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ANALYSIS OF TENSILE CAPACITY OF REINFORCED CONCRETE COLUMNS AND ITS DUCTILITY PERFORMANCE TOWARDS SEISMIC BEHAVIOR

Vigneshvar R
Masters Student, School of Civil and Chemical Engineering,
VIT University, Vellore, Tamil Nadu.

Hareesh M
Assistant Professor, School of Civil and Chemical Engineering,
VIT University, Vellore, Tamil Nadu.

Sekar S K
Senior Professor, School of Civil and Chemical Engineering,
VIT University, Vellore, Tamil Nadu.

ABSTRACT

In the limit state of collapse design approach for reinforced concrete (RC) columns, the conceptual design criteria is formulated based on the balanced limiting strains i.e. simultaneous crushing of concrete and yielding of steel occurs in extreme concrete fiber and steel, which is designated as 0.0035 and $0.002+(f_y+1.15/E_s)$ *respectively . But the tensile strain in extreme layer of steel is permitted to reach any value more than the prescribed value under crucial scenarios of high seismic influence. Therefore the premature yielding of extreme steel layer over the crushing of concrete, i.e. the under reinforced design of RC columns is not authentified by the existing design approach. Adding to this whenever RC columns are subjected to seismic forces, reversal of stresses occurs i.e. the predominant compressive forces in column changes its behavior to tensile forces. Hence it is mandatory to determine the tensile capacity of column and its corresponding ductile behavior and the strain energy stored in it. The tensile capacity of the column and the range of tension failure under combined compressive axial load and bending is thus identified by determining the Balanced Axial load factor* λ *,in which the computation involves the limiting strain states in concrete and steel. A numerical study is made over the Balanced Axial Load factor* λ *by, varying parameters such as Column section, Percentage of reinforcement excessive limiting strains in steel and with the orientation of the column. Hence a more accepted under reinforced design approach i.e. ductile design is proposed for columns subjected to seismic forces.*

Key words: limiting strain, reversal of stresses, tensile capacity, Balanced Axial Load factor, ductility.

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1. INTRODUCTION

Analysis of any RC column section is authenticated with the aid of Design interaction curve (P-M Curve), in which the curve is a plot between Ultimate Load and Ultimate Moment, with the objective of assessing the safety of column section subjected to specified factored load effects. The points P_{ur} and M_{ur} lies on the design interaction curve whereas the point P_u and M_u is any point within the interaction curve region. For the purpose of assessing safety against collapse, the coordinate point of P_u and M_u should lie within the interaction curve region and any combination of P_u & M_u outside the curve region is considered unsafe for design. In general, any interaction curve comprises of three parts namely the compression failure region, the balanced point and the tension failure region. Whenever a RC column is subjected to seismic forces, it must be assured that the column fails in tension rather than in compression, for the purpose of enhancing the ductile behavior of column. Hence the balanced point must be determined to identify the tension capacity of column, since it acts as a threshold point between the tension and compression failure regions of interaction curve for any column section.

2. BALANCED COLUMN SECTION

As per IS:456(4), the maximum compressive strain in concrete is prescribed as 0.0035, for flexural limit state design, and the tensile strain in the extreme layer of steel is prescribed as $0.002+(f_y+1.15/E_s)$. But in practical, under high seismic scenarios, the limiting strain in extreme layer of steel may go beyond the prescribed the value given in code. Hence the premature flexural yielding of steel over crushing of concrete i.e. the under reinforced design (ductile behavior) is no authenticated by the existing design procedure.

The balanced axial load is to be determined from the balanced strain condition of an RC column section for determining the range of tension failure. The force equilibrium at this balanced strain condition gives the balanced axial load P_b on the section as,

$$P_b = C_c + C_s - T \quad (1)$$

Where C_c is the compression in concrete, C_s is the compression in steel and T is the tension in steel.

