Technical Note

Modified Binquet and Lee's Design Curves for Bearing Capacity of Reinforced Foundation Bed

B. Dey*

Introduction

For improvement of bearing capacity of soil, inclusion of reinforcing materials in the soil mass is an established practice now. Various investigators (Binquet and Lee, 1975a, 1975b; Mandal and Manjunath, 1990; Singh, 1983; Saran, 1998) have amply revealed the beneficial effect of oriented tensile reinforcement in soil for improvement of its bearing capacity.

Binquet and Lee (1975a, b) were the first to report a systematic study on bearing capacity of reinforced foundation bed. They carried out a good number of model tests on strip footing resting on horizontally reinforced sand bed (1975a) and suggested a design approach for strip footing on reinforced sandy bed (1975b). The design approach suggested by them has been briefly discussed in subsequent paragraphs.

Design Approach as Proposed by Binquet and Lee

Binquet and Lee (1975b) evaluated stresses in the reinforced foundation bed using Boussinesq's equations and suggested expressions for the tension developed in the reinforcement (T_D) and the pullout frictional resistance of the reinforcement (T_f) in terms of dimensionless length ratios and dimensionless forces (Fig.1). From the properties and dimension of reinforcement, Binquet and Lee (1975b) suggested the expression for tie breaking force (R_Y). The expressions for T_D, T_f and R_Y are given below. For details of the expressions, the paper by Binquet and Lee (1975b) may please be referred.

* Scientist, Central Building Research Institute, Roorkee – 247667, Uttaranchal, India.

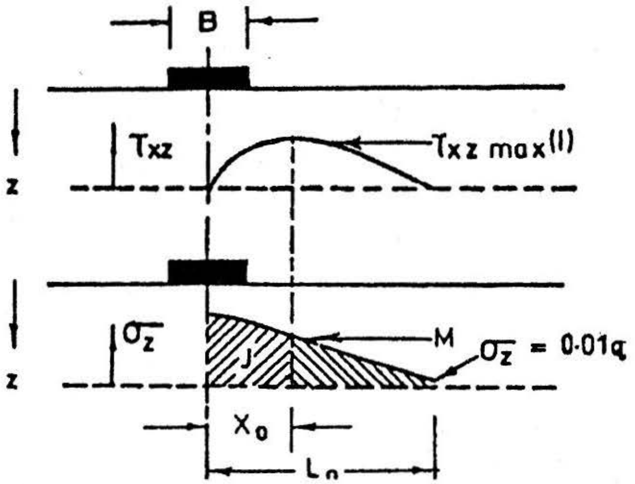

FIGURE 1 : Dimensionless Length Ratios and Dimensionless Forces

$$T_D(Z,N) = \frac{1}{N}\left[J\left(\frac{Z}{B}\right)B - I\left(\frac{Z}{B}\right)\Delta H\right]q_0\left(\frac{q}{q_0}-1\right) \tag{1}$$

$$T_f(Z) = 2fLDR\frac{1}{N}\left[M\left(\frac{Z}{B}\right)Bq_0\left(\frac{q}{q_0}\right)+\gamma(L_0-X_0)(Z+D)\right] \tag{2}$$

$$R_y = \frac{WN_R tf_y}{FS_y} \tag{3}$$

Assuming the tie pullout failure condition as the criteria, Binquet and Lee worked out the required length of the reinforcement for different layers by comparing T_D and T_f. From the expression for tie breaking force (R_Y), the required thickness of reinforcement was calculated by them.

Comments on the Approach and Objective of Present Work

The analytical results obtained by Binquet and Lee (1975b) indicated that maximum tension developed at the bottom most layer of reinforcement (Table 1) while the model test results of Binquet and Lee (1975a) showed the reverse trend as the upper layer of reinforcement broke during model tests (Fig.2).

