Development of P-M Interaction Chart for a Fibre Reinforced Polymer (FRP) Composite Column

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Abstract: The Fibre Reinforced Polymer (FRP) tubular composite column is a new form of column which helps in obtaining the higher structural performance. The composite column considered here is same like steel-concrete composite column, except that the outer steel section and the reinforcing steel bars are replaced with the hollow FRP section and FRP bars. The manual calculation for developing the interaction chart is difficult and time consuming. And, there have been no attempts made for developing P-M interaction charts for FRP composite columns. So, the purpose of the study is to develop the design of composite column by solving the equations of different points of interaction chart. In order to study the effect of various parameters on the P-M interaction chart, the parametric study is carried out. The parameters considered for this study are the percentage of reinforcements, gross sectional area and shape of the composite column. Finally the charts are developed considering different reinforcement percentage (varying from 1 % to 6 %) for square and circular column.

Index Terms - **Composite column, Concrete Filled Tube (CFT), interaction chart, uni-axial bending, bi-axial bending**

I. Introduction

A composite Fibre Reinforced Polymer (FRP) column is a structural member, which is made of a polymer matrix, consisting fibre section, concrete and reinforcing bars. It is light in weight and hence, gives very high strength to weight ratio. It is easy in transportation and can be installed easily. It provides sufficient load carrying capacity to support axial loads and bending moment. The integral behavior of concrete and the fibre elements makes a column very cost effective and structural efficient member among the broad range of structural elements in building. FRP columns are much durable and provide high corrosion resistance too. Due to this it has become more popular as a structural member in new construction technology. Nowadays, the composite slabs, composite beams and composite columns are widely used in many countries.

The different types of FRP composite columns used here are as per follow:

1. Concrete encased fibre section
2. Concrete filled hollow fibre section

The cross-section of the concrete encased and the concrete filled hollow fibre section is shown in the below Fig. 1.

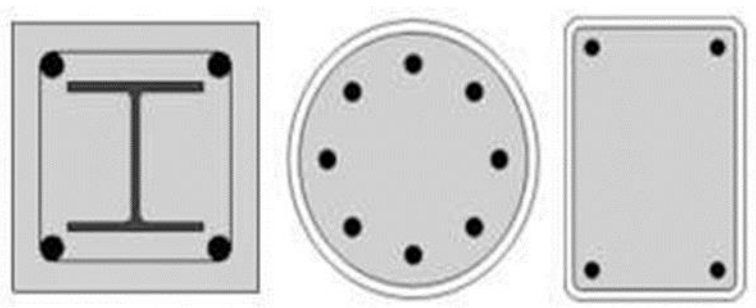

Fig. 1 Types of FRP composite column [1]

II. Literature Review

Rosmanit and Parenica [2] found the capacity of composite steel-concrete column and the resistance of composite columns at the ultimate limit state using Visual Basic (VB) software. Panchal [3] made a simplified method for different types of composite structural elements by developing VB.net software. Panchal and Patel [4] developed P-M interaction chart of composite column considering steel hollow section with the use of Euro Code 4 (EC-4). Lelli et al. [5] used FRP composites and advanced composite materials in rehabilitation of concrete structures due to their advantageous effects as a structural element. Gediya and Koradia [6] developed a design of composite column subjected to compressive force & uni-axial bending considering load-moment diagram by generating on a simple excel program.

There is no research done for making the P-M interaction charts for the composite columns using FRP material. For doing the current research work, different sizes of section of FRP material have been used and the charts are made.

III. METHODOLOGY

A typical load-moment interaction chart shows the axial load and the ultimate bending moment capacity of a given column cross section. Using design interaction chart for a given column section, quick judgment as to whether or not the section is safe can be made.

At present, Indian standard code for design of composite column is not available; hence design of composite column is carried out using EC-4. Here, the method is based on simple European buckling curves, described as follow:

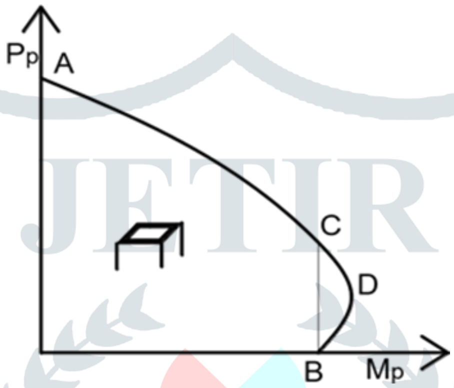

Fig.2 Interaction chart for composite column [7]

P-M curve is developed by various points as per EC-4, which suggests whether the section is safe or not.

