The performance of structures with circular columns and square columns in the structure of Rancacili Silinder II building

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Abstract. In general, structural planning is only limited to count the safety and durability of the building in holding and accommodating the load on the structure, without calculating or determining the performance level of the structure. The structure performance itself is used to determine the performance level of a structure against an earthquake design based on the level of damage to the structure when it is affected by an earthquake with a certain return period. This research was conducted to determine the level of structural performance based on variations in column with a case study of the Rancacili Silinder II building. Structural performance analysis was carried out using three structural models, the structure with a circular column and a square column (Structure type I) according to existing conditions, the structure with a circular column (Structure type II), and the structure with a square column (Structure type III). The structure type I uses the same column dimensions from base floor to the roof, but structure type II and III the column dimensions change smaller from the base floor to the roof. Determination of performance levels based on ATC-40 with seismic load analysis of spectrum response. For force calculations in using ETABS V.16.2.0. The results of this study indicate that the structure type I has the smallest displacement value among the three models, with a displacement value of the X direction at 50,198 mm. While the structure type II has the smallest displacement value of the Y direction at 46,995 mm among the three models. The structure performance based on ATC-40 from the three structural models shows that they are at the same level of performance, Immediate occupancy (IO), where after an earthquake there is only a little damage and has the strength and stiffness approximately the same as the pre-earthquake conditions.

1. Introduction
Indonesia is one of the countries located on the ring of fire of the Pacific region and is the center of the meeting of several plates of the earth such as the Indo-Australian plate, Eurasian plate, and Pacific plate so that the territory of Indonesia often experiences earthquakes which cause enormous damage and losses to building structure. To minimize damage to building structures must have the ability to withstand various types of lateral loads such as earthquakes by increasing their rigidity, one of which is the use of columns.

In the column planning there are many possible cross-sectional variations that can be used. The cross-section shape that is most often used is a column with a square cross section and a circular section column. The cross-section shape of the column will affect the strength of the column and the overall stiffness of the structure. Columns with square crossings are the most widely used column types because
the execution of the process is easy and the manufacturing price is cheap [1], whereas columns with round cross-section have the capacity to receive axial loads greater than square and rectangular columns [2].

In general, structural planning is only limited to taking into account the safety and durability of the building in holding and accommodating the load that works on the structure alone without calculating or determining the level of performance of the structure. The structure performance itself is used to determine the level of performance of a structure against an earthquake plan that is seen from the level of damage to the structure when affected by an earthquake with a certain return period. This study aims to determine the use of variations in column shape seen from the performance of the structure. This study took a case study of Rancacili Silinder II Building in Bandung City. The column structure studied uses two types of columns, namely round columns and square columns. Structural analysis using ETABS V.16.2.0 program.

2. Literature review
The earthquake-resistant structure is a structure that is resistant (not damaged and does not collapse) when struck by an earthquake, not a structure that is solely (in planning) already calculated with the earthquake load [3].

2.1. Spectrum response method
According to SNI 1726-2012 the spectral response must be made based on the following data [4]:

2.1.1. The parameter of accelerated bedrock is mapped. Ss parameters (base rock acceleration in the short period) and S1 (bedrock acceleration period of 1 second) must be determined respectively from the acceleration response of 0.2 seconds and 1 second in the ground motion map in chapter 14 of SNI 1726-2012 with the possibility of 2% exceeded in 50 years (MCER, 2% in 50 years), and expressed in decimal numbers on gravitational acceleration. Acceleration response spectrum parameters in the short period (SMS) and 1 second period (SM1) adjusted to the influence of site classification, must be determined by the following formulation:

\[
\text{SMS} = F_a S_s
\]
\[
\text{SM1} = F_v S_1
\]

Figure 1. Map of earthquake areas in Indonesia for, SS.
Figure 2. Earthquake area map in Indonesia for, $S_1$.

