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ORIGINAL RESEARCH ARTICLE

LOADING ECCENTRICITY ISSUE ON THE PERFORMANCE OF REINFORCED CONCRETE COLUMNS

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ABSTRACT
Column is a structural element that transmits floor and beam loads to the foundation safely if properly designed. It is mostly loaded axially or eccentrically at the column-beam interface. Although several research articles are available on column performance (both eccentric and axial), but there is a behavioural challenge on a column loading position parallel to the axis in relation to the flexural reinforcement requirement for Reinforced Concrete (RC) column. This paper looks inward to address the challenge by providing an understanding on the complete behaviour of RC Column flexural requirement in relations with load and its point of application for both short and slender columns. This study uses a numerical data for the column analysis under varied loads and eccentricities values, and numerical deformation and stresses determination using ABAQUS. The Finite Element analysis (FEM) result indicates that increasing column axial load leads to an anticipated higher flexural reinforcement to enhance the column capacity, and is rational. Additionally, the established behaviour between the flexural reinforcement requirement and loading eccentricity for a rectangular column can be predicted easily using established linear relations for both column types considered in this study. Moreover, the Finite Element Method analysis result for the short column similarly indicates an interesting relationship where 16 % change in load value will translate to about 16 % change in deformation value irrespective of either axial or eccentrically loaded points.

1.0 Introduction

Column is a structural element that transmits loads via itself to the foundation. Reinforced Concrete Column (RCC) plays a very vital role in transferring the structural loads from beams or slabs to the foundation. The RCCs are primarily compression members that could be categorised into either short or slender columns. There are several scholarly articles that covers areas such as ductility, slenderness ratio and buckling effects for rectangular RCC (Zeghiche and Chaouti, 2005). However, most columns are loaded either axially or eccentrically at the column beam interface, but there exists very little information on its behaviour at that interface; for example column load position in relation to the flexural reinforcement requirement. Hence, this makes it imperative to investigate how column load and its positions with respect to the column-centroid and its reinforcement requirement for stability relates to each other. Although previous research findings reveal that increases in load eccentricity results in decreasing load carrying capacity (Zeghiche and Chaouti, 2005), but not much was covered on how the variations influences the flexural capacity requirement.

It is known that eccentric loadings in the same direction causes the largest deflection, so also local buckling plays a very vital role and Euler's buckling is of little importance while dealing with short column (Chen and Liew, 2003). In related work conducted by Barrera et al. (2011) on reinforced concrete column subjected to constant axial load, the result suggests that failure due to compression is more pronounced when axial load, concrete strength and both transverse and longitudinal reinforcement ratios are increased. Similar experimental work on concrete-filled stainless-steel tubular columns was also carried out, but the column was loaded with either fibre reinforced concrete (Ehab and Mariam, 2012) or steel jacketed column (Cavaleri et al., 2016; Eze-Eldeen, 2016). This shows that there is a missing gap on the loading position parallel to the column axis as well as the flexural column reinforcement. This paper looks inward to present the missing link. The study results will aid the understanding of the complete behaviour of RCC flexural requirement in relations with load and its point of application for both short and slender columns. Moreover, most reinforced concrete sections could either be subjected to either axial loads or biaxial bending characterised by the structure (Bonet et al., 2011), that's notwithstanding, the load contour method emphasis bending moment separately in either direction (Bresler, 1960). Additionally, this study addresses both short and slender column types, and their numerical performance with the use of ABAQUS software.

2.0 Materials and Method

2.1 Short column

A braced short column type was adopted for this study. The adopted short column design details followed the provision in accordance with the BS 8110 (1997). Hence, the column effective height, l_e is from the use of eq. (1)

$$l_e = bl_o \tag{1}$$

where b is an column ends condition determinant factor and the values are obtained from tables 3.19 and 3.20 of BS 8110 (1997). The parameter l_o in eq. (1) stands for the actual column height. Hence, for an axially loaded column, the design ultimate load, N relation to the flexural reinforcement area, A_{sc} is

$$N = 0.45 f_{cu} bh + A_{sc} 0.95 f_y \tag{2}$$

The parameters f_{cu} and f_y are the respective concrete and steel characteristic strength. Similarly, $b*h$ defines the column cross sectional area (Figure 1). For an eccentrically (e) loaded column carrying an axial force, N, the increased moment, M_a as shown by Eq.

