The flexural buckling comparison between open and close cross sections in high column structure

W D Rhini * and F Sri
Department of Civil Engineering, Faculty of Engineering, University of Muhammadiyah Sumatera Utara
Jl. Kapt. Muchtar Basri #03, Medan 20238, North Sumatera, Indonesia

* Email: rhiniwulan@umsu.ac.id

Abstract. Selection a cross-section of column on building construction needs to keep on a constant review to flexural buckling. The flexural buckling of column affects construction behavior overall. The aim of this study is comparing open and close of a cross-section column profile against flexural buckling. The hollow and pipe are representing close cross-sectional column profiles while I and T profiles are other represent. All profiles used the same material and properties, 400 Mpa of tensile strength and 740 mm² area of cross-sectional. The high of column was 24 m which, both ends be fixed. Load Resistance Factor Design (LRFD)- SNI 1729:2015 method was applied to analyze the flexural buckling. The T profile was a control to determine percentage of column slender other profiles. The result showed that the slender was 53.43%, 75.57%, and 86.67% for hollow, pipe, and I respectively to T profile. The study indicates that the high column and inertia of cross-sectional were important role in flexural buckling failure.

Keywords: Flexural buckling, open and close cross-section, SNI 1729:2015, high column

1. Introduction
Steel is one of the most widely used construction materials in Indonesia. Bridges, warehouses, factories, airport terminals, office buildings, and apartments typically use structural steel. In Indonesia, steel is widely used since the 1970s [1].

The steel structures, either columns, and beams must be a strength, stiff, and durable for life service of structures. In designing steel columns must be safe and able to accept service load, the columns should have the ability to the predictable overload or understrength. Overload can occur due to changes in building construction, too low for the assessment of the effects of excessive simplification in the analysis of his structure, and cause of the variations in the construction procedure [2].

Tables enlisting the section properties of commercially available structural steel sections are frequently used to help the designer obtain the required section properties such as weight, area, inertia, and radius of gyration. The design code of structural steel in Indonesia, SNI 1729:2015 [3], uses the Load and Resistance Factor Design (LRFD) concept. In LRFD, the factored load is compared with the nominal strength of the selected steel section [1].

2. Profile cross-section performance
The hollow and pipe are representing close cross-sectional column profiles while I and T profiles are other represent. Each section has the same area properties. Ratio b/t must be in control to classify
whether section properties are with or without elements slender elements [4]-[5]. Control value $r_{\text{min}}$ against $r_t$. If $r_t > r_{\text{min}}$ going flexural buckling. Table 1 presents data on properties of each cross-section. Calculation of analysis done on a numeric based on SNI 1729-2015 [3].

| Tabel 1. Section Properties | Dimension | 
|-----------------------------|-----------|
| Section Properties | B (cm) | H (cm) | t (cm) | $r_x$ (cm) | $r_y$ (cm) | b/t | $A_g$ (cm²) |
| Flens | 62 | 60 | 4 | 24.9 | 15 | < 0.56 | 704 |
| | \(\frac{31}{4}\) | \(\frac{200000}{400}\) | \(\frac{\sqrt{200000}}{400}\) |
| Web | 100 | 80 | 4 | 24.5 | 21.85 | < 0.56 | 704 |
| | \(\frac{52}{4}\) | \(\frac{200000}{400}\) | \(\frac{\sqrt{200000}}{400}\) |
| Flens | 60 | - | 4 | 19.85 | - | < 0.11 | 704 |
| | \(\frac{60}{4}\) | \(\frac{200000}{400}\) | \(\frac{\sqrt{200000}}{400}\) |
| Flens | 61.5 | 61.5 | 4 | 24.33 | 24.33 | < 1.40 | 704 |
| | \(\frac{61.5 - 8}{4}\) | \(\frac{200000}{400}\) | \(\frac{\sqrt{200000}}{400}\) |
3. Assumptions and analysis
The hollow and pipe are representing close cross-sectional column profiles while I and T profiles are other represent. All profiles used the same material and properties, 400 Mpa of tensile strength and 740 mm$^2$ area of cross-sectional. The high of column was 24 m which, both ends be fixed. Load Resistance Factor Design (LRFD) method was applied to analyze the flexural buckling failure.

