

Capacity Analysis of Reinforced Concrete vs. Composite Column on a 7 Floor Building

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Abstract Designing columns with reinforced concrete material is often used in building construction so that reinforced concrete has several advantages. It is the availability of material, but requires a large dimension in holding high capacity. To reduce the dimensions of the column structure, a composite structure can be designed. In this study, an analysis will be carried out to determine the difference in dimensions that can be provided by reinforced concrete columns and composite columns holding an equivalent nominal capacity. This analysis was carried out in a case study of the planning of a 7-story lecture building. The initial design of the column applied is a reinforced concrete column which will then be redesigned with a composite structure using a WF steel profile. Based on the results of the research analysis, it shows that in holding the nominal capacity equivalent, the dimensions of the composite column used are smaller than the reinforced concrete column. In addition, the volume requirement of the material is also lower. This indicates that the composite column is good enough to be applied in building planning. In terms of price, all sizes of composite of profile WF columns are relatively more expensive than ordinary reinforced concrete columns.

Keywords Nominal Capacity, Reinforced Concrete Column, Composite Column

require design accurately so that the building can be used properly and safely. So it needs to design a column as a compression member which carries an axial load on the foundation, according to research [15]. The column must be designed in such a way that it does not collapse, because the collapse of the column can cause the total collapse of the entire building.

The capacity of the column to withstand the load is influenced by the components that make up the column, namely concrete which is weak in tension. Therefore, concrete can be combined with steel which has high tensile strength. Either with reinforcing steel as a reinforced concrete column or with the addition of a steel profile into a composite column [2], reinforced concrete column structures are more widely used in building construction. This is because reinforced concrete column structures have many advantages, one of which is the flexibility of form and resistance to water and fire, but in holding high capacity large dimensions are required.

The composite column structure in its planning can produce a design of smaller element dimensions than reinforced concrete columns so that it can save the floor area of the building structure [1]. In addition, the use of composite columns also has the advantage that they can increase tensile strength, structural rigidity and can increase resistance to fire hazards [7]. Composite columns that use steel tubes filled with concrete can also increase the compressive strength when filled with high-strength concrete with high-strength steel tubes as well [4]. In addition, use of columns can be reinforced with stainless steel spirals or stainless steel is 197% more corrosion

1. Introduction

The buildings that are increasing from year to year

resistant than using carbon steel [5].

Column tests on elliptical stainless steel filled with concrete were found to be sensitive for both the thickness of the steel tube and the strength of the concrete. A higher tube thickness results in a higher load-carrying capacity, as well as resulting in increased ductility. Higher-strength concrete increases the bearing capacity but reduces ductility [6]. Increasing the compressive strength of damaged columns can be done by using CFRP. A comparison between poor and medium-quality concrete columns shows that CFRP local coating is more effective in the case of poor-quality concrete [8]. Then in terms of column repair due to cyclic loading, the results showed that the cyclic load and the resulting damage caused a reduction in the axial stiffness of all damaged specimens. Hybrid column repair can restore stiffness and strength due to axial loads [3].

The next research analyzes the difference in dimensions that can be provided by reinforced concrete columns and composite columns in bearing loads with an equivalent nominal capacity and the types of failure that can occur in reinforced concrete columns and composite columns. The composite column used is a square column with a WF steel profile wrapped in concrete.

2. Methodology

The methodology used in this research is a literature study, namely the collection of building data and information obtained from the detailed engineering design of the construction of the lecture building of the Faculty of Economics and Business, University of Jember.

The study begins with data collection which includes material specifications and dimensions of the building structure, followed by load analysis which includes dead load, live load, and design earthquake load with a design response spectrum. Then carried out structural modeling and analysis of the nominal capacity of reinforced concrete columns. Based on the nominal capacity value of the reinforced concrete column, the calculation of the initial design of the composite column is carried out to determine the dimensions of the column to be used. The case study in this study was carried out on the planning of a 7-story lecture building. The initial design of the columns in this building was redesigned using a composite material with a WF steel profile covered with concrete. The strength of the composite column beyond to support axial loads which are used as a reference based on SNI-1727- 2013[12] is:

$$P_{no} = F_y A_s + F_{ysr} A_{sr} + 0,85 f_c' A \quad (1)$$

$$(a) \text{ Bila } \frac{P_{no}}{P_e} \leq 2,25$$

$$P_n = P_{no} \left[0,685 \frac{P_{no}}{P_e} \right] \quad (2)$$

$$(b) \text{ Bila } \frac{P_{no}}{P_e} > 2,25$$

$$P_n = 0,877 P_e \quad (3)$$

$$\phi = 0,75$$

3. Results and Discussion

Structure Model

The building structure in this study is a 7-story reinforced concrete structure with a floor height of 27.7 m.; the height on floors 1-5 is 4 m and the height on the 6th floor is 5 m (see fig.1). The dimensions of the structure used in this study were adjusted to the existing data. The dimensions of reinforced concrete columns are of three types, namely K1, K2, and K3. The dimensions of each column are 60x60cm, 50x50 cm, and 40x40 cm. Structural modeling with a structural analysis program is as follows:

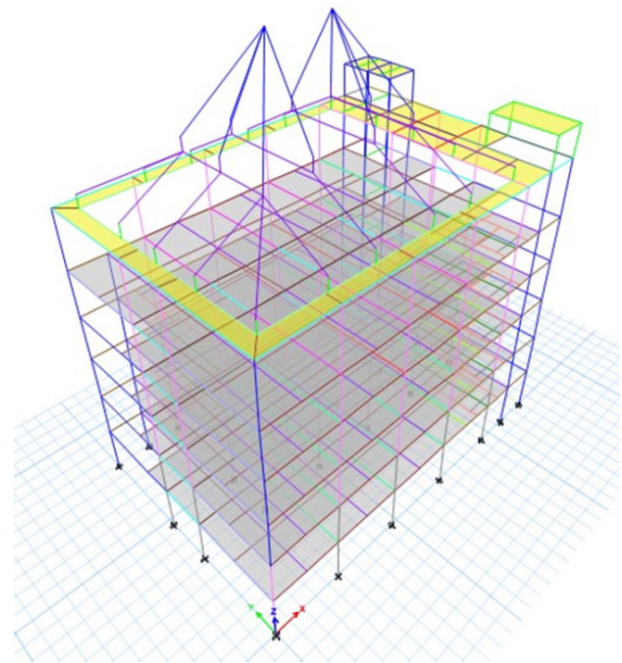


Figure 1. Structural Model

Loading in this study used dead load, live load, and earthquake load. Dead load and live load are adjusted to (SNI-1727, 2013)[12] regarding loading on building structures. Earthquake loads are planned with a design response spectrum based on (SNI-1726, 2019)[11] by determining the type of soil, which includes moderate soil with risk category IV, the location is in Jember, East Java. The design response spectrum diagram is (see fig.2):

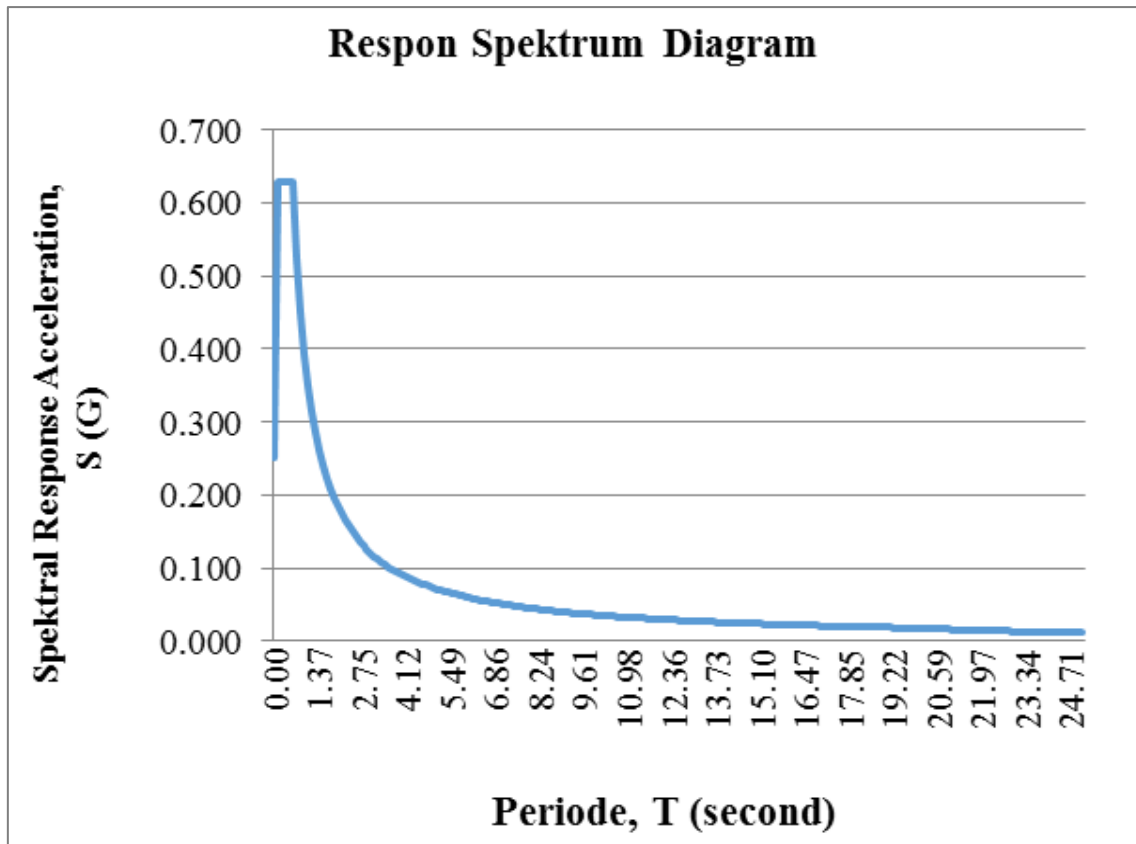


Figure 2. Response spectrum design

Analysis of reinforced concrete columns refers to (SNI-2847, 2019)[13]. Based on the results of structural analysis on reinforced concrete columns, the results of reinforcement are as table 1 follows:

Table 1. Column reinforcement details

column	size (mm)	Longitudinally reinforcement
	b x h	
K1	600 x 600	16 d19
K2	500 x 500	12 d19
K3	400 x 400	12 d16

The results of the transverse reinforcement for columns K1, K2, and K3 (see fig.3):

shear reinforcement of end-span: d12–100 mm

shear reinforcement of mid-span: d12–150 mm

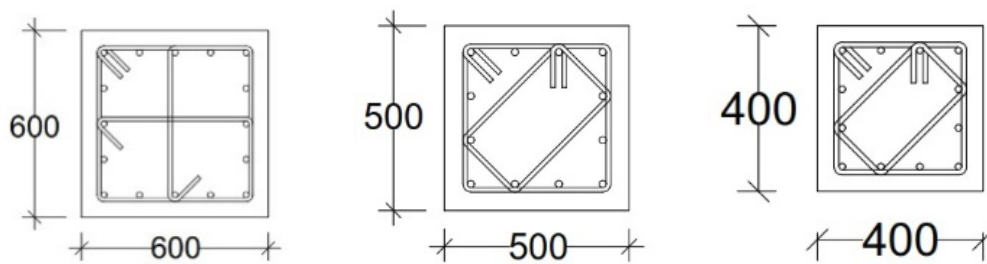


Figure 3. Type of reinforced concrete columns

Table 2. Column Capacity

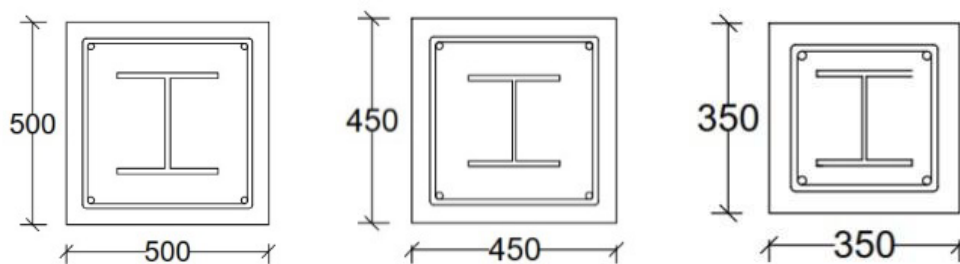
Columns type	size(mm)	Pn (kN)
	b x h	
K1	600 x 600	6660,5955
K2	500 x 500	4700,3266
K3	400 x 400	3078,1334

Composite Columns Analysis

The composite structure used is a square column with a WF steel profile wrapped in concrete. The composite structure is designed to be able to withstand a nominal capacity equivalent to a reinforced concrete column (see Table 2). The dimensions and steel profiles used in the composite column are as follows:

Table 3. Composite column details

Columns type	size(mm)	WF profile
	b x h	
C1	500 x 500	250x250x14x14
C2	450 x 450	200x200x8x12
C3	350 x 350	175x175x7,5x11

**Figure 4.** Composite column type

Longitudinal reinforcement was used in each composite column, namely, C1 used 4D19, 4D19, and C3 used 4D19. With transverse reinforcement in columns, C1 and C2 d12-200 with a stirrup spacing of 200 mm and column C3 used d12-150 mm. (see Table 3, fig.4) Based on the results of the analysis, the nominal capacity of the composite column see Table 4):

Table 4. Column Capacity

Columns type	sizes (mm)	Pn (kN)
	b x h	
K1	500 x 500	6660,5955
K2	450 x 450	4700,3266
K3	350 x 350	3078,1334

Composite Column and Base Plate Joint

The connection to the base plate is designed with a welded joint. 4 anchors with d24 mm were used. The dimensions of the base plate are 25 x 25 cm with a thickness of 30 mm and an anchor length of 500 mm. pedestal dimensions 500 x 500 mm(see fig.5)