In order to obtain a more precise and explicit value of balanced axial load , a balanced axial load factor (λ) is determined such that $\lambda = P_b / P_{uz}$ where the balanced axial load is normalized with respect to ultimate uniaxial compression capacity given by

$$P_{uz} = 0.45 f_{ck} bD + 0.75 f_y A_{sc} \quad (2)$$

Where b & D represents the width and depth of the column section, f_{ck} is the concrete grade, f_y is the grade of steel i.e. the yield strength of steel and A_{sc} is the total area of reinforcement. The Balanced load factor λ for any RC column section needs to be large enough to ensure tension failure and to enhance ductility during seismic effect. The λ is calculated as per the following procedure:

Step 1: Determine the depth of Neutral Axis (N.A) x_{ub} for the balanced strain condition by using the code specified maximum strain values in concrete and steel.

Step 2: Calculate C_c, C_s & T using the design stress strain curve as,

$$C_c=0.362f_{ck}bx_u \quad (3)$$

$$C_s=\Sigma(f_{si}-f_{ci})A_{si} \quad (4)$$

$$T= \Sigma(f_{si}.A_{si}) \quad (5)$$

Where, fsi & f_{ci} denotes the stresses in the ith layer of steel and A_{si} is the Area of steel in that layer.

Step 3: Obtain λ from Eq (1) as,

$$\lambda = \frac{C_c + C_s - T}{0.45f_{ck}bD+0.75f_yA_{sc}} \quad (6)$$

3. NUMERICAL STUDY

The numerical study is made by varying the λ with respect to various column sections and distribution of steel. For a more explicit study, two different cases of steel distribution is considered namely, Case A: Reinforcement on all four sides & Case B: Reinforcement on two opposite sides.

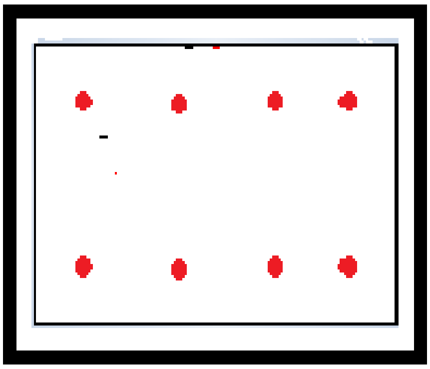

Figure 1 (a) Case A

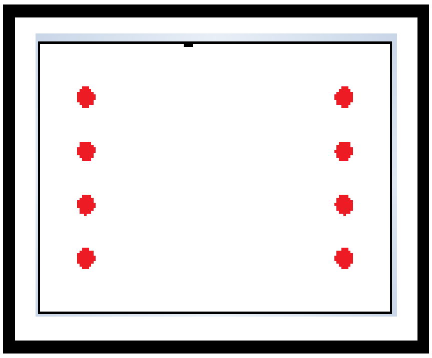

Figure 1 (b) Case B

The grade of concrete adopted for study is M20 and grade of steel adopted is Fe415. The Area of steel is Ast is kept constant for all the sections considered for study. The above mentioned analogy is done as a comparative analysis between columns oriented along X direction and for columns oriented along Y axis. The balanced axial load factor (λ) is varied with various column sections for both the cases of reinforcement considered oriented along X & Y axis.

