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A Comparative Study On Load-Moment Interaction Diagrams For L Shaped Rc Columns With That Of Circular Columns.

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ABSTRACT

This paper aims at analyzing and comparing the behavior of uni-axially eccentrically loaded columns of L shaped section with that of Circular columns using an analytical method in developing moment-curvature relationships. The conventional method of analyzing rectangular columns subjected to bending using interaction diagrams is presented with Design aid for Reinforced concrete structures, SP-16.This study provides an insight to the moment carrying capacity and curvature of L shaped column and circular columns, the moment curvature relation of L; shaped and circular columns was also compared with that of ETABS to estimate the possible deviations. The moment-curvature relations for columns with grade of concrete as M_{30} and grade of steel Fe 415 is presented.

Keywords—L shaped and Circular columns, Interaction Diagrams, Moment Curvature Relationship, Load Moment Interaction.

I. INTRODUCTION

A. General

In all the structural system, Columns are the main structural component and have to be designed with very special care because their failure in carrying the load will result in the collapse of the structural system itself in contrary to the failure of beams which will be of localized nature. In this paper, a method of analyzing the complete behavior of columns of L shaped cross-section and Circular columns is proposed, wherein the analysis is based on the study of moment curvature relationship derived from load-moment interaction diagrams developed using a strain based method. The sectional characteristics of special shaped columns like L columns are different in comparison to that of conventional rectangular and circular columns with their influence in load moment carrying capacities mainly because the centre of gravity for L columns lies outside the section. Due to lack of codal provisions on behavioral and design aspects of L shaped columns in this work, emphasis is on establishing strength characteristics of L columns as well as Circular columns which is interpreted in the form of interaction diagrams and moment curvature relations. A computer analysis method was developed by Mon-Chen Liu (1), for the analysis of L shaped RC columns and are validated using numerical and experimental results.The effects of several types of cross sections on the inter relationship of axial load, moment and curvature was studied and results showed a considerable influence of shape of cross-section on the failure envelop (3).Research on columns of l shaped cross section subjected to combined biaxial bending and tension was carried out to evaluate ultimate strength of the columns of L shape (4).Inverse method of analysis was adopted to develop a failure envelop which intern was used to evaluate the ultimate capacity of L shaped columns and the results were compared with the experimental investigation (6).The application of interaction diagrams and load contours developed for L shaped in designing L shaped columns was presented in a research work (7).It was presented in a research work that the actual buckling stress for a column can also be developed by exact theory which gives the failure envelop of steel columns of various shapes such as box, I,H AND T shapes (8).The present work is to develop interaction diagrams and corresponding moment-curvature relations for L shaped RC columns as well as for Circular RC columns and to do a comparative study on Load-moment interaction diagrams for L shaped and Circular RC columns.

B. Interaction Curve

The interaction diagram is a visual representation of combined loads (bending and axial) that will cause column failure. It is drawn in order to determine if the maximum axial load and moment exceeds the capacity of the column. The interaction curve is a complete graphical representation of the design strength of a uniaxially eccentrically loaded column of given proportions. In this P_u represents ultimate load carrying capacity of concrete column and Mu represents ultimate moment carrying capacity of concrete column. Using the design interaction curve for a given column section, it is possible to make a quick judgment as to whether the section is safe or not under a specified factor load effect combination (P_u and M_u). If the points given by the co-ordinates (P_u and M_u) are within the design interaction curve, the column is implied to be safe. In other words, the design interaction curve serves as a failure envelope, though, it must be noted that the term 'safe' actually implies that the risk of failure deemed by the code is acceptably low.

1. Salient Points on the Column Interaction Curve

The salient points marked in the interaction curve in fig 1 correspond to the failure strain profiles.

- The point 1 in fig 1 corresponds to the axial loading condition with e=0. In this case of pure axial compression, $M_{uR} = 0$ and P_{uR} is indicated as P_{u0} given by the equation

$$P_{u0} = 0.446\, f_{ck}\, A_c + X\, fy\, A_s$$

Where, A_c = Area of concrete excluding area of steel incorporated in the section
A_s = Area of steel present in the section
F_y = Grade of steel
X= 0.77 and 0.75 for steel grades of Fe 415 and Fe 500 respectively.

- The point 1' in fig 1 corresponds to the axial loading condition with minimum eccentricity e_{min}.
- The point 3 in fig 1 corresponds to the condition where neutral axis position is equal to the depth of the section i.e $x_u = D$ where $e = e_d$. For $e < e_d$, the entire column section is under compression and the neutral axis is located outside the section ($x_u > D$), with $0.002 < e_{cu} < 0.0035$. For $e > e_d$, the neutral axis is located within the section ($x_u < D$), with $e_{cu} = 0.0035$ at the highly compressed edge. Point 2 represents general case, with neutral axis outside the section ($e < e_d$).
- The point 4 in fig 1 corresponds to the balanced failure condition with both concrete and steel undergoing maximum yield thereby representing pure flexure condition.
- The point 5 in fig 1 corresponds to the pure bending condition and at this stage the concrete suffers pure tensile failure.

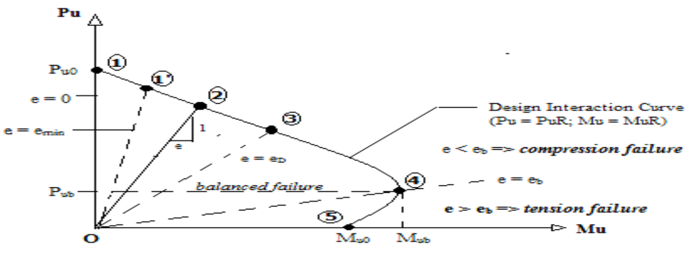

Figure 1: Idealized Moment –Curvature Relation

C. **Moment Curvature Relation**

Moment curvature diagram is a graphical representation of variation of moment of resistance of section with respect to curvature. Moment of resistance is the moment generated by compressive and tensile stress resultants. Curvature is the angle in radians made by the final portion of the cross section based on the assumed extreme fiber strain in the vertical direction. It is also very useful in determining the ductility of steel connection or reinforced member. In seismic design, rotation capacity becomes important factor. This diagram helps us to understand even if plastic capacity is reached there will some energy dissipation potential. The member may not carry more load after certain point but it can deform without losing capacity. This is nothing but ductility. In seismic design it is essential to know the ductility behavior to prevent sudden collapse mechanism.

