Experimental Study on Tee Shaped Footing under Eccentric Vertical Loading
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Abstract— For designing foundations subjected to earthquake forces, adopting values of horizontal and vertical seismic coefficients, equivalent seismic forces can be conveniently evaluated. These forces in combination with static forces make the foundations subjected to eccentric vertical and inclined loads. In addition to vertical axial loads, the footings of structures are often subjected to eccentric loads caused by the force of earth pressure, earthquakes, water, wind etc. Due to eccentric loading, the two edges settle by different amounts, causing the footing to tilt. The Tee shaped footing is proposed as a footing shape for improving the bearing capacity of shallow footings against the action of eccentric loads. The vertical insertion of the rigid Tee shaped footing, into the bearing soil, provides considerable resistance, against both of sliding and overturning, enough to regain the reduction in bearing capacity and increase in settlement. In the study, a series of experimental results by loading footing eccentrically along and perpendicular axes in horizontal plane for reporting ultimate loads and settlement of Tee shaped footing has been considered out. Total 144 models tests were conducted for investigating the effects of different parameters, such as problem geometry. The problem geometry was represented by two parameters, the load eccentricity (e) and the projection depth (D) of Tee shaped footing into dense sand soil. The experimental results proved that the ultimate bearing capacity of a footing under loads could be improved by projection.

Key words: T-shaped footing, cohesion less soil, Eccentricity width ratio, Depth to width ratio

I. INTRODUCTION
Shallow foundations are used to support different types of structures. These structures may transfer concentric or eccentric loads to their footings, depending upon the type of the loading. The footings of portal framed buildings are often subjected to eccentric loads caused by the force of earth pressures, earthquakes, water, wind, etc. Sometimes the corner of the column of these portal-framed buildings is located very close to the property line, and hence subjected to eccentric loading. The problems of footings subjected to eccentric loads are frequently encountered by an engineer in case of the footing of the retaining wall, columns, stanchions, and portal framed buildings and also in tall buildings subjected to seismic forces & wind pressure. For designing footings subjected to earthquake forces, adopting appropriate values of the horizontal and vertical seismic coefficients, equivalent seismic forces can be conveniently evaluated. These forces in combination with static forces make the foundations subjected to eccentric and/or eccentric-inclined loads. Due to an eccentric loading, the two edges settle by different amounts, causing the footing to tilt and the pressure below the footing does not remain uniform. The amount of tilt and the pressure at the base depend on the value of the eccentricity width ratio.

The method of foundation design requires that they must possess sufficient safety against failure and settlement must be kept within the tolerable limit. These requirements are dependent on the bearing capacity and compressibility of soil. It is commonly believed that the settlement criterion is more critical than the bearing capacity in the designs of shallow foundations. By limiting the total settlements, differential settlements and any subsequent distresses the structure are ensured to be safe. Generally the settlements of shallow foundations such as pad or strip footings are limited to 25 mm. To have a safe design, the eccentricity must satisfy the criterion of less than 1/6 of the footing width (e < B/6) so as to avoid tension between the foundation and the soil.

Corner columns in most of the cases are subjected to moments along two different planes (i.e. biaxial bending). This biaxial bending develop the eccentricity along two mutually perpendicular directions, also even if the footings are subjected to axial load they may be located near the property line along the two directions this is also another reason of footings being subjected to two way eccentric loading. A footing may also be subjected to inclined loading in case of high rise structures, these structures are subjected to large amount of wind forces and are designed for sway under these forces, in such a case the loading which comes on the footing is considered to be inclined. The effect of the loading is such that it tends to tilt the footing in the direction of the loading.

Mahiyar & Patel [12] introduced the concept of Angle Shaped Footing in which the tilt due to eccentric load was reduced to zero by providing vertical downward projection which remains embedded in soil. In an angle shaped footing the soil particles near the footing projection are prevented from moving laterally thus footing projection causes footing to tilt in direction opposite the one in which the footing has tendency to tilt. Thus tilt of the footing can be reduced to zero by providing a downward footing projection of required depth toward the loading side.

