

Performance of T-shaped Footing on Layered Sand

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ABSTRACT: Bearing capacity and settlement are two main criteria for designing the foundation of a structure. Traditional bearing capacity theories for determining ultimate bearing capacity of foundation assume that soil below the footing as homogeneous. However, this is not true in all cases. But, layered soils are mostly encountered in practice. The footings of retaining wall, portal framed buildings, abutments of bridges, offshore structures are not only subjected to vertical or inclined load but also to eccentric loading. Due to load eccentricity the overall stability of the foundation decreases with increase in settlement and tilting of the foundation which reduces bearing capacity. To overcome this reduction in bearing capacity of foundation, T-shaped footing can be used as an alternative. The vertical downward projection of T-shaped footing provides stability against lateral load acting on the structure. In this experimental investigation, an attempt has been made to study the effect of layered type of sand on bearing capacity of T-shaped foundation. Model plate load test were performed on T-shaped footing over layered sand. The depth of insertion cut-off of T-shaped footing was varies in the ratio of $D/B = 0.25, 0.5, 0.75, 1$. Depth of top layer of sand was varied in the ratio of $d_1/D = 0.5, 1, 1.5, 2$. The results were plotted in terms of load-settlement curves. From results it was concluded that UBC of T-shaped footing increases with increase in the depth of insertion cut-off and it reaches its optimum value at insertion depth equal to 0.5 times the width of footing. In case of T-shaped footing on layered sand, ultimate bearing capacity and BCR of T-shaped footing increases with increase in depth of top layer up to the depth of top layer equal 1.5 times depth of insertion cut-off.

KEYWORDS: Strip footing, T-shaped footing, Layered soil, Medium sand, Fine gravel, eccentric loading.

I. INTRODUCTION

Traditional bearing capacity theories for determining the ultimate bearing capacity of shallow foundations assume that the bearing stratum is homogenous and infinite. The best estimation of bearing capacity and settlement on layered soil are possible only, if the pressure-settlement characteristics of the foundation-soil are known for the size of the footing. The footings of retaining wall, portal framed buildings, abutments of bridges, offshore structures are not only subjected to vertical or inclined load but also to moments. Footings are also subjected to sliding and overturning which also reduces the bearing capacity and sometimes results into failure of structure. Thus, due to improper designing aspects or some natural calamities structures built on foundation with multilayer soil and subjected to various loads (horizontal load, vertical loads, moments and eccentric loads) may be collapse. In such cases, T-shaped footing can be used as a foundation which improves bearing capacity of footing against the action of inclined and eccentric forces. The vertical insertion of the rigid T-shaped footing into bearing soil provides considerable resistance against both sliding & overturning. Due to this there is a reduction in settlement of footing & increase in bearing capacity of soil.

II. LITERATURE REVIEW

Verma *et al.* (2013)¹ conducted an experimental study to determine bearing capacity of granular layered soils by plate load test. From their experimental work, it was concluded that as the depth of top layer of sand (fine gravel) increased, bearing capacity increased and settlement decreased.

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Kumawat and Dr. Mahiyar (2015)² conducted an experimental study on T-shaped footing under eccentric vertical loading. In their study, different sizes of square footing were used and effect of varying D/B ratio, e/B ratio was studied. In case of Tee shaped footing, load intensity within permissible tilt is effective up to an eccentricity width ratio of 0.15 only.

Kaya and Ornek (2013)³ conducted an experimental and numerical studies of T-shaped footings. In their study, loose and dense sand were subjected to eccentric loading by varying H/B ratio. It was observed that, the ultimate values of bearing capacity were increased when the sand gets denser.

Thakare and Kapse (2015)⁴ conducted a numerical analysis on T-shaped footing on sand using PLAXIS 2D. Effect of depth and inclination of insertion cut-off for different load inclination angles and eccentricities ratio on performance of T-shaped footing the selected parameters were studied. It was concluded that bearing capacity increases as the depth of insertion cut off reached its optimum value at insertion depth equal to 0.6 times the width of footing. Bearing capacity ratio increases as with increase in eccentricity ratio as well as inclination of load.