At point A, pure axial compression ($M_A = 0$),

$$P_A = P_P = A_a P_y + \alpha_c A_c P_{ck} + A_f P_{sk} \tag{1}$$

Where

$P_y = 0.87\, f_y$, $P_{ck} = 0.4\, f_{ck}$ *and* $P_{fk} = 0.67\, f_{fk}$

At point B, Pure axial bending ($P_B = 0$),

$$M_B = P_y\,(Z_{pa} - Z_{pan}) + 0.5P_{ck}\,(Z_{pc} - Z_{pcn}) + P_{sk}\,(Z_{pf} - Z_{pfn}) \tag{2}$$

where

$Z_{pan} = t\, hn^2$

$Z_{pcn} = b_c h_n^2 - Z_{pfn} - Z_{pan}$

At point C, axial compression and moment resistance of section given as,

$$P_C = A_c P_{ck} \tag{3}$$

$$M_C = M_P = P_y\,(Z_{pa} - Z_{pan}) + 0.5P_{ck}\,(Z_{pc} - Z_{pcn}) + P_{sk}\,(Z_{pf} - Z_{pfn}) \tag{4}$$

At point D, Moment resistance of section is maximum and axial compression is half of $P_{C,}$

$$P_D = 0.5 A_c P_{ck} \tag{5}$$

$$M_D = M_P = P_y\,(Z_{pa}) + 0.5P_{ck}\,(Z_{pc}) + P_{fk}\,(Z_{pf}) \tag{6}$$

Where, Value of Z_{pan}, Z_{pcn}, Z_{pfn} depend on h_n,

For concrete encased steel section,

About major axis,

$$h_n = \frac{A_c\, P_{ck} - A'_c\,(2\,P_{ck} - P_{ck})}{2\,b_c\,P_{ck} + 2\,t_w\,(2\,P_y - P_{ck})} \quad (7)$$

About minor axis,

$$h_n = \frac{A_c\, P_{ck} - A'_c\,(2\,P_{ck} - P_{ck})}{2\,h_c\,P_{ck} + 2\,h\,(2\,P_y - P_{ck})} \quad (8)$$

For concrete filled tubular section,

$$h_n = \frac{A_c\, P_{ck} - A'_s\,(2\,P_{fk} - P_{ck})}{2\,d\,P_{ck} + 4\,t\,(2\,P_y - P_{ck})} \quad (9)$$

For the minor axis, h_n is calculated by interchanging value of b_c by h_c.

Condition must be satisfied for section for moment resistance of section.

$M \leq 0.9\mu M_p$

Where, μ is moment resistant ratio

For axial compression resistance of section

$\chi_x P_p > p$

$\chi_y P_p > p$

where

$$\chi_x = \frac{1}{(\phi_x + \{\phi_x^2 - \lambda^2\}^{\frac{1}{2}})}$$

and $\phi_x = 0.5\,[1 + \alpha_x\,(\lambda_x - 0.2) + \lambda_x^2]$

$$\chi_y = \frac{1}{(\phi_y + \{\phi_y^2 - \lambda^2\}^{\frac{1}{2}})}$$

and $\phi_y = 0.5\,[1 + \alpha_y\,(\lambda_y - 0.2) + \lambda_y^2]$

So these conditions must be satisfied for a safer section.

IV. EXAMPLES OF INTERACTION CHART

Developed charts of concrete encased section and the CFT section for uni-axial and bi-axial bending for different cross-section and different percentage of reinforcement are shown in figures

The interaction charts for circular CFT section with different cross section and thickness is shown in Fig. 3 & 4.