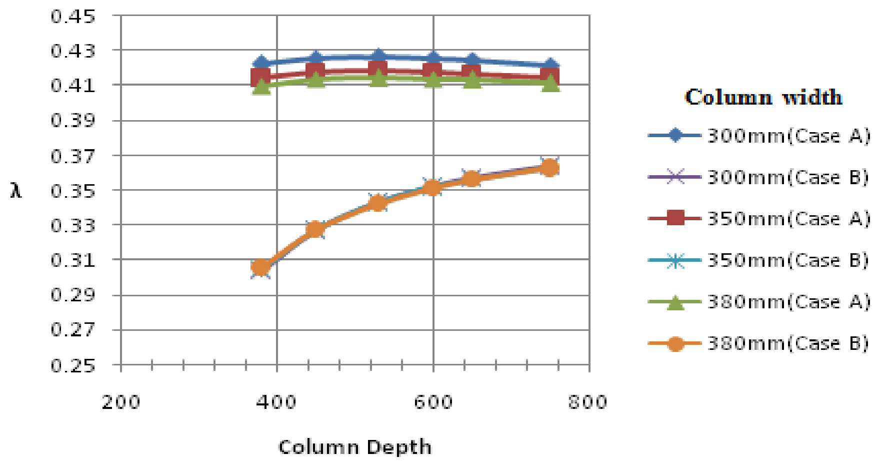

Figure 2 Behavior of λ with depth of column oriented along X axis

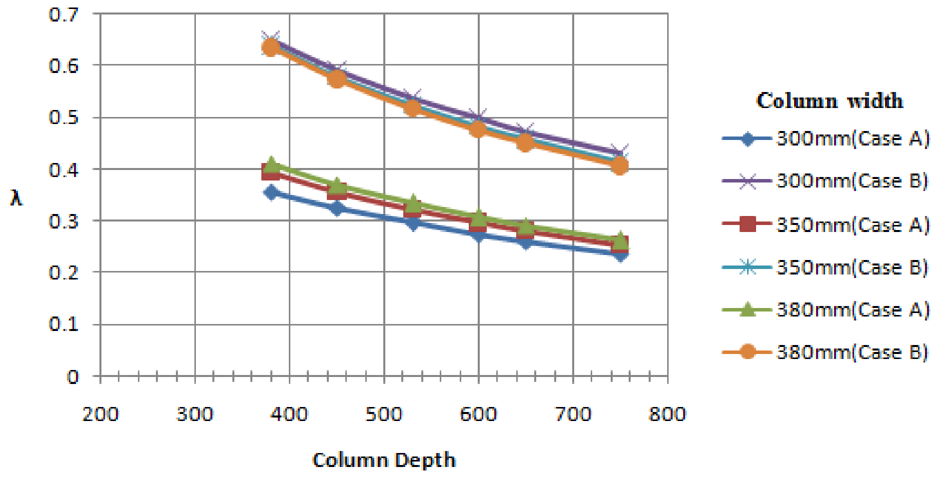

Figure 3 Behavior of λ with depth of column oriented along Y axis

The key observations of the above considered study are:

1. For columns oriented along X direction, the balanced axial load factor (λ) increases with increase in depth of column section.
2. For columns oriented along X direction, the balanced axial load factor (λ) exhibits a higher magnitude for Case A i.e. reinforcements on all sides.
3. For columns oriented along Y direction, the balanced axial load factor (λ) decreases with increase in depth of column section.
4. For columns oriented along Y direction, the balanced axial load factor (λ) exhibits a higher magnitude for Case B i.e. reinforcements on two opposite sides.

The behavior of balanced axial load factor (λ) is studied over the percentage of reinforcement for a particular column cross section of 380mm X 450mm oriented along the X direction as shown below:

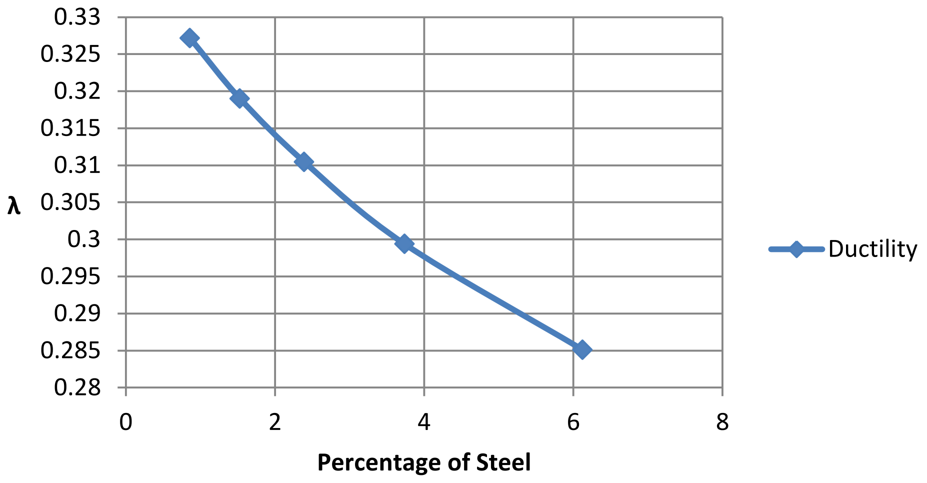

Figure 4 Behavior of λ with percentage of steel

From the above numerical study, it is observed that the percentage of steel reinforcement increases with decrease in balanced axial load factor (λ). Hence it is explicit that, the ductility of column section is significantly more with minimum percentage of reinforcement as the balanced axial load factor (λ) shows an inversely linear fashion with percentage of reinforcement.

