# FINITE ELEMENT ANALYSIS OF T-SHAPED FOOTING OF VARYING PROJECTION LOCATION USING ANSYS

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**Abstract -** *The load transferred to the soil strata has a tendency to move soil in vertical and horizontal directions and as a result settlements of foundation take place. Also when the footing is subjected to eccentric loading, it undergoes tilt. In the past researches, Angle Shaped Footings had been introduced to reduce the tilt up to zero. In Angle Shaped Footing, the footing is confined by providing vertical or inclined downward projection which remains embedded in soil. The concept of Angle Shaped Footing, which is found to be very useful in case of eccentric loading, was extended to T-Shaped footing. In Angle Shaped Footings, the vertical projection is provided at the edge while in T-Shaped footing, the vertical projection is provided at the centre. The vertical downward projection at centre is provided to improve the bearing capacity of soil against the application of central vertical loading which also provides considerable resistance against both overturning and sliding. Hence in the present work, different models of T-Shaped Footing have been analyzed with the change in the depth and location of vertical footing projection under the application of eccentric loading. The position of vertical projection is obtained for which tilt of footing becomes zero or brought within permissible limits of tilt as per Indian Standard Code. The deformations and stresses are also determined in both horizontal and vertical directions for different depths of projection under different eccentricities. The whole analysis has been performed over the ANSYS version 18.2.*

***Key Words*: T-Shaped Footing, Footing Projection, Eccentric Vertical Load, Tilt, D/B Ratio, $e_x$/B Ratio, ANSYS.**

## 1. INTRODUCTION

For designing foundation subjected to lateral forces such as earthquake, wind forces etc., eccentric loading can be conveniently evaluated. Due to eccentric loading the two edges settle by different amounts, causing the footing to tilt. Any conventional footing may be uneconomical for horizontal forces such as earthquake force, wind forces and eccentric loading. It shows excessive tilt under such conditions. There is a problem due to moments on footings. The conventional footings are settling more and bulky in size. The application of unconventional types of footings include the T- Shaped footing for cantilever retaining wall with shear key to resist horizontal forces and also friction pile which transfer load through skin friction. In both the case there is projection which counters horizontal force and settlement. It introduced vertical projection which may be very helpful to reduce settlement and tilt of footing. Also we can use Vane shaped projection in footing to counter eccentric loading effects.

### 1.1 T-Shaped Footing

The concept of Angle Shaped Footing was extended to T-Shaped footing. These footings are provided with vertical downward projection at centre to improve the bearing capacity of soil against the application of central vertical loading. It provides considerable resistance against overturning and sliding, the settlement due to loading and is enough to regain the reduction in bearing capacity.

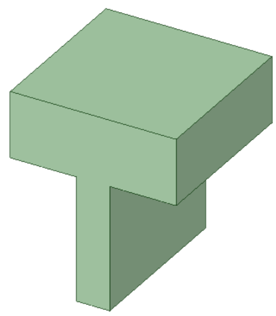

**Fig -1**: T-Shaped Footing

### 1.2 Terminologies Used

The following terminologies have been used throughout the present study:-

1. **Eccentricity-width ratio**: - The ratio of load eccentricity along x-direction ($e_x$) to the width of footing is termed as eccentricity width ratio. It is expressed as $e_x$/B.

2. **Position of footing projection**: - The position of vertical footing projection from the centre of footing is termed as position of footing projection. It is expressed as C/B.

**Table -1: Symbols Used in the Study**

| Parameter | Symbol |
|---|---|
| Width of footing | B |
| Depth of footing | D |
| Eccentricity-width ratio | $e_x/B$ |
| Position of footing projection from centre of footing | C |

## 2. LITRATURE REVIEW

**Mahiyar H.K. (2000)**

Footings are often subjected to eccentric loading due to (1) moments with or without axial forces; (2) the oblique loading; and (3) their location near the property line. Due to eccentric loading, the footing tilts and the pressure below the footing does not remain uniform. The tilt of footing increases with an increase in the eccentricity and the bearing capacity reduces considerably. Therefore, footing sizes increase and make the design uneconomical. The finite-element analysis of an angle shaped footing under eccentric loading has been carried out in the present study. One side vertical projection of footing confines the soil and prevents its lateral movement. It was concluded that footing subjected to uniaxial eccentric loads can be designed for no or negligible tilt by giving the footing an angle shape. The depth of footing projection will depend upon the eccentricity width ratio.