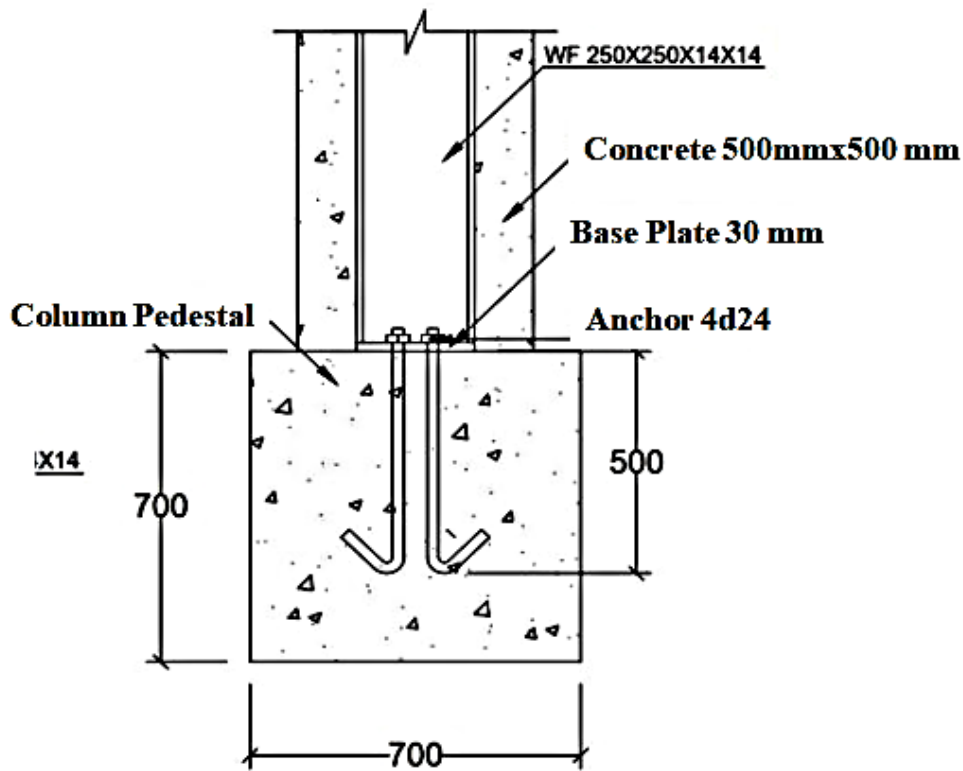


Figure 5. Column dan base plate conection

Comparison of reinforced concrete columns and composite columns in holding equivalent nominal capacity can be seen in the following table 5:

Table 5. Comparison of dimensions with an equivalent nominal capacity

Column type		size(cm)	Area(cm ²)	Pn (kN)
Reinforced concrete	K1	600x600	360.000	6660,5955
	K2	500x500	250.000	4700,3266
	K3	400x400	160.000	3078,1334
composite	C1	500x500	250.000	6852,2072
	C2	450x450	202.500	4949,1738
	C3	350x350	122.500	3194,6008

Based on the table above, the comparison chart for the dimensions of reinforced concrete columns and composite columns in holding the nominal capacity of the column see fig.6 and table 6.