For a given percentage of steel and cross section of column (380mmX450mm) , the behavior of balanced axial load factor (λ) is studied with increasing limiting strain value $\varepsilon_{st\ max}$ in extreme layer of steel for both the cases of distribution of steel considered for analysis, as shown below:

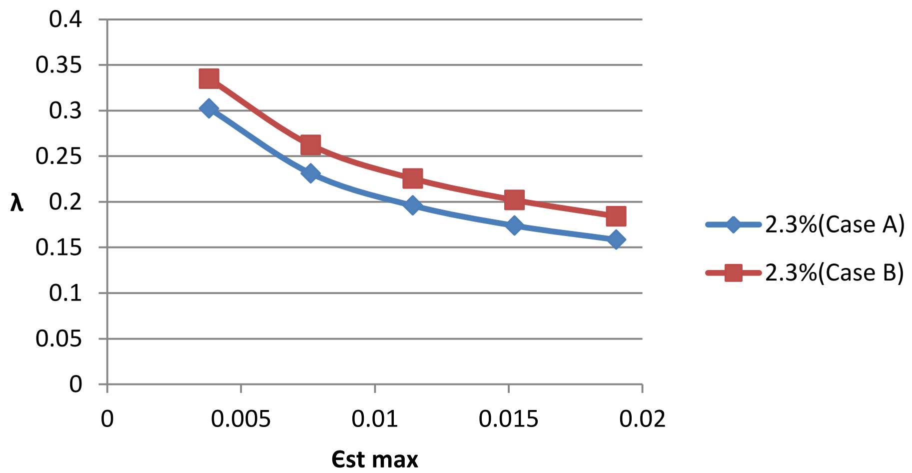

Figure 5 Behavior of λ with multiples of limiting strain in steel $\varepsilon_{st\ max}$

The prime observations made from the above analysis is that:

1. The balanced axial load factor (λ) shows an inversely linear fashion with $\varepsilon_{st\ max}$ i.e. λ decreases with increase in limiting strain in steel.

2. For a particular percentage of reinforcement and a limiting tensile strain $\varepsilon_{st\ max}$, the axial load acting on the column section needs to be restricted, in order to ensure the failure of column through tension rather than compression, under seismic effects.

4. STRAIN DUCTILITY

This numerical study involves the variation of Strain ductility μ_{st} with steel ratio ρ_s , for particular balanced axial load factors (λ). The Strain ductility μ_{st} of column section is calculated as the ratio of maximum tensile strain in longitudinal steel $\varepsilon_{st\ max}$ to that of limiting tensile strain in longitudinal steel ε_s. The steel ratio ρ_s is the ratio of area of steel $A_{st,b}$ required for a strain level of ε_s to the area of steel A_{st} required for a strain level of $\varepsilon_{st\ max}$. The steel ratio is varied with strain ductility for a particular cross section of 380mm X 450mm, with reinforcement distributed on two opposite sides, with varying balanced axial load factors (λ) as shown below:

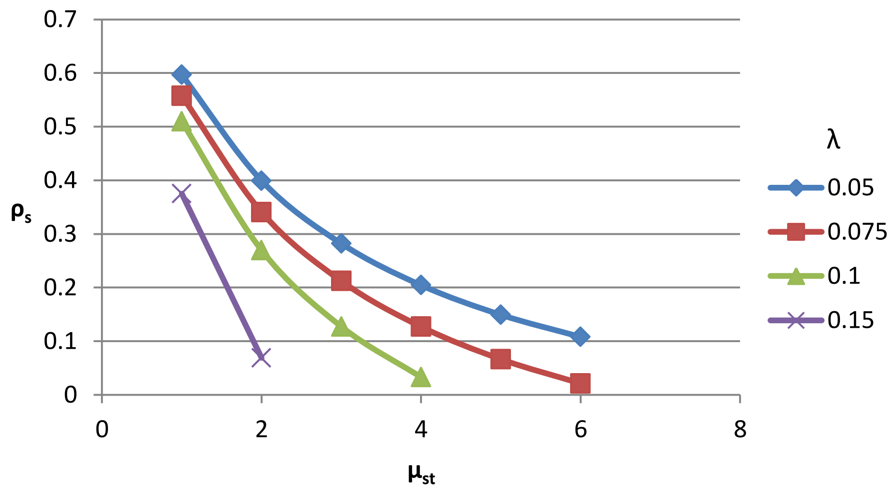

Figure 6 Behavior of λ with longitudinal steel ratio of column sections

It is to be observed from the above study, that:

1. The strain ductility capacity of the given column section decreases with increase in axial load, for the same steel ratio.

