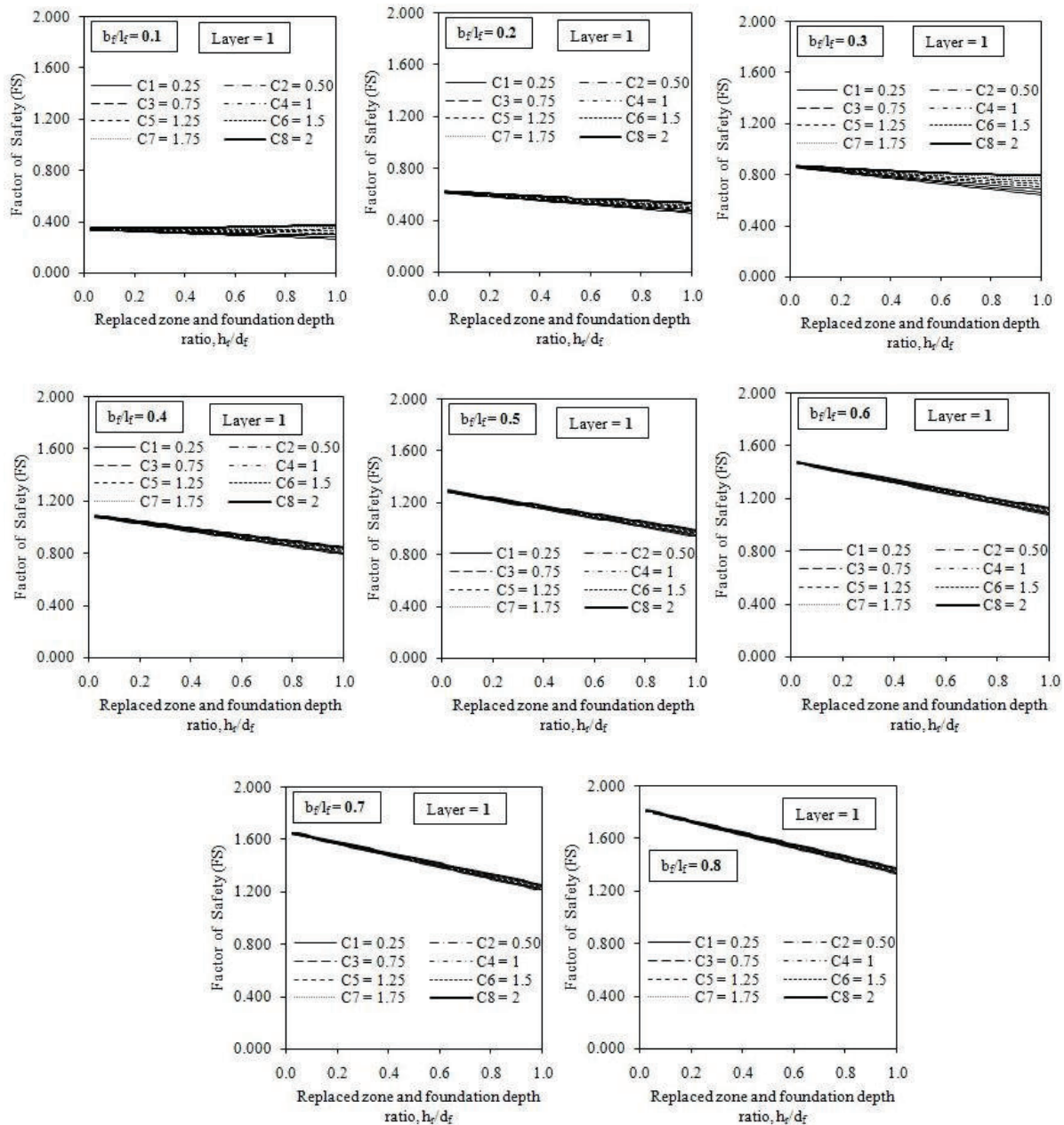


Figure 2: Variations of factor safety for single layer reinforcements in replaced zone