By varying two dimensionless parameters namely e/B and D/B he developed the equation for no tilt for angle shaped footing as of following type, which is found to be independent of the material of footing and the properties of the underlying sandy soil i.e.

\[ D/B=85.77(e/B)^2-8.95(e/B)^3+3.42(e/B)-0.0012 \]

Where,
B = width of footing;
D = depth of footing projection;
e, = eccentricity along x-axis;

The footing projections prevent the tilt in the direction in which the footing has the tendency to tilt, thus can reducing the tilt to zero.

Construction of vertical projections at the base of the footing, confining the underlying soil, generates a soil
resistance on projection sides that helps the footing to resist sliding. Since the direction of wind and earthquake force cannot be fixed whereas in Angle Shaped footing the projection is required towards the eccentricity side only. Although the Angle shaped footings are useful even if the eccentricity is in opposite side but it is less effective. From the very limited dynamic study of such footings it has been observed that the tilt cannot be prevented due to dynamic loading.

The idea of angle shaped footing is now extended to Tee shaped footing. These footings are having vertical projection at centre. The Tee shaped footing is used to improve the bearing capacity of soil against the action of eccentric loads. The vertical projection of the Tee shaped footing, into the soil provides considerable resistance, against both sliding and overturning, enough to regain the reduction in bearing capacity and the increase in settlement due to eccentric loads.

Since one decade Angle Shaped Footing is an effective option to be used to sustain vertical and inclined eccentric loads. As angle shaped footing is unsymmetrical in shape and in this type of footing co-ordinate of loading is specified, whereas in case of earthquake and wind the co-ordinate of load

II. EXPERIMENTAL SET UP & METHODOLOGY
Experimental program was carried using the facility in the Structure Laboratory of the Civil Engineering Department of Shri G.S.Institute of Technology & Science, Indore. Sample Models are prepared in workshop of college. The experimental setup consist following accessories

- **Tank:** A steel tank of Rectangular size fabricated in workshop with loading frame. The size of tank is 1.2 X1.2 in plan and 1.2 m in height the loading frame build up by the channel section to withstand appropriate load. This tank is filled with sand by rainfall technique. Then we have attached the loading frame. Four dial gauges at four corners are placed to take the reading of settlement. Sand in tank is leveled and gently compacted

- **Load Cell:** We have use load cell of capacity 2 tones in over experiment.
- **Dial Gauge:** We have use dial gauge limit 25mm.
- **Load Meter:** Load meter digital value of load applied by hydraulic jack. From load meter we got the values of load intensity.

Cannot be predicted so we have chosen a square type T-shaped footing in which shape is symmetric but loading is unsymmetrical. It is therefore proposed to use T-shaped footing which makes the footings symmetrical. To know the behavior of T-shaped footing; following parameters have been studied experimentally.

- Size of footing 250mmx250mm, 200mmx200, 150mmx150mm.
- Load eccentricity e/B=0,0.1,0.2,0.3,0.4&0.5.
- Footing projection D/B=0,0.2,0.4&0.6.
A. Test procedure:
Filling the tank by rainfall technique. Leveling the sand bed and then gentle tapping. Inserting the model into sand bed. Use level tube to level the plate and use plumb bob to level the load pointer. Then bringing the load pointer near to point mark on plate where load has to apply with help of hydraulic lack. Set all four dial gauge on corners of plate. Set load meter to zero reading. Taking load reading by load meter and settlement reading by dial gauge at a certain intervals of load. Maximum load is taken as a value at which load in load cell start reducing.

B. Properties of sand:
Maximum dry unit weight (kN/m$^3$) =16.8, Minimum dry unit weight (kN/m$^3$) = 15
The angle of shearing resistance of the sand = 28˚.

C. Observations:
To know the behavior of T-shaped footing, following parameters have been studied experimentally.

1) Size of footing
- 250mmx250mm,
- 200mmx200 mm
- 150mmx150mm.

2) Load eccentricity $e/B$=0.0,0.1,0.2,0.3,0.4 & 0.5.

