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Analysis Effect of Variation Form and Dimension on Structure Reinforced Concrete Column in Kali Kendeng Bridge

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Abstract. Square columns is a rectangular column which has a single stirrup shape and wide distances in - between. In addition, the round column is a column with a spiral section and has a relatively short distance or a relatively smaller distance in - between. Parameters in column planning include reinforcement requirements, column slenderness, buckling factors, interaction diagrams, and ductility. The study used existing rectangular column data with dimensions of 3.5x3.5 m from Kali Kendeng Bridge in the Semarang-Surakarta Toll Road Construction Project. From the field data, variations in the shape of the columns became rounded columns by calculating the moment of inertia of the two cross sections. Variations in dimensions was performed by calculating reinforcement ratio requirements, aiming to produce an effective column design. The first step is to analyze the bridge loading with earthquake loading SNI for the 2833: 2016 bridge and SNI loading for the bridge 1725: 2016. After that, do the calculation of reinforced concrete column requirements and be checked through the SAP2000 application. Then analyze SAP2000 output, so that the moment and shear forces are obtained in square and round columns. Then with the same material that is 30 MPa quality concrete and 390 MPa quality steel, the results obtained slenderness, bending factor and the radius of inertia between square and round columns are the same. The maximum moment value in a square column is 60704.8718 kN-m and the maximum shear is 2358.14 kN. In addition, the round column obtained a maximum moment of 60685.1944 kN-m and a maximum shear of 2358.65 kN. An overview of the relative ductility aspect of 2.7 kN between square and round columns and the ductility value shows the reduced cross-sectional area the smaller the ductility value. Therefore, it is concluded that a round column is better in terms of holding moment and sliding, than a square shaped column.

Keywords Square Column, Round Column

INTRODUCTION

Reinforced concrete columns are composites of materials that are resistant to tension and pressure. Steel is a tensile resistant material, while concrete is a pressure resistant material. Bridge columns have different shapes and types in their use, depending on location, soil type, and available time [1]. Usually, the columns used on the bridge pillars are square – shaped. The advantage of a square column is that it can be made easily and the plan is simpler. However, there are several bridges that use circular or circular column designs.

The construction of the Semarang - Surakarta toll road segment of the Salatiga - Surakarta toll road segment includes several bridge developments, including the Kali Kendeng bridge located in Pamotan Village, Susukan District, Semarang Regency. The bridge has a total length of 493 m and the width of the bridge is 25.2 m which is designed with the existing square cross section 3.5 x 3.5 m and there are 11 column points. The span length between columns is 40 m and the width between columns is 8.1 m. The deepest valley point is 39.5 m so it requires a long column. The author aims to vary the design of square and round columns in one of the longest columns at point P7 with a height of 39.5 m because a long bridge pillar has the greatest possibility of structural failure due to bending and slenderness factors. Square columns and round columns produce cross-sectional capacities, internal forces such as axial forces, shear forces and different moment styles so that a comparative analysis of both calculations is performed and variations in the dimensions of the square columns are 3.5 x 3.5 m^2, 3 , 45 x 3.45 m^2, 3.4 x 3.4 m^2 and 3.3 x 3.3 m2. While the round column diameter of 3.99 m, 3.97 m, 3.87 m, 3.76 m. Then do a review of the level of ductility associated with column interaction diagrams and cross-sectional areas. Based on the problem above, the purpose of this study is to design a bridge column by varying the shape, dimensions and then analyzing the moment and sliding to achieve the desired strength level at Kali Kendeng bridge on the Semarang-Surakarta toll road [4].

Bridge Loading

In this bridge planning, bridge engineering planning rules are used [7]. Based on the regulations used, a bridge structure must be planned for the strengths of the following loads:

1. Primary Load

Loads which are the main load in the calculation of stresses on each bridge plan [7].

2. Dead Load

All fixed loads originating from the weight of the bridge or part of the bridge under review, including any additional elements categorized to be a permanent unit with it.

3. Live load

All loads originating from the weight of moving / traffic vehicles and / or pedestrians that are considered to work on bridges.

4. Traffic load

All live loads, vertical and horizontal directions, due to vehicle action on the bridge including its relationship to dynamic effects, but not due to collisions.