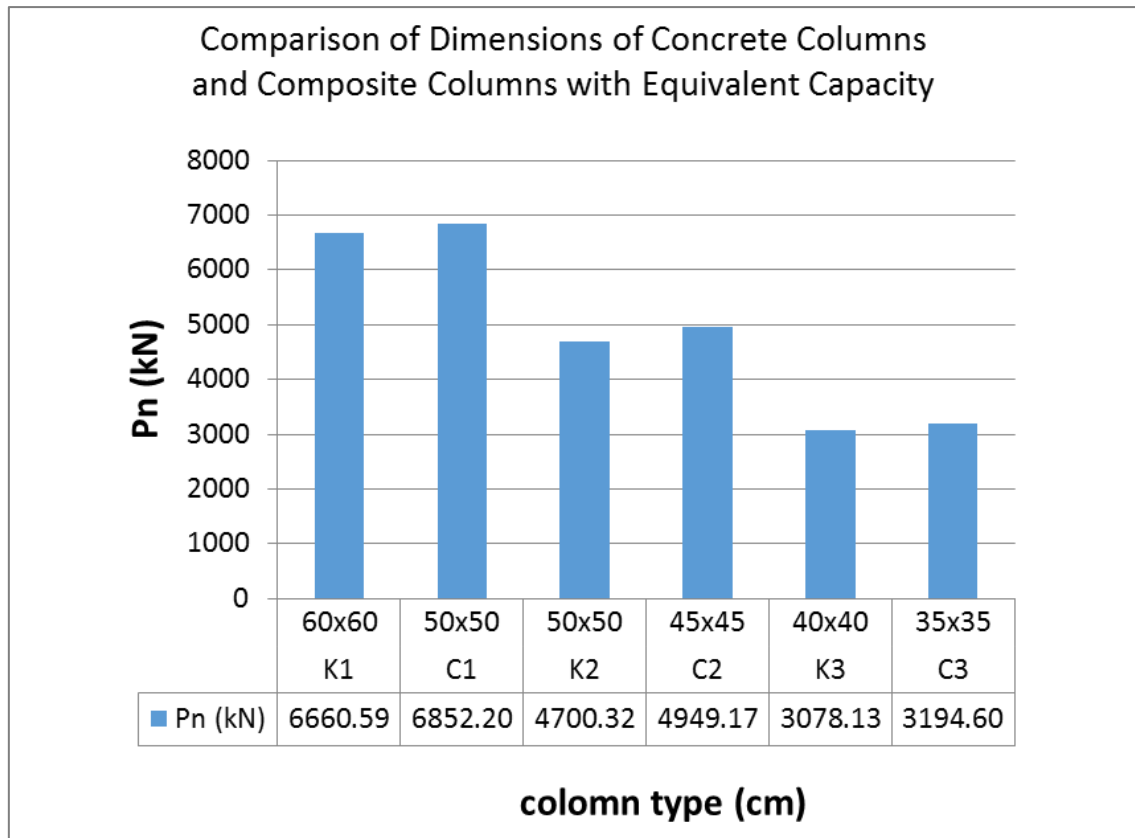


Figure 6. Comparison graph of column dimensions

Table 6. The volume of column material

Column	Reinforced concrete		Totally volume(m ³)
	concrete (m ³)	Steel (m ³)	
K1	1,44	0,018	1,458
K2	1,00	0,014	1,014
K3	0,64	0,010	0,650
C1	1,00	0,046	1,046
C2	0,81	0,030	0,840
C3	0,49	0,024	0,514

Column cost analysis per meter length

Analysis of work unit prices based on SNI 7394:2008 [14](Procedures Calculation of the unit price of concrete works for building construction and Housing) or PUPR Ministerial Decree No. 28/PRT/M/2016 (Unit Price Analysis of Work Public Works), see table 7:

Table 7. Price Per Unit

No	Description of item price per unit	Unit	Price (IDR)
1	Concrete	m ³	802.873
2	steel reinforcement installation	Kg	16.198
3	Formwork for columns	m ²	150.000
4	WF profile	kg	18.600

Based on the data above, the price per meter length of each column can be obtained by the following calculation (see Table 8):

Table 8. Cost analysis

Column	size (mm)	Reinforcing steel			Formwork area			Concrete(m ³)				Total (Rp) (1)+(2)+(3)	
		(a)(kg)	(b)price (IDR)	(1)=(a)x(b) (IDR)	(c) area (m ²)	(d) price (IDR)	(2)='(c)x(d) IDR	(e) Total Volume (m ³)	(f) Reinfor. Volume (m ³)	(g)=(e)- (f) (m ³)	(h) concrete price /m ³ (IDR)		(3)=(g)x(h) (IDR)
K1	600x600	39,25	16.198	635.772	2,4	150.000	360.000	0,36	0,00453	0,35547	802.873	285.397	1.281.169
K2	500x500	29,44	16.198	476.869	2	150.000	300.000	0,25	0,0034	0,2466	802.873	197.989	974.858
K3	400x400	20,86	16.198	337.890	1,6	150.000	240.000	0,16	0,0024	0,1576	802.873	126.533	704.423
C1	500x500	82	18.600	1.525.200	2	150.000	300.000	0,25	0,01047	0,23953	802.873	192.312	2.017.512
C2	450x450	49,9	18.600	928.140	1,8	150.000	270.000	0,2025	0,006353	0,196147	802.873	157.481	1.355.621
C3	350x350	42,2	18.600	784.920	1,4	150.000	210.000	0,1225	0,005121	0,117379	802.873	94.240	1.089.160

by combining table 5 table 6 and table 8, the following bar chart is obtained fig.7:

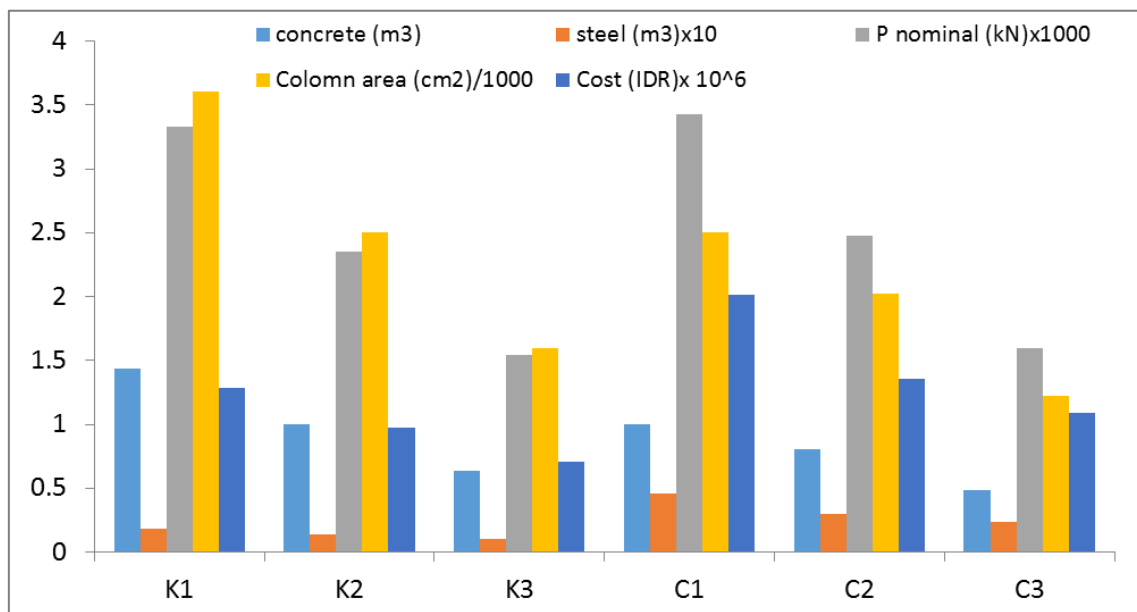


Figure 7. Comparison graph of material requirements, nominal capacity of columns and cost

From Figure 7, it can be seen that the composite column can reduce the cross-sectional area of the column with a larger Pn. The profiled steel in the composite column can increase the compressive strength of the column even though the profile steel has greater tensile properties than the compressive strength. So this explains that the bonding strength between profile steel and concrete has an important role in increasing Pn. In terms of price, all sizes of composite of profile WF columns are relatively more expensive than ordinary reinforced concrete columns.

Failure of reinforced concrete columns Analysis

According to research [10], the analysis of the type of

collapse in the column is determined based on the interaction diagram. There are 2 types of failure in the column, namely the compression zone and the tension zone. Determination of the type of failure can be determined by comparing the values of the ultimate axial force (Pu) and the axial force in a balanced condition (Pnb). Column interaction diagrams can not only be used in determining the type of failure but can also determine the strength of the column to withstand the load.

Reinforced Concrete Column Interaction Diagram

The diagram of reinforced concrete columns interaction in columns K1, K2, and K3 are obtained fig 8, fig9, fig 10:

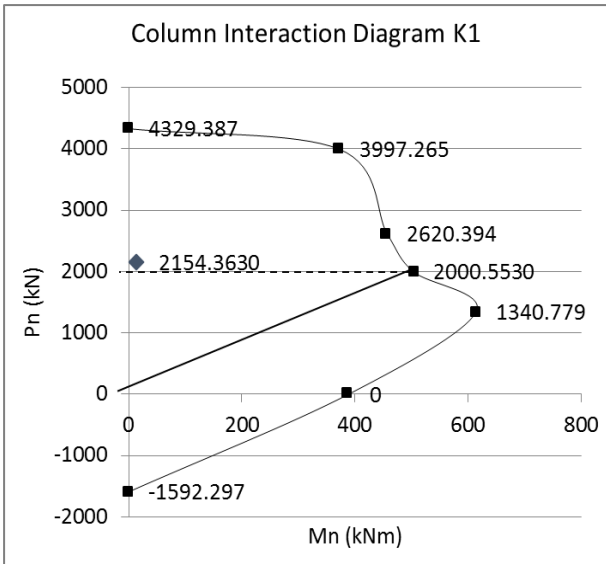


Figure 8. Column Interaction Diagram K1

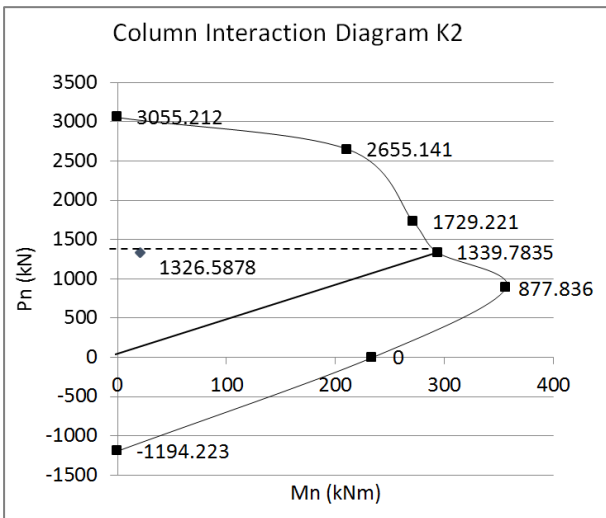


Figure 9. Column Interaction Diagram K2

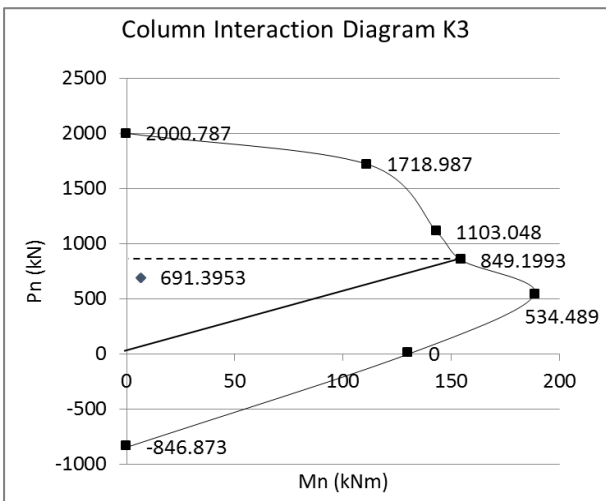


Figure 10. Column interaction diagram K3

Based on Figures 8, 9, and 10, it can be seen that the type of failure that occurs in each column is as follows:

Table 9. Types of failure of reinforced concrete columns

Column	Pu (kN)	Pnb (kN)	failure
K1	2154,3630	2000,5530	Pressure area
K2	1326,5878	1339,7835	Tension area
K3	691,3953	849,1993	Tension area

Composite Column Interaction Diagram

According to research [9], the composite column interaction diagram in determining the type of failure and strength of the C1, C2, and C3 columns see fig. 11, fig.12 and fig. 13 as follows:

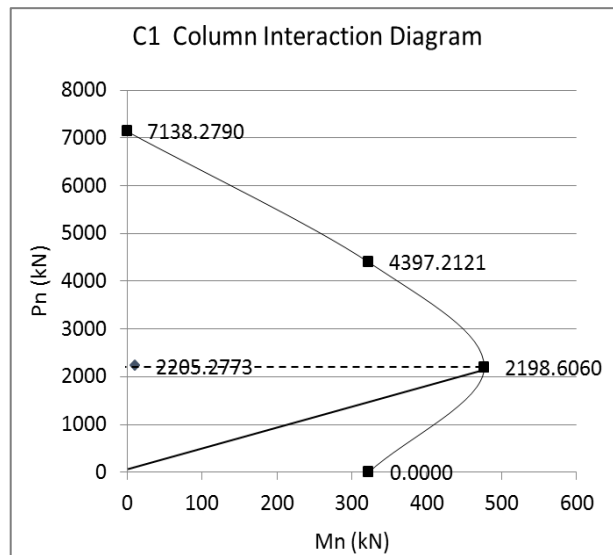


Figure 11. C1. column interaction diagram

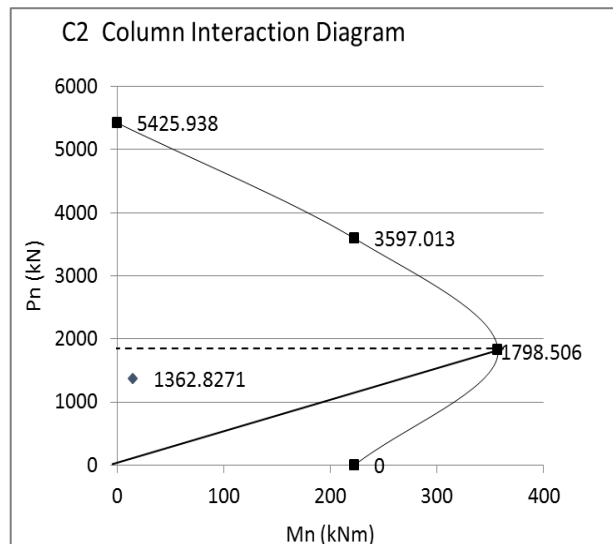


Figure 12. C2. column interaction diagram

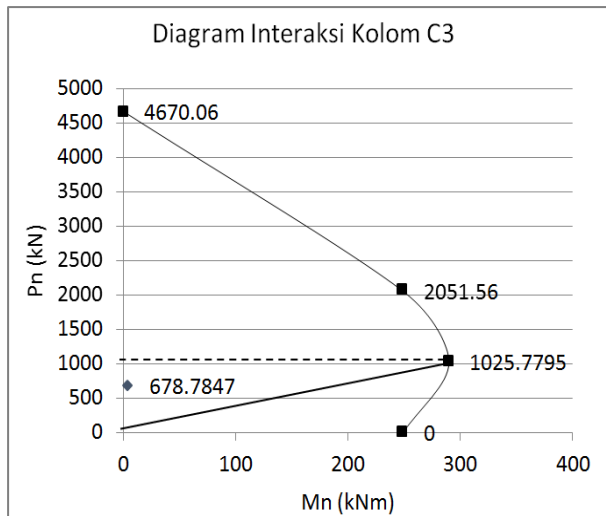


Figure 13. C3. column interaction diagram

Based on Figures 11, 12, and 13, it can be seen that the type of failure that occurred in each column is as see Table 10:

Table 10. Types of composite column collapse

Column	Pu (kN)	Pnb (kN)	Zone failure
C1	2205,2773	2198,6060	Pressure
C2	1362,8271	1798,5063	Tension
C3	678,7847	1025,7795	Tension

4. Conclusions

Based on the results of the discussion in this study, it can be concluded that in holding the nominal capacity equivalent, the dimensions of the composite column used are smaller than those of reinforced concrete columns. In addition, in terms of the total volume of composite column material requirements are also lower than reinforced concrete columns. This shows that composite columns can be a better choice for use in the structure. The results of the analysis based on the type of column failure showed that in the reinforced concrete column and the composite column. There was C1 column collapse due to the compression zone and in the K2, C2, and K3, C3 columns there was column collapse due to the tension zone. In terms of price, all sizes of composite of profile WF columns are relatively more expensive than ordinary reinforced concrete columns.

REFERENCES

- [1] Alfirdaus, A. P., Dapas, S. O., & Handono, B. D. (2019). "Technical Evaluation of the Use of Steel-Concrete Composite Columns in Multi-Story Buildings". *Civil Static Journal*, 7(2), 285–290.
- [2] Andreas, M., Margaretha, M., Yuniarto, R., & Lie, H. A. (2017). "Effect of Steel Configuration and Slenderness Factor on Column Compressive Capacity". *Jurnal Karya Teknik Sipil*, 6(1), 366–374.
- [3] Chellapandian M, Saumitra Jain, Suriya Prakash S and Akanshu Sharma (2019). "Effect of Cyclic Damage on the Performance of RC Square Columns Strengthened Using Hybrid FRP Composites under Axial Compression". *Fibers Journal*. www.mdpi.com/journal/fibers.
- [4] Guo-Chang Li 1, Bo-Wen Chen, Zhi-Jian Yang, Han-bin Ge 2 and Xiao Li (2021). "Axial Behavior of High-Strength Concrete-Filled High-Strength Square Steel Tubular Stub Columns". *Advanced Steel Construction – Vol. 17 No. 2* (2021) 158–168.
- [5] John W. Wright¹ and Chris P. Pantelides (2021) "Axial Compression Capacity Of Concrete Columns Reinforced With Corrosion-Resistant Metallic Reinforcement". *Wright and Pantelides Journal of Infrastructure Preservation and Resilience* (2021) 2:2.
- [6] Lam, D., Gardner, L. and Burdett, M. (2010). "Behaviour of axially loaded concrete-filled stainless steel elliptical stub columns". *Advances in Structural Engineering*. 13(3), 493–500.
- [7] Maharani, P. S., & Faimun, F. (2019). "Modification of the Planning of the Grand Dharmahasada Lagoon Building Using a CFT Concrete Steel Composite Structure with an Eccentric Braced Frame System Type Two-Story-X Braced". *Jurnal Teknik ITS*, 8(1), 10–17.
- [8] Marta Del Zoppo, Marco Di Ludovico, Alberto Balsamo and Andrea Prota (2018) "Comparative Analysis of Existing RC Columns Jacketed with CFRP or FRCC". *Polymers* 2018, 10, 361; doi: 10.3390/polym10040361
- [9] Milanovic, M., & Cvetkovska, M. (2015). "Interaction Diagrams Axial Force-Bending Moment for Fire Exposed Steel-Concrete Composite Sections". *Applications of Structural Fire Engineering*, (15-16 October), 275–280.
- [10] [10] Sartika, Indra Gunawan, S.T., M. T., & Endang S Hisyam, S.T., M. T. (2017). "Structural Analysis of Reinforced Concrete Building Based on SNI 2847-2002 and SNI 2847-2013" (Case Study: Mother and Child Hospital "Rona" Pangkalpinang Building). *Civil Engineering Journal*, 5(1), 57–69
- [11] SNI-1726. (2019). "Earthquake Resistance Design Procedures For Building And Non Building Structures"
- [12] SNI-1727. (2013). "Minimum Load for The Design Of Buildings And Other Structures".
- [13] SNI-2847. (2019). *Structural Concrete Requirements for Buildings and Explanation (ACI 318M-14 dan ACI 318RM-14, MOD)*.
- [14] SNI 7394:2008. *Procedures Calculation of the unit price of concrete works for building construction and Housing*) or PUPR Ministerial Decree No. 28/PRT/M/2016.
- [15] Toni, N., Suryanita, R., & Ismeddiyanto. (2015). "Prediction of Collapse Rate of Reinforced Concrete Column Due to Static Loading Using Artificial Neural Networks" (ANN). *Engineering Journal* 2(2), 1-9.

[16] SNI 7394:2008 (Procedures Calculation of the unit price of concrete works for building construction and Housing) or

PUPR Ministerial Decree No. 28/PRT/M/2016 (Unit Price Analysis of Work Public Works)