1. Salient Features of Moment Curvature Curve

The analysis structure is generally done by the conventional elastic theory even though the design is done by the limit state method by taking in to account the material non linearity. This is permitted by the code (Cl. 22.1 of IS: 456:2000(9).This method holds good in determinate as well as in indeterminate structures, even under factored load conditions till the moment-curvature relationship remains linear. For under reinforced sections this is valid until the reinforcing steel provided has not yielded. However once yielding take place (at any section), the behavior of a structure enters an inelastic phase, and the simplified conventional linear elastic structural analysis is no longer valid. Inelastic analysis is thus called for to determine the bending moments for loading beyond the yielding stage. In simplified limit analysis the moment-curvature relation is an idealized bilinear elastic-plastic relation as shown in Figure 2.

With the yielding of the tension steel the ultimate moment of resistance (M_{ur}) is assume to have reached the critical section. On increasing the strain the moment resisted by the section does not increase any further however there is a significant increase in curvature. Formation of further plastic hinges take place, and finally the limitation in ductile behavior (i.e. the curvature φ reaching its ultimate value) at any one plastic hinge location results in the crushing of concrete. Therefore, moment-curvature relation for all flexural members is important modeling parameter for nonlinear structural analysis.

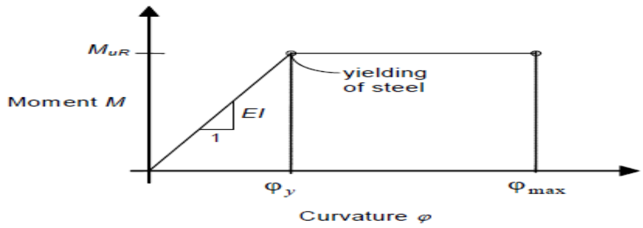

Figure 2: Idealized Moment-Curvature Relation

II. METHODOLOGY

A. **Design Methods**

Working method strategy and limit state technique are the two standard design theories utilized concerning to reinforced concrete design. The design philosophy that was applied in the past was working stress method of design. This conventional outline approach which depends on linear elastic theory is still under training in a few nations in which working loads are considered with the end goal of design with no extension for different vulnerabilities which the structure endures amid its administration period. In this task "Limit State Method" outline approach is embraced for the investigation.

Following are the basic assumptions made in the limit state design philosophy

- The plane section normal to that axis of column before deformation remains plane after deformation, i.e. the strain at any point is proportional to its distance from the neutral axis.
- The tensile strength of concrete is neglected.
- The failure of the concrete is governed by the maximum strain criteria. For member under concentric load the ultimate strain in concrete is taken as 0.002. The ultimate strain in concrete in bending is taken as 0.0035. For the entire section in compression under axial load and moment, the transition of strain from 0.002 for pure axial load condition to 0.0035 for pure bending condition governs the failure of the column section. The strain distribution line passes through the point of interaction F of strain distribution line of

two extreme conditions of uniform strain of 0.002 for purely axial load case and when strain at the least compressed edge is 0.0 and strain at the highly compressed edge is 0.0035 for the neutral axis lying at the edge of the least compressed edge (fig 3).Thus the maximum strain at the most compressed edge of the section shall be taken as 0.0035 minus 0.75 times strain in the least compressed edge of the section.

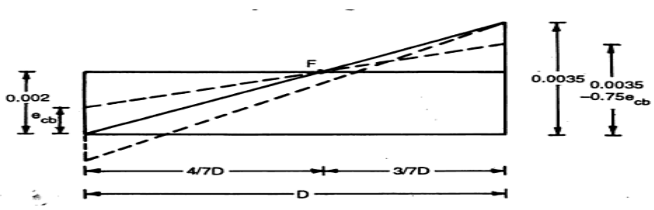

Figure. 3: Limiting strain diagram for column section

- The design stress-strain curve of concrete is shown in fig 4. Compressive strength of concrete in the structure is assumed to be 0.67 times fact. Partial safety factor equal to 1.5 is applied to the strength of concrete in addition to it. Therefore, the design strength of concrete is 0.67fck/1.5, i.e.0.446fck. The equation of the parabolic part of the curve is given by f_{cc}=446f_{ck} (e_c-250e_c^2).
- The short-term static modulus of elasticity of concrete is given by,

$$Ec= 5000*fck^{0.5}$$

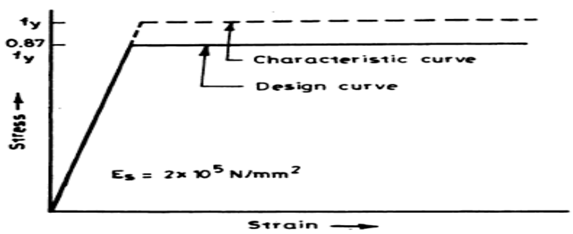

Figure 4: Design stress- strain curve for steel

- The design stress-strain curve for mild deformed bars is as shown in fig 5. The partial factor of safety, to the strength of steel is taken as 1.15. Therefore, the design strength is fy/1.15, i.e. 0.87fy. For mild steel, the design stress-strain curve is linear up to a stress of 0.87fy and thereafter, the strain increases at constant stress.

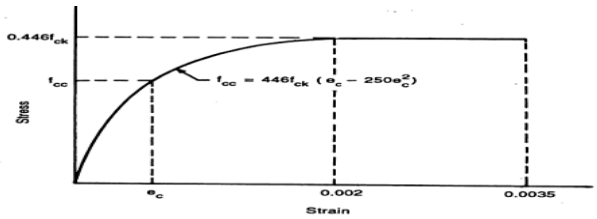

Figure 5: Design stress- strain curve for concrete.

III. DESIGN PROCEDURE

A. **Introduction**

The co-ordinates of the design interaction curve, MuR (on x hub) and PuR (on y pivot) can be resolved for any discretionary profundity of nonpartisan hub x_u. Having found (around) x_u/D the co-ordinates of the design interaction curve can be acquired with an arrangement of customary additions.