TABLE 1 : Summary of Design Example Calculation {after Binquet and Lee (1975b)}

Layer Number	1	2	3	4	5
Depth to layer, Z, in 'm'	0.305	0.61	0.915	1.22	1.525
Z/B	0.33	0.67	1.0	1.33	1.67
$I(Z/B)$; Fig.5a	0.29	0.22	0.18	0.14	0.12
$J(Z/B)$; Fig.5b	0.35	0.35	0.34	0.34	0.34
$T_D(Z, N)$ in kN/m	98.84	107.94	109.24	114.45	117.05
L_o/B; Fig.4	1.25	2.0	2.7	3.25	3.6
L_o in 'm'	1.14	1.83	2.47	2.97	3.29
X_o/B; Fig.4	0.5	0.6	0.8	1.0	1.2
X_o in 'm'	0.46	0.55	0.73	0.915	1.098
$M(Z/B)$; Fig.5b	0.12	0.14	0.14	0.15	0.15
$T_f(Z)$ in kN/m	76.66	93.34	98.22	109.27	112.85

The present study was undertaken with a view to modify the curves developed by Binquet and Lee (1975b) for design of strip footing on reinforced soil so that the same can reflect the trend of findings of model study, carried out by them (1975a).

Analysis

The analytical approach suggested by Binquet and Lee (1975b) has

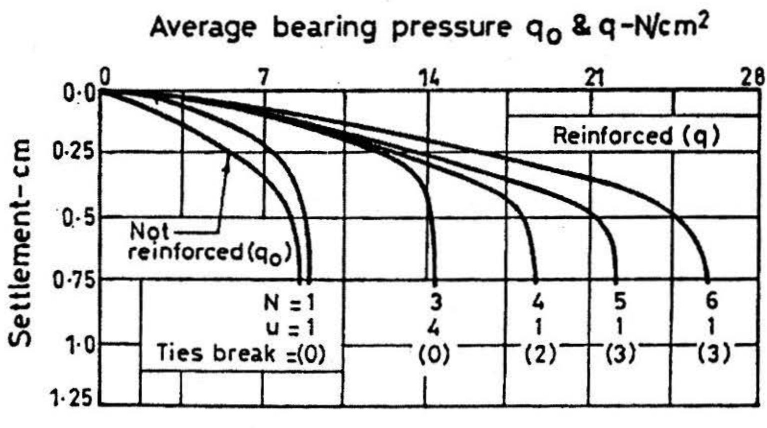

FIGURE 2 : Load Settlement Curves for Strip Footing on Reinforced Foundation Bed

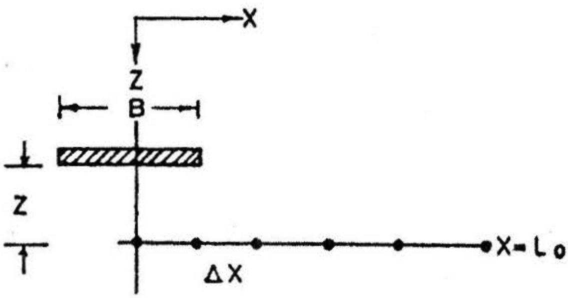

FIGURE 3 : Points Considered for Evaluation of Stresses at a Particular Depth

been followed in the present study. Using Boussinesq's equations vertical and shear stresses at predetermined values of depth (Z/B) have been calculated. At a particular depth the stresses have been determined at various points along X-axis till the value of x equals to L_o (Fig.3).

For different values of Δx (0.5B to 0.01B) corresponding values of dimensionless length parameters X_0/B and L_0/B have been worked out. The analysis of results indicates that the values of the length parameters practically do not change with variation of Δx below 0.1B. For different values of Δx (0.1B to 0.01B) the corresponding values of the dimensionless forces – $I(Z/B)$, $J(Z/B)$ and $M(Z/B)$ – have also been evaluated. The results show the similar trend as obtained in the case of X_0/B and L_0/B. So without further trial with lesser value of Δx, the value of Δx has been assumed as 0.1B.