From literature review, it is clear that work on performance of T-shaped footing on layered sand is lagging. Thus, present experimental work was carried out to enhance the knowledge about behaviour of T-shaped footing on layered sand with respect to following parameters.

- Effect of depth of insertion cut-off of T-shaped footing
- Effect of depth of layers of sandy soil with different densities
- Effect of eccentricity

III. SYSTEM DEVELOPMENT

In this experimental study, performance of T-shaped footing on single and layered sand bed has been studied. For this purpose, experimental investigations were carried out on model T-shaped footings in a test setup.

A. TEST MATERIALS AND THEIR PROPERTIES

• Test Sand

For the model tests, cohesionless, dry, clean and hand washed Kanhan and Wardha sands were used as the foundation material. These sands are available in Nagpur (Maharashtra). The particle size of sand decided for the test was passing through 2 mm IS sieve for Kanhan Sand and passing through 10 mm and retained on 4.75 mm IS sieve for Wardha Sand. The properties of sand determined are listed in Table 1. In this experimental investigation, Kanhan sand and Wardha sand are termed as medium sand and fine gravel respectively.

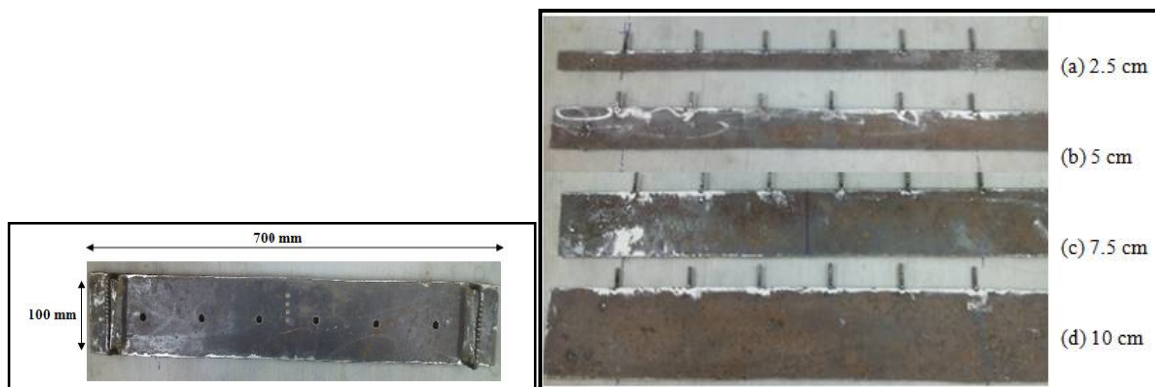
Table 1 Properties of Medium Sand (Kanhan Sand) and Fine Gravel (Wardha Sand) Used in Experimental Work

| Sr. No | Properties | Medium Sand | Fine Gravel |
|--------|---|-------------|-------------|
| 1 | Specific Gravity | 2.65 | 2.67 |
| 2 | Maximum Unit Weight (γ_{max}) (kN/m ³) | 17.70 | 18.06 |
| 3 | Minimum Unit Weight (γ_{min}) (kN/m ³) | 17.27 | 16.96 |
| 4 | Angle of Internal Friction (ϕ) | 28° | 35° |
| 5 | Cohesion (kN/m ²) | 0 | 0 |
| 6 | IS Classification | SP | SW |

• **Model T-Shaped Footing**

The model T-shaped footing was fabricated by using mild steel plate having dimensions of top rectangular plate as 700 mm × 100 mm and 20 mm thick. This rectangular plate has a little groove at the centre to facilitate the application of load. It has small holes at specific interval, so that bottom plate would be attached to the strip footing easily. The plan of model strip footing is as shown in Figure 2.

The insertion cut-off with different depth has been used in this study. The depth of insertion was varied in the ratio of $D/B = 0.25 B, 0.5 B, 0.75 B, B$, where, B is the width of strip footing. The Figure 3 shows various sizes of insertion cut off used in this study. These insertion cut-offs (*i.e.* bottom plate) has screws at specific distance which will be easily inserted in the holes provided to the top rectangular plate (*i.e.* strip footing), for the purpose of fixing these plates to the top plate.