1. Design Procedure for developing Interaction Curve for L shaped RC columns

- For the case of neutral axis lying inside the section **$K=X_u/D < 1$**

Step 1: Assume f_{ck} , f_y and diameter of reinforcing bars.
Step 2: Axial load carrying capacity of concrete = 0.361*f_{ck}*b*d
Step 3: Axial load carrying capacity of steel

- e_{sc} = 0.0035 [D-d']/D>0.002
- f_{cc}= 0.446 f_{ck}
- e_c <0.002
- f_{cc} = 0.446 e_c f_{ck} [1-250 e_c]
- Total Axial load, P_u= (0.361 f_{ck} B D)+ ∑Ast(stress in steel-stress in concrete)
- Ultimate moment, M_u=0.361 f_{ck} b d [C.G-d']
- Curvature, Ø = (0.0035/X_u)
- N-A lies outside the section K= X_U/D >1
- (0.0035-0.75 e_{cb})/ (D+0.1D)=e_{bb}/0.1D
- e_{cu} = 0.0035-0.75e_{cb}
- C_c' =C_c/(f_{ck} B D) and Y_c' =Y_c/D
- Axial load carrying capacity of concrete= Cc'f_{ck} B D

Stress calculation

- e_{cb} = e_{cu}(D-d')/D>0.002
- f_{cc}= 0.446 f_{ck}
- e_{cb}< 0.002
- f_{cc} =0.446 e_{cb} f_{ck} [1-250 e_{cb}]
- Total Axial load, Pu= (Cc' f_{ck} B D) +∑Ast (stress in steel-stress in concrete)
- Moment, Mu= (Cc' f_{ck} B D) [CG-Yc'd]
- Curvature, Ø = (e_{cu} / X_u)

2. Design Procedure for developing Interaction curve for Circular RC columns

- For the case of neutral axis lying inside the section **K =Xu/D <1**

Step 1: Assume Area same as that of L shaped column and fix the diameter of the Circular Column, f_{ck} , f_y and diameter of reinforcing bars.
Step 2: Axial load carrying capacity of concrete = **0.4*f_{ck}*A**
Step 3: Axial load carrying capacity of steel

- e_{sc}= 0.0035 [D-d']/D>0.002
- f_{cc}= 0.446 f_{ck}
- e_c < 0.002
- f_{cc}= 0.446 $e_c f_{ck}$ [1-250 e_c]
- Total Axial load, Pu= (0.4f_{ck}A) +∑Ast (stress in steel-stress in concrete)
- Ultimate moment, Mu=0.4f_{ck}A [C.G-d']
- Curvature, Ø = (0.0035/Xu)

- N-A lies outside the section K= X_U/D >1
- (0.0035-0.75 e_{cb})/(D+0.1D)=e_{bb}/0.1D
- e_{cu}=0.0035-0.75e_{cb}
- Axial load carrying capacity of concrete= 0.4f_{ck}A

Stress calculation

- e_{cb}=e_{cu}(D-d')/D>0.002
- f_{cc}=0.446 f_{ck}
- e_{cb}<0.002
- f_{cc} =0.446 e_c b f_{ck} [1-250 e_{cb}]
- Total Axial load, Pu= (0.4 f_{ck}A) +∑Ast (stress in steel-stress in concrete)
- Moment, Mu= (0.4f_{ck}A) [CG-d']
- Curvature, Ø = (e_{cu} / Xu)

The stress in steel corresponding to a particular strain is obtained from table A of SP -16:1980(10)

Table 1: Coefficients C_c' and Y_c'

$K = X_U/D$	$C_c' = C_c/f_{ck}\,BD$	$Y_c'=Y_c/f_{ck}BD$
1	0.361	0.416
1.05	0.374	0.432
1.1	0.384	0.443
1.2	0.399	0.458
1.3	0.409	0.468
1.4	0.417	0.475
1.5	0.422	0.480
2.0	0.435	0.491
2.5	0.44	0.495
3.0	0.442	0.497
4.0	0.444	0.499

IV. RESULT AND DISCUSSION

A. General

An example of L shaped RC column as well as an example of Circular RC column of equal Area is considered and a comparative study on both is done mainly considering the load and moment carrying capacity along with the effect on Moment-curvature relationship, a sample result was also compared with that of ETABS result to analyze the possible deviation because of the whitney's stress block parameters adopted, in comparison to the parabolic rectangular stress block adopted in the proposed exact method.

- Grade of concrete = 30 N/mm2
- Grade of steel = 415 N/mm2
- Diameter of reinforcing bars =16 mm

1. Example of L Column (When Highly Compressed Edge Lies on Web)

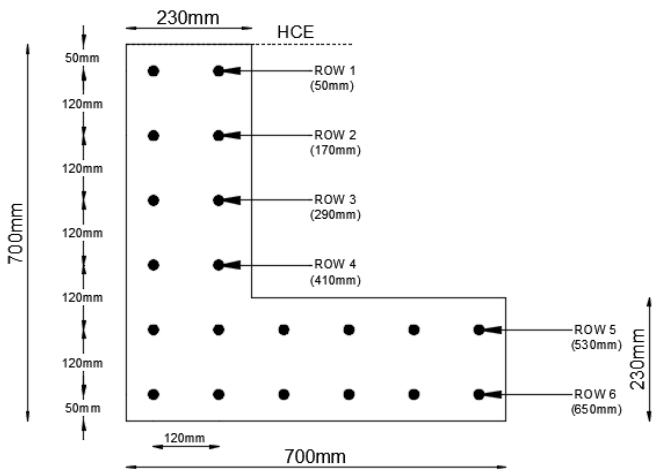

Figure 6: Column with Neutral axis varied along 700mm (downwards).

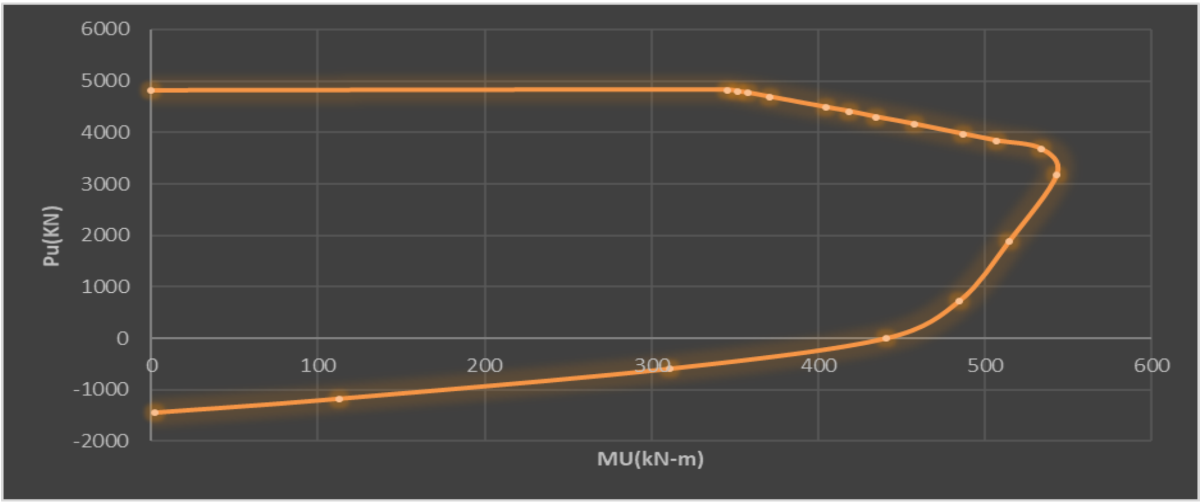

Figure 7: Interaction curve for L-shape concrete column for M_{30} Grade of concrete and Fe 415 steel