4.2 Double Layer (Layer = 2) Reinforcement within Thickness of Reinforcing Zone

Double layer starts from 50mm and ends at 2000mm. Factor of safety is decreasing gradually with the increment of replaced zone thickness except width to length ratio of mat of 0.1. Mat foundation acts as slightly continuous foundation when width to length ratio is 0.1. Factor of safety is uniform over the thickness of replaced zone for coefficient $C5 = 1.25$. Factor of safety is increasing with the increment of foundation coefficient. Higher thickness of reinforcing zone expresses stable condition of soil for width to length ratio of 0.1 and foundation coefficient at 2. In others cases, higher thickness of reinforcing zone expresses unstable condition of soil which occurs differential settlement of mat. Factor of safety is maximums when width to length ratio of mat is 0.8, thickness of replaced zone is 50mm and foundation coefficient is 2. Double layer reinforcements of reinforcing zone are expressed by Figure 3.

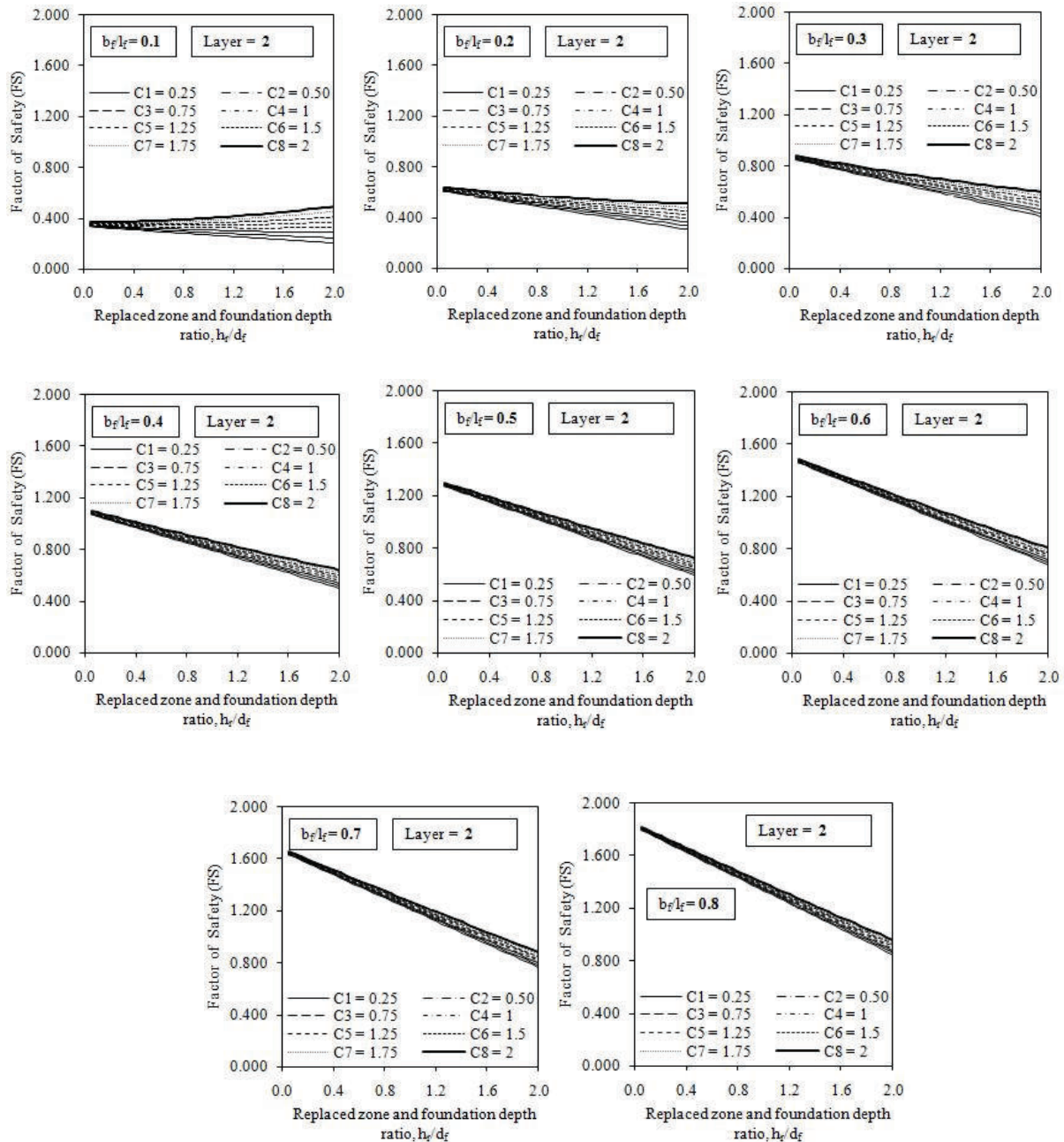


Figure 3: Variations of factor safety for double layer reinforcements in replaced zone

4.3 Triple Layer (Layer = 3) Reinforcement within Thickness of Reinforcing Zone

Ultimate bearing capacity of very soft clay is gradually increasing with the increment of thickness of reinforcing zone when width to length ratio of mat is 0.1 and foundation coefficient is 2. Factor of safety is gradually decreasing with the increment of thickness of replaced zone except width to length ratio of mat is 0.1. Larger ratio of width to length of mat foundation indicates instability of soil as well as mat when thickness of reinforcing zone is large. In this case, maximum factor of safety is observed to be 1.8 when thickness of replaced zone is 75mm and foundation coefficient is 2. Variations of factor safety with various variable parameters are expressed by Figure 4.