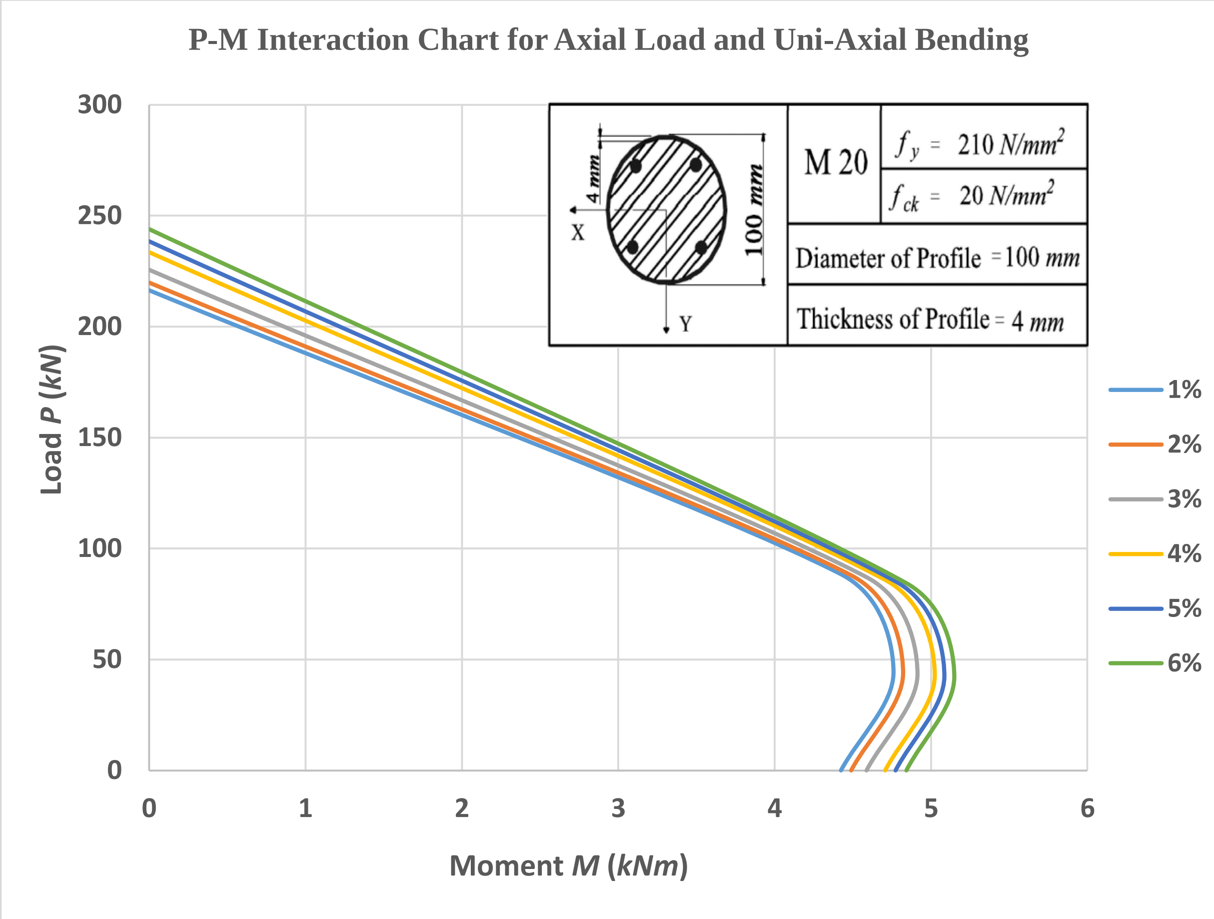

Fig. 3 P-M interaction chart for circular CFT secion of 100 *mm* diameter and 4 *mm* tube thickness