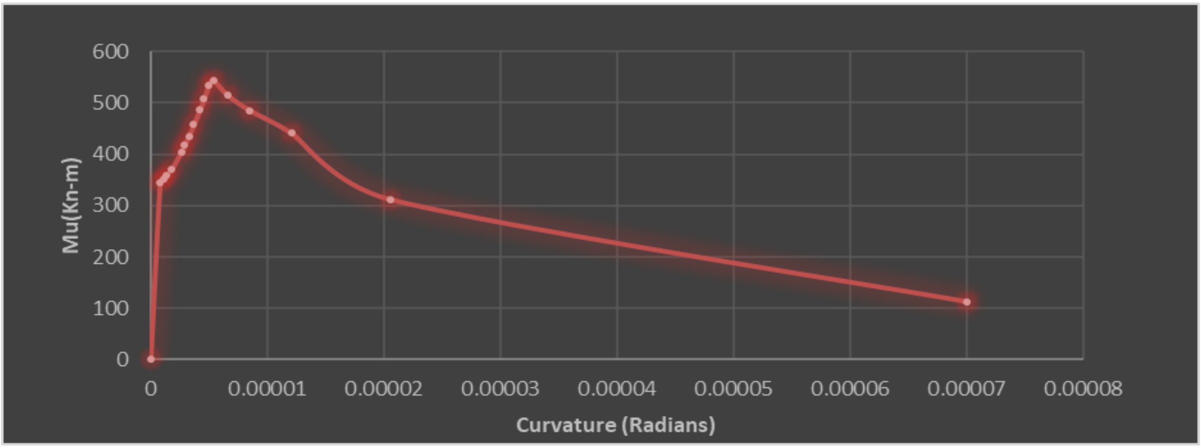

Figure 8: Moment curvature curve for L-shape concrete column for M_{30} grade of concrete and Fe 415 steel.

2. Example of L Column (When Highly Compressed Edge Lies on Flange)

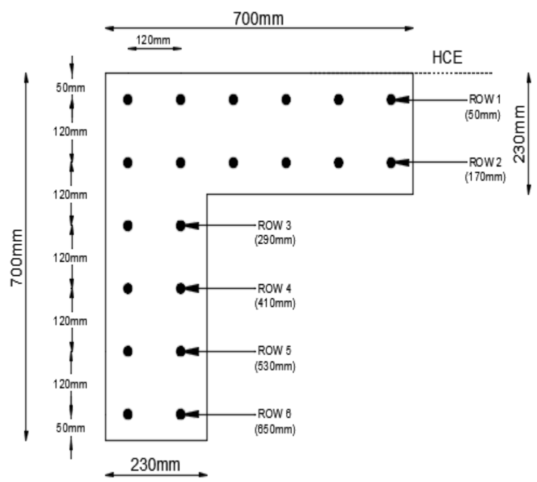

Figure 9: Column with Neutral axis varied along 700mm (downwards).

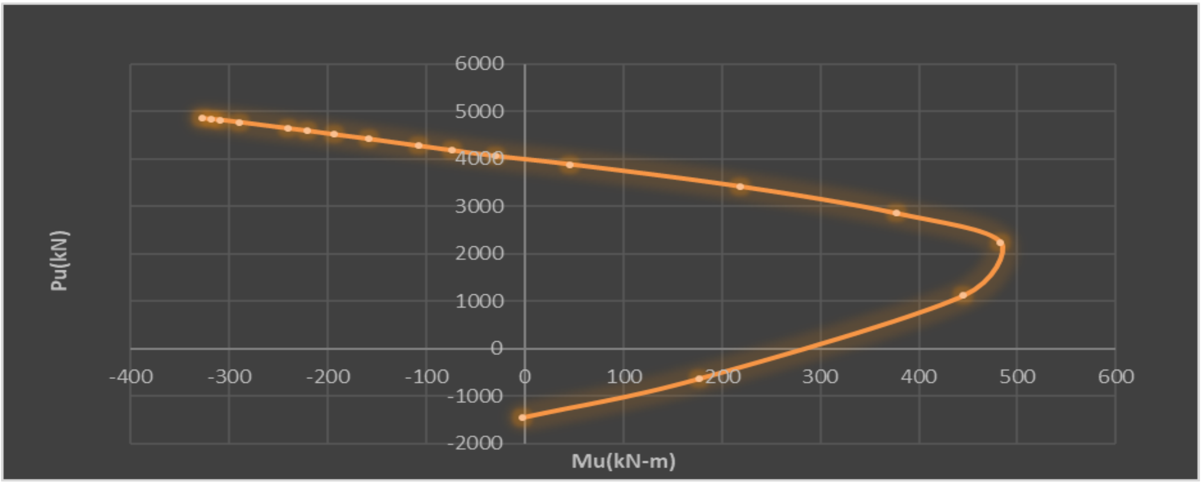

Figure 10: Interaction curve for Inverted L-shape concrete column for M_{30} Grade of concrete and Fe 415 steel

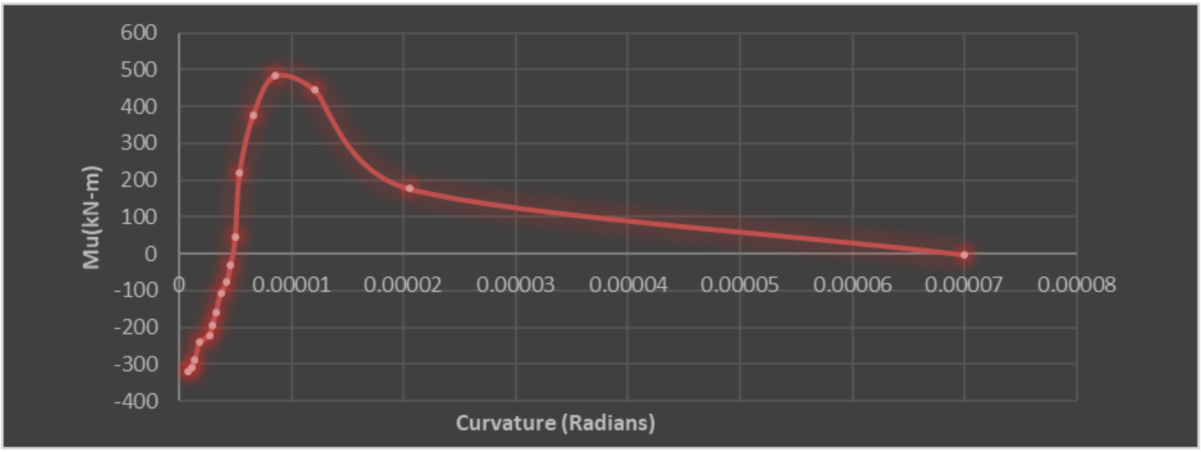

Figure 11: Moment curvature curve for Inverted L-shape concrete column for M_{30} grade of concrete and Fe 415 steel.