2. On the other hand, for the same axial load level, the area of steel required decreases to obtain the desired ductility of the section.

5. BEHAVIOUR OF BALANCED LOAD FACTOR WITH UNEQUALLY SPACED REINFORCEMENT

The effect of Balanced axial load factor (λ) is again computed on par with the unequal spacing of distribution of longitudinal reinforcement in various column sections, oriented along X and Y axes. A comparative analysis over Balanced axial load factor (λ)is done between the sections with equally spaced reinforcement distribution and with unequally spaced reinforcement distribution, for columns oriented along major and minor axes, as show below:

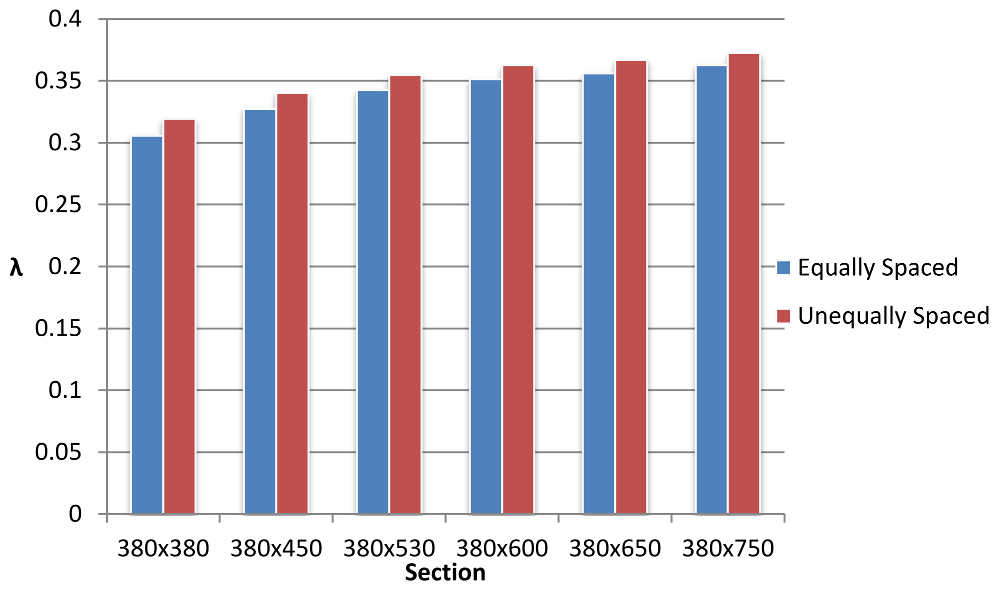

Figure 7 Effect of λ with Unequal distribution of column sections oriented along X axis