**Kanungo A. (2000)**
Studied the angle shaped footing in which (e/B) and (D/B) were in accordance with the equation proposed by Mahiyar H.K. (2000):

$$D/B = 85.77\{e/B\}^3 - 8.95\{e/B\}^2 + 3.42\{e/B\} - 0.0012$$

And found that the tilt is zero. The various sizes of footings were considered. It was concluded that bearing capacity increase with increase in size of footing, the bearing capacity also increase with increase in (D/B) value

**Joshi D. (2000)**
Studied angle shaped footing subjected to eccentric inclined loading. The inclination on either side of vertical axis was provided and the angle of footing projection was also varied. The footings were found to be useful in resisting eccentric inclined load, although the load carrying capacity was less.

**Gupta D. (2000)**
Studied angle shaped footing with rectangular shaped in which eccentricity was provided on longer and shorter side. It was concluded that eccentricity along shorter side and footing projection on longer side is more effective.

**Mahiyar H.K. (2003)**
Studied the effect of shear parameters on load carrying capacity on angle shaped footing and concluded that load carrying capacity increase with increase in angle of internal friction and tilt is zero at all value.

## 3. OBJECTIVES OF THE STUDY

The objectives of the study are as follows:-

1. To study the effect of depth of footing projection:- Depth of vertical projection is varied and load is applied vertically at various eccentricities for every depth. The values of Displacements and Normal Stresses in both X and Y directions are determined using the ANSYS Software.
2. To study the effect of positioning the projection:- Keeping the eccentricity constant i.e. $e_x/B = 0.15$, position of vertical projection (i.e. C/B ratio) varied towards the side of load eccentricity and the depth of projection also changed. The value of Tilt is observed in each case. After plotting the curves of C/B ratio and tilt, the position of projection i.e. C/B ratio for zero or allowable tilt was determined.X

As modelling the soil and footing with projection and using the readymade ANSYS Software the various outputs were noted. These are the displacements along the direction of load (i.e. $\Delta_y$) and in the lateral direction (i.e. $\Delta_x$) and normal stresses in the direction of loading (i.e. $\sigma_y$) and in the lateral direction (i.e. $\sigma_x$).

**Following parameters have been considered:-**

- Depth of downward footing projection (D) is varied as D/B = 0, 0.25, 0.5, 0.75 & 1.0
- Eccentricity($e_x$) to width(B) ratio i.e. $e_x/B$ is kept as = 0.00, 0.05, 0.1 & 0.15
- Position of footing projection from centre and expressed as C/B is varied from 0.05 to 0.4
- Vertical load : 250 kN
- Material of Footing : Concrete M-40
- Type of Soil : Sandy Soil
- Dimensions of Footing : 1.0m x 1.0m x 0.4m
- Thickness of Projection : 200 mm
- Dimensions of Soil Block : 5.0mx 5.0m x 3.0m

**Table -2: Properties of Soil Material Used in ANSYS**

| S. No. | Properties of Soil | Values |
|---|---|---|
| 1 | Density | 1834.864 kg/m$^3$ |
| 2 | Young's Modulus | 16.864 MPa |
| 3 | Poisson's Ratio | 0.333 |
| 4 | Internal Friction Angle | $30^0$ |
| 5 | Initial Cohesion | 0 |
| 6 | Dilatancy Angle | $30^0$ |

| | | |
|---|---|---|
| 7 | Residual Internal Friction Angle | $15^0$ |
| 8 | Residual Cohession | 0 |

To perform analysis, various models are made using ANSYS Software:

**Table -3: No. of Models made in ANSYS**

| D/B Ratio | No. of models (for different values of C) |
|---|---|
| 0 | 1 |
| 0.25 | 9 |
| 0.5 | 9 |
| 0.75 | 9 |
| 1.0 | 9 |
| **Total no. of models** | **37** |

