SEISMIC ANALYSIS OF STRIP FOOTING ON REINFORCED SOIL BED

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ABSTRACT

Binquet and Lee (1975b) gave a theoretical analysis to find out the pressure intensity of isolated strip footing footings resting on reinforced earth slab for a given settlement. To calculate these forces two dimensionless parameters are defined. These parameters are \( J_z \) and \( I_z \) and they depend on \( Z / B \) ratio. To calculate these parameters equations are being formulated. As these equations are complicated to be used in practise by designers, the design charts are being prepared to give these values readily to the designers without many efforts. These charts are being produced considering the static case i.e. for \( \alpha_h = 0 \). No seismic effect was taken in consideration while developing these charts. Through this paper, it will be an attempt to consider the seismic effect on the strip footing resting on reinforced earth bed by producing similar type of charts for different values of \( \alpha_h \) ranging upto 0.2. With the availability of such charts, designers can not only be able to find the bearing capacity ratio for strip resting on reinforced bed but they can easily be able to find out the bearing capacity ratio for strip footing on reinforced bed considering seismic effect. These charts will be very helpful as in present scenario seismicity is given prime importance in designing any structure.

Keywords: Soil, Bearing Capacity, Footings / Foundations, Earthquakes

INTRODUCTION

Reinforcing soil to improve its bearing capacity is a very old concept. From literature review it was supposed that this concept was as old as about 3000 years. It was used in Ziggurats, Babylonian temples more than 3000 years ago. But in the modern context this concept gained its importance in early 1970’s. Vidal was the first person in modern times to come up with the idea of reinforcing soil. He used this concept to improve the bearing capacity of footings.

The need to reinforce soil come with the problems faced by designers when they have to deal with places with low bearing capacity of soil and also where there is availability of clay deposit in the top layer. Due to these conditions structure has to undergo excessive settlement. This leads to damage in structure, reduction in durability of structure and also the performance level of structure decreases to the larger extent. The traditional options are available to overcome this problem. It includes placing of pile foundation through a weak soil deposit, excavating and replacing soil with suitable soil so to increase bearing capacity, pre consolidation of soil deposit, applying some techniques for densification of soil and finally increasing the dimensions of the footing to be placed.
But all these methods are expensive either due to process involved in it or due to need of skilled labor. Also the duration of project is increased vastly. The appropriate and alternative solution to this problem is to reinforce soil with some reinforcing element so that above mentioned problems can be overcome.

Reinforcing soil with geo-synthetic is one such alternative. This is a type of ground improvement technique only. In this geo-synthetic, which is a planar, polymeric (synthetic or natural) material used in contact with soil/rock and/or any other geotechnical material in civil engineering applications, is used to improve the bearing capacity of the soil. This is being placed horizontally in the soil. A reinforced earth bed is defined as a soil foundation system containing horizontally bedded thin flat metal strips or ties. These are being placed in free drainage granular soils as good bonding is being required between the ties and the soil. This bonding is in terms of frictional force that is being acting in between ties and soil. This placing of strips in soil provides tensile strength to the soil. It is well known fact that soil can withstand compressive forces but it is very poor in taking tensile forces. Thus, geo-synthetic takes care of tensile forces that are coming on soil. The beneficial effect of incorporating tensile reinforcing strips in granular fills has been studied by many investigators such as Lee et. al., Richardson and Lee, Schlosser and Long, Uesawa and Nasu, and Zen.

Since the time it was used by designers, its demand is increasing with passage of time. It is well accepted worldwide and it has special attraction among the designers of developing countries as it is very cost effective. According to Jewell, 30% saving can be done in the project when using reinforced soil bed as compared to the conventional solutions, both in developed and developing countries.

The purpose of geo-synthetic is to add tensile properties to the soil (which is a material with good compressive characteristics) to produce a new material that has both compressive and tensile strength. Ground improvement is a result of the transference of tensile stresses from the soil to the reinforcement due to friction developed between them. For a geo-synthetic acting as reinforcement, the most important properties are the tensile strength, the tensile modulus and the interface shear strength. Tensile strength is important because the reinforcing element needs to resist tensile stresses transferred from the soil. The tensile modulus needs also to be considered in design, as geo-synthetic needs to resist tensile stresses under deformations compatible with those allowable for the soil. The interface shear strength is of utmost important for the soil–reinforcement interaction, as it is responsible for transference of stresses from the soil to the geo-synthetic.