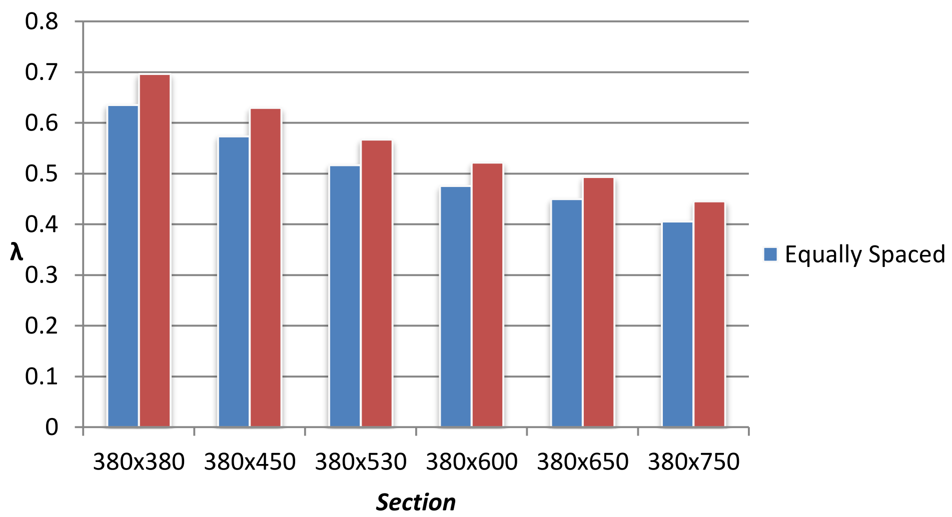

Figure 8 Effect of λ with Unequal distribution of column sections oriented along Y axis

From the above study, it is explicit that, the Balanced axial load factor (λ) is significantly more when bars are unequally spaced rather than when bars are equally spaced in column section, ensuring more tensile failure. The above study is also validated with the help of load moment (P-M) interaction curve. The P-M interaction curve is prepared for a column section of size 380mmX450mm, separately for bars equally spaced and unequally spaced. The stress and strain exerted on each row of the bars are calculated and the plot between load and moment is obtained by varying the neutral axis depths and the corresponding ultimate resisting moments is calculated and plotted as shown below:

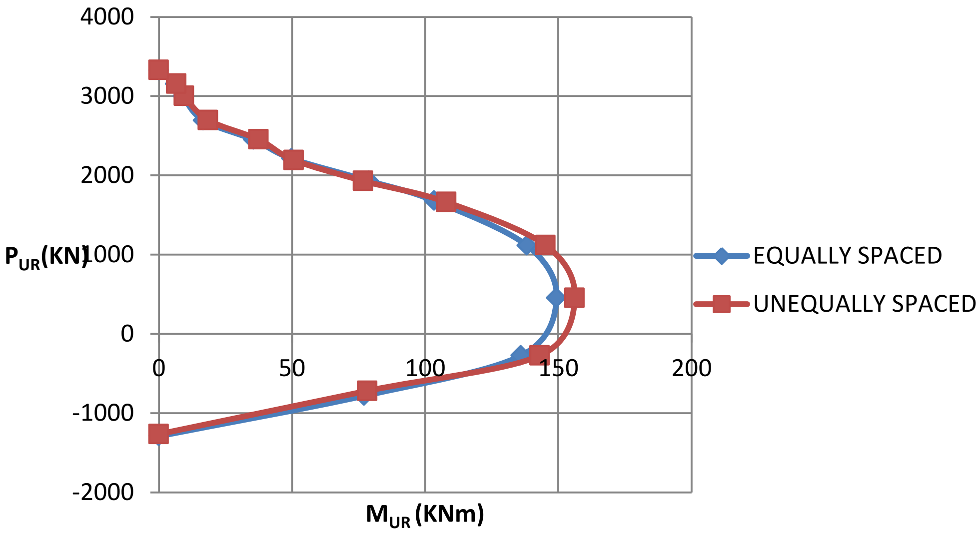

Figure 9 Interaction curves for equal and unequally spaced reinforcement

From the above graph, it is evident that the column section with unequally spaced longitudinal reinforcement shows more ultimate moment resisting capacity compared to column section with equally spaced longitudinal reinforcement.

6. CONCLUSIONS

The salient observations of the numerical study are:

1. The balanced load factor (λ) increases with column depth (Along X axis, with reinforcement in two opposite sides), & decreases with column depth (Along Y axis, with reinforcement in all sides), ensuring more tensile region in the P-M interaction curve thereby providing more ductility. Thus if a column is ought to be oriented along X or Y axis, the fashion of reinforcement is to be considered accordingly to ensure ductility.

2. The balanced load factor (λ) is found to be inversely proportional to the percentage of steel provided.

3. The balanced load factor decreases with increase in limiting strain in steel, thus the tension failure region gets reduced.

4. The amount and distribution of longitudinal steel and the balanced axial load factor (λ) of column section determine the ductility capacity of the section.

5. The column sections with unequally spaced longitudinal reinforcement exhibits more moment resisting capacity compared to equally spaced longitudinal reinforcement, thus ensuring more tensile capacity to the column section.

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