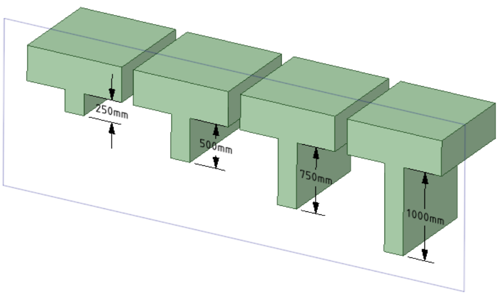


**Fig -2**: Footings with varying D/B Ratio

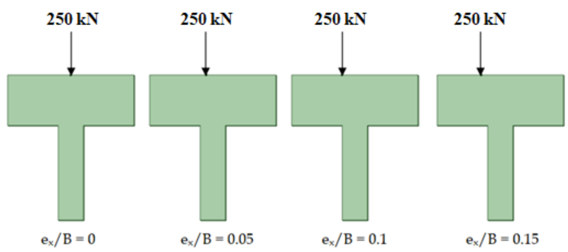


**Fig -3:** Footings with different $e_x$/B Ratio

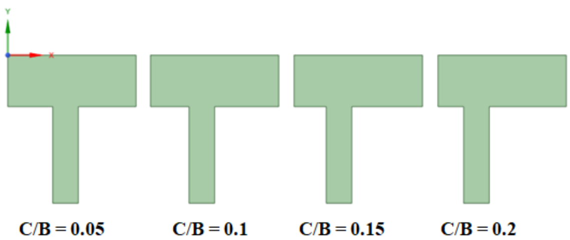


**Fig -4:** Footings with varying location of projection

**Following location of nodes are considered for the observations:**

Using the readymade software i.e. ANSYS version 18.2 the result for displacements and stresses were determined at various nodes. However we have noted the results of displacements $\Delta_x$ and $\Delta_y$, normal stresses $\sigma_x$ and $\sigma_y$ at some prominent points as marked and shown in Fig -5

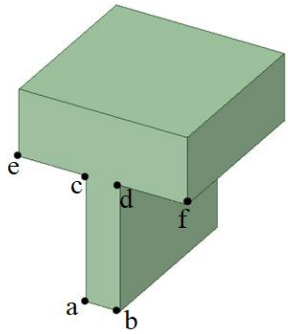


**Fig -5:** Location of nodes under observation

### 3.1 Determination of TILT:

Tilt is defined as ratio of difference between near end and far end settlement to width of footing. The value of Tilt over the T-Shaped Footing has been calculated from the observed values of vertical displacement or displacement in Y-direction at **node e** and **node f** as shown below:

$$\text{Tilt} = \frac{(\text{vertical displacement at node e}) - (\text{vertical displacement at node f})}{\text{width of footing}}$$

## 4. METHODOLOGY

To solve deflection and stresses, we have used Finite Element Method. As these require lots of calculation which is not manually feasible hence we have used **ANSYS Software** to calculate displacements and stresses over footing. The analysis has been performed over ANSYS version 18.2.

**Following steps are adopted during the study:**

1. For the analysis Workbench 18.2 need to be opened in the ANSYS 18.2 software.
2. After this, the Static Structural is selected from the analysis systems from the toolbox on the left hand side of the window.
3. The material is added in the engineering data, properties of the material can be set as per our requirement.
4. The model for the analysis has been made in the geometry module, according to the dimensions given in the problem formulation.
5. After this mechanical application is opened by clicking on the model module. When the mechanical application gets opened, the workbench

automatically attaches the geometry made in the geometry module. The steps involved in the mechanical application are given below:

a) First the material is assigned to the geometry made in the geometry module.
b) The contact region of bonded type is provided at the interface of concrete and soil such that the footing represents the contact body and the soil block represents the target body.
c) After this, the meshing details have to be given to the software. In our problem, the footing is modelled in the software with a uniform mesh element of approximate size 100 mm and for the soil block we have used the meshing size of 200 mm. We have used the eight noded element.
d) After the meshing, the boundary conditions are provided as frictionless support from the five faces i.e. all around the soil block and from the bottom face also.
e) In the next step, the load is applied at the centre of footing by inserting the force of value 250 kN.
f) In the final step the solutions required are inserted, and then the software runs the analysis and gives the results.