3) Footing projection $D/B$=0.0,0.2,0.4 & 0.6

By varying above parameters maximum load intensity and settlement at four corners is noted. Using combinations of above parameters in form of different cases, we have determined following: The load intensity of footing with different depth of projection under different load eccentricity. The maximum load intensity under permissible tilt value. The effect of load eccentricity on load intensity. The settlement of footing with different depth of projection at different load eccentricity. The effect of size of footing on maximum load intensity

III. RESULTS
The type of failure in sandy soil was observed as general shear failure. In this type of failure a peak value of load intensity is clearly defined in the curve of settlement. Collecting all the data of Load intensity and settlement to have a tabular comparison

| Values of load intensity (kN/m²) at different load eccentricity for different depth of projection when loaded along projection |
|---|---|---|---|---|
| $e/B$ | 0.0 | 0.1 | 0.2 | 0.3 |
| 0 | 140 | 125 | 100 | 75 |
| 0.1 | 100 | 95 | 80 | 65 |
| 0.2 | 80 | 75 | 60 | 45 |
| 0.3 | 50 | 45 | 30 | 15 |

| Values of load intensity (kN/m²) at different load eccentricity for different depth of projection when loaded perpendicular to projection |
|---|---|---|---|---|
| $e/B$ | 0.0 | 0.1 | 0.2 | 0.3 |
| 0 | 140 | 125 | 100 | 75 |
| 0.1 | 100 | 95 | 80 | 65 |
| 0.2 | 80 | 75 | 60 | 45 |
| 0.3 | 50 | 45 | 30 | 15 |
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We have plotted bar charts to know the effect of size of plate on load intensity within permissible Tilt (kappa) at different load eccentricity ratio for different depth of projections.

Fig. 1: Bar Chart 2 For load eccentricity e/B=0.1, When footing loaded along projection depth:

Fig. 2: Bar Chart 3 for load eccentricity e/B=0.2, When footing loaded along projection depth:

Fig. 3: Bar Chart 4 for load eccentricity e/B=0.1, When footing loaded perpendicular to projection depth:

Fig. 4: Bar Chart 5 for load eccentricity e/B=0.2, When footing loaded perpendicular to projection depth:

Fig. 5: Bar Chart

Fig. 6: Bar Chart 6 for load eccentricity e/B=0.0, When footing loaded along projection depth:

Fig. 7: Bar Chart 7 For load eccentricity e/B=0.1, When footing loaded along projection depth:

Fig. 8: Bar Chart 8 for load eccentricity e/B=0.2, When footing loaded along projection depth:
IV. DISCUSSION

In this study, experimental investigation for ultimate loads intensities of Tee shaped footings is reported. The effect of eccentricity and effect of depth of projection under vertical eccentric loading was investigated. At the end of the test, the load intensity vs settlement and load intensity vs tilt were plotted. Based on the result of this investigation, with variables as $e/B$, $y/B$ width of footing are the discussion:

Position of eccentric loads:

A. When loaded along the projection: For constant $e/B=0.2$, $D/B=0.6$, size 250x250mm compared without projection.
   - Maximum load intensity increases about 32kPa.
   - Maximum settlement increases about 1.94mm.
   - Maximum tilt decreases about 0.00508.

B. When loaded perpendicular to the projection: For constant $e/B=0.2$, $D/B=0.6$, size 250x250mm compared without projection.
   - Maximum load intensity increases about 24kPa.
   - Maximum settlement increases about 1.48mm.
   - Maximum tilt increases about 0.02105.

1) Depth of Footing Projection:
   - Maximum load intensity increases as depth of projection increases for eccentric load ranges from 0.0 to 0.3, after that it start reducing.
   - Maximum settlement increases as depth of footing increases
   - Maximum tilt decreases for eccentricity up to 0.2, after that it start increases.

2) Size of footing:
   - Load intensity increases with increase in size of footing
   - Maximum settlement decreases with decreases in size of footing.

V. CONCLUSIONS

After carrying out a total of 144 experiments and calculating the tilt in different cases it has been found that in Tee shaped footing that the load intensity with in permissible tilt is effective up to an eccentricity width ratio of 0.15 only beyond which the maximum load intensity under permissible tilt, although more then normal conventional footing but practically of no use.

However it is expected that due to the symmetry the Tee -shaped footing shall be useful under dynamic loading.

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