3. Example for Circular Column

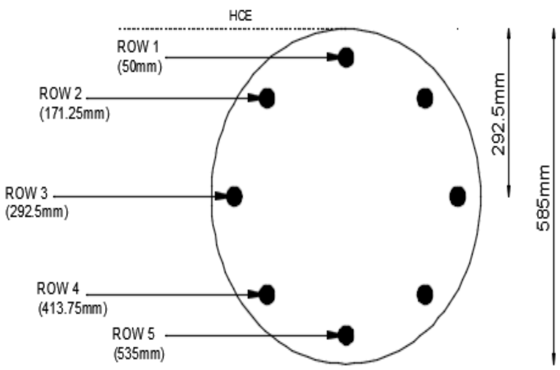

Figure 12: Circular Column with Neutral axis varied downwards (HCE at top)

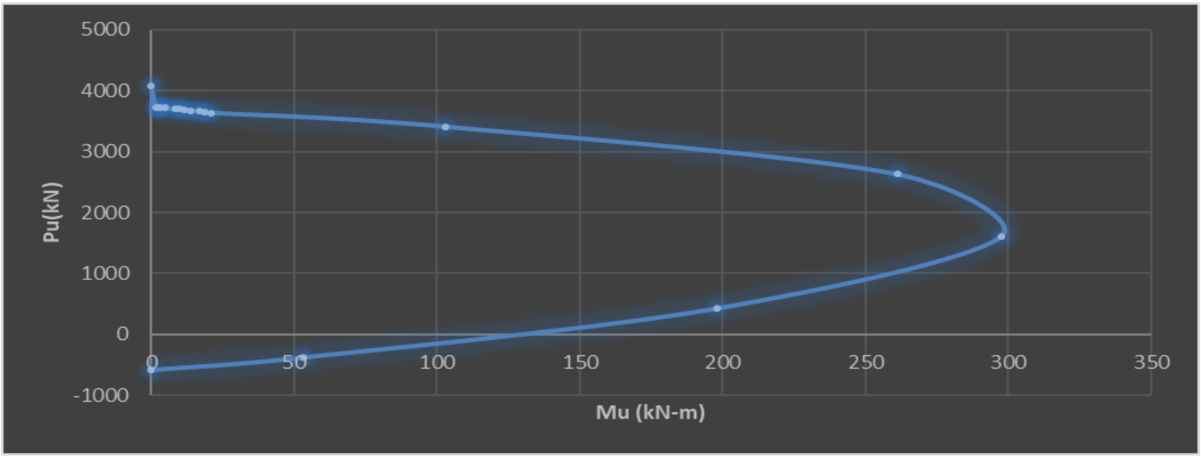

Figure 13: Interaction curve for Inverted L-shape concrete column for M_{30} Grade of concrete and Fe 415 steel

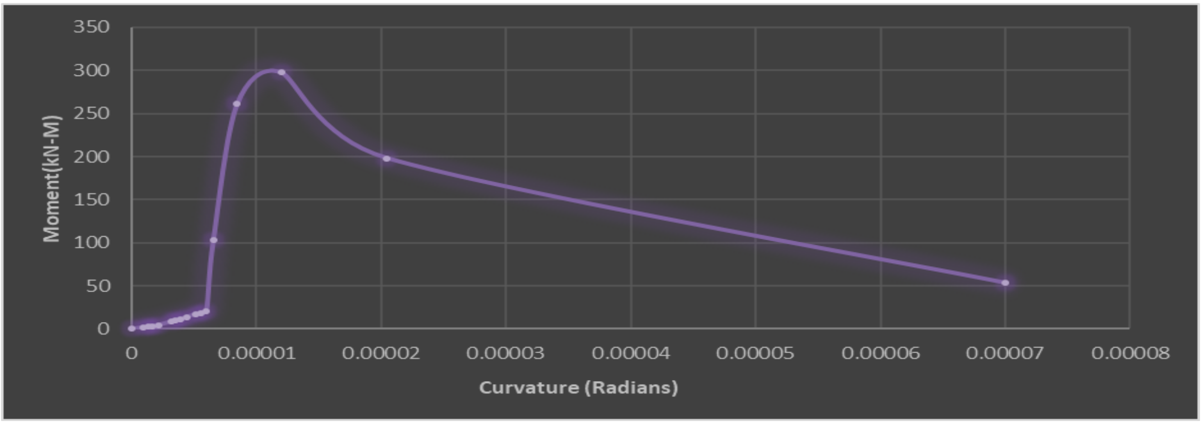

Figure 14: Moment curvature curve for Inverted L-shape concrete column for M_{30} grade of concrete and Fe 415 steel.

4. Comparison of L section (HCE lies in the web) and circular column:

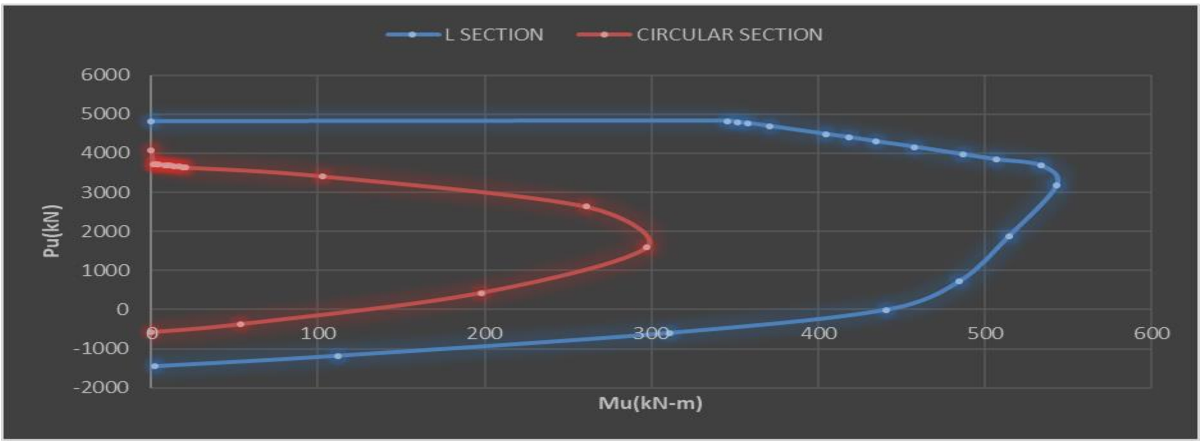

Figure 15: Comparison of Interaction diagram Circular column section and L shape section column of M30 grade concrete and Fe415 steel.