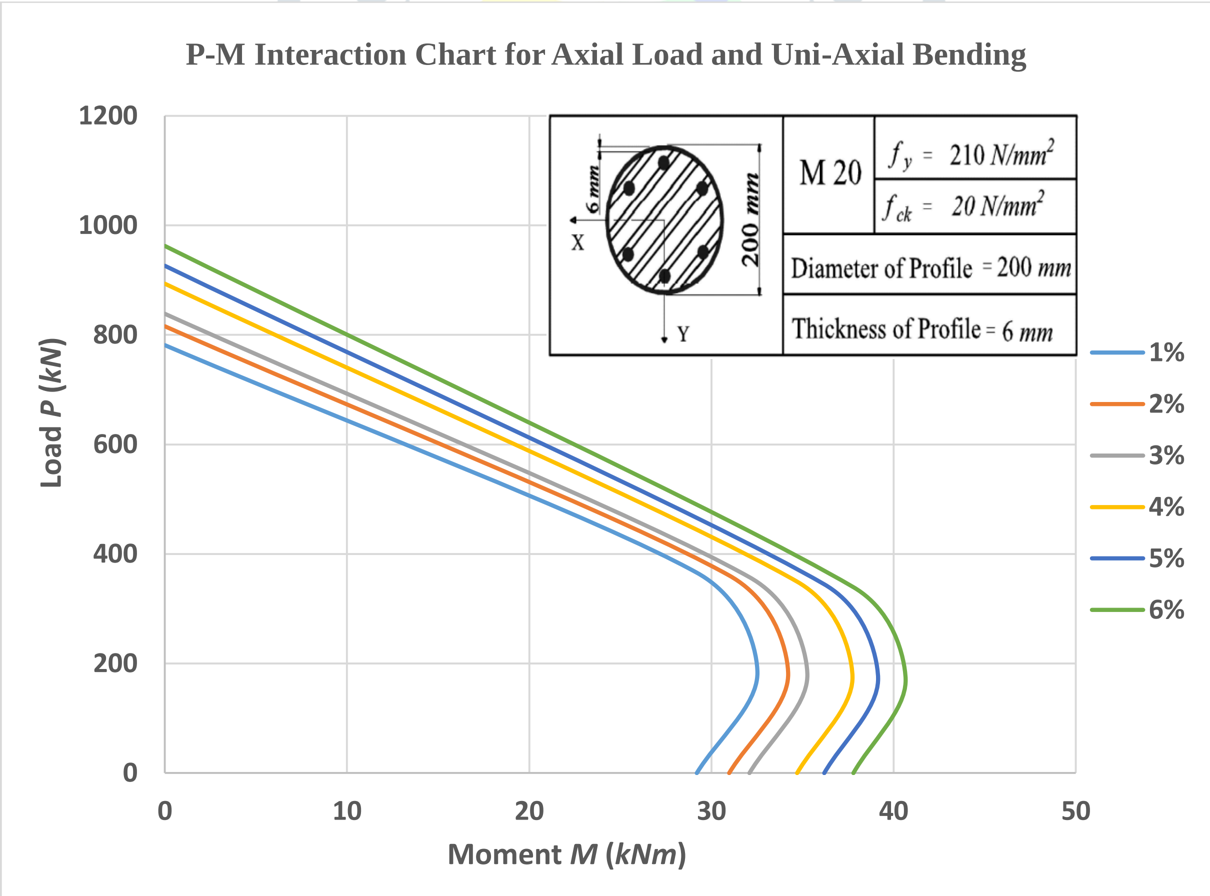

Fig. 4 P-M interaction chart for circular CFT section of 200 *mm* diameter and 6 *mm* tube thickness

The interaction charts for square CFT section with different cross section and thickness is shown in Fig. 5 & 6.

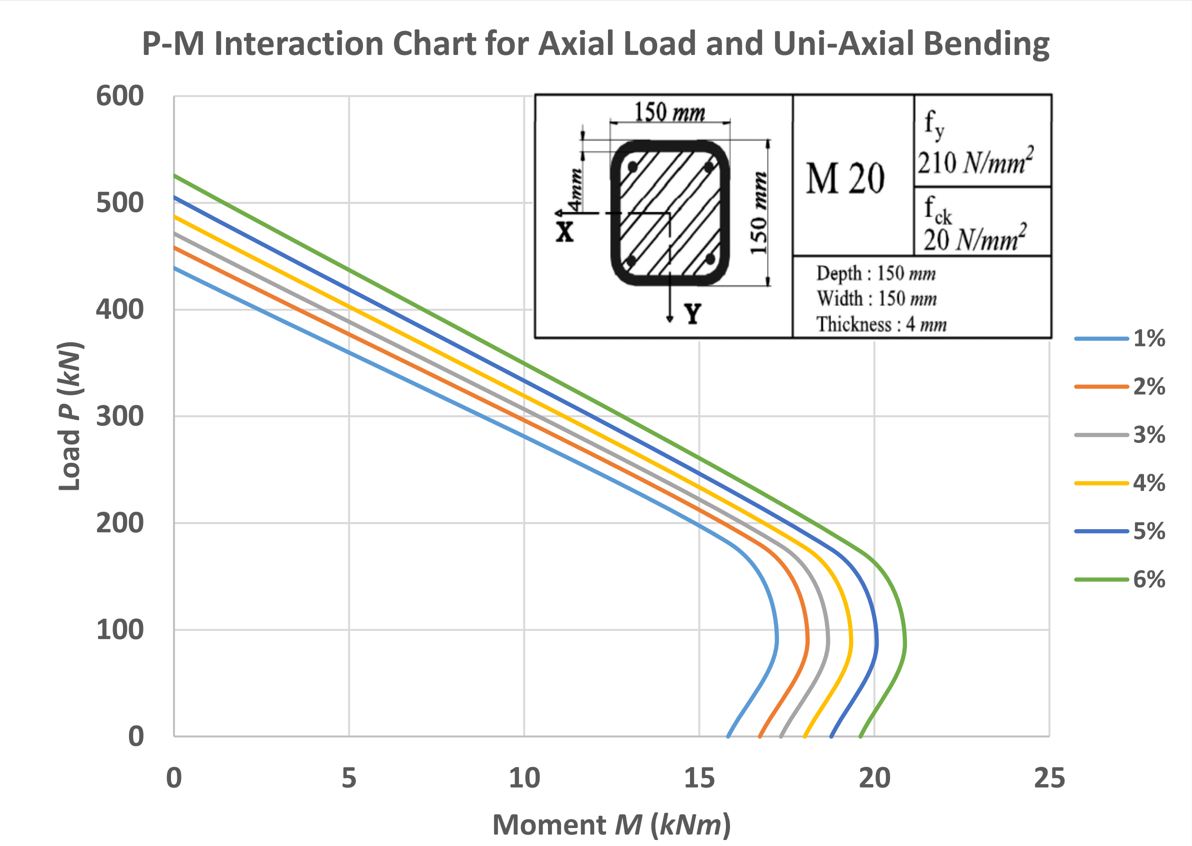

Fig. 5 P-M interaction chart for square section of 150 *mm* × 150 *mm* width and 4 *mm* tube thickness

