International Journal of Research and Review
Vol. 10; Issue: 4; April 2023
Website: www.ijrrjournal.com
Research Paper
E-ISSN: 2349-9788; P-ISSN: 2454-2237

Optimization of Reinforcement Ratio in Reinforced Concrete Columns Using Interaction Diagrams

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DOI: https://doi.org/10.52403/ijrr.20230425

ABSTRACT

Reinforced concrete columns are structural members used to carry compressive loads. Column planning is important, considering that the column is the main structural element supporting the loads on a building. Column planning is generally used in moment and axial force interaction diagrams for a certain reinforcement ratio. Although there is currently much software available, Interaction diagrams made in this paper can be said to be a simple way of column planning. The method used in this paper is a numerical calculation method with the help of Ms Excel. This paper aims to optimize the planning of reinforced concrete columns using Mn and Pn interaction diagrams. Furthermore, the optimization results of the column planning interaction diagram have been obtained. A reinforcement ratio of 2% is a better result to apply.

Keywords: column, interaction diagram, reinforcement ratio.

INTRODUCTION

A reinforced concrete column is a structural part used to carry compressive loads. In this case, it may be short or slender (long) depending on the slenderness ratio of the column (Ahmed, 2021; Kim, 2006). Column planning is important, considering the column is the main structural element supporting the loads acting on a building. In contrast to beams, the forces acting on columns are a combination of bending moments and axial forces (Eduardo, Melo, and Melo 2016; Khalaf and Abbas 2019; Chikh, Gahmous, and Benzaid 2012; Rodrigues et al. 2015; Al-Ansari 2019; Fillo, Čuhák, and Minárová 2017; Magalhães 2019; Pallaluta, Ti.M., Irawan, P., Maekawa, K. 1995; Paultre and Khayat 2005; Omar, Gomes, and Reis 2010). With the axial force, solving the balance equation becomes more difficult. Columns are vertical elements of frame buildings or frames that carry loads from beams. The column element is a compression rod so that the collapse in a column can cause the failure of the floor above it and the collapse of the building as a whole. The collapse of the structural column must be considered economically and in terms of the safety of human life. Thus, it is necessary to be more careful in planning columns by providing a safety factor more significant than other structural elements such as beams and slabs. Moreover, compressive failure in columns does not provide a sufficiently clear initial warning. To give sufficient safety to the analysis and planning of columns, the Indonesian concrete regulations provide rules regarding a smaller strength reduction factor than other elements, such as bending, shear, and torsion (Waryosh et al., 2018) on slabs and beams. Columns can be classified based on the shape and arrangement of the reinforcement, the position of the load acting on the cross-section, and the column length related to the cross-section dimensions (SNI 2847, 2019). Types of columns based on the shape and type of reinforcement can be divided into three categories, as shown in Figure 1. To facilitate column planning, interaction diagrams generally used (Hong et al., 2022) of moments and axial forces for specific reinforcement ratios (Stasi, 2010). Based on the position of the load relative to the cross-section, it can be divided into columns with centric loads, columns with axial loads, and single spice moments and biaxial columns (Figure 2). Even though there is currently a lot of software available, the interaction diagrams developed can be considered practical for column planning (Arfiadi 2017). The diagram developed is based on one-way bending. For a review of two-way bending, one can refer, for example, to (Ludovico et al., 2010). A complete review of column planning can be seen in (Fattah 2012). The capacity of the reinforced concrete section to withstand the combination of axial forces and bending moments can be described as an interaction curve between the two forces, called the Mn Pn column interaction diagram.