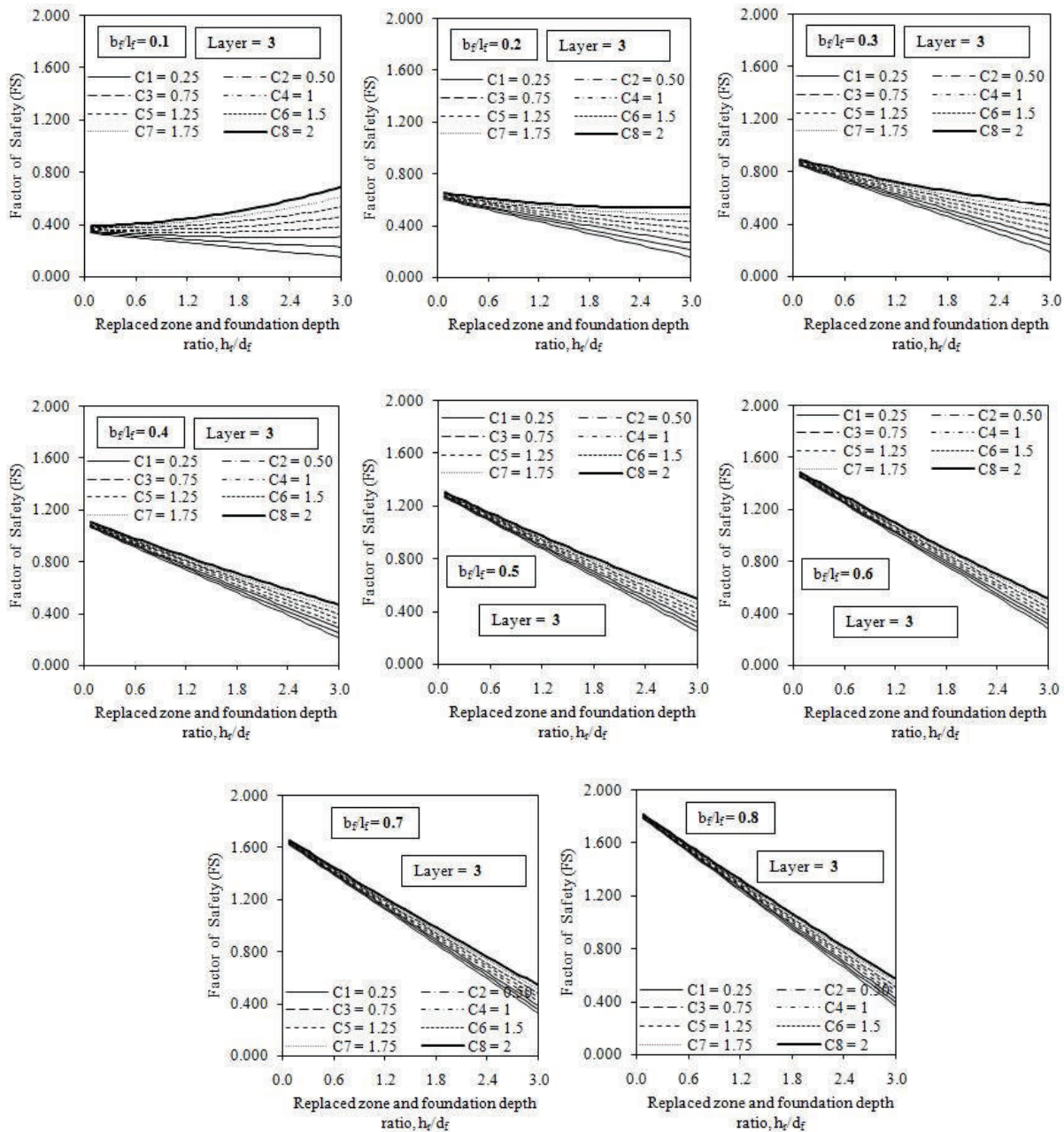


Figure 4: Variations of factor safety for triple layer reinforcements in replaced zone

4.4 Fourth Layer (Layer = 4) Reinforcement within Thickness of Reinforcing Zone

Variations of factor of safety are uniform with the variations of reinforcing zone thickness and width to length ratio of mat. Zero factor of safety is observed at width to length ratio of mat is 0.3. Zero factor of safety indicates failure of very soft soil. Higher thickness of reinforcing zone is represented instability of soft soil except width to length ratios of mat are 0.1 and 0.2. For higher width to length ratio of mat expresses stability and instability of very soft clay when thicknesses of reinforcing zone are 100mm and 3600mm. Variations of ultimate bearing capacity is represented by Figure 5.