Following the procedure as proposed by Binquet and Lee (1975b), the design of footing on reinforced sand bed has been done. The values of all other parameters were the same as used by Binquet and Lee except the values of dimensionless length parameters and dimensionless forces which were obtained from Figs.4 and 5(a, b) respectively. The values of rest of the parameters as used by Binquet and Lee in the design of footing are given below:

$$
\begin{aligned}
f &= 0.21; \\
LDR &= 0.6; \\
\gamma &= 15.72 \ kN/m^3; \\
q_o &= 0.52 \times 10^3 \ kN/m^2; \\
q/q_o &= 5.1; \ B=0.915; \\
D &= 0.915; \\
\Delta x &= 0.305; \\
N &= 5.
\end{aligned}
$$

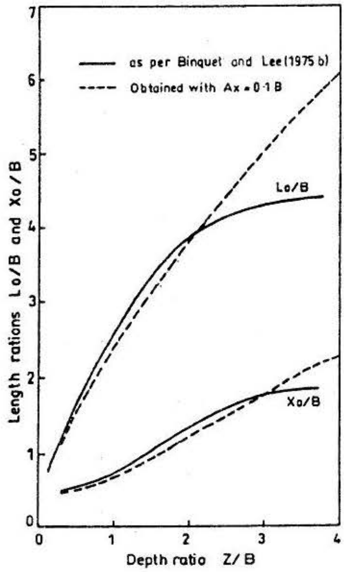

FIGURE 4 : Variation of Dimensionless Length Ratios - X_o/B and L_o/B

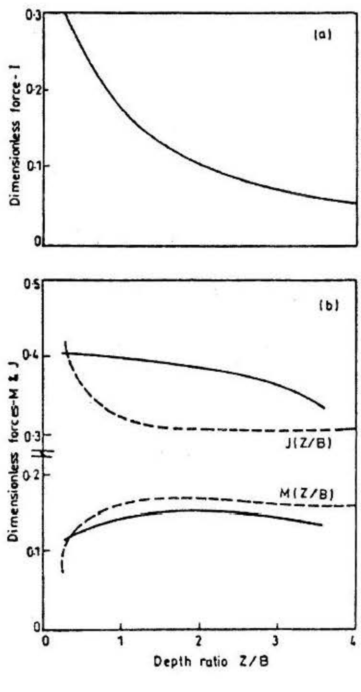

FIGURE 5 : Variation of Dimensionless Forces - $I(Z/B)$, $J(Z/B)$ and $M(Z/B)$

The results, obtained using the modified curves, have been presented in Table 2.

Discussion

The study indicates that the dimensionless length parameters and dimensionless forces attain practically constant value at $\Delta x = 0.1B$.

From Fig.4, it is clear that the curve for X_o/B drawn with $\Delta x = 0.1B$ shows less value of X_o/B than that reported by Binquet and Lee (1975b) up to $Z/B = 3$ beyond which the curve indicates higher values of X_o/B in comparison to the reported values. In case of curve for L_o/B drawn with $\Delta x = 0.1B$, the values of L_o/B is less than the reported value up to $Z/B = 2$ after this the curve for L_o/B shows higher value than that reported by Binquet and Lee.

From Fig.5a, it is clear that the curve for $I(Z/B)$ having $\Delta x = 0.1B$ and that reported by Binquet and Lee (1975b) practically overlap each other. Figure 5(b) shows that the curve for $J(Z/B)$ drawn with $\Delta x = 0.1B$ differs considerably both in nature and magnitude from that reported by Binquet and Lee (1975b) while the curve for $M(Z/B)$ that drawn with $\Delta x = 0.1B$ and that reported by Binquet and Lee differs in magnitude only.