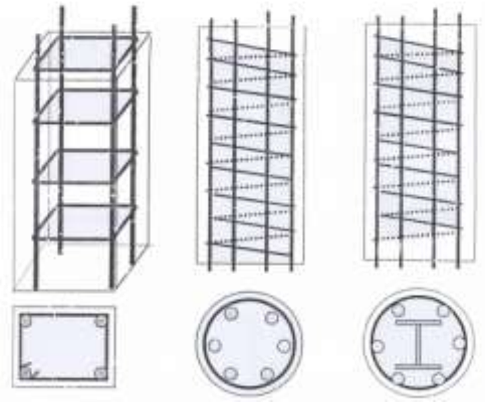

Figure 1. Column types and reinforcement

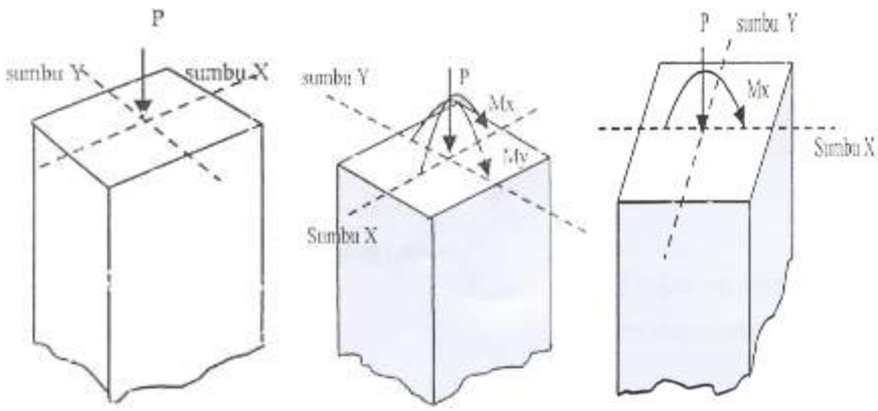

Figure 2. Internal force column

Each point on the curve represents a combination of the nominal force Pn and the nominal moment Mn corresponding to the location of the neutral axis. This interaction diagram can be divided into two regions: the area determined by tensile failure and the area defined by compressive failure, with the boundary being the balanced point. The equation used in making the interaction diagram is adjusted to SNI 2847-2019 regulations. The calculation will be reviewed in 5 conditions: axial compression state, balanced state, compression fracture state, tensile fracture state, and pure flexural state. This paper aims to optimize column planning through Mn and Pn interaction diagrams.

1. Axial compression state

$$Mu = 0 \quad (1)$$

$$Pu = 0{,}85 \times F'c \times (Ag - Ast) + (Ast \times Fy) \quad (2)$$

2. Balanced state

$$d = h - d` \quad (3)$$

$$Xb = \left[\frac{600}{600 + Fy}\right] \times d \quad (4)$$

$$a = 0.85 \times Xb \quad (5)$$

$$fs` = \left[\frac{Xb - d`}{Xb}\right] \times 600 \quad (6)$$

$$fs = \left[\frac{d - Xb}{Xb}\right] \times 600 \quad (7)$$

$$Cc = \frac{0.85 \times f`c \times a \times b}{1000} \quad (8)$$

$$Cs = \frac{As` \times (fs` - 0.85 \times f`c)}{1000} \quad (9)$$

$$Ts = \frac{As \times fs}{1000} \quad (10)$$

$$Pu = Cc + Cs\_Ts \quad (11)$$

$$Mu = Cc \times \left(\frac{h}{2} - \frac{a}{2}\right) + Cs \times \left(\frac{h}{2} - d`\right) + Ts\left(d - \frac{h}{2}\right) \quad (12)$$

$$e_b = \frac{Mn}{Pn} \quad (13)$$

3. Compression fracture state

$$d = h - d` \quad (14)$$

$$X = 1.5 \times Xb \quad (15)$$

$$a = 0.85 \times X \quad (16)$$

$$fs` = \left[\frac{X - d`}{X}\right] \times 600 \quad (17)$$

$$Cc = \frac{0.85 \times f`c \times b \times a}{1000} \quad (18)$$

$$fs = \left[\frac{d - X}{X}\right] \times 600 \quad (19)$$

$$Cs = \frac{As` \times (fs` - 0.85 \times f`c)}{1000} \quad (20)$$

$$Ts = \frac{As \times fs}{1000} \quad (21)$$

$$Pu = Cc + Cs\_Ts \quad (22)$$

$$Mu = Cc \times \left(\frac{h}{2} - \frac{a}{2}\right) + Cs \times \left(\frac{h}{2} - d`\right) + Ts\left(d - \frac{h}{2}\right) \quad (23)$$