With the passage of time many investigators have tried to study this concept experimentally with different types of footings and also studied the behavior of footings resting on reinforced soil. Some of these investigators are Binquet and Lee, Akinmusuru and Akinbolade, Saran and Talwar, Fragszy and Lawton, Saran et al., Guido et al., Dembicki et al., Sridharan et al., Sreekanieth, Santani and Sonpal, Huang and Tatsuoka, Mandal et al., Shankria, Dixit, Khing et al., Rao et al., Yetimoglu et al., Sridharan, Kumar and Al-Smadi. The main findings of these investigators were that by preparing a suitable reinforced earth bed, the ultimate bearing capacity of the footing can be increased by 3 to 4 times and the settlement/tilt can also be brought down to 30% for the same footing resting on unreinforced soil bed.

Apart from the bearing capacity and settlement criteria, seismicity of the place plays an important role in the designing of the foundation. Due to this, seismic bearing capacity of soil for a place gained importance to be known. Through this paper, it is an attempt to give dimensionless charts produced through an analytical approach considering seismic horizontal coefficient. With the help of these charts designer can easily compute the seismic bearing capacity of soil knowing the seismic behaviour of soil at the site.

**ANALYSIS**

**Assumptions**
The analysis is based on the following assumptions:

(i) The central soil zone moves down with respect to the outer zones. The boundary between the downward moving and outward moving zones has been assumed as a locus of points of maximum shear stress at every depth z.

(ii) At the plane separating the downward and lateral movements, the ties are assumed to undergo two right angled bends around two frictionless rollers and $T_D$ is a vertically acting tensile force (Fig. 1).

(iii) The tie-soil friction coefficient has been assumed to vary with depth as per following equation:

\[ f_x = m f \]  \quad \ldots (1)

where, $m$ = mobilization factor given by

\[ m = \left[ 1 - \frac{z}{B} \right]^{0.7 + 0.3} \] for $z/B < 1.0 \quad \ldots (2a) \]

\[ m = \left[ 2 - \frac{z}{B} \right]^{0.3} \] for $z/B > 1.0 \quad \ldots (2b) \]

(iv) For $N_k$ number of reinforcing layers provided in the foundation soil, developed tie force has been assumed to be in the proportion of $m_1: m_2: \ldots: m_N$ such that, $m_1 + m_2 + \ldots + m_N = 1$ and failure has been assumed for various combinations of tie-pull-out and tie breakage at different levels.

(v) The forces evaluated in the analysis are for the same size of footing and same settlement for a footing on reinforced and unreinforced soil.

(vi) Elastic theory is applied to estimate the stress distribution inside the soil mass.

(vii) Principle of superposition is applied for calculating the forces on the reinforced as well as the unreinforced soil element.

**Developed Tie Force ($T_D$)**

To evaluate the forces developed in the ties due to applied load on the footing, it was assumed that the plane separating the downward and lateral moving zones is the locus of points of maximum shear stress $\tau_{xz}$ at every depth $z$. This $\tau_{xz}$ max is the net result of $\tau_{xz, max_{vert}}$ due to vertical loading and $\tau_{xz, max_{hor}}$ due to horizontal loading. In Fig. 1, ac and a’c’ are assumed as separating planes. Fig. 2 shows the separating planes for $\alpha_h = 0.0$ and $\alpha_h = 0.20$. All other separating planes for different values of $\alpha_h$ i.e., 0.05, 0.1 and 0.15 lie between these two limits.
Considering elements ABCD and ABC’D’ at depth z (Fig. 2) which represent the volume of soil lying between two adjacent layers of reinforcement. The forces acting on elements are shown in the figure for unreinforced and reinforced foundation soil. $F_{	ext{VAD}}(q, \alpha_h, q, (1 \pm \alpha_v), z)$, $F^\prime_{\text{VAD}}(q, \alpha_h, q, (1 \pm \alpha_v), z)$, $F_{\text{VBC}}(q, \alpha_h, q, (1 \pm \alpha_v), z)$ and $F^\prime_{\text{VBC}}(q, \alpha_h, q, (1 \pm \alpha_v), z)$ are the normal forces and $S(q, \alpha_h, q, (1 \pm \alpha_v), z)$ and $S^\prime(q, \alpha_h, q, (1 \pm \alpha_v), z)$ are the vertical shear forces acting on the boundaries of the element of unreinforced soil. These forces are due to normal and shear stresses at depth z, due to vertical and horizontal loading caused by the applied bearing pressure $q_o$ on the footing. A similar set of forces also exist for the reinforced soil foundation which is caused by applied
bearing pressure $q$. In addition, there will be a force developed in the tie, $T_D$. Considering vertical equilibrium as bearing capacity needs to satisfy vertical equilibrium only.