(a) Strip footing

(b) Insertion Cut-off

Fig. 3 Insertion Cut-off of Different Depths Used in Experimental Investigation

B. EXPERIMENTAL PROGRAM

In present experimental investigation, plate load tests have been carried out in accordance with IS 1888- 1982. The test tank was made of 4 mm thick M.S. sheets having internal dimensions 800 mm × 600 mm in plan and 750 mm high. Sufficient horizontal and vertical bracings at sufficient intervals were provided to prevent it from bulging. To prepare sand bed using medium sand, rainfall technique was used. 60 cm height of fall was used to achieve 60 % of relative density of medium sand. The density of fine gravel was maintained by compacting known weight of sand to the required depth to achieve 60 % of relative density. After completely filling the tank with the sand to the required level, the bed was levelled. The load was applied on the footing with the help of screw jack.



Fig 4.Complete Experimental Setup

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In case of T-shaped footing on single layer sand bed, the sand bed was first prepared up to the level corresponding to the bottom level of insertion cut-off (*i.e.* bottom plate). The insertion cut-off was placed vertically on sand bed such that centre of bottom plate would match with centre of screw jack. Preparation of sand bed was then continued till the full depth of sand bed. The top surface of sand bed was levelled and then the top plate was kept over the sand bed. The screws attached to the insertion cut-off (bottom plate) were fixed to the top plate by bolts, so that insertion cut-off and top plate would act as a monolithic structure. In case of layered sand bed, depth of upper layer of sand, medium sand (*i.e.* Kanhan sand) was varied as 0.5D, D, 1.5D, 2D (D is the depth of insertion cut-off *i.e.* bottom plate). In case of layered sand bed, same procedure was adopted; only the location of insertion cut-off on sand bed was varied with respect to d_1/D ratio. After the preparation of sand bed along with T-shaped footing, proving ring was fixed to the screw jack.

The complete experimental set up is shown in Fig.4. The load was applied on the T-shaped footing in increments of one-fifth of estimated ultimate bearing capacity and the settlements were recorded with dial gauges. Each load increment was kept constant till the rate of settlement become less than 0.02 mm/min. The next increment of load was then applied and the settlement was measured. This procedure was continued till the failure of foundation or up to settlement reached at 10 % of width of T-shaped footing. The details of parametric study are given in Table 2.

Table 2: Details of Parametric Study Layered Sand Bed

| Sr. No. | Parameter | Value |
|---------|--|--|
| 1 | Depth of Insertion Cut-off Ratio (D/B ratio) | 0, 0.25 B, 0.5 B, 0.75 B, B |
| 2 | Eccentricity Ratio of loading (e/B ratio) | 0, 0.1 B, 0.2 B, 0.3 B |
| 3 | Depth Ratio of Top Layer of Sand (d_1/D) | 0, 0.5 D, D, 1.5 D, 2 D (for $e/B=0$) |

IV. EXPERIMENTAL RESULTS

The results obtained from model plate load tests were plotted in terms of load-settlement curves and bearing capacity ratios were determined in each case. Bearing capacity ratio is the ratio of UBC of T-shaped footing with respect to UBC of strip footing, for similar condition of sand bed. To determine bearing capacity ratios of T-shaped footing on layered sand, ultimate bearing capacity of strip footing on layered sand deposit was required. For that purpose, model plate load tests were conducted on strip footing by varying depth of top layer of sand bed. The UBC of strip footing on single layer of medium sand is found to be 89 kN/m² and 138 kN/m² in case of fine gravel. Table 3 shows UBC of strip footing on layered sand bed. Fig. 6 shows the variation of UBC of strip footing on layered sand bed. From Fig.6 it is observed that UBC of strip footing on layered sand is more as compared its UBC on single layer of sand bed. Thus, as the depth of top layer of sand bed increases, UBC of strip footing increases.