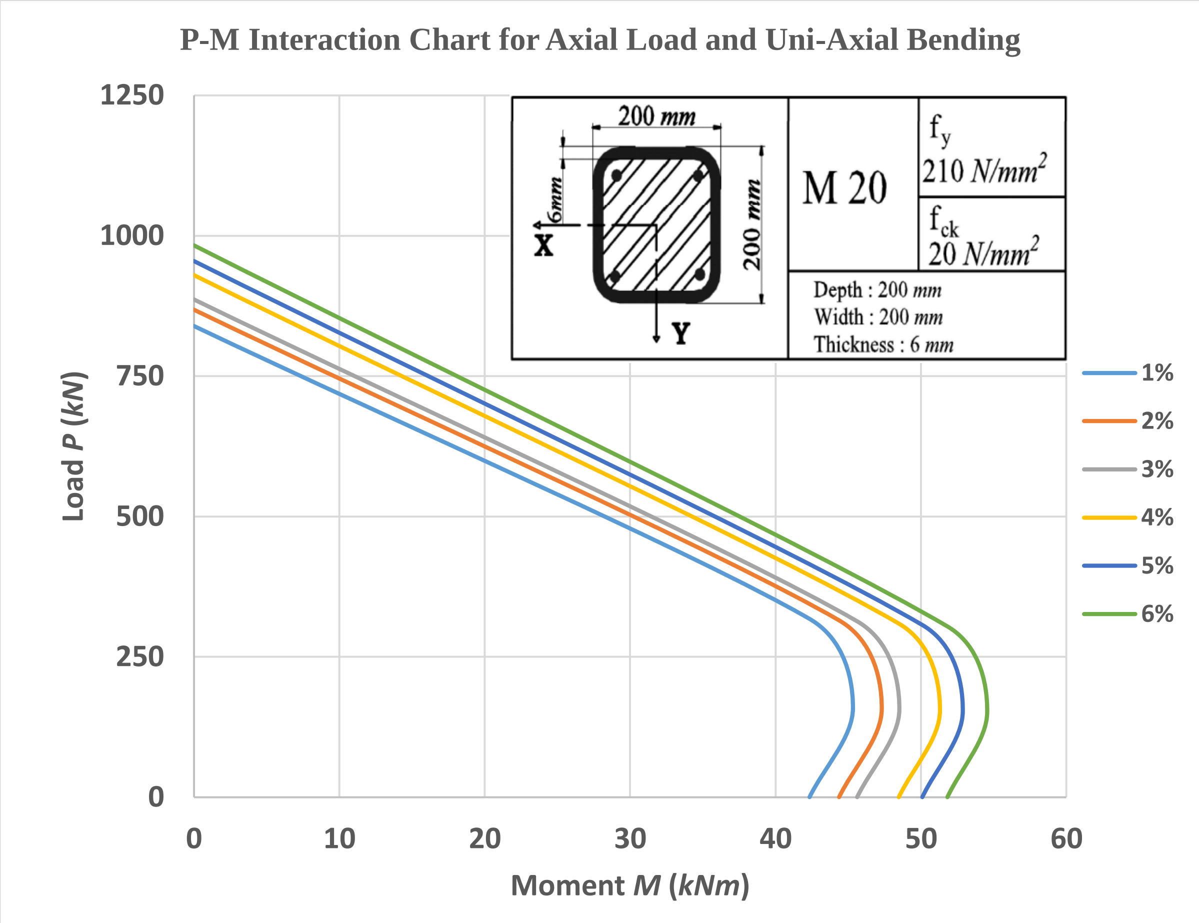

Fig. 6 P-M interaction chart for square section of 200 *mm* × 200 *mm* width and 6 *mm* tube thickness

The interaction charts for concrete encased section with different cross section is shown in Fig. 7 & 8.