$$M_a = M + N(h/2 - d_2) \tag{3}$$

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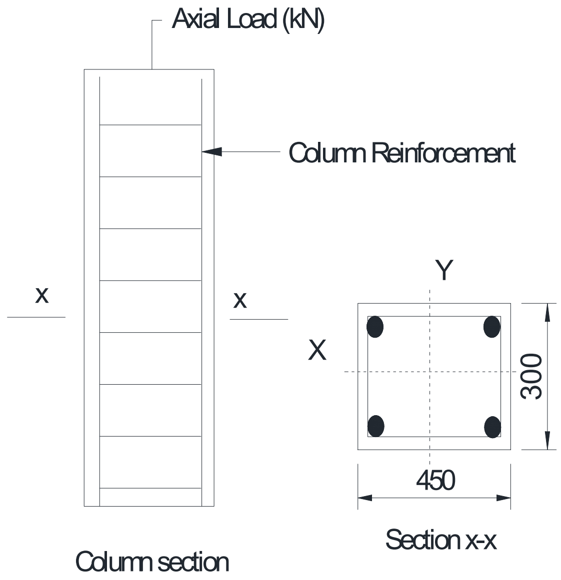

Figure 1. Short column dimensions

Hence, the flexural reinforcement requirements are obtained through designing the member to withstand M_a using

$$M_a = 0.156 f_{cu} bd^2 + 0.95 f_y A_s^{'}(d - d^{'})$$

$$0.95 f_y A_s = 0.2 f_{cu} bd + 0.95 f_y A_s^{'} \tag{4}$$

In Eq. $A_s^{'}$ stands for the area of reinforcement at the tension zone. This implies that

$$A_s = \frac{0.2 f_{cu} bd + 0.95 f_y A_s^{'}}{0.95 f_y} \tag{5}$$

The resulting output value in Eq. will be reduce by $N/0.95 f_y$

Slender Column

Slender column (Figure 2) are designed to withstand not only the axial load, but increased moment, M_i as shown using Eq. as found in BS 8110 (1997).

$$M_i = N\alpha_u \tag{6}$$

The column deflection $(\alpha_u = \beta_a kh)$, where the coefficient $\beta_a = \frac{1}{2000}\left(\frac{l_e}{b^{'}}\right)^2$ and $b^{'}$ is the least column dimension. Similarly, k stands for a deflection reduction factor computed from

$$k = \frac{N_{uz} - N}{N_{uz} - N_{al}} \leq 1.0 \tag{7}$$

where N_{uz} and N_{al} are from:

$$N_{uz} = 0.45 f_{cu} + 0.95 f_y A_{sc}$$

$$N_{al} = 0.25 f_{cu} A_{sc}$$

However, subjecting the column to an eccentric load will result in additional moment, M_{add}, and this is from

$$M_{add} = N * e_{min}$$
$$\text{where } e_{min} \leq h / 20 \text{ or } 20mm \tag{8}$$

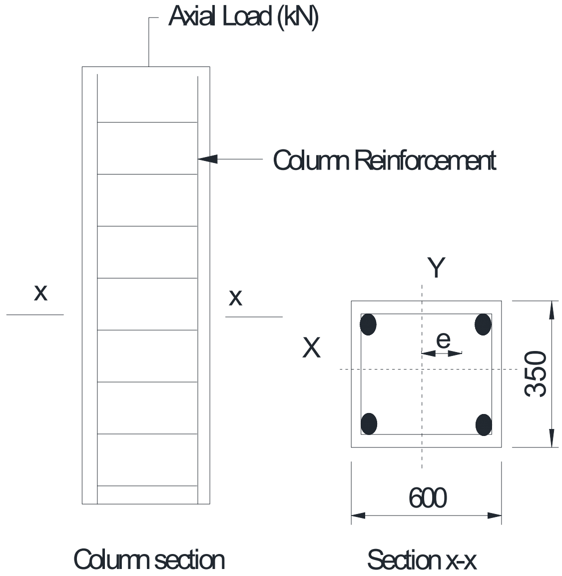

Figure 2. Slender Column dimensions

Therefore, the total moment, $m_t = M_i + M_{add}$. For the purpose of this analysis, three different axial loads (1500 kN, 1750 kN and 2000 kN) values are considered under both short and slender columns. Similarly, the initial eccentricity value was 25 mm, and subsequent 100% increments that translate to respective 50 mm and 75 mm. Figure 2 shows the column dimensions and loading position. Those values chosen have high likely of occurrence in the real life situation.