$$\sum V = 0$$

Equilibrium of the element, D'C'D, in the unreinforced soil may be expressed as

$$F_{VAD}(q_o\alpha_h, q_o(1 + \alpha_v), z) + F'_{VAD}(q_o\alpha_h, q_o(1 + \alpha_v), z) - F_{VBC}(q_o\alpha_h, q_o(1 + \alpha_v), z) - F_{VBC}(q_o\alpha_h, q_o(1 + \alpha_v), z) - S(q_o\alpha_h, q_o(1 + \alpha_v), z) + \tau_{xz}(q_o\alpha_h, q_o(1 + \alpha_v), z) + dW.(1 + \alpha_v) = 0 \quad \ldots (3)$$

For single layer of reinforcement in the foundation soil at depth $z$, the equilibrium of the element D'C'D may be expressed as

$$F_{VAD}(q\alpha_h, q(1 + \alpha_v), z) + F'_{VAD}(q\alpha_h, q(1 + \alpha_v), z) - F_{VBC}(q\alpha_h, q(1 + \alpha_v), z) - F_{VBC}(q\alpha_h, q(1 + \alpha_v), z) - S(q\alpha_h, q(1 + \alpha_v), z) - S'(q\alpha_h, q(1 + \alpha_v), z) - T_D + dW.(1 + \alpha_v) = 0 \quad \ldots (4)$$

It has been assumed in the analysis that forces are evaluated for the same size of footing, $B$, and the same settlement, $\Delta$, for the footing on reinforced and unreinforced soil, so $F_{VBC}$ and $F'_{VBC}$ shall be same for reinforced and unreinforced soil. The additional load $(q - q_o)$ shall be taken by the reinforcement above the level C'C. Therefore,

$$F_{VBC}(q_o\alpha_h, q_o(1 + \alpha_v), z) - F'_{VBC}(q_o\alpha_h, q_o(1 + \alpha_v), z) = F_{VBC}(q\alpha_h, q(1 + \alpha_v), z) - F'_{VBC}(q\alpha_h, q(1 + \alpha_v), z) \quad \ldots (5)$$

Combining equations 3, 4 and 5, we get

$$F_{VAD}(q\alpha_h, q(1 + \alpha_v), z) + F'_{VAD}(q\alpha_h, q(1 + \alpha_v), z) - F_{VAD}(q_o\alpha_h, q_o(1 + \alpha_v), z) - F'_{VAD}(q_o\alpha_h, q_o(1 + \alpha_v), z) - S(q\alpha_h, q(1 + \alpha_v), z) - S'(q_o\alpha_h, q_o(1 + \alpha_v), z) - S'(q_o\alpha_h, q_o(1 + \alpha_v), z) - 2T_D + \tau_{xz}(q_o\alpha_h, q_o(1 + \alpha_v), z) + dW.(1 + \alpha_v) = 0 \quad \ldots (6)$$

where, for reinforced soil

$$F_{VAD}(q\alpha_h, q(1 + \alpha_v), z) = \int_{X_o}^{X'} \sigma_z(q\alpha_h, q(1 + \alpha_v), x, z)dx \quad \ldots (7)$$

$$F'_{VAD}(q\alpha_h, q(1 + \alpha_v), z) = \int_{X_o}^{X'} \sigma'_z(q\alpha_h, q(1 + \alpha_v), x, z)dx \quad \ldots (8)$$

$$S(q\alpha_h, q(1 + \alpha_v), z) = \tau_{xz}(q\alpha_h, q(1 + \alpha_v), X_o, z) \Delta H \quad \ldots (9)$$

$$S'(q\alpha_h, q(1 + \alpha_v), z) = \tau'_{xz}(q\alpha_h, q(1 + \alpha_v), X_o', z) \Delta H \quad \ldots (10)$$

where $X_o$ and $X'_o$ are the values of X at which $\tau_{xz}$ is maximum.
Similarly, for unreinforced soil

\[ F_{VAD}(q_o \alpha_h, q_o (1 \pm \alpha_i), z) = \int_0^{X_o} \sigma_z (q_o \alpha_h, q_o (1 \pm \alpha_i), x, z) dx \]  \hspace{1cm} \ldots (11) \]

\[ F'_{VAD}(q_o \alpha_h, q_o (1 \pm \alpha_i), z) = \int_{X_o}^{0} \sigma'_z (q_o \alpha_h, q_o (1 \pm \alpha_i), x, z) dx \]  \hspace{1cm} \ldots (12) \]

\[ S(q_o \alpha_h, q_o (1 \pm \alpha_i), z) = \tau_{xz} (q_o \alpha_h, q_o (1 \pm \alpha_i), X_o, z) \Delta H \]  \hspace{1cm} \ldots (13) \]

\[ S'(q_o \alpha_h, q_o (1 \pm \alpha_i), z) = \tau'_{xz} (q_o \alpha_h, q_o (1 \pm \alpha_i), X'_o, z) \Delta H \]  \hspace{1cm} \ldots (14) \]