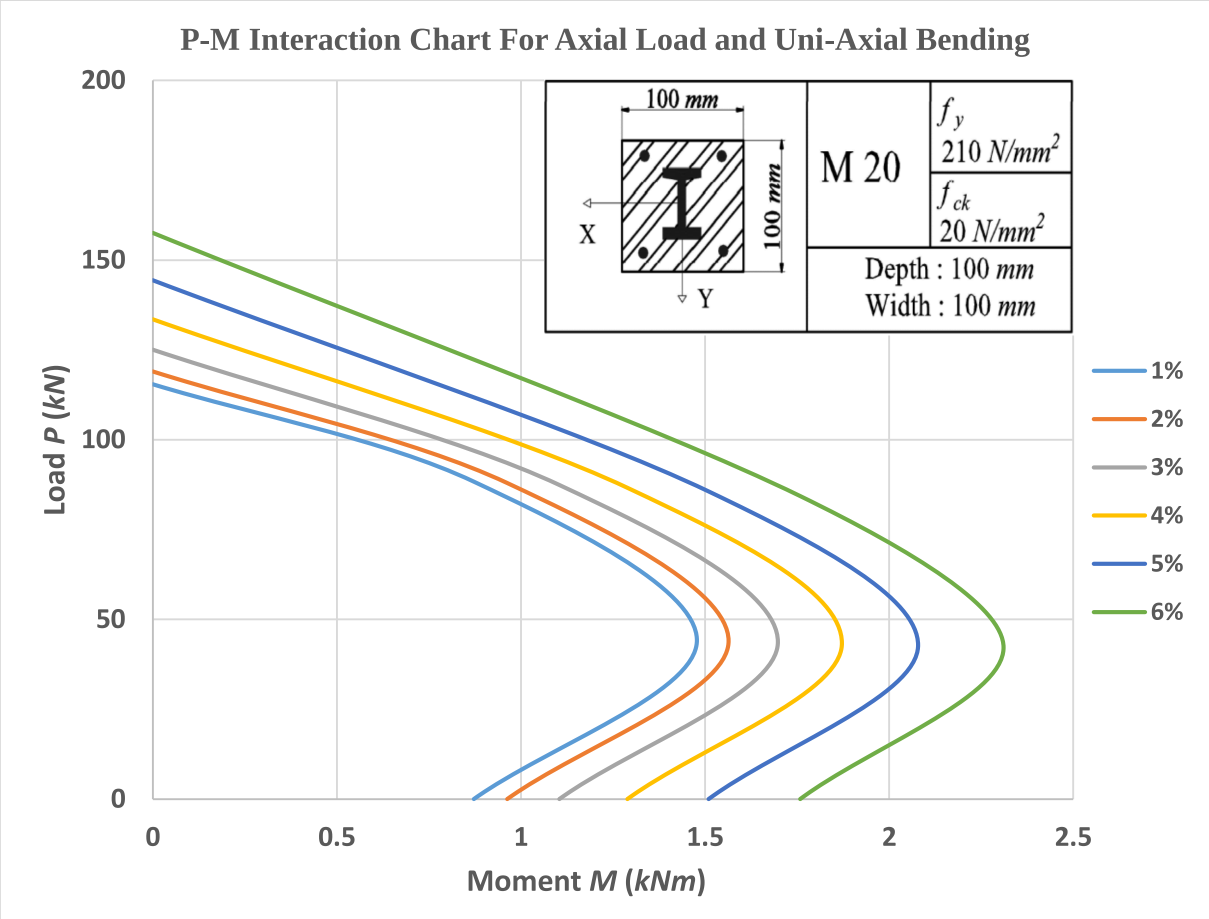

Fig. 7 P-M interaction chart for concrete encased section of 100 *mm* × 100 *mm* width