3.0 Numerical Model

This study uses ABAQUS software application to mimic the behaviour of the RC concrete column. The finite element model considers both the non-linearity behaviour of the concrete and reinforcement medium. The concrete part was deformable solid element while the reinforcement part is also deformable-wire element. Figure 3 shows the typical parts-merged and meshed.

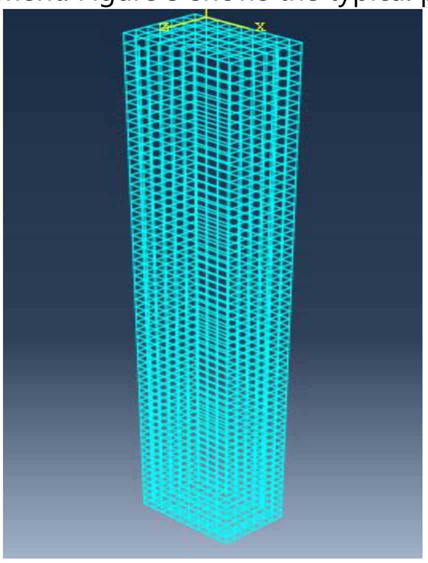

Figure 3. Meshed Specimen type

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This study concrete behaviour was modelled using the concrete damage plasticity, where the failure mechanism is by crushing and cracking. This model requires the use of elastic modulus, poisons ratio, the plastic damage parameters and the description of the tensile and compressive behaviour. The stress-strain relationship presented in Hamza and Mohannad (2018) was adopted to construct the concrete uniaxial compressive stress-strain curve, and this is by

$$\delta_C = \frac{E_c \varepsilon_c}{1+(R+R_e-2)\left({}^{\varepsilon_c}\!/_{\varepsilon_o}\right)-(2R-1)\left({}^{\varepsilon_c}\!/_{\varepsilon_o}\right)^2+R\left({}^{\varepsilon_c}\!/_{\varepsilon_o}\right)^3} \tag{9}$$

$$\text{where } R = \frac{R_e(R_o-1)}{(R_e-1)^2} - R_e^{-1}$$

$$R_e = \frac{E_c}{E_0}$$

$$E_o = \frac{f_c}{\varepsilon_o} \tag{10}$$

The constant parameters R_o and R_e have a value of 4, while the concrete elastic modulus and its corresponding strain vales are $E_c = 4700\sqrt{f_c}$ and $\varepsilon_o = (0.2 f_{cu} + 13.06).10^{-4}$, respectively. The parameter f_c represents the characteristics concrete strength.

Similarly, the strain-stress relationship for the steel element was in accordance with the method proposed by literature (Hamza and Mohannad, 2018). To simulate the behaviour of the concrete and the reinforcement steel, the embedded region function in ABAQUS was used. Additionally, for the purpose of this numerical analysis, only two axial loading cases (1500 kN and 1750 kN) are used and the loading eccentric (e) considered was 25 mm. The reason for such values selection is based on their likely of occurrence in real life situation. However, because of similarity in the flexural behaviour for the two columns considered in this study, only the flexural reinforcement characteristics for the short column were used for the ABAQUS analysis. The Von-misses stresses and deformation values were recorded for interpretation.

Results and discussion

Figure 4 show the flexural behaviour of short column under the different parametric conditions stated above.

