Comparative Study of Stress Distribution in Foundation for an Eccentrically Loaded Footing

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Abstract— The footing is designed as rigid structure. When the load applied on footing is eccentric, the pressure distribution in elastic case is given by (P/A ± M/I*y). Pressure distribution no longer remains uniform. The moment the pressure exceeds ultimate bearing capacity of soil .The soil yields and redistribution of the soil pressure takes place. This process continues till the ultimate pressure below the footing becomes equals to ultimate bearing capacity of soil with reduce width of footing (Bowles). At this stage the effective settlement of the footing is more than elastic case. This causes differential settlement in the footing columns. Results in tilting of the structure, has been observed in practice in buildings with columns on property line. As such an attempt has been made to study the actual pressure diagram under the footing by analysing the footing soil media by Finite Element Method using SAP software. The study is made for uniaxially and biaxially loaded columns and to incorporate the results in the design of footings for eccentrically loaded columns. Non linear and linear analysis is performed for eight cases of uniaxially and bi axially loaded footings.

Key words: Modelling, MATLAB Transformer, Inrush Current, Solar Power Plant, Switching Method, Harmonics

I. Introduction

Foundation is an integral part of a structure whether it may be a building, bridge and dam etc. The function of the foundation is to receive the load from the superstructure and transmit it to the Underlying soil or rock. Soil is used as a construction material for various civil engineering structures. Structure on a ground with adequate bearing capacity is one of the basic requirements for the stability of a structure. Most of the studies for bearing capacity calculation are based on the foundation under vertical and central load. However in some cases due to bending moments and horizontal thrusts transferred from the superstructure, structures like retaining walls, abutments, waterfront structures, industrial machines and portal framed buildings are often subjected to eccentric load. This may be due to (a) moments with or without axial forces (b) the oblique loading and (c) their location near the property line etc. When the load is transferred at the base of the footing, movement of the soil particles in the horizontal and vertical direction occurs. For the footings under eccentric loading, the two edges settle by different amounts, causing the footing tilt. The amount of tilt and the pressure at the base depend upon the value of eccentricity width ratio (e/B). When this ratio is more than 1/6, the contact pressure will be tensile at the edge away from the load. However, since the soil is poor in tension, such situation cannot develop; hence, the footing loses contact with the soil and tilting of the footing occurs. Due to eccentric loading, the footing tilts and the pressure below the footing does not remain uniform.

Footings serving as foundations for retaining walls, abutments, stanchions and portal framed buildings may be subjected to moments and shears in addition to vertical loads. An eccentric load or an eccentric-inclined load may replace these forces and moments. Further, founding of structure on a ground with adequate bearing capacity is one of the basic requirements for the stability of a structure. However, in some situations, structures are required to be built even on weak or difficult soils. Under such circumstances, improvement of bearing capacity of such soil is of great importance for the safety and long term stability of the structures. Inclusion of reinforcing layers within the sub-soil is an effective and economical method amongst many others.

The tilt of footing increases with an increase in the eccentricity and the bearing capacity reduces. Many times reinforcing materials like geogrid, geotextile, geonet etc. are inserted into the granular materials to improve the bearing capacity of poor sub-soil. Over the last two decades the use of geogrids for soil reinforcement has increased greatly because geogrids are dimensionally stable and combine feature such as high tensile modulus (low strain at high load), open geogrid structure, positive shear connection characteristics, light weight, and long service life. Geogrids are made of high-modulus polymer materials, such as polypropylene and polyethylene, and are prepared by tensile drawing. Nelton Ltd. of the United Kingdom was the first producer of geogrids in 1982. The major function of geogrid is soil reinforcement interaction. There are two types of geogrid i.e. uniaxial and biaxial depending on the nature of manufacturing.