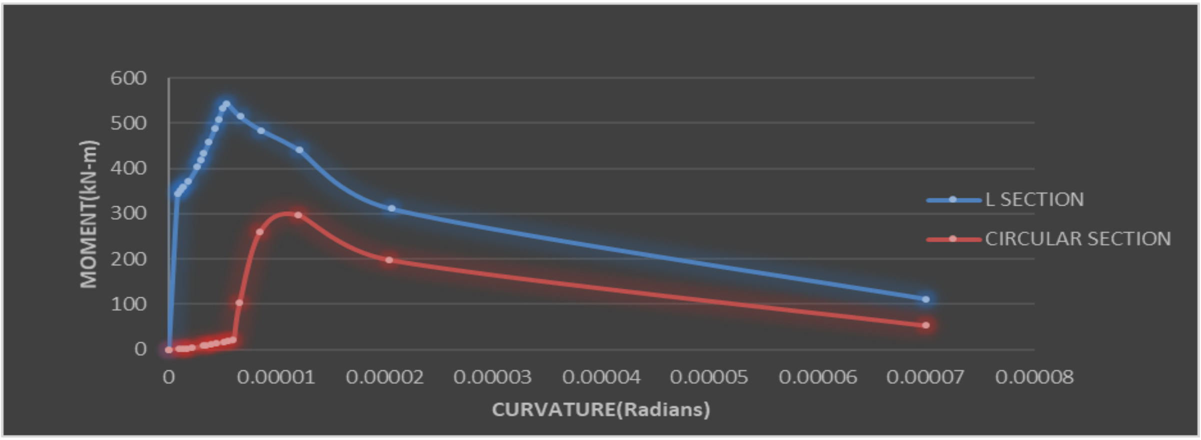

Figure 16: Comparison of Moment Curvature of Circular column section and L shape section column of M_{30} grade concrete and Fe415 steel.

5. Comparison of L section (HCE lies in the flange) and circular column:

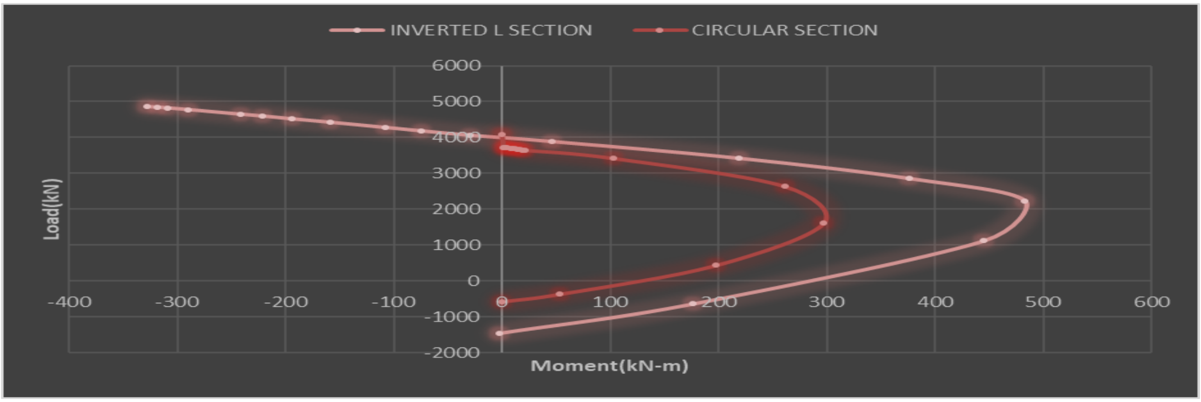

Figure 17: Comparison of Interaction diagram of Circular column section and Inverted L shape section column of M_{30} grade concrete and Fe415 steel.

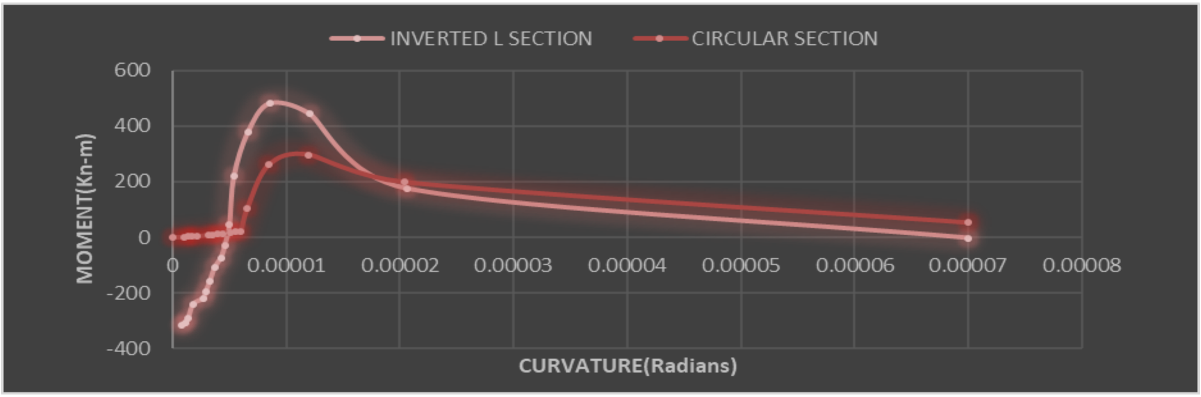

Figure 18: Comparison of Moment Curvature of Circular column section and Inverted L shape section column of M_{30} grade concrete and Fe415 steel.