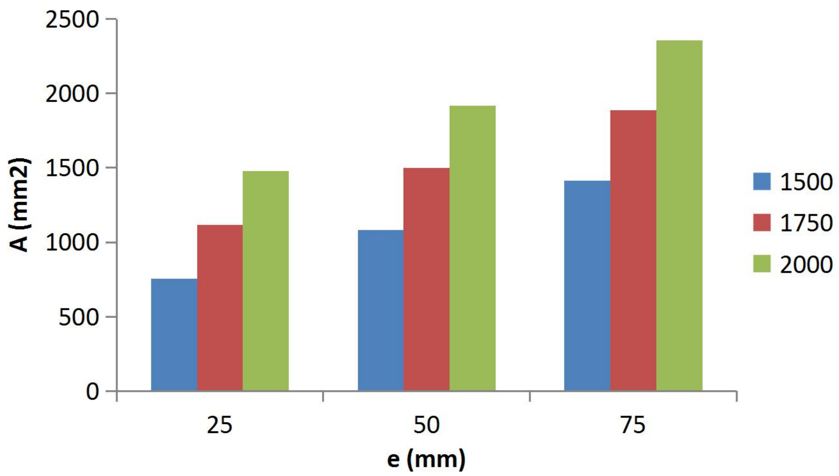

Figure 4. Short Column Flexural requirement behaviour

In Figure 4, gradual increase of the loading eccentricity from 25 mm to 50 mm results in 44% surge in flexural requirement (A) with 1500 kN axial load. However, surging load yields to flexural reinforcement decreases to about 30% with further 250 kN load increment from 1750 kN. Similar scenario happens when the e values changes to 75 mm from 50 mm and the corresponding values are 30 and 23%, respectively. The analysis of the short column behaviour reveals that, increasing the axial load value from 1500 to 1750 kN $(e = 25mm)$ results in about 32% surge in flexural reinforcement. However, further load increment result in much lesser value than the previously reported surge (24%).

This study result indicates that increasing column axial load leads to an anticipated higher flexural reinforcement to shore up the column capacity, and is rational. Additionally, the established behaviour between the flexural reinforcement requirement and loading eccentricity for a rectangular column could be easily described with linear relation. For example, consider an axial load value of 1500 kN, its linear equation of best fit is $y = 330x + 423$, where y is the dependent variable (short column).

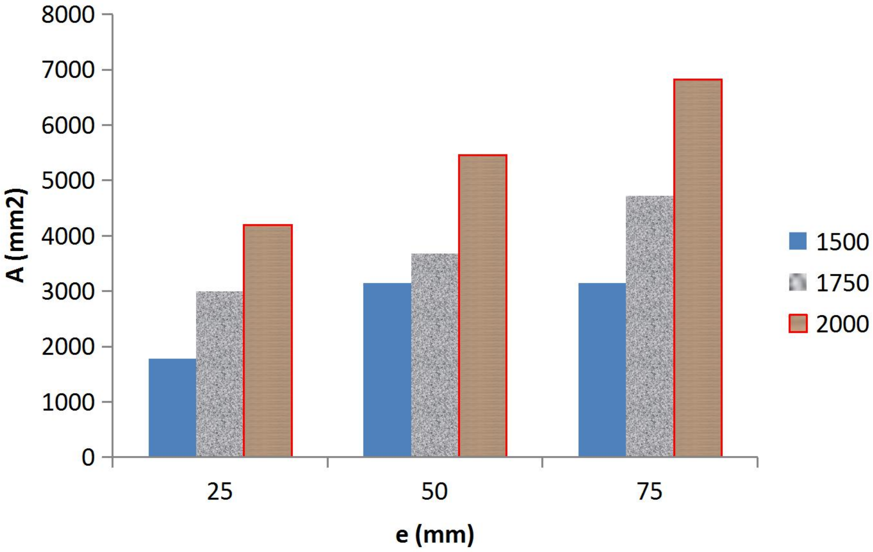

Figure 5. Slender Column Flexural requirement behaviour

There is no doubt, the slender column requires more steel than the short column (see Figure 5). Similar to the behaviour shown with the short column, the flexural requirement linearly increases with increasing eccentricity. Generally, eccentrically loaded column exhibits a conservative flexural requirement especially with increasing eccentricity and similar characteristic behaviour are found in literature (Ehab and Mariam, 2012). However, reducing this high level of conservatism could be interesting research areas that need to be explored.

3.1 Finite Element Analysis result

Figure 6 and 7 presents the finite Element Method (FEM) analysis outcomes for the Von-Misses stress values for both the axial and eccentrically loaded condition, but for short column. The axial stress resistance values increase with increasing axial load value. This behaviour could be attributed to the additional flexural reinforcement that enhances the concrete resistance.