3.1. Nominal Compressive Strength
The design compressive strength $P_n$. The nominal compressive strength $P_n$ which shows at Equation (1), shall be the lowest value obtained based on the applicable limit states of flexural buckling [6].

$$P_n = F_{cr}A_g$$

3.2. Critical Stress
The critical stress, $F_{cr}$, is determined as Equation (2) and (3).

$$\frac{KL}{r} \leq 4.71 \frac{E}{F_y} : F_{cr} = \left[0.658 \frac{F_y}{F_e}\right] F_y$$

$$\frac{KL}{r} > 4.71 \frac{E}{F_y} : F_{cr} = 0.887 F_e$$

3.3. The radius of gyration equivalents against torsional buckling ($r_t$)
In determining the radius of gyration equivalents against torsion is influenced by the constant warping ($C_w$), the torsion constant ($J$), the length of the rod ($L$) and polar moment of inertia ($I_p$). Equation (4) shows that the radius of gyration of the flange components in flexural compression plus one-third of the web area in compression due to the application of major axis bending moment alone [6].

$$r_t = \sqrt{\frac{C_w + 0.04J(KL)^2}{I_p}}$$

4. Result and Discussion
Table 2 shows the results of the parameters used to determine the cross-section are flexural buckling, torsional or flexural-torsional buckling. By comparing the value of $r_t$ with $r_x$ or $r_y$ buckling behavior can be known where that will occur in the column. Views to the I profile at the time of KL value 0 up to 200 cm, the value of $r_t < r_{min}$, torsional buckling occurs. For KL 400 up to 1200 cm flexural buckling behavior going on. So is the T profile, flexural-torsional buckling is very dominated the start of the KL 0 up to 1200 cm. For the close cross-section $J = I_p = I_x + I_y$; then it is clear that $I_x$ (flexural stiffness) only 0.5 from $I_p$ (torsional stiffness) then that determine flexural buckling [7].

| KL  | The radius of gyration equivalents against torsional buckling ($r_t$) | Pipe  | Hollow |
|-----|--------------------------|-------|--------|
| 0   | 14.47                    | 1.30  |        |
| 200 | 14.82                    | 3.10  |        |
| 400 | 15.81                    | 5.78  |        |
| 600 | 17.33                    | 8.55  |        |
| 800 | 19.26                    | 11.34 |        |
| 1000| 21.49                    | 14.15 |        |
| 1200| 23.93                    | 16.95 |        |

For the close cross-section

$J = I_p = I_x + I_y$; then it is clear that $I_x$ (flexural stiffness) only 0.5 from $I_p$ (torsional stiffness) then that determine flexural buckling is [7].

Figure 1 shows the relationship curve nominal compressive strength with slender. Of the four section properties, profile T has high slenderness, which affects the nominal compressive strength to be low, so flexural-torsional buckling occurs. Whereas the hollow profile has low slenderness, at KL 200 cm the hollow profile reaches the maximum nominal compressive strength value. The T profile was a control
to determine percentage of column slender other profiles. The result showed that the slender was 53.43%, 75.57%, and 86.67% for hollow, pipe, and I respectively to T profile.

![Figure 1. Relationship curve nominal compressive strength with slender](image)

Close cross-sections have smaller slenderness compared to open sections. From the two close sections, the hollow profile has the smallest slenderness and has a nominal compressive strength greater than the other cross-section because of the influence of column height and cross-section inertia. The greater the slenderness ratio, the greater the buckling effect experienced by a column either flexural buckling, torsional or flexural-torsional buckling and the smaller the nominal compressive strength.

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