Table 3: Ultimate Bearing Capacities of Strip Footing on Layered Sand Bed

| Sr. No. | d_1 (cm) | d_2 (cm) | d_1/d_2 ratio | UBC (kN/m ²) |
|---------|------------|------------|-----------------|--------------------------|
| 1 | 0 | 50 | 0 | 138 |
| 2 | 1.25 | 48.75 | 0.025 | 146.604 |
| 3 | 2.5 | 47.5 | 0.052 | 151.886 |
| 4 | 3.75 | 46.25 | 0.081 | 155.883 |
| 5 | 5 | 45 | 0.111 | 160.736 |
| 6 | 7.5 | 42.5 | 0.176 | 167.731 |
| 7 | 10 | 40 | 0.25 | 175.58 |
| 8 | 11.25 | 38.75 | 0.290 | 182.946 |
| 9 | 15 | 35 | 0.428 | 190.143 |
| 10 | 20 | 30 | 0.666 | 198.422 |

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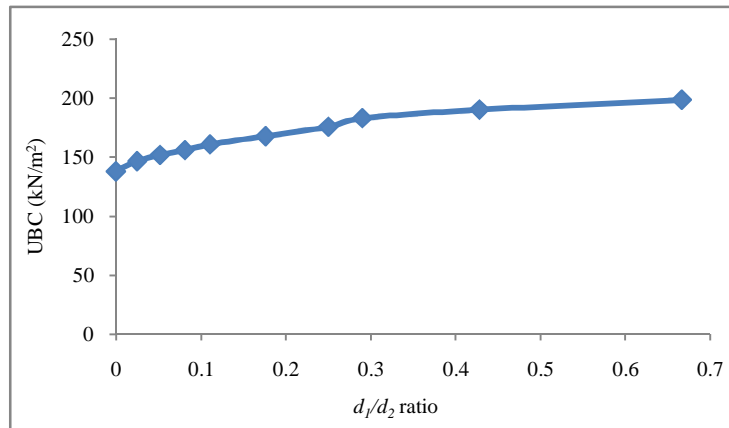


Fig. 6 Variation of UBC of Strip Footing on Layered Sand Bed

Model plate load tests were conducted on T-shaped footing on single layer of medium sand bed and fine gravel bed. The depth of insertion cut-off (D) was varied with the ratio of D/B = 0.25, 0.5, 0.75, 1. Table 4 shows values of ultimate bearing capacities and bearing capacity ratios of T-shaped footing on single layer of medium sand and fine gravel bed. Fig. 7 shows variation of UBC of T-shaped footing on single layer of medium sand and fine gravel bed. Fig. 8 shows variation of BCR of T-shaped footing on single layer of medium sand and fine gravel bed. From Fig. 7, it is observed that as the depth of insertion cut-off increases, UBC of T-shaped footing increases. It reached to its optimum value when depth of insertion is equal to half the width of footing. Similarly, from Fig. 8, it is observed that as the depth of insertion cut-off increases, BCR of T-shaped footing increases and it reached to its optimum value when D/B ratio is equal to half the width of footing. Thus, from Fig. 7 and 8 it is observed that the bearing capacity of T-shaped footing is more in case of fine gravel sand bed as compared to that of medium sand bed.

Table 4 Ultimate Bearing Capacity and Bearing Capacity Ratio of T-shaped Footing on Single Layer of Sand

| Sr. No. | D/B ratio | UBC (kN/m ²) | | BCR | |
|---------|-----------|--------------------------|-------------|-------------|-------------|
| | | Medium Sand | Fine Gravel | Medium Sand | Fine Gravel |
| 1 | 0 | 89 | 138 | 1 | 1 |
| 2 | 0.25 | 104 | 174.726 | 1.16 | 1.26 |
| 3 | 5 | 116 | 198.42 | 1.3 | 1.43 |
| 4 | 0.75 | 119 | 204.56 | 1.33 | 1.48 |
| 5 | 1 | 119 | 209.84 | 1.33 | 1.52 |