- Plan Traffic Channels
- "D" Lane Loads
- "T" Truck Loads
- Dynamic Load Factor
- Brake Force

5. Enviromental Actions

- Effect of Temperature

The magnitude of the deviation due to temperature load (ΔT) must be based on the maximum and minimum temperatures defined in the design as follows:

$$\Delta T = \alpha.L\ (Tmax\ design - Tmin\ design)\ ...(1)$$

Description:
L is the length of the bridge component (mm)
α is the expansion coefficient temperature (mm / mm / °C)

TABLE 1. Material Properties Due to Temperature

Material	Temperature Extent Coefficient (α)	Modulus Elasticity (MPa)
Steel	12 x 10-6 per °C	200.000
Concrete		
Strength <30 Mpa	10 x 10-6 per °C	4700√fc'
Strength >30 MPa	11 x 10-6 per °C	4700√fc'

- Wind Load

The wind pressure specified in this article is assumed to be caused by a planned wind with a base speed (VB) of 90 to 126 km / h. Wind loads must be assumed to be uniformly distributed on surfaces exposed to the wind.

- Earthquake load

$$EQ = Csm / Rd \times Wt \ldots (2)$$

Description
EQ is the static horizontal earthquake force (kN)
Csm is the coefficient of elastic earthquake response
Rd is the modified response factor
Wt is the total weight of the structure consisting of dead load and appropriate live load (kN)

Column slenderness

For columns without stiffener using the formula :

$$(k_x\ Lu) / r < 22 \ldots(3)$$

Description :
k = Factor length of column
Lu = Net length of column
r = Inertia radius

Diagram of interaction

The column is considered to be able to withstand the working load if the axial load value needs to be equal to Pu and the moment load needs to be Mu that has been plotted on the axis of the diagram, the intersection point is in the interaction diagram. But on the contrary if the intersection point is outside the interaction diagram, then the column is not able to withstand the load [3].

Buckling factor

Long columns that have greater rigidity to one axis (strong axis) compared to the other axis (weak axis) can bend to the weak axis. The tip conditions greatly affect the critical load. If the two columns are identical, only the conditions of the ends are different, then the column which has a pinched edge can carry a greater burden than the column that ends at the joint. General relationship between column length and buckling load. Failure in the short column is material destruction, whereas failure in the long column is due to buckling. The longer a column, the smaller the load bearing capacity.

RESEARCH METHODOLOGY

This study used planning data obtained from the Semarang-Boyolali toll road construction project. Where the type of data is used basically to determine the strength of the column structure and explain the effectiveness of the column on the bridge structure. The stages of completion of this study are as follows:

1. Collecting data in the form of technical, non-technical data and design references
2. Loading Analysis
3. Processing data to be calculated in order to get the column cross-sectional area, the maximum moment value, and the maximum shear value.
4. Analysis of the results of calculations from SAP2000 and PCA Column applications to consider the efficiency and effectiveness of the existing column structure.
5. Conclusion

The tools used in this research consisted of computers that are equipped with supporting software: SAP2000, PCA Column, Microsoft Word, and Microsoft Excel.

RESULTS AND DISCUSSION

1. Technical Data Structures

Source of structural technical data was obtained from the Semarang - Surakarta toll road project, namely the concrete used K-350 with a different modulus of elasticity of 25332,084 MPa on the pillar while the girder 36406,043 MPa. In concrete material the poison ratio is 0.2, the concrete density is 25 kN / m^2 and its mass density is 2355 kg / m^3. Steel material used has a melting stress of 390 MPa. Modeling using pin support. Because the pin supports the force in vertical, horizontal and moment directions. The loading in this model is an even load on a propped plate by the girder then passed down through the bridge column. While the earthquake and wind loads are also given horizontally because they are lateral loads.

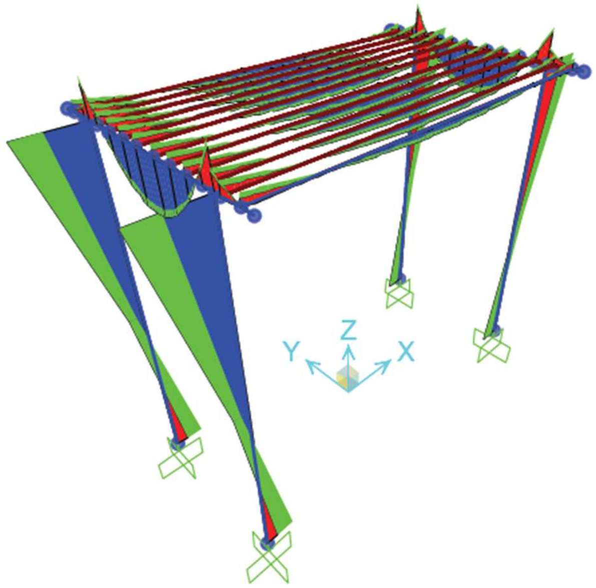

FIGURE 1. Modelling with SAP

2. Calculating Moment of Inertia

To find the value of a cross section of a round column, it is the same value as a square column, then it is calculated using the moment of inertia of the x-axis (Ix) and the y-axis (Iy). Based on the data in the square column dimensions b = 3.5 and h = 3.5.

$Ix = 1/12 \times b \times h^3$
$= 12{,}45\ m^4$
$Iy = 1/12 \times b^3 \times h$
$= 12{,}45\ m^4$

The moment of inertia must be the most critical. Because the moments at x and y are the same, 0.00125 m^4 taken is as a reference. Next calculate the moment of inertia for round columns.

$$I = 1/64 \times \pi \times D^4$$
$$(12{,}45 \times 64)/3{,}14 = D^4$$
$$D = \sqrt[4]{253{,}7}$$
$$D = 3{,}99\ m$$

So, we get the circle diameter for the round column is 3.9 m (rounded up to 4 m).

3. Calculating the Cross-Section Area of Column

Before calculating the cross-sectional area of the column, we must calculate the value of Pu where the P value is the calculation of the bridge loading, the value of which is obtained from existing data with SNI reference [8]. The results are as follows.

TABLE 2. Values of Axial Force

Load	P (kN)
Dead (MA)	17463
Additional dead (MS)	16903,4
Live (TD)	23814
Brake (TB)	15876
Wind (EW)	1.016,0640
Earthquake (EQ)	11510,35
Temperature (ET)	101165,82

Load Combination from SNI reference [8] are :

1,2MS+2MA+1,4TD+1,2ET+1,4TB

= 232175,064

To determine the value of Pu, the combination produces the highest value, which is combination, so the value of Pu = 232175 kN

Pu = 232175 kN
f'c = 30 MPa
fy = 390 Mpa
Φ for stirrup reinforcement taken 0,65
ρg = 3% = 0,03

Ag needed = Pu/(0,8*ϕ[0,85*f^' c(1-ρg)+f^' y*ρg])
= (232175*10^3)/(0,8*0,65[0,85*30(1-0,03)+390*0,03])
= 12.254.436,25 mm^2

To determine the actual ag, by the formula

Ag actual = √(12.254.436,25) mm^2
= 3500,633 mm Dibulatkan menjadi 3500 mm
Ag actual = 3500 x 3500
= 122.500.000 mm^2

Load on the concrete area,
ϕPn Concrete = 0,8*ϕ*[0,85*f'c*(1-ρg)*Ag]
= 0,8*0,65[0,85*30*(1-0,03)*12.250.000*10-3]
= 157561 kN

Load supported by reinforcing steel
ϕPn steel = Pu – ϕPn concrete
= 74613 kN
Ast needed = (ϕPn baja)/(0,8*ϕ*fy)
= (74613*10^3)/(0,8*0,65*390)
= 367914 mm2
ϕPn max = 0,8*ϕ[0,85*f'c(Ag – As) + (fy*As)
= 0,8*0,7[0,85*30(1.256*104 – 400.352) + (390*400.352)
= 273.776.445,6 kN

Security checks , φPn max ≥ Pu
273,776,445.6 kN ≥ 232. 175kN .... SAFE

Based on the above calculation, it means that the cross-sectional area of 3.5 mx 3.5 m meets the standard where the Pu value does not exceed or equal φPn max value.

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4. Loading

The calculation of load based on SNI 1725: 2016 concerns about the calculation of loading for the bridge, calculation was carried out manually based on data taken from the project location calculated according to SNI 1725: 2016 concerning Loading for Bridges. After the loading calculation is completed then it is input into the SAP2000 application to calculate the moment and shear that occurs in the column structure reviewed, namely Column P7 Kali Kendeng Bridge Semarang - Surakarta Toll Road. The results of the calculation of loading are as follows.

TABLE 3. The Calculation of Load

Type of Load	Ultimate Factor	Code of Load	Q (ton/m)	P (ton)	M (ton.m)
Girder	1,2	q1	1,88		
Vehicle Floor Plate	1,3	q2	1,39		
Asphalt, Water Load	2	q3	0,32		
Diaphragma Load	1,3	q4	0,14		
Vehicle Load	1,8	TD	1,58	13,72	
Brake Force	1,8	TB			15,62
Temperature Influence	1,2	ET			15,18
Wind Load	1,2	EW	0,10		
Earthquake Load	1	EQ	1,14		

5. Calculation of Reinforcement Column

Reinforcement of a Square Column

From Table in [6], we get steel reinforcement bars and are installed evenly along the circumference of the stirrup, for this purpose a D32 reinforcement with 24 longitudinal bars is used.

Planned stirrup reinforcement:

From the table obtained D13 steel reinforcement rod for stirrup. The distance of the stirrups must not be more than:

48 times the diameter of the stirrups bar = 48 (13) = 624 mm

16 times the diameter of the longitudinal bars = 16 (32) = 512 mm

The size of the smallest direction column (width) = 3500 mm

Reinforcement Round Column

From table in [6], we get the use of D32 reinforcement with 10 longitudinal bars. Column core diameter (from edge to outer edge of the spiral),

Dc = D - 2 * Cover
= 4000 mm - 80 mm
= 3920 mm

Cross-section area of the core of the column (outer edge to the outer edge of the spiral),

Ac = 1⁄4 * π * Dc^2
= 1/4 * 3.14 * 3920^2
= 12,062,624 mm^2

Ratio of spiral reinforcement,

ρs min = 0.45 (Ag / Ac-1) f'c / fy
= 0.45 (12,560,000 / 12,062,624 -1) 30/390
= 0.45 (1.04 - 1) 0.076
= 0.00136

From table it can be determined that steel reinforcement bars are taken D12 for spiral reinforcement. Therefore,

Asp = 1/4 * π * 122 = 113.04 mm^2

Maximum spacing,

actual ρs = (4 * Asp) / (Dc * S)

0.00136 = (4 * 113.04) / (3920 * S)

S max = 452.16 / 5.33

= 84.83 mm

Requirements for the spiral spacing distance ≥ 25 mm and ≤ 80 mm, then the S max taken is 80 mm.

Net spacing, = 80 - 12 = 68 mm

Calculation of Slenderness, Buckling Factor, and Column Interaction Diagram

Calculation of Slenderness of the Column

Rounded Column

$$r=\sqrt{\frac{I}{A}} \quad ...(5)$$

Cross-sectional Area (A) = ¼ * π * D2
= 0.25 * 3.14 * 3992
= 122500 cm2 = 12,25 m^2

The inertia is equal to 12.45 m^4. So that the value

r =√(I/A)

r = 1,008 m = 100,8 cm

For the k value obtained is joint-pin = 0.7

(k x lu)/r ≥ 22

(0.7*395)/100,8 ≥ 22

27,4 ≥ 22…………… including the slender coloumn

Square Coloumn

For a square column the value of r = 0.3h is known or using the formula, r = √IA. For the cross-sectional area (A) = b * h
= 3,5 * 3,5 = 12,25 m^2

Inertia (I) = 1/12 * b * h^3
= 0,083 * 3,5 * 3,53 = 12,45 m^4

So that the value of r = √(I/A)

r = √(12,45/12,25)

r = 1,008 m = 100,8 cm

For the value of k obtained is joint-pin = 0,7

(k x lu)/r ≤ 22

(0.7*395)/100,8 ≤ 22

27,4 ≤ 22…………… including the slender coloumn

If the value of the slender column is greater then it can make the ability of the column to hold the moment decreases which can be proven in the interaction diagram below.

Buckling Factor

Buckling stress (F) calculation according to Istimawan Dipohusodo (1994) can be seen as below.

Figures slenderness (λ) = (length of bending (Lk))/(radius of inertia (r))

F = (π^2*E*I)/ 〖(Kl)〗 ^2

If, E = √4700 * f'c = 68,55 * 30 = 2056,5 N/mm2 = 2056500 kN/m2 , I = 12,45 m4

Then, F = (π^2*E*I)/ 〖(Kl)〗 ^2

= (〖3,14〗 ^2*2056500*12,45)/ 〖(48,98)〗 ^2

= 105225,22 kN

From the above calculation, the value of slenderness and factor value bend the same column between the round column and the square column because it has the same moment of inertia value. Through calculations with the same equation, the value of slenderness and buckling factor of columns in each dimension sample obtained the following results:

TABLE 4. Slenderness Value and Buckling Factor Column

Dimension	Slenderness Value	Buckling Factor (kN)	r (m)	Inertia (m^4)
3,5 x 3,5	27,4	105225,2	1,008	12,45
3,45 x 3,45	27,81	100999	0,993	11,758
3,4 x 3,4	28,2	96829,06	0,979	11,09

3 x 3	29,08	87367,63	0,95	9,843

a. Diagram of Interaction
   Using the PCA Column application, the results of PM interaction diagram are obtained as follows:

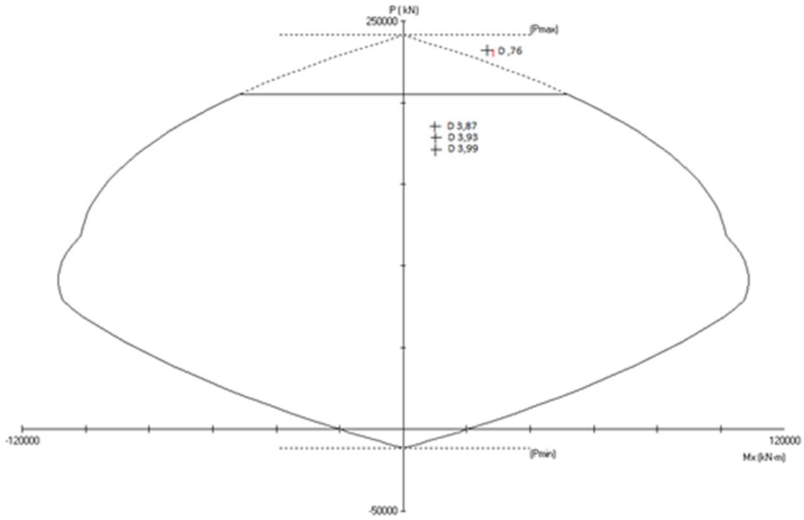


FIGURE 2. Square Column Interaction Diagram

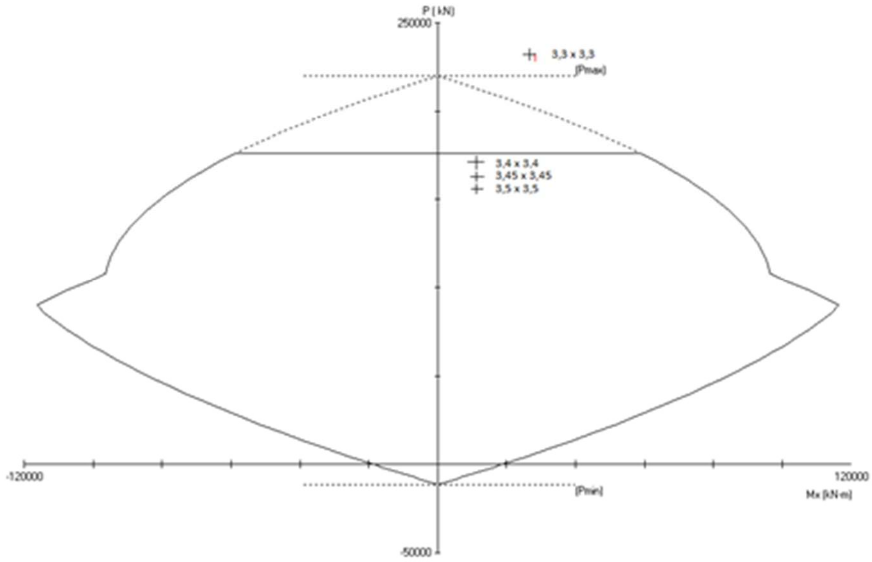


FIGURE 3. Round Column Interaction Diagram

From the results of the application of the PCA column, it can be concluded that the square and round columns safely hold the Pu value of 232175 kN, except for the square column dimensions of 3.3 x 3.3 m and the round column diameter of 3,76 m. Proven by the column in the interaction diagram.

6. Calculation Results using the SAP2000 Application

Calculation of the moment and shear in the bridge column structure which is reviewed using the SAP2000 application with the following results.

Moment and shear calculation which are then analyzed are the moment calculation in square columns with existing or actual size as in project location. Then a comparison with the round column has been calculated using the moment of inertia. After that, the dimensions of the square column are decreased but still with the same amount of reinforcement for the purpose of comparing the moment and sliding results on the bridge column structure.

TABLE 5. Calculation of Moment and Shear Maximum

Dimension (m)	Coloumn Form	Momen Force (kN.m)	Shear Force(kN)
3,5 x 3,5	Square	60704,8718	2358,142
D 3,99	Round	60685,1944	2358,652
3,45 x 3,45	Square	60322,5898	2343,229
D 3,93	Round	60280,5968	2342,818
3,4 x 3,4	Square	59915,87	2327,35
D 3,87	Round	59848,75	2325,91
3,3 x 3,3	Square	39682,12	1537,451
D 3,76	Round	39589,23	1534,553

7. Results of Calculation Stress Ductility

Ductility calculations are reviewed with stress values obtained from SAP2000 output. Then calculated with the stress ductility equation as follows.

$$\mu\varepsilon = \frac{\varepsilon}{\varepsilon\, y} \ldots(6)$$

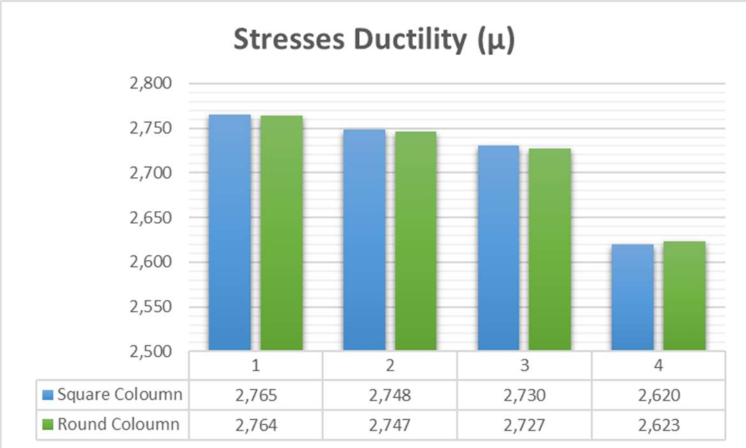
Description :
∈ = Maximum Stress
∈ = Yield Stress = 390 Mpa

Then after calculating the ductility stress that occurs between round columns and square columns the result is only a slight difference. The comparison is as shown in **FIGURE 7.**

TABLE 6. Recapitulation of Stress Ductility Calculations

Dimension (m)	Column Form	ε (kN/m2)	µ
3,5 x 3,5	Square	107843,94	2,765229231
3,45 x 3,45	Square	107182,15	2,748260256
3,4 x 3,4	Square	106477,37	2,730188974
3,3 x 3,3	Square	102176,75	2,619916667
D 3,99	Round	107815,24	2,764493333
D 3.93	Round	107114,52	2,746526154
D 3,87	Round	106365,85	2,727329487
D 3,76	Round	102313,15	2,623414103

FIGURE 4. Comparison of Stresses Ductility between Round and Square columns



CONCLUSION

Based on comparison of the forces in which a square column works, it produces a force greater than a round column but is relatively similar and slightly larger than a square column with a moment difference value of 19.67 kNm and a sliding difference of 0.51 kN. The square column has moments of 60704.8718 kNm and shear of 2358.14 kN compared to round columns which have moments of 60685.1944 kNm and shear of 2358.65 kN. From the amount of material, especially the reinforcement produced, round columns have more reinforcement than square columns. The value of buckling and bending stress are similar so that it can be said that there is no influence or change in the comparison.

Based on the value of the stress ductility produced relatively similar ductility values between square columns and round columns. The stresses generated by the square column is higher than the round column with the difference in value between the square column and the round column increases when the dimensions get smaller. From the results of the above analysis, it can be concluded that the round column has more strength compared to the square column. Because it is based on using benchmarks such as the moment and shear force, ductility factors, slenderness factors and column buckling factors.

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