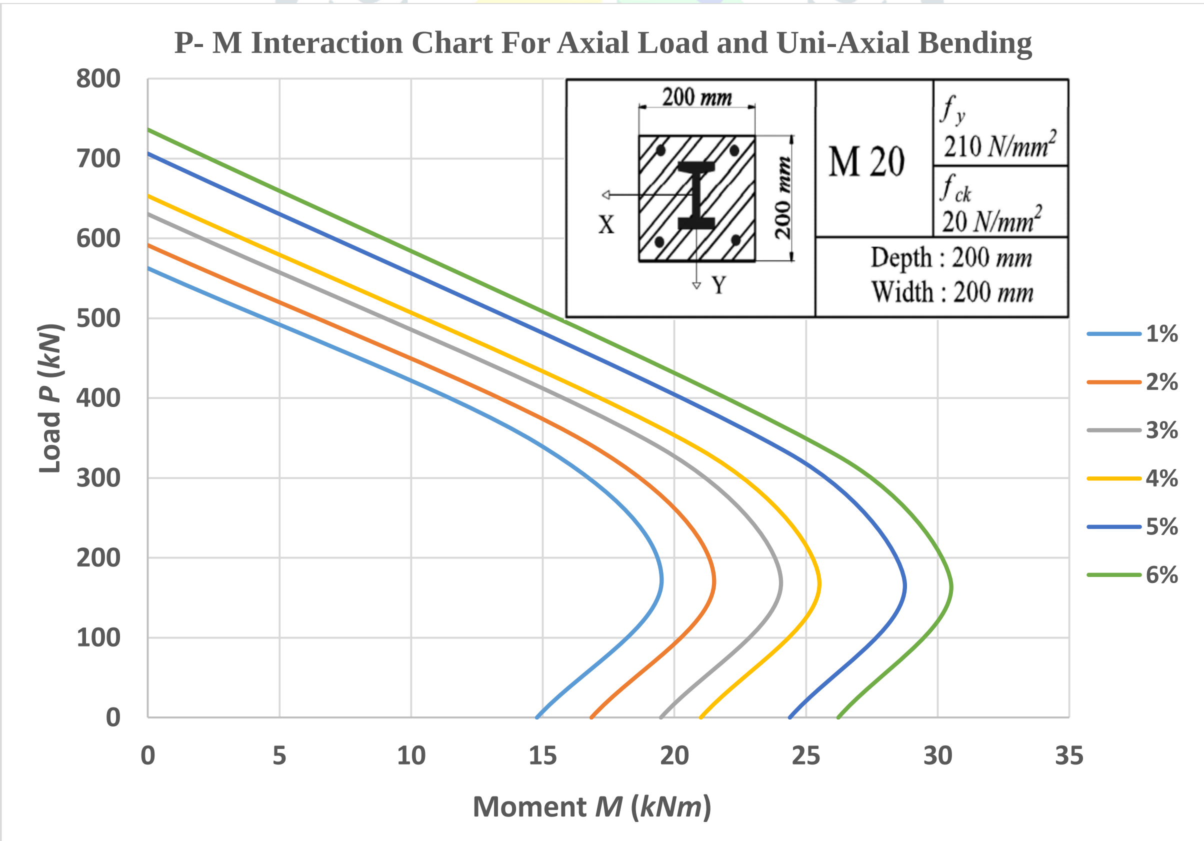

Fig. 8 P-M interaction chart for concrete encased section of 200 *mm* × 200 *mm* width

The interaction charts for square encased section with different cross section with biaxial bending is shown in Fig. 9 & 10.

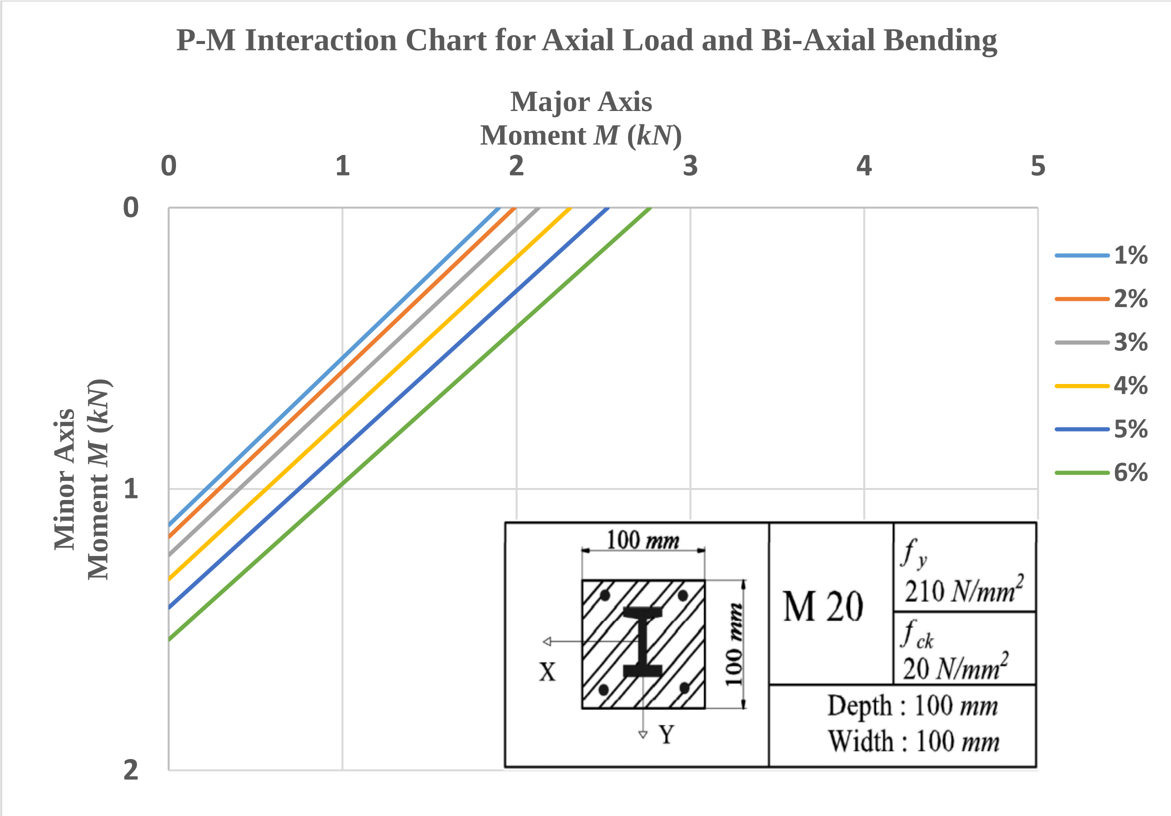

Fig. 9 P-M interaction chart for concrete encased section of 100 *mm* × 100 *mm* width with bi-axial bending