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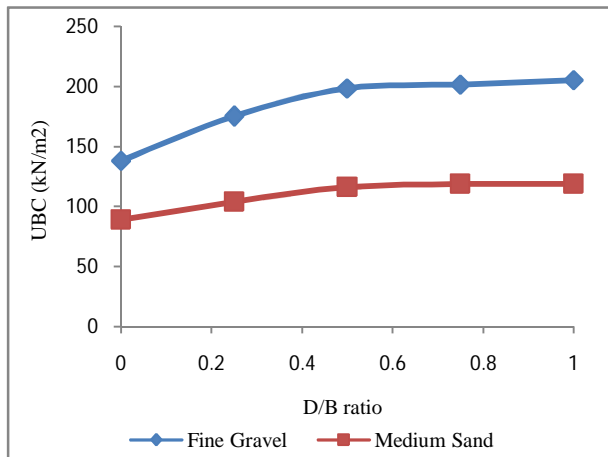


Fig. 7 Variation of UBC of T-shaped Footing on Single Layer of Medium Sand and Fine Gravel

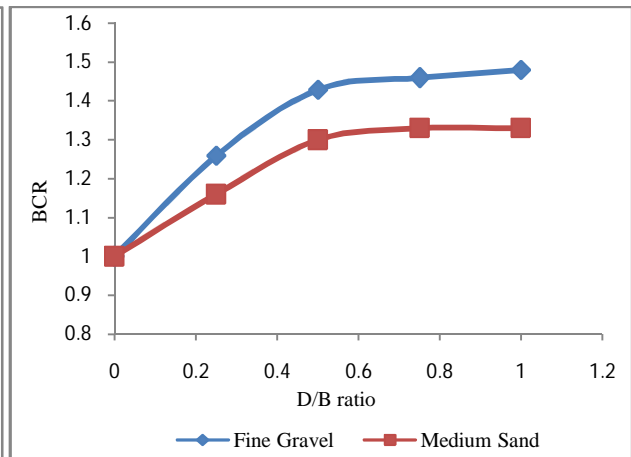


Fig. 8 Variation of BCR of T-shaped Footing on Single Layer of Medium Sand and Fine Gravel

Model plate load tests were conducted on T-shaped footing by varying depth of top layer of sand (d_1) with respect to depth of insertion cut-off (*i.e.* d_1/D ratio), where top layer of sand bed was made by medium sand. Table 5 shows variation of ultimate bearing capacities and bearing capacity ratios of T-shaped footing on layered sand. Fig. 9 shows variation of UBC of T-shaped footing on layered sand bed. Fig. 10 shows variation of BCR of T-shaped footing on layered sand bed.

Table 5 UBC and BCR of T-shaped Footing on Layered Sand Bed

| Sr. No. | D/B ratio | d_1/D | UBC (kN/m ²) | BCR |
|---------|-------------|---------|--------------------------|------|
| 1 | 0.25 | 0 | 174.726 | 1.26 |
| | | 0.5 | 196.709 | 1.34 |
| | | 1 | 212.554 | 1.39 |
| | | 1.5 | 225.69 | 1.44 |
| | | 2 | 233.66 | 1.45 |
| 2 | 0.5 | 0 | 198.42 | 1.43 |
| | | 0.5 | 226.63 | 1.49 |
| | | 1 | 252.953 | 1.57 |
| | | 1.5 | 272.224 | 1.62 |
| | | 2 | 289.78 | 1.65 |
| 3 | 0.75 | 0 | 204.56 | 1.48 |
| | | 0.5 | 241.533 | 1.54 |
| | | 1 | 272.22 | 1.62 |
| | | 1.5 | 305.627 | 1.67 |
| | | 2 | 319.76 | 1.68 |
| 4 | 1 | 0 | 209.84 | 1.52 |
| | | 0.5 | 253.46 | 1.57 |
| | | 1 | 288.926 | 1.64 |
| | | 1.5 | 318.9 | 1.67 |
| | | 2 | 339.887 | 1.71 |