In every building the load is transferred to soil by foundation. It is necessary to design &Check it properly for probable failures. The foundation may fail due to excessive settlement, shear, tilting etc. A foundation is the lower part of a structure that transmit the load to the soil or rock. It includes the soil or rock. Thus, the word foundation refers to the soil under structure as well as any intervening load carrying member. In the design of any foundation system the aim is to provide adequate foundation to support load margin of safety against bearing capacity failure i.e. against a soil shear failure and to keep the settlements within tolerable limits. Thus, there arises a necessity of consideration of two different criteria, viz, the stability criterion and the settlement criterion in the design of foundation system.

It is known from the observation of the behavior of foundation subjected to a load that bearing capacity failure usually occurs as the shear failure of the soil supporting the footing. The minimum gross pressure intensity at the base of foundation at which the soil fails in shear is called the ultimate bearing capacity, qu. The ultimate bearing capacity divided by the desired factor of safe bearing capacity. For the design capacity of foundation it is not only safety against shear failure which is considered but also likely settlement. A pressure intensity which is considered safe both with respect to shear failure called the allowable bearing pressure and the design load. Thus the allowable bearing pressure is excessive settlement detrimental to the structure

II. STUDY UNDERTAKEN

It was always key point of research for determining the settlement & bearing capacity of the soil under eccentric loading. This study helps to investigate the effect of eccentric loading on the footing. The actual contact pressure distribution depends upon the flexural rigidity of the footing and the elastic properties of the sub grade. Here, the footing is considered as rigid while the soil is having intermediate characteristics. Hence for comparing the results, the values of stress for a section at the surface of contact between the base of a surface of footing and the underlying soil mass have been determined & plotted using sap2000.

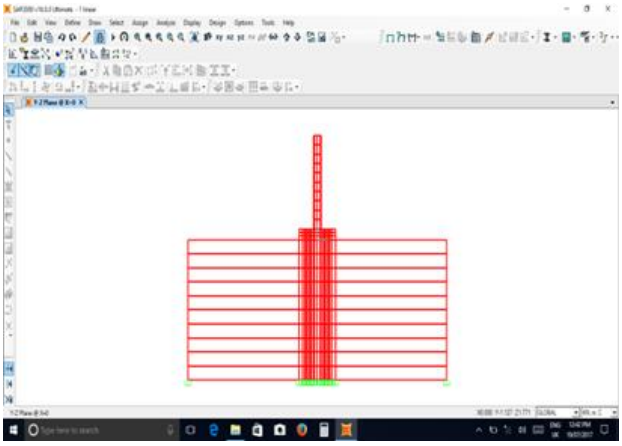
The modeling of a structure as a 3-D member in SAP is prepared as per following procedure:

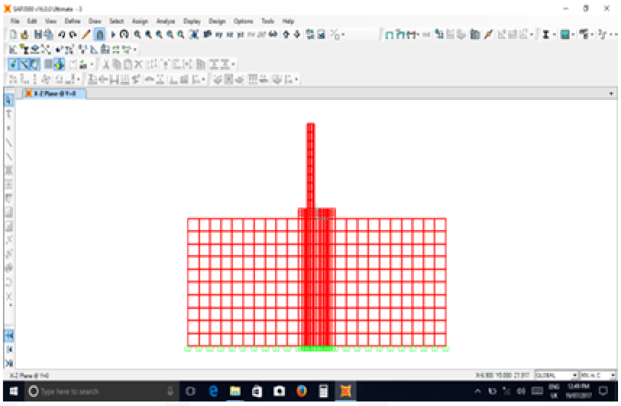
– Draw the geometry of the member by inserting coordinates.
– Define the materials and area sections for the members
– Define the loading values to be applied on the structures.
– Now assign the defined section as the members.
– After assigning everything, set the analysis to be carried out and press run analysis.