Equations 7 to 14 may also be written in the dimensionless form as below:

\[ F_{VAD}(q \alpha_h, q(1 \pm \alpha_i), z) = J_z qB \]  \hspace{1cm} \ldots (15) \]

\[ F'_{VAD}(q \alpha_h, q(1 \pm \alpha_i), z) = J'_z qB \]  \hspace{1cm} \ldots (17) \]

\[ S(q \alpha_h, q(1 \pm \alpha_i), z) = I_z q \Delta H \]  \hspace{1cm} \ldots (19) \]

\[ I_z = \frac{\tau_{xz max}(q \alpha_h, q(1 \pm \alpha_i), x, z)}{q} \]  \hspace{1cm} \ldots (20) \]

\[ S'(q \alpha_h, q(1 \pm \alpha_i), z) = I'_z q \Delta H \]  \hspace{1cm} \ldots (21) \]

\[ I'_z = \frac{\tau'_{xz max}(q \alpha_h, q(1 \pm \alpha_i), x', z)}{q} \]  \hspace{1cm} \ldots (22) \]
Similarly,

\[ F_{VAD}(q_o, \alpha_h, q_o(1\pm \alpha_v), z) = J \cdot q_o B \]  \hspace{1cm} \ldots (23)

where \( J \cdot = \int_0^x \frac{\sigma_z(q_o, \alpha_h, q_o(1\pm \alpha_v), x, z)dx}{q_o B} \) \hspace{1cm} \ldots (24)

\[ F'_{VAD}(q_o, \alpha_h, q_o(1\pm \alpha_v), z) = J' \cdot q_o B \]  \hspace{1cm} \ldots (25)

in which \( J' \cdot = \frac{\int_0^x \sigma_z(q_o, \alpha_h, q_o(1\pm \alpha_v), x, z)dx}{q_o B} \) \hspace{1cm} \ldots (26)

\[ S(q_o, \alpha_h, q_o(1\pm \alpha_v), z) = I \cdot q_o \Delta H \]  \hspace{1cm} \ldots (27)

where, \( I \cdot = \frac{\tau_{\text{max}}(q_o, \alpha_h, q_o(1\pm \alpha_v), x, z)}{q_o} \) \hspace{1cm} \ldots (28)

\[ S'(q_o, \alpha_h, q_o(1\pm \alpha_v), z) = I' \cdot q_o \Delta H \]  \hspace{1cm} \ldots (29)

where, \( I' \cdot = \frac{\tau_{\text{max}}(q_o, \alpha_h, q_o(1\pm \alpha_v), x, z)}{q_o} \) \hspace{1cm} \ldots (30)

The values of \( X_o/B \) corresponding to \( z/B \) values can be taken from the non-dimensional chart as shown in Fig. 3.

![Non dimensional chart](image)

Fig. 3. Non dimensional length for pressure ratio calculation of isolated strip footing on reinforced soil for \( \alpha_h = 0.0 \) and \( \alpha_h = 0.20 \).
In above equations $J_z$ and $I_z$ are dimensionless quantities whose values can be calculated at different depths under the footing using Boussinesq equations for normal and shear stresses. Substituting equation 16, 18, 20, 22, 24, 26, 28 and 30 in equation 7.

$$2T_p = [(J_z + J_z)B - (I_z + I_z)\Delta H](q - q_o)$$ … (32)

which may be expressed in terms of pressure ratio ($p_r$) as

$$2T_p = [(J_z + J_z)B - (I_z + I_z)\Delta H]q_o(p_r - 1)$$ … (33)

The seismic analysis is done using two factors $I_z$ and $J_z$. The figure shown below gives the value of these parameters for $\alpha_h = 0$ and $\alpha_h = 0.20$.

**RESULTS and CONCLUSIONS**

1. From Fig. 2 it can be easily seen that with the increase in seismicity i.e., increase in horizontal seismic coefficient there is shifting in the plane of maximum shear stress. It is due to the fact that the
footing is subjected to a shear loads also in addition to the vertical load. Therefore, the shear stresses in the soil mass get changed.

2. From Fig. 3 it is evident that the values of $I_z$ and $J_z$ are changing with the change in horizontal seismic coefficient. The values of these parameters when considering the seismic effect are decreasing when considering the right hand side of the central line as compared to the value obtained under static condition. On the other hand, the values of these parameters when considering the seismic effect are increasing when considering the left hand side of the central line as compared to the value obtained under static condition. The overall effect the values of these parameters are to decrease the bearing capacity of the footing with the increase in horizontal seismic coefficient ($\alpha_h$).

REFERENCES