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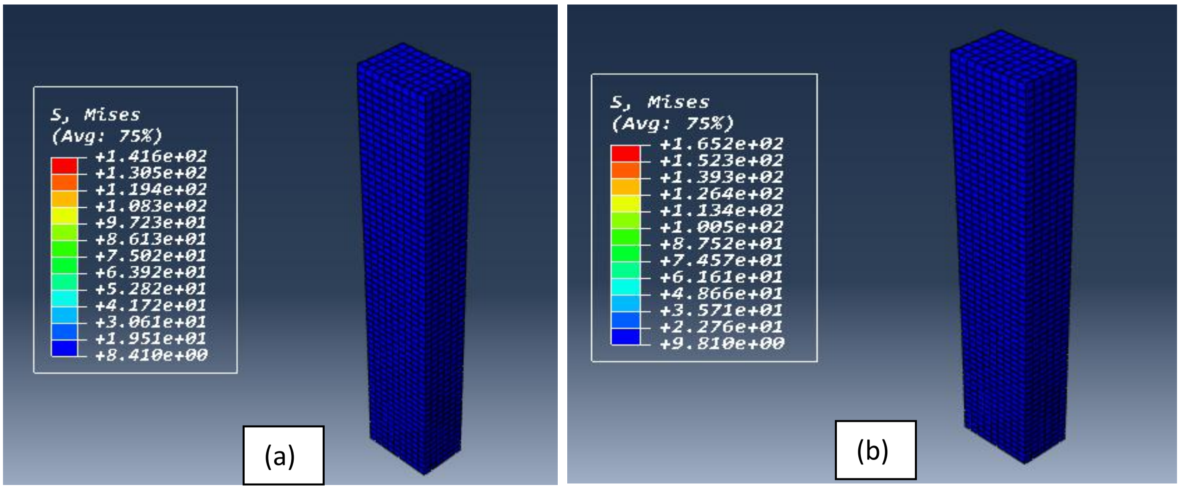

Figure 6 Von Misses Stress values under axial load (a) 1500 kN axial load (b) 1750 kN axial load

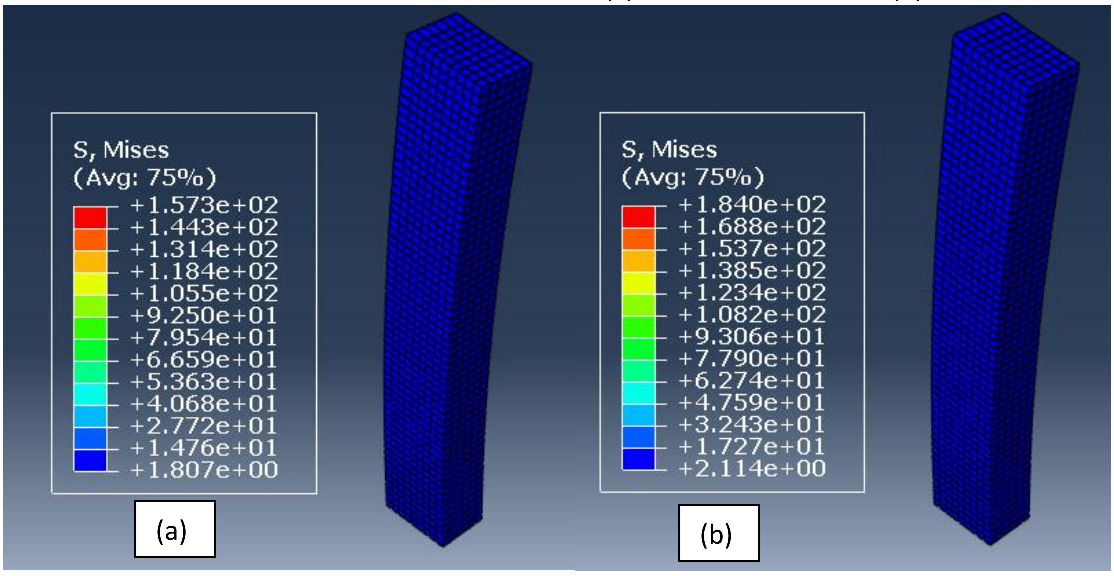

Figure 7. Von Misses Stress values on 25 mm-eccentric loading (a) 1500 kN (b) 1750 kN

Figure 8 shows the deformation behaviour for the column analysed. As expected, the deformation values increase with increasing column load (Figure 8 a and b). Interestingly, 16 % change in axial load will result in 16 % change in deformation value irrespective of point of load application either axial or eccentrically loaded (Figures 8 a-d), because the 25 mm loading eccentricity have no influence on the deformation capacity. In general, Stewart and Rosowsky (1998) showed that the serviceability condition is mostly influenced by the concrete strength f_{ck} rather than other deformation influencing factors (Kachalla et al., 2018).