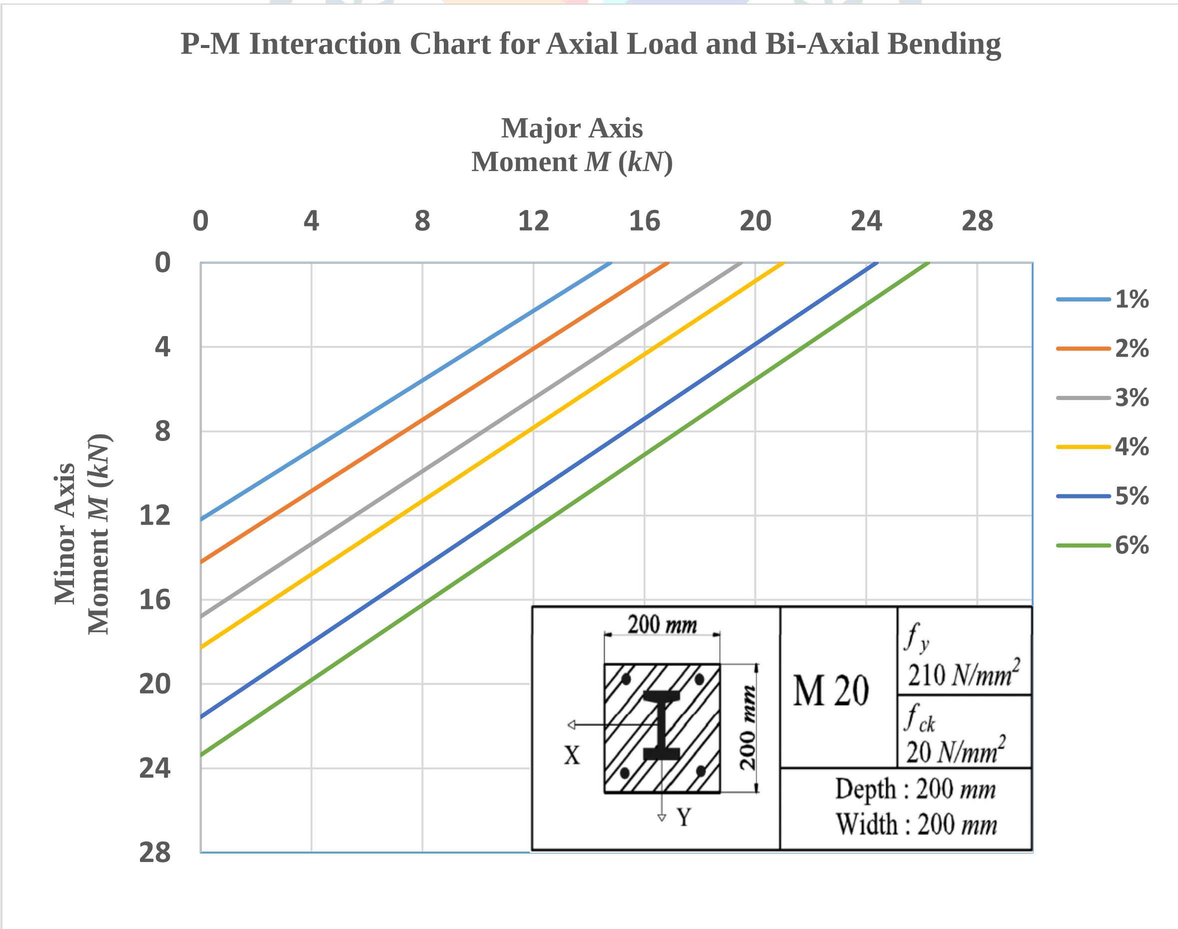

Fig. 10 P-M interaction chart for concrete encased section of 200 *mm* × 200 *mm* width with bi-axial bendin

V. CONCLUSIONS

In this study, CFT sections and the concrete encased sections with different cross-section subjected to uni-axial and bi-axial bending have been analysed and the P-M interaction charts are plotted considering varying percentages of reinforcement. Following conclusions may be drawn from the above study.

1. P-M interaction charts for the circular and square CFT sections as well as square encased sections have been developed with the help of Euro Code 4.
2. The developed interaction chart helps in understanding the relationship between the load and moment carrying capacity of the different sections of the column.
3. Based on these charts, load and moment relation of a column can be understood by solving the different equations of the interaction chart.
4. By changing the percentage of reinforcement fibre, the load and moment carrying capacity of the given section have been increased.
5. When the cross-section size of the column is increased, the strength of the column is also increased.
6. By comparing the circular and square CFT sections, an increase in strength has been found in the square CFT section.
7. There is an increment in the strength in the concrete encased section due to the confinement effect.
8. The developed bi-axial charts can help to check the load and moment effects in both the axis.
9. Moreover, these charts helps in eliminating manual calculations for finding out moment and load carrying capacity of columns and it also save lots of time.

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