**Table 1.** Site coefficient, $F_a$.

| Site Class | $S_{a0.25}$ | $S_{a0.5}$ | $S_{a0.75}$ | $S_{a1.0}$ | $S_{a1.25}$ |
|------------|-------------|-------------|-------------|-------------|-------------|
| SA         | 0.8         | 0.8         | 0.8         | 0.8         | 0.8         |
| SB         | 1.0         | 1.0         | 1.0         | 1.0         | 1.0         |
| SC         | 1.2         | 1.2         | 1.1         | 1.0         | 1.0         |
| SD         | 1.6         | 1.4         | 1.2         | 1.1         | 1.0         |
| SE         | 2.5         | 1.7         | 1.2         | 0.9         | 0.9         |
| SF         |             |             |             |             |             |

**Table 2.** Site coefficient, $F_v$.

| Site Class | $S_{v0.1}$ | $S_{v0.2}$ | $S_{v0.3}$ | $S_{v0.4}$ | $S_{v0.5}$ |
|------------|-------------|-------------|-------------|-------------|-------------|
| SA         | 0.8         | 0.8         | 0.8         | 0.8         | 0.8         |
| SB         | 1.0         | 1.0         | 1.0         | 1.0         | 1.0         |
| SC         | 1.7         | 1.6         | 1.5         | 1.4         | 1.3         |
| SD         | 2.4         | 2.0         | 1.8         | 1.6         | 1.5         |
| SE         | 3.5         | 3.2         | 2.8         | 2.4         | 2.4         |
| SF         |             |             |             |             |             |

The design spectra acceleration parameters for short periods and 1 second periods must be determined based on the following equation:

\[
S_{DS} = \frac{2}{3} = S_{MS}
\]

\[
S_{D1} = \frac{2}{3} = S_{M1}
\]
where:

- $S_s$ = Spectral response parameter acceleration earthquake for short periods
- $S_1$ = Spectral response parameter acceleration earthquake for a period of 1.0 seconds.
- $F_a$ = Spectral response parameter acceleration for the maximum earthquake that is reviewed depends on the location class and $S_1$ value.
- $S_{DS}$ = Spectral response parameter acceleration short period design
- $S_{D1}$ = Spectral response parameter acceleration design period of 1 second.
- $T$ = Period

2.1.2. Site class parameters. Based on the properties of the soil on the site, the sites are classified as sites of SA (hard rock), SB (rock), SC (very dense and soft rock hard) soil, SD (medium soil), SE (soft soil), and SF (special land that requires specific geotechnical investigation and specific response analysis).

2.1.3. Spectrum response design. From the spectral acceleration parameters of the design, spectrum response graphs can be made, by following the provisions below:

- For period ($T$) smaller than $T_0$, the design acceleration response spectrum, $S_a$, must be taken from the equation:

$$S_a = S_{DS} \left( 0.4 + 0.6 \frac{T}{T_0} \right)$$  \hspace{1cm} (5)

- For $T \geq T_0$ and $T \leq T_S$, the response spectrum of the design acceleration, $S_a = S_{DS}$

- For $T > T_S$, the design acceleration response spectrum, $S_a$, is taken based on the following equation:

$$S_a = \frac{S_{D1}}{T}$$  \hspace{1cm} (7)

$$T_0 = 0.2 \frac{S_{D1}}{S_{DS}}$$  \hspace{1cm} (8)

$$T_S = \frac{S_{D1}}{S_{DS}}$$  \hspace{1cm} (9)

2.2. Structural natural period

According to SNI 1726-2012 [4], the fundamental period of the structure, $T$, cannot exceed the results of the coefficient for the upper limit of the calculated period ($C_u$) from table 3 and the fundamental period of approach, $T_a$, in seconds, must be determined from the following equation:

$$T_a = C_t h_n^x$$  \hspace{1cm} (10)

$$T_{a \text{ max}} = T_a C_u$$  \hspace{1cm} (11)

Where:

$h_n$ is the height of the structure, in (m), above the base to the highest level of the structure, and the $C_t$ and $x$ coefficients are determined from table 4.
Table 3. Coefficients for the upper limit of the calculated period.

| The parameter of acceleration response spectra at 1 second, $S_{DL}$ | Coefficient $C_n$ |
|-------------------------|-------------------|
| $\geq 0.4$              | 1.4               |
| 0.3                     | 1.4               |
| 0.2                     | 1.5               |
| 0.15                    | 1.6               |
| $\leq 0.1$              | 1.7               |

Table 4. Periodical parameter value approach of $C_t$ and $x$.

| Structure type                                      | $C_t$   | $x$  |
|----------------------------------------------------|---------|------|
| Moment bearing steel frame                          | 0.0724  | 0.8  |
| Moment bearing concrete frame                       | 0.0466  | 0.9  |
| Steel frame with eccentric brakes                   | 0.0731  | 0.75 |
| Steel frame with brackets confined to buckling      | 0.0731  | 0.75 