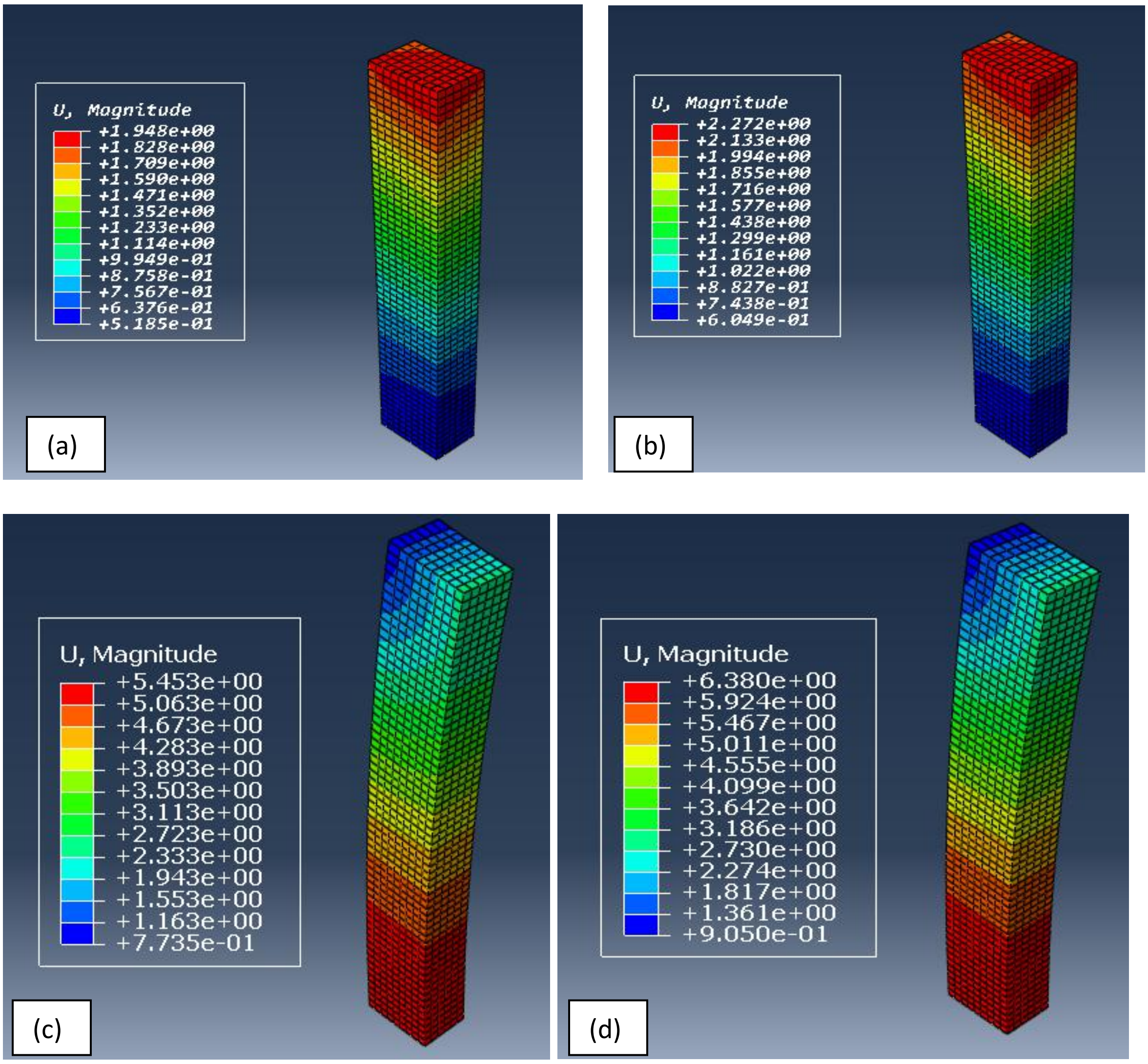

Figure 8. Deformation behaviour (a) 1500 kN, (b) 1750 kN, (c) 1500 kN @ Eccentricity of 25 mm (d) 1750 kN @ Eccentricity of 25 mm

4.0 Conclusion

This paper looks inward to address the missing link on the loading position parallel to the column axis as well as the flexural reinforcement requirement for RC column in order provide an understanding on the complete behaviour of RC Column flexural requirement in relations with load and its point of application for both short and slender columns. Numerical data were used for the study analysis for both the short and slender columns under varied loads and eccentricities condition. The study result indicates that increasing column axial load leads to an anticipated higher flexural reinforcement to enhance the column capacity, and is rational. Moreover, FEM analysis result for the short column similarly indicates an interesting relationship between the deformation and loading eccentricity function. Additionally, the established behaviour between the flexural reinforcement requirement and loading eccentricity for a rectangular column can be predicted easily by the use established linear relations for both short and long column types. However, the study results indicate that eccentrically loaded column exhibits a conservative flexural requirement especially with increasing eccentricity. Hence, reducing this high level of conservatism could be an interesting field that needs further explorations.

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