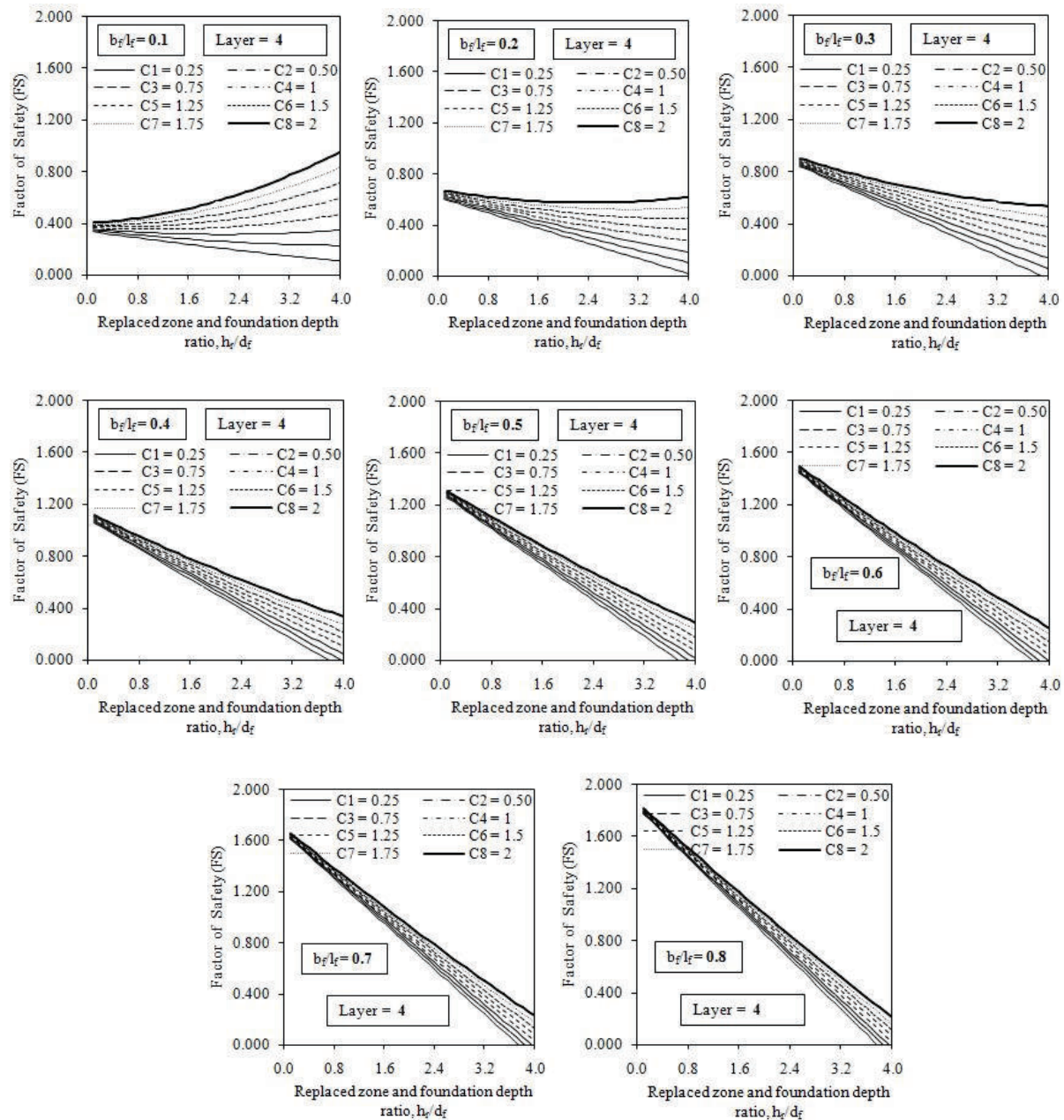


Figure 5: Variations of factor safety for fourth layer reinforcements in replaced zone

4.5 Fifth Layer (Layer = 5) Reinforcement within Thickness of Reinforcing Zone

Factor of safety is zero at all width to length ratio of mat except 0.1. Zero factor of safety expresses worst condition of very soft clay. In this situation, reinforcing layers are not improved the condition of soil. If thickness of replaced zone is minimum such as 125mm then factor of safety is maximum at width to length ratio of mat is 0.8. In this layer, maximum factor of safety is 1.7 at width to length ratio of mat is 0.8 and thickness of replaced zone is 125mm. For fifth layer reinforcing, results are expressed by Figure 6. Uniform variations of results are observed for various foundation coefficients at all width to length ratio of mat.