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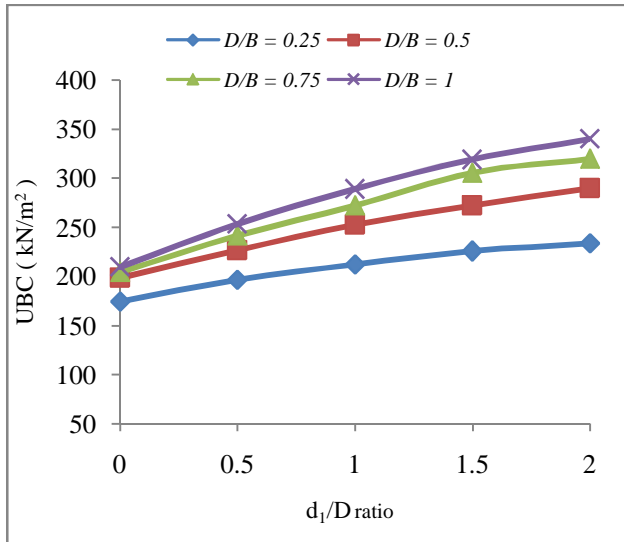


Fig.9. Variation of UBC of T-shaped Footing on Layered Sand Bed

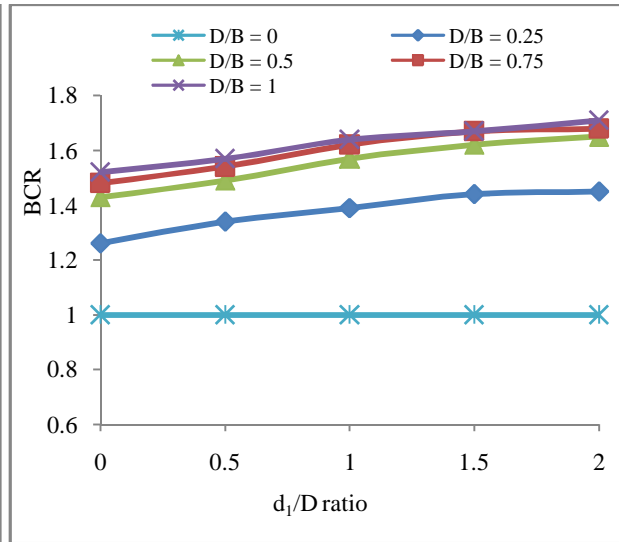


Fig. 10. Variation of BCR of T-shaped Footing on Layered Sand Bed

From Fig. 9, it is observed that as the depth of top layer of sand increases, UBC of T-shaped footing increases. From Fig. 10, it is observed that as the depth of top layer of sand increases, BCR of T-shaped footing increases and it reached to its optimum value when depth of top layer of sand is equal to 1.5 times the depth of insertion cut-off. Thus, bearing capacity of T-shaped footing on layered sand bed is more as compared to its bearing capacity on single layer sand bed of both types of sands.

Table 6 UBC and BCR of T-shaped Footing on Medium Sand Subjected to Eccentric Loading

| Sr. No. | <i>e</i> / <i>B</i> ratio | <i>D</i> / <i>B</i> ratio | UBC (kN/m ²) | BCR |
|---------|---------------------------|---------------------------|--------------------------|------|
| 1 | 0.1 | 0 | 77 | 1 |
| | | 0.25 | 96 | 1.24 |
| | | 0.5 | 105.34 | 1.36 |
| | | 0.75 | 105.34 | 1.36 |
| | | 1 | 105.34 | 1.36 |
| 2 | 0.2 | 0 | 66 | 1 |
| | | 0.25 | 82 | 1.24 |
| | | 0.5 | 90 | 1.36 |
| | | 0.75 | 95 | 1.43 |
| | | 1 | 96 | 1.45 |
| 3 | 0.3 | 0 | 60 | 1 |
| | | 0.25 | 78.94 | 1.31 |
| | | 0.5 | 84.22 | 1.4 |
| | | 0.75 | 93.07 | 1.55 |
| | | 1 | 94.23 | 1.57 |