6. Comparison of Manual Results with ETABS

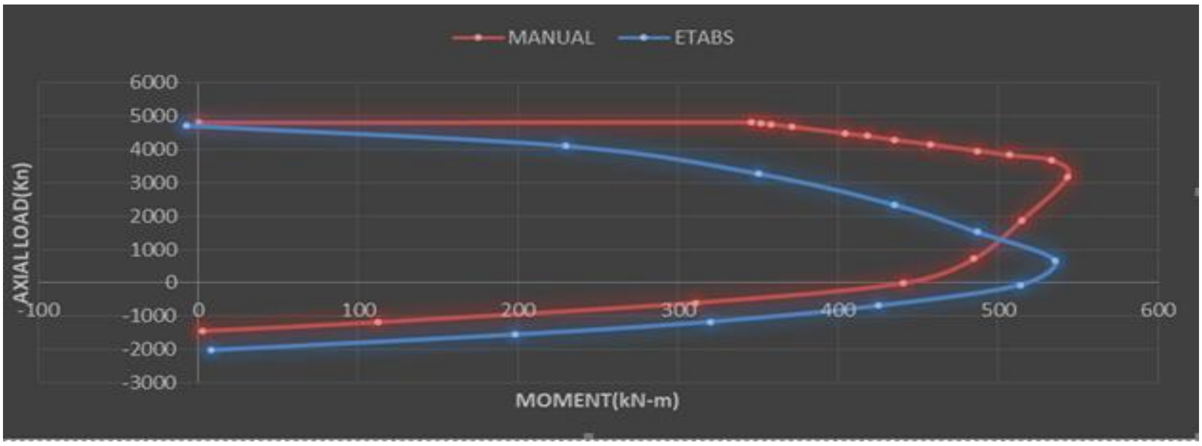

Figure 19: Comparison of Interaction Curve of L shape column Manual results with ETABS for M_{30} grade concrete

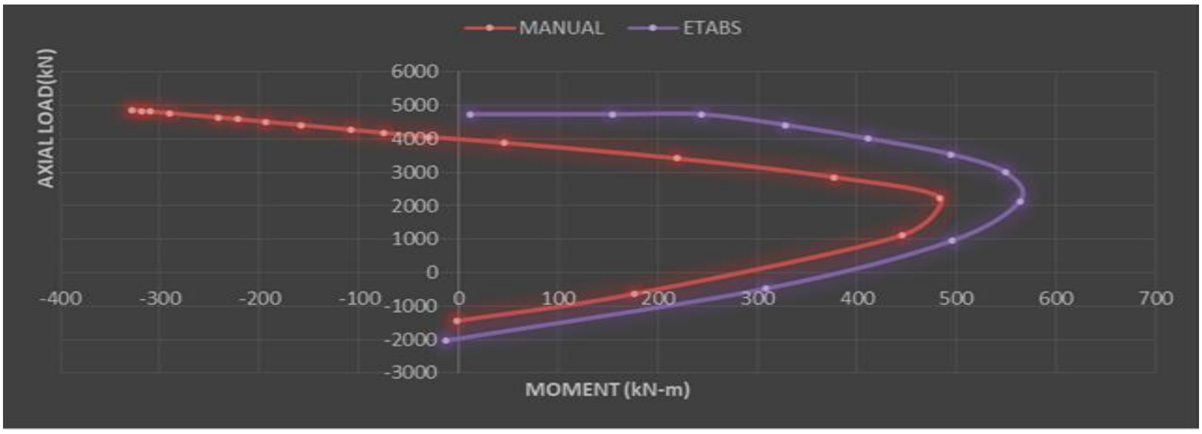

Figure 20: Comparison of Interaction Curve of inverted L shape column Manual results with ETABS for M_{30} grade concrete.

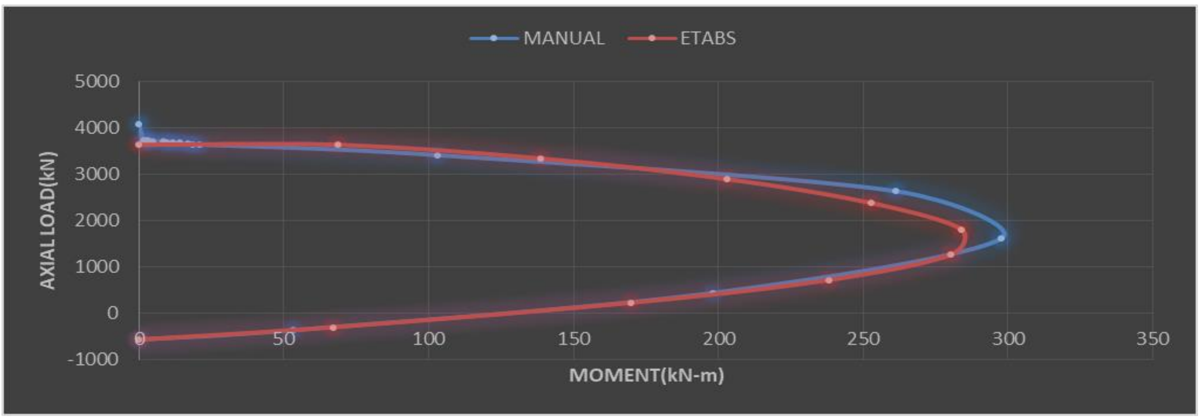

Figure 21: Comparison of Interaction Curve of Circular column Manual results with ETABS for M_{30} grade concrete

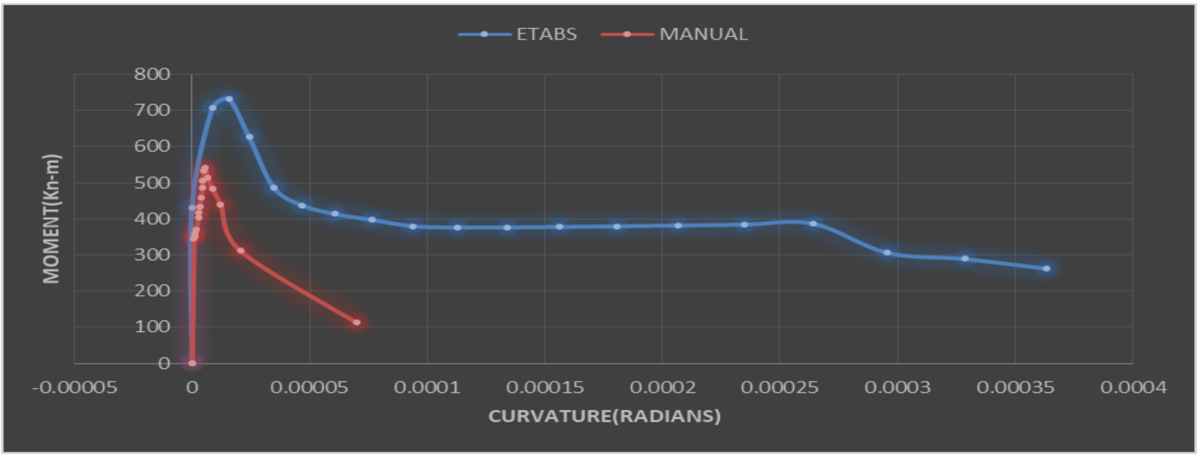

Figure 22: Comparison of Moment Curvature of L shape column Manual results with ETABS for M_{30} grade concrete