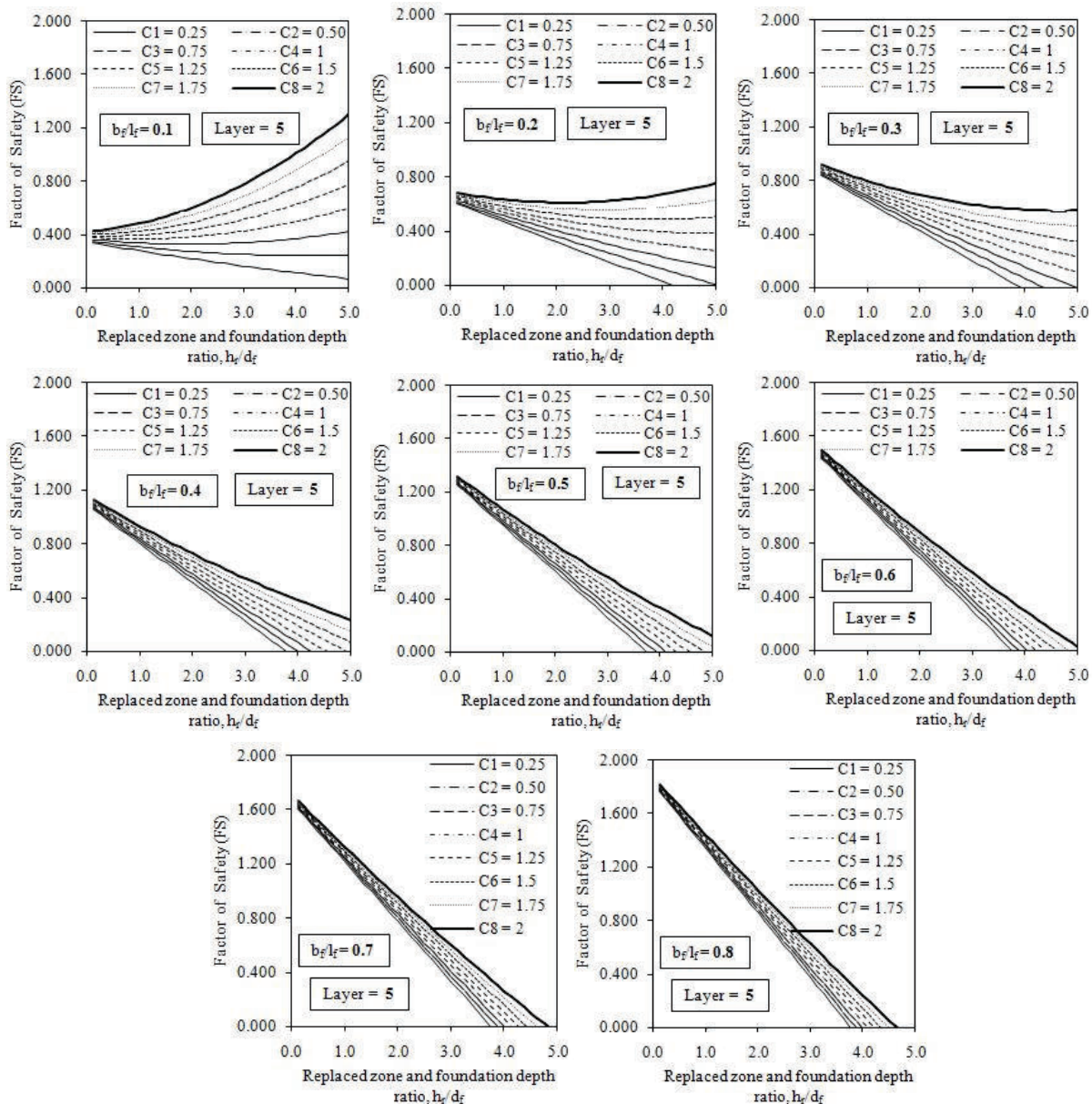


Figure 6: Variations of factor safety for fifth layer reinforcements in replaced zone

5. Conclusions

Number of reinforcing layers is influenced bearing capacity of very soft clay but higher number of reinforcing layers with higher thicknesses of layers indicates worst condition of soil. Zero factor of safety shows failure mode of very soft clay. Three reinforcing layers are suitable for mat foundation for any thickness of reinforcing zone at 0.1 widths to length ratio of mat. When width to length ratio of mat varies from 0.2 to 0.8 then suitable thickness of reinforcing layers are 25mm, 50mm and 75mm for single, double and triple layer earth reinforcing for getting higher factor of safety. Fourth and fifth layer earth reinforcing have been expressed zero factor of safety for all values of width to length ratio of mat except 0.1 widths to length ratio. Maximum factor of safety has been observed at 0.8 widths to length ratio of mat for three layers reinforcing and maximum foundation coefficient. Higher thickness of reinforcing zone is not suitable when width to length ratio of mat varies from 0.2 to 0.8. Based on the present study, suitable width to length ratio of mat is 0.1 because factor of safety is increasing gradually with the increment of thickness of reinforcing zone. However, no abnormalities have been found of analysis results and uniform variation of factor of safety has been observed with the variations of various parameters.

6. References

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