6. Above steps are repeated for every model to get the results.

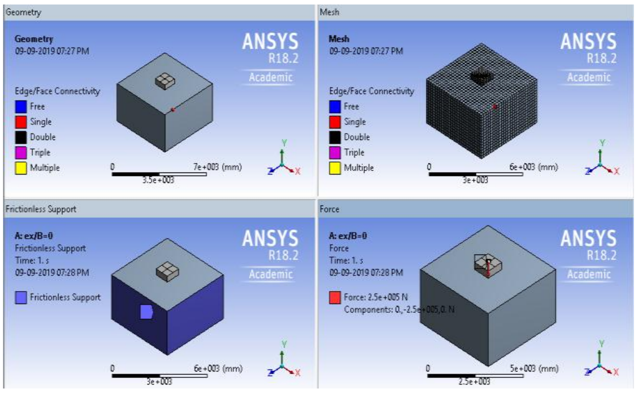


**Fig -6:** Different Steps in ANSYS

## 5. RESULTS AND DISCUSSIONS

### 5.1 General

Solutions are obtained from the analysis through ANSYS and the curves are plotted for the different cases of D/B ratio and $e_x$/B ratio for the following results:

1) Displacement in Y-direction
2) Displacement in X-direction
3) Normal Stresses in Y-direction
4) Normal Stresses in X-direction
5) Tilt of footing