From Fig.2, it is clear that maximum tension develops in the upper layer of reinforcement as during model tests only top layers of reinforcement

TABLE 2 : Summary of Design of Footing on Reinforced Soil (Using Modified Curves)

Layer number	1	2	3	4	5
Depth to layer, Z, in 'm'	0.305	0.61	0.915	1.22	1.525
Z/B	0.33	0.67	1.0	1.33	1.67
$I(Z/B)$; Fig.5a	0.29	0.22	0.18	0.14	0.12
$J(Z/B)$; Fig.5b	0.39	0.34	0.32	0.31	0.31
$T_D(Z, N)$ in kN/m	114.45	104.04	101.44	102.74	105.34
L_o/B; Fig.4	1.25	1.9	2.5	3.0	3.4
L_o in 'm'	1.14	1.74	2.29	2.75	3.11
X_o/B; Fig.4	0.5	0.55	0.7	0.85	1.0
X_o in 'm'	0.46	0.50	0.64	0.78	0.915
$M(Z/B)$; Fig.5b	0.12	0.15	0.16	0.17	0.17
$T_f(Z)$ in kN/m	76.67	99.21	109.80	120.62	125.17

break. From Table 2, it is also apparent that the top layer of reinforcement has the maximum predicted value of tension.

Further it has been observed that tie tension, T_D, decreases initially with depth but shows an increasing trend at greater depth. This may probably be due to the simplified assumption of Binquet and Lee in the analysis that the tension developed in each layer of reinforcement varies inversely with the number of layers of reinforcement which may not be justified in actual case.

Conclusion

From the above study it may be inferred that

i) When drawn with $\Delta x = 0.1B$, the curve for dimensionless force $J(Z/B)$ changes considerably as compared to the curve of the original paper and reflects the trend of development of tie tension in different layers of reinforcement as obtained in the model study.

ii) The curves for other parameters when drawn with $\Delta x = 0.1B$ shows either no change or minor variations from the curves reported in the paper and do not indicate any substantial change in the trend of model test results.

iii) Further studies are needed for modification of the assumption regarding development of tension in various layers of reinforcement.

Acknowledgement

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References

BINQUET, J. and LEE, K.L. (1975a) : "Bearing Capacity Tests on Reinforced Earth Slabes", *Jl. Geotech. Engg. Divn.*, ASCE, Vol.101, GT-12, pp.1241-1255.

BINQUET, J. and LEE, K.L. (1975b) : "Bearing Capacity Analysis on Reinforced Earth Slabes", *Jl. Geotech. Engg. Divn.*, ASCE, Vol.101, GT-12, pp.1257-1276.

MANDAL, J.N. and MANJUNATH, V.R. (1990) : "Bearing Capacity of Single Layer of Geosynthetic Sand Subgrade", *Proc. of Indian Geotechnical Conference*, Bombay, pp.7-10.

SARAN, S. (1998) : "Behaviour of Footings on Reinforced Sand", *Proc. of the National Workshop on Reinforcement of Ground and Slopes*, IIT, Kanpur, August 1999, pp.74-85.

SINGH, H.S. (1983) : "Bearing Capacity of Reinforced Soil Beds", *Ph.D Thesis*, Indian Institute of Science, Bangalore.

Notations

B	=	width of footing
D	=	height of surcharge from base of the footing
f	=	soil reinforcement friction coefficient
F_Y	=	yield strength of tie material
F_{SY}	=	factor of on yield strength
I(Z/B), J(Z/B) and M(Z/B)	=	dimensionless forces
L_o	=	at a particular depth, distance of the point along X-axis where $\sigma_z = 0.01q$
LDR	=	area of reinforcement per unit length of footing
N	=	nos. of layers of reinforcement
N_R	=	nos. of ties per unit length of footing
q_o	=	average contact pressure on the unreinforced soil for a particular settlement
q	=	average contact pressure on the reinforced soil for the same settlement as considered for the unreinforced soil
R_Y	=	allowable tensile resistance of the ties
T_D	=	tension developed in the reinforcement
T_f	=	soil tie pullout frictional resistance
W	=	width of a single tie
X_o	=	distance of the point along X-axis where $t_{xz\text{-}max}$ occurs at a particular depth
Δx	=	at a particular depth, distance between two consecutive points on X-axis at which stresses have been considered
Z	=	depth from footing base
σ_z	=	vertical stress at a point
τ_{xz}	=	shear stress at a point