T-shaped footing with different depths of insertion cut-off was subjected to eccentric loading. The load with different eccentricity was applied on T-shaped footing with eccentricity (*e*) to width of strip footing ratio (*i.e.* *e*/*b* ratio) = 0.1, 0.2

and 0.3 and model plate load tests were conducted on sand bed of medium sand. Load-settlement curves were obtained from these tests and UBC of T-shaped footing was determined. Table 6 shows values of UBC and BCR of T-shaped footing on medium sand bed. Fig.11 shows variation of UBC of T-Shaped footing on single layer of medium sand bed. Fig. 12 shows variation of BCR of T-shaped footing on single layer of medium sand bed. From Fig.11, it is observed that as the eccentricity ratio increases UBC of T-shaped footing decreases however from Fig.12, it is observed that BCR of T-shaped footing increases with increase in load eccentricity ratio, particularly in case of T-shaped footing with D/B ratio greater than 0.50.

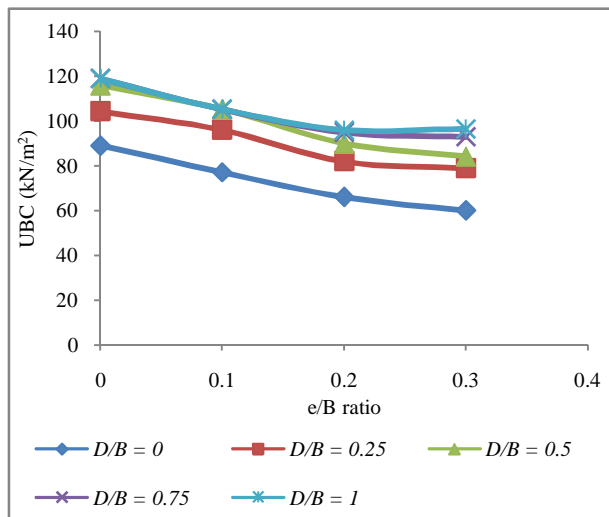


Fig. 11 Variation of UBC of T-shaped Footing over Medium Sand Subjected to Eccentric Loading

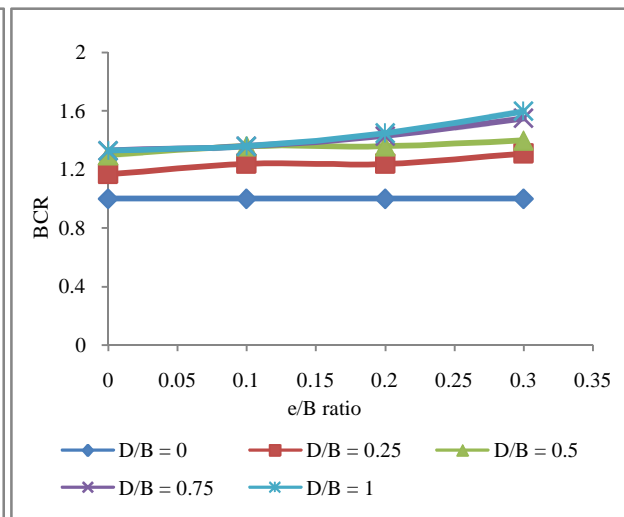


Fig. 12 Variation of BCR of T-shaped Footing on Medium Sand Subjected to Eccentric Loading

V. CONCLUSIONS

From the experimental investigations on T-shaped footing on single and layered sand bed following conclusions are drawn

1. UBC of T-shaped footing on fine gravel bed is more as compared to that on medium sand bed.
2. UBC of T-shaped footing increases with increase in depth of insertion cut-off. The bearing capacity reached to its optimum value when depth of insertion cut-off is 0.5 times the width of footing.
3. The BCR of T-shaped footing on layered sand bed increases with increase in depth of insertion cut-off and it reaches to its maximum value when depth of insertion cut-off is 0.5 times of the width of footing, after that increment in BCR of T-shaped footing is marginal.
4. The BCR of T-shaped footing on layered sand increases with increase in depth of top layer of sand bed and it reaches to its optimum value when depth of top layer of sand bed is equal to 1.5 times of the depth of insertion cut-off.
5. Bearing Capacity Ratio of T-shaped footing increases marginally with increase in load eccentricity ratio.

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