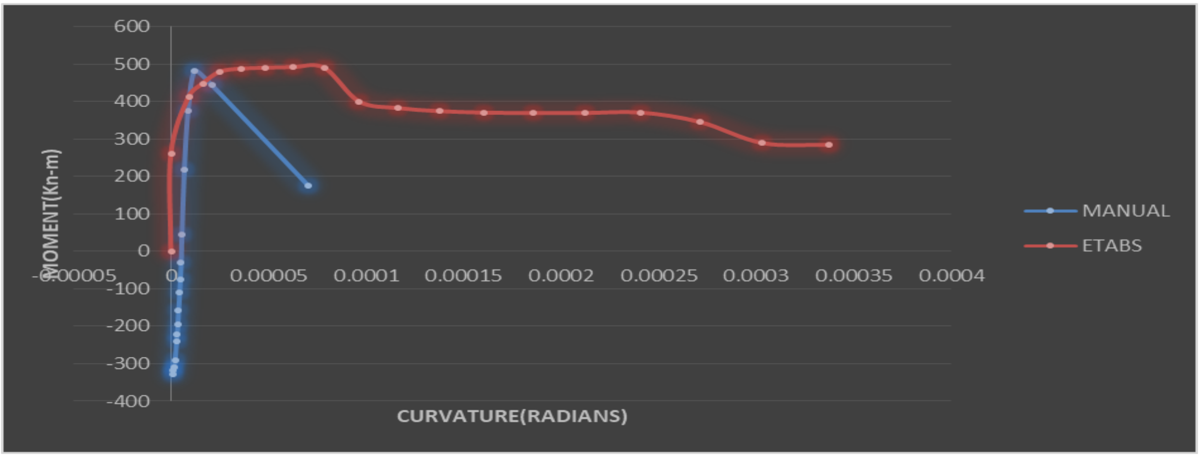

Figure 23: Comparison of Moment Curvature of inverted L shape column Manual results with ETABS for M_{30} grade concrete

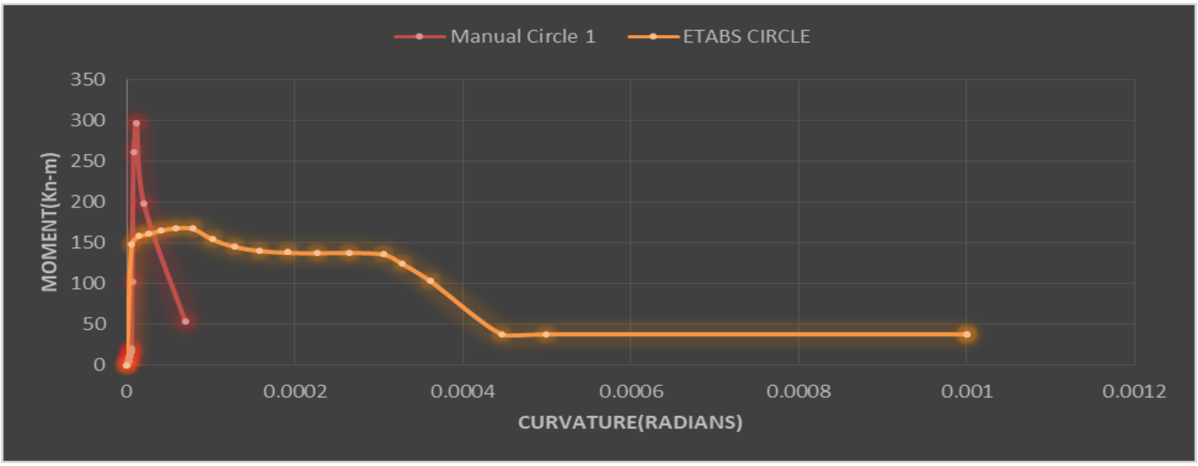

Figure 24: Comparison of Moment Curvature of Circular column Manual results with ETABS for M_{30} grade concrete

V. CONCLUSION

The analytical investigation carried on ultimate design load and moment capacities of L and Circular Shaped short columns has resulted the following concluding remarks in their relation to their performance.

- The comparison of load moment interaction between L and Circular shaped column showed that L columns have significant higher performance in resisting the load and moment combination maintaining the same area of concrete and steel.
- The ultimate moment carrying capacity of L shaped column with web being highly compressed edge presented a 45.22% increase compared to Circular shaped section which is of significant importance in terms of structural performance (Fig 15).
- The ultimate moment carrying capacity of L shaped column with flange being highly compressed edge presented a 38.41% increase compared to Circular shaped section which is of significant importance in terms of structural performance (Fig 17).
- The ultimate load carrying capacity of L shaped column with web being highly compressed edge presented a 15.45% increase compared to Circular shaped column section.
- The ultimate load carrying capacity of L shaped column with flange being highly compressed edge presented a 15.98% increase compared to Circular shaped column section.
- Study on Moment curvature relation for L shape column with web being highly compressed edge depicts that moment carrying capacity for all curvature are noticeable higher than the circular section. This has significant importance in seismic performance
- The study on Moment curvature relation for L column with flange being highly compressed edge depicts that moment capacity for L columns under curvature values less than 0.00002 is higher than that for circular section. This trend slightly reverses beyond the curvature 0.00002(Fig 18).
- The interaction diagrams developed by analytical method presented in research work were compared with that developed by ETABS and results established that for L column(Fig 22) with web being highly compressed edge ETABS underestimates the moment capacity by 5.36%, for L column(Fig 23) when flange being highly compressed edge ETABS underestimates moment capacity by 17.30% and for circular column(Fig 24) ETABS underestimates moment capacity by 20.01%.
- The possible deviation in the result is mainly due to the equivalent rectangular stress block adopted in ETABS.
- Whereas the suggested in analytical investigation is of parabolic rectangular type considering the nonlinear behavior of the material hence being more accurate.

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