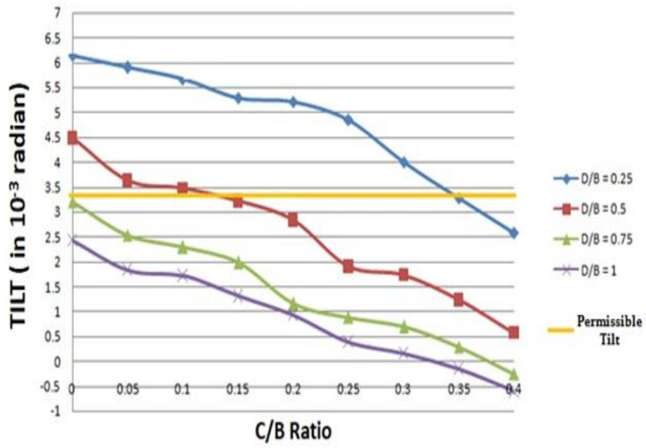


**Chart-1:** Graph between Tilt and C/B Ratio at $e_x$/B = 0.15

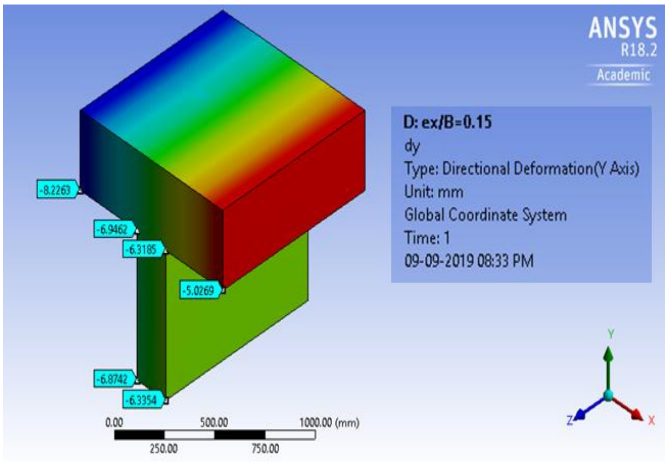


**Fig -7:** Solution of Deformation in Y-direction of footing for D/B = 0.75 at $e_x$/B = 0.15

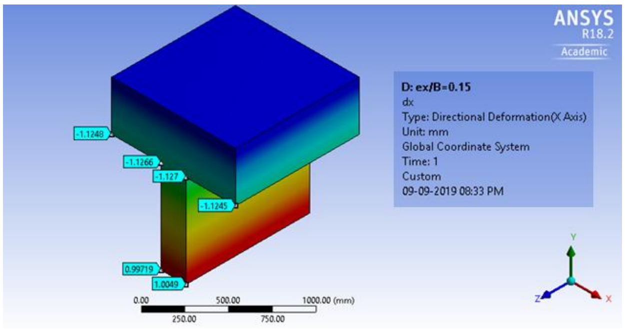


**Fig -8:** Solution of Deformation in X-direction of footing for D/B = 0.75 at $e_x$/B = 0.15

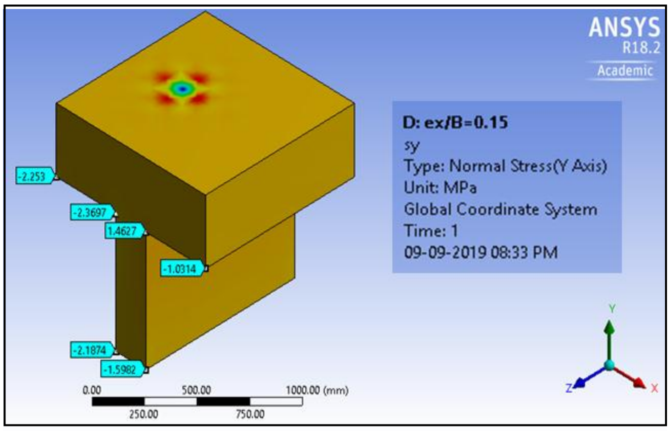


**Fig -9:** Solution of Stresses in Y-direction of footing for D/B = 0.75 at $e_x/B$ = 0.15

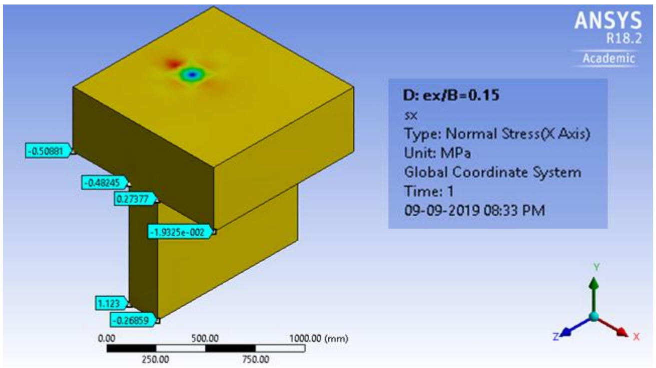


**Fig -10**: Solution of Stresses in X-direction of footing for D/B = 0.75 at $e_x/B$ = 0.15

### 5.2 Discussions

From the analysis by ANSYS Software over T-Shaped Footing of size 1.0 m x 1.0 m x 0.4 m with different depths of projection and varying locations of projection, following points have been observed:

#### 5.2.1 Displacements in Y-direction

a) On increasing the eccentricity of load, the value of vertical displacement (or displacement in Y-direction) increases.
b) As the depth of the footing projection increases, the value of vertical displacement (or displacement in Y-direction) decreases.

#### 5.2.2 Displacements in X-direction

There is no horizontal displacement (or displacement in X-direction) occurs when load is applied at centre of footing.

a) On increasing the eccentricity of load, the value of horizontal displacement (or displacement in X-direction) increases.
b) As the depth of the footing projection increases, the value of horizontal displacement or displacement in X-direction decreases.

#### 5.2.3 Stresses in Y-direction

There is no definite pattern obtained from the curves of stresses in Y-direction.

#### 5.2.4 Stresses in X-direction

There is no definite pattern obtained from the curves of stresses in X-direction.

#### 5.2.5 Tilt of Footing

a) As the depth of the footing projection increases, the value of tilt decreases when the eccentricity of load is kept constant (i.e. $e_x/B$ = 0.15).
b) The value of tilt decreases when the position of footing projection is shifted towards the eccentricity of load up to a certain value.
c) At $e_x/B$ = 0.15, the values of tilt are within permissible limit when D/B ratio is 0.75 and 1.0
d) At $e_x/B$ = 0.15, when D/B ratio is 0.25 and 0.5, the location of footing projection is to be changed to bring the values of tilt within permissible limit.
e) As per the equation of Angle Shaped Footing i.e.,

$$\mathbf{D/B = 85.77\{e/B\}^3 - 8.95\{e/B\}^2 + 3.42\{e/B\} - 0.0012}$$

D/B value for no tilt to occur is found to be 0.6 for $e_x/B$ = 0.15. An ANSYS model for such case is created and verified for this equation of no tilt.

## 6. CONCLUSIONS

From the analysis by ANSYS Software carried out on T-Shaped Footing of size 1.0 m x 1.0 m x 0.4 m with different depths of projection and varying locations of projection, following conclusions can be drawn:

1) The vertical displacement decreases with increase in depth of projection (D) keeping the value of load and eccentricity width ratio ($e_x/B$ ratio) constant.
2) The vertical displacement increases with increase in eccentricity width ratio ($e_x/B$ ratio) when the depth of projection and the value of load are kept constant.
3) The value of tilt decreases with increase in depth of projection (D) for a constant value of eccentricity width ratio ($e_x/B$ ratio).
4) As per the equation of Angle Shaped Footing (i.e. $\mathbf{D/B = 85.77\{e/B\}^3 - 8.95\{e/B\}^2 + 3.42\{e/B\} - 0.0012}$, D/B value for no tilt to occur is found to be 0.6 for $e_x/B$ = 0.15. An ANSYS model for such case is created and verified for this equation of no tilt.
5) For eccentricity width ratio ($e_x/B$ ratio) =0.15, at D/B ratio equal to 1, the value of tilt becomes zero when

location of footing projection (C) = 325mm. i.e. C/B is equal to 0.325

6) At $e_x/B = 0.15$, the values of tilt are within permissible limit when D/B ratio is 0.75 and 1.0 for position of footing projection (expressed as C/B) lying from 0 to 0.4
7) At $e_x/B = 0.15$, when D/B ratio is 0.25 and 0.5, the location of footing projection is to be changed to bring the values of tilt within permissible limit which can be ascertained from the chart.
8) The slightly different values of tilt are observed when calculated from different nodes at same horizontal line at a particular section of footing which shows that there is a slight bending in the footing.
9) The right angle between the footing and the projection before loading does not remain right angle ($90^o$) when subjected to eccentric loading. There is a reduction in this value and the reduction continues with the increase in either D/B ratio or $e_x/B$ value.

## REFERENCES

[1] Mahiyar H.K. and Patel A.N. (1992) “The Effect of Lateral Confinement on the Bearing Capacity of Fine Sand,” Indian Geotechnical Journal Vol. 22, No.4, pp. 227.

[2] Mahiyar H.K. and Patel A.N. (2000) “Analysis of Angle Shaped Footing under eccentric loading” Journal of geotechnical and Geoenvironmental engineering division of ASCE vol. 126 No.1, pp. 1151-1156 Dec-2000.

[3] Mahiyar H.K. and Patel A.N. (2001)”Moment –Tilt characteristics of angle shape footing under eccentric loading”, Proceedings of Indian Geotechnical Conference at Indore.

[4] Mahiyar H.K. et al. (2009) “Moment tilt characteristics of Angle Shaped Footing under eccentric inclined loading”-published in international journal of theoretical and applied mechanics ISSN 0973-4562 Vol 4 no.1 pp. 1085-1092 June 1, 2009.

[5] Patra, C.R., Das, B.M., Bhoi, M. and Shin, E.C. (2006). Eccentrically loaded strip foundation on geogrid-reinforced sand. *Geotextiles and Geomembranes*, Vol. 24, No. 4, pp. 254–259.

[6] Joshi, D.P. and Mahiyar, H.K. (2009). Effectiveness of Angle Shaped Footings resting on soil under eccentric inclined load. *International Journal of Theoretical Applied Mechanics*, Vol. 4, No. 1, pp.95-105.

[7] Meyerhof, G. G. (1953). The bearing capacity of foundations under eccentric and inclined loads. *In: Proceedings of the Third International Conference on Soil Mechanics and Foundation Engineering*, pp.440–445.

[8] Prakash, S. and Saran, S. (1971). Bearing capacity of eccentrically loaded footings. *Journal of SM and FE Division ASCE*, Vol. 97, No. 1, pp. 95-117.

[9] Uzuner, B.A. (1975). Centrally and eccentrically loaded strip foundations on sand. PhD thesis, Strathclyde University, Glasgow, Scotland.

[10] Joshi D. P. and Mahiyer H.K. (2009), “Behaviour of an Angle Shaped Footing under Eccentric Inclined Loading”, IGC, Guntur, INDIA, pp.609-613.

[11] Kanungo A. (2004), “Experimental Study of Angle Shaped Footing on cohesive and cohesion less soil under eccentric loading” M.E. thesis submitted to R.G.P.V. Bhopal. Loukidis, D., Chakraborty, T. and Salgado, R. (2008). Bearing capacity of strip footings on purely frictional

[12] Soil under eccentric and inclined loads. *Canadian Geotechnical Journal*, Vol. 45, No. 6, pp.768–787.

[13] Gupta D. (2000) “Experiment Studies on angle shape rectangular footing under eccentric loading” M.E. thesis submitted to D.A.V.V. Indore.

[14] Radheshyam Kumawat (2017), “The Experimental study of T-Shaped Footing subjected to Eccentric Vertical Loading at Various Depth of Footing Projection” M.E. thesis submitted to S.G.S.I.T.S. Indore.