$$e_b = \frac{Mn}{Pn} \quad (24)$$

4. Compression fracture state

$$d = h - d` \quad (25)$$

$$X = 0.5 \times Xb \quad (26)$$

$$a = 0.85 \times X \quad (27)$$

$$fs` = \left[\frac{X - d`}{X}\right] \times 600 \quad (28)$$

$$fs = \left[\frac{d - X}{X}\right] \times 600 \quad (29)$$

$$Cc = \frac{0.85 \times f`c \times b \times a}{1000} \quad (30)$$

$$Cs = \frac{As` \times (fs` - 0.85 \times f`c)}{1000} \quad (31)$$

$$Ts = \frac{As \times fs}{1000} \quad (32)$$

$$Pu = Cc + Cs\_Ts \quad (33)$$

$$Mu = Cc \times \left(\frac{h}{2} - \frac{a}{2}\right) + Cs \times \left(\frac{h}{2} - d`\right) + Ts\left(d - \frac{h}{2}\right) \quad (33)$$

$$e_b = \frac{Mn}{Pn} \quad (34)$$

5. Compression fracture state

$$a = \frac{As \times fy}{0.85 \times f`c \times b} \quad (35)$$

$$Pu = 0 \quad (36)$$

$$Mu = As \times fy \times \left(d - \frac{a}{2}\right) \quad (37)$$

METHODS

The method used in this paper is a numerical calculation method with the help of Ms. Excel. Calculations will be adjusted to the equations shown in the literature review. Then the data used in the calculations are as follows:

1. F'c = 30 MPa;
2. Fy = 350 MPa;
3. Size of Column = 500 x 500 mm;
4. Pmax = 2000 kN;

5. Mmax = 600 kN.

RESULT

In manufacturing column interaction diagrams calculated with the reinforcement ratio used, 1%, 1.25%, 1.5%, 1.75%, 2%, 2.25%, 2.5%, 2.75%, 3%, 3 .25%, 3.5%, 3.75%, and 4%. Column interaction diagrams with variations of different reinforcement ratios allow for determining the expected nominal moment values. So optimization of the column reinforcement ratio can be achieved. The results of creating an interaction diagram for the size of a column of 500 x 500 mm are shown in Figure 3. Pmax and Mmax load values are plotted, and results are obtained for an Mn value of 755 kNm. Furthermore, the calculation of the main reinforcement requirement is carried out. The results obtained are the need for reinforcement of as many as 8 rods with a diameter of 22 mm reinforcement used. Moment control is declared to comply with the requirements.

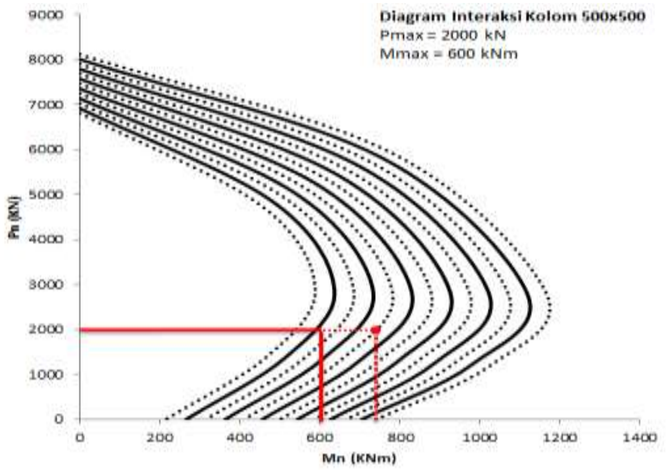

Figure 3. Interaction diagram

CONCLUSION

The results of optimizing the column planning interaction diagram have been obtained. A reinforcement ratio of 2% is a better result to apply.

Declaration by Authors

Acknowledgement: None
Source of Funding: None
Conflict of Interest: The authors declare no conflict of interest.

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How to cite this article: Samsul A Rahman Sidik Hasibuan, Irwan, Dwifi Aprillia Karisma et.al. Optimization of reinforcement ratio in reinforced concrete columns using interaction diagrams. *International Journal of Research and Review*. 2023; 10(4): 200-204.
DOI: *https://doi.org/10.52403/ijrr.20230425*

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