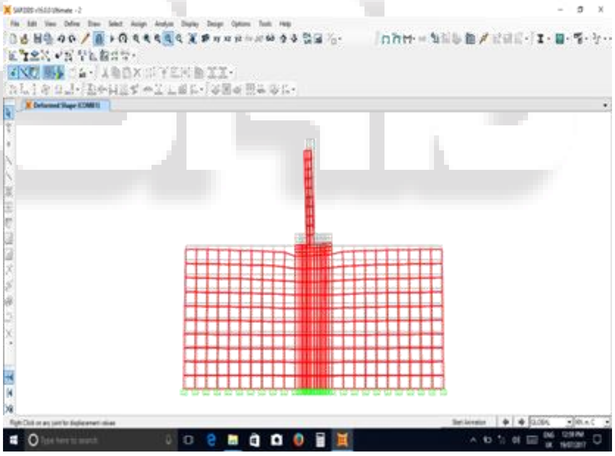
SAP program will generate the results like joint displacements & stresses for each member. The detailed properties of the material used for different members and the various models have been prepared for a eccentric loading for different position of loading using SAP2000 are shown below. For the purpose of comparison, different models are prepared for the different positions of the column resting on the square footing on which load of 500 KN on either corners of column are applied & analyzed. For evaluation of results, linear & non linear analysis has been carried out only for the externally applied load using sap2000. The results obtained from the analysis are plotted in graphical representation. Details of material data, its properties and models of 3 –D member for different positions of column are tabulated & figured out below:

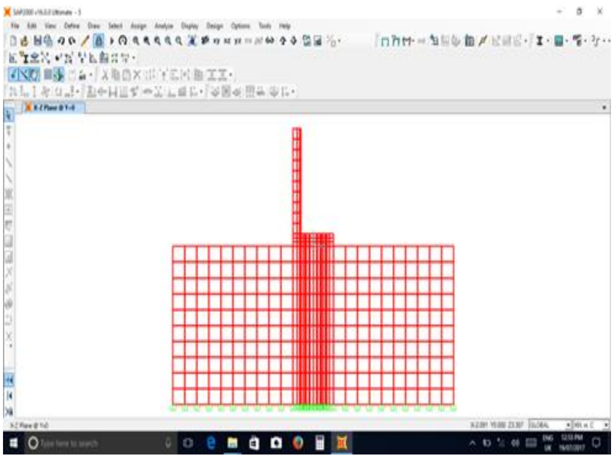
Particulars	Size	Material Used	Material Properties			
			(γ) KN/m^3	(E) KN/m^2	(μ)	(G)
Column	300mmX300mm	Concrete (M20)	25	22360680	0.2	9316950
Footing	1500mmX1500mm	Concrete (M15)	25	19364917	0.2	8068715
Soil	10500mmX 10500mm	Soil	15.696	74800	0.29	28992.248

Table 1: Material Size and Properties









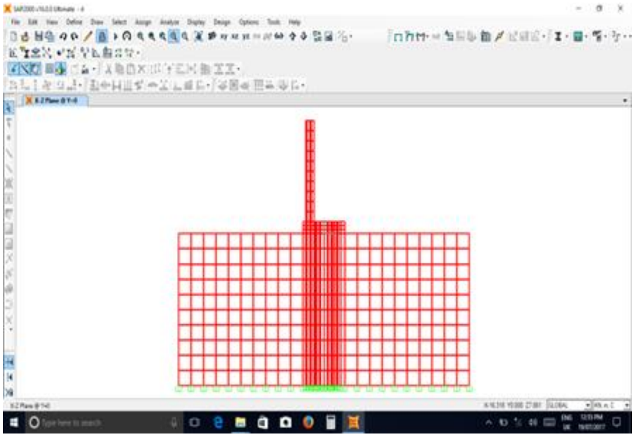


Fig. 1: Different Models of different positions of column placed on a footing

Two major cases taken as a problem are Uniaxial and Biaxial footing problems. Further the cases under each major category are taken under consideration for analysis purpose. The sub-cases are as follows:

A. Uniaxial Eccentric Loading (Linear & Nonlinear) Analysis:

Load applied on the footing at

1) Case 1: At the center concentric loading.
2) Case 2: At the distance of b/12 towards left from C.G. of footing area in X direction.
3) Case 3: At the distance of b/6 towards left from C.G. of footing area in X direction.
4) Case 4: At the distance of b/3 towards left from C.G. of footing area in X direction.
5) Case 5: At the distance of b/2.5 towards left from C.G. of footing area in X direction.

B. Biaxial Eccentric Loading (Linear & Nonlinear) Analysis:

1) Case1: At the center concentric loading.
2) Case 2: At the distance of b/6 in both directions from C.G. of footing area.
3) Case 3: At the distance of b/2.5 in both directions from C.G. of footing area.

III. Results and Discussion

A. Uniaxial in X-Direction

1) CASE 1: When the Column is at Centre of Footing

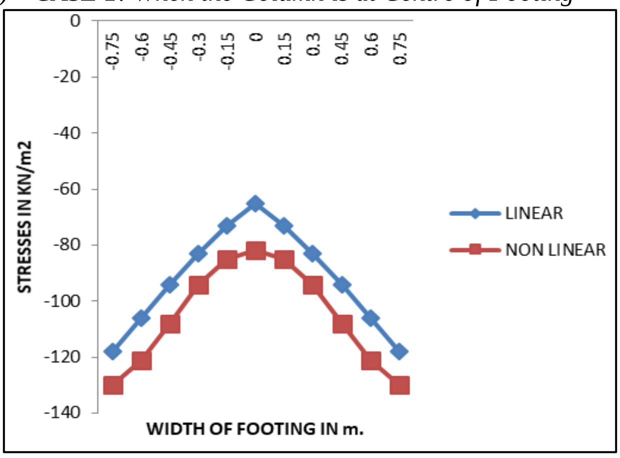


Fig. 2: Stress Diagram (X-AXIS)

The stresses developed in nonlinear footing are greater than linear footing throughout the footing width. It is also to be noted that the maximum stresses developed at the corners of the footing.

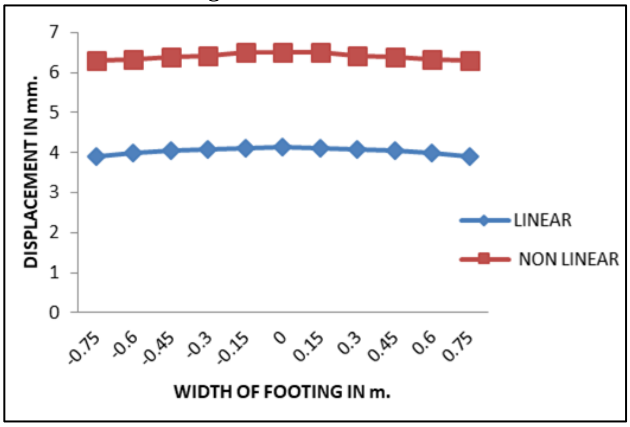


Fig. 3: Displacement Diagram (X-AXIS)

The Displacement in case of nonlinear footing are greater than linear footing throughout the footing width. The displacement is almost constant with negligible difference across the width length.

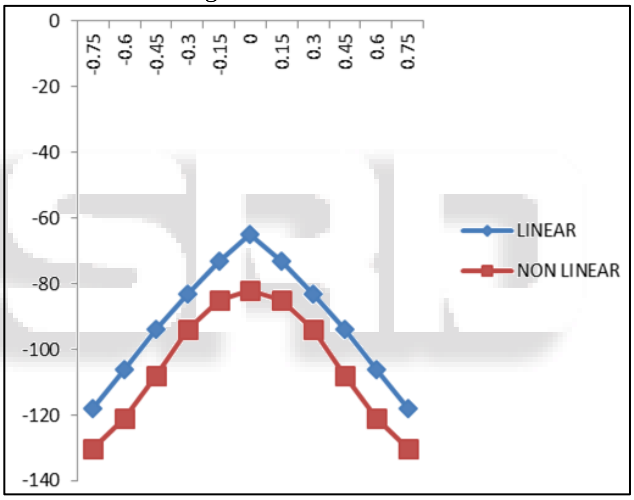


Fig. 4: Stress Diagram (Y-AXIS)

The stresses developed in nonlinear footing are greater than linear footing throughout the footing width. It is also to be noted that the maximum stresses developed at the corners of the footing.

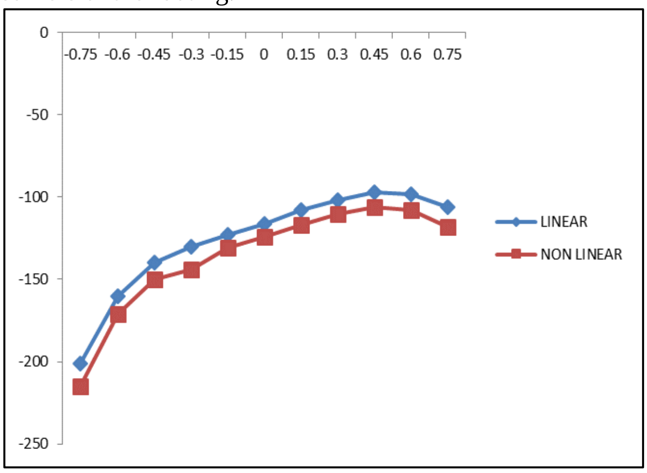


Fig. 5: Displacement Diagram (Y-AXIS)

The Displacement in case of nonlinear footing are greater than linear footing throughout the footing width. The displacement is almost constant with negligible difference across the width length

2) CASE – 2: When Column is at A Distance of B/12 towards Left from the Centre of Column in X-Direction.

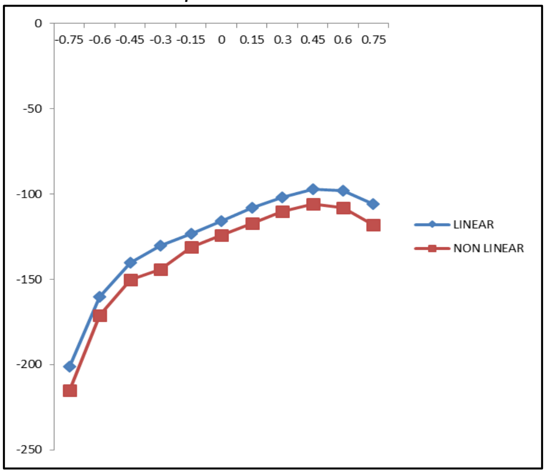


Fig. 6: Stress Diagram (X-AXIS)

The stresses developed in nonlinear footing are greater than linear footing throughout the footing width. It is also to be noted that the maximum stresses developed at the left corners of the footing.

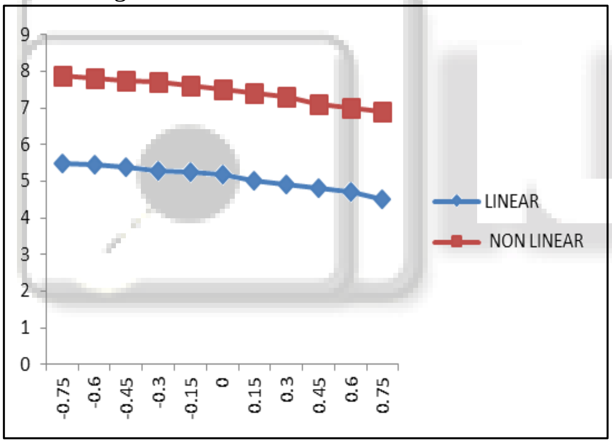


Fig. 7: Displacement Diagram (X-AXIS)

The Displacement in case of nonlinear footing are greater than linear footing throughout the footing width. The displacement is greater at left corner of the footing.

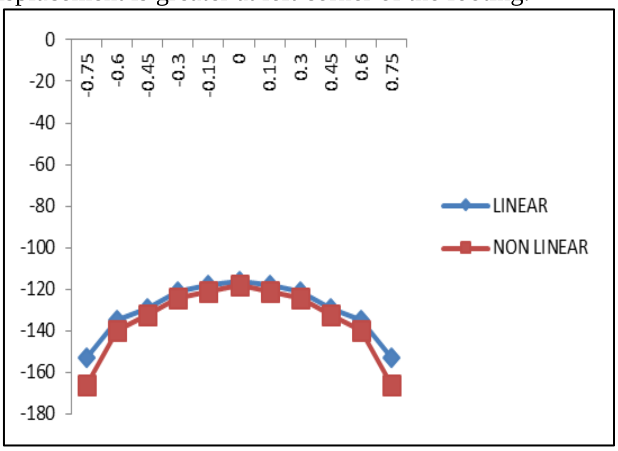


Fig. 8: Stress Diagram (Y-AXIS)

The stresses developed in nonlinear footing are greater than linear footing throughout the footing width. It is also to be noted that the maximum stresses developed at the corners of the footing.

3) CASE – 3: When Column is at a Distance of B/2.5 from the Centre in Both the Directions Respectively.

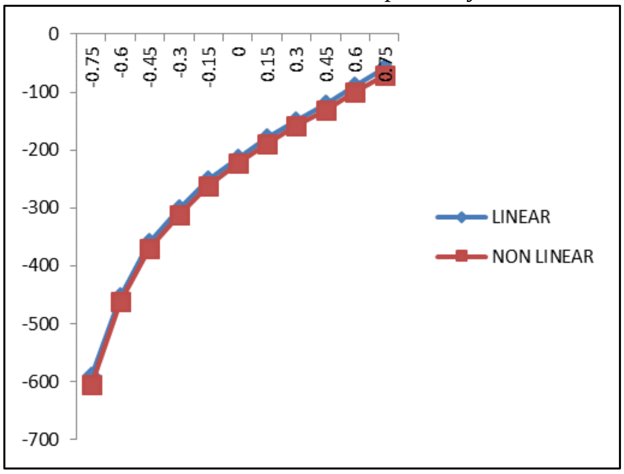


Fig. 9: Stress Diagram (X-AXIS)

The stresses developed in nonlinear footing are greater than linear footing throughout the footing width. It is also to be noted that the maximum stresses developed at the left corners of the footing.

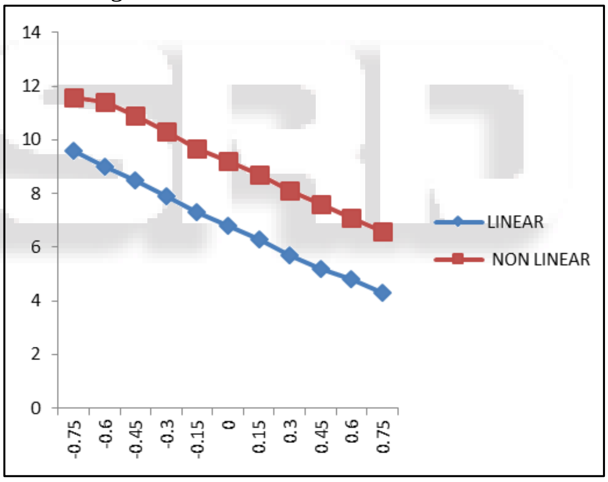


Fig. 10: Displacement Diagram (X-AXIS)

The Displacement in case of nonlinear footing are greater than linear footing throughout the footing width. The displacement is greater at left corner of the footing.

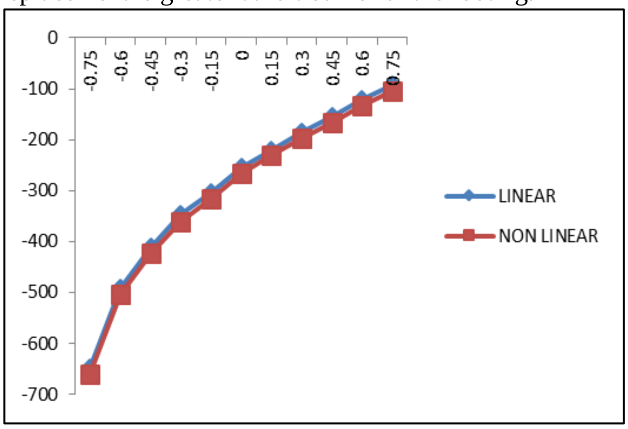


Fig. 11: Stress Diagram (Y-AXIS)

The stresses developed in nonlinear footing are greater than linear footing throughout the footing width. It is also to be noted that the maximum stresses developed at the left corners of the footing.

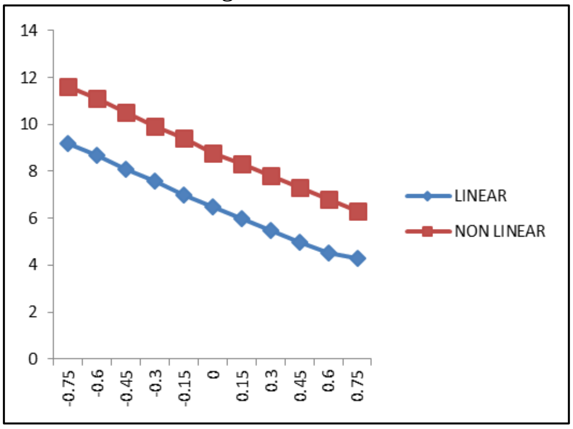


Fig. 12: Displacement Diagram (Y-AXIS)

The Displacement in case of nonlinear footing are greater than linear footing throughout the footing width. The displacement is greater at left corner of the footing.

The values of stresses & displacement in the region where the footing lies with the bed of soil have been tabulated below for constant load of 500 KN and constant size footing 1500mm*1500mm

Stress at	Case	Stresses in KN/m^2		Displacement in mm	
		Linear	Non linear	Linear	Non linear
Centre	Uniaxial	118	130	4.15	6.52
Centre	Biaxial	118	130	4.15	6.52

Table 2: Concentric loading

Stress at	Case	Stresses in KN/m^2		Displacement in mm	
		Linear	Non linear	Linear	Non linear
The distance of b/12 towards left from C.G. of footing area	uniaxial	201	215	5.5	7.9
The distance of b/6 towards left from C.G. of footing area	uniaxial	250	266	6	8.4
The distance of b/3 towards left from C.G. of footing area	uniaxial	363	379	7.1	9.5
The distance of b/2.5 towards left from C.G. of footing area	uniaxial	407	416	7.5	9.9
The distance of b/6 towards left from C.G. of footing area	Biaxial	280	293	6.4	8.7
The distance of b/2.5 towards left from C.G. of footing area	Biaxial	590	605	9.6	11.6

Table 3: Eccentric loading

IV. CONCLUSION

The conclusion can be listed and discussed by observing the comparative outcomes of the graphs for all cases under uniaxial and biaxial category.

It is noted that minimum stresses and displacement is found in case of footing at center which is case1 for both uniaxial and biaxial category. The same result is found in both linear and nonlinear footing problem.

For all uniaxial and biaxial cases examined the stresses and displacement found in nonlinear footing problem are greater than linear footing problem.

It is also concluded that as the column position shifted towards left, for both uniaxial and biaxial footing problem the stresses and displacement increases. As a result case5 in uniaxial problem and case 3 in biaxial problem is under maximum stresses and displacement.

Stresses and displacement increases towards left side with variation in cases subjected to shifted position of column towards left. In uniaxial X direction stresses and displacement increases towards left side with variation in case1 to case 5 respectively. While in Y direction values of stresses and displacement is almost constant and unchanged along the footing width for each uniaxial case.

Stresses and displacement increases towards left side with variation in cases subjected to shifted position of column towards left. In biaxial footing problem both X and Y directional stresses and displacement increases towards left side with variation in case1 to case 5 respectively.

It is concluded that software modeling and analysis can be effectively used and applied in real word for footing design. It is recommended to use software as a part of regular footing design practices to save time and money spent in footing design. It is also safer and error less to use software application for footing design.

Generally the tension zone is obtained beyond the point of maximum eccentricity i.e. b/6, but in this case it has been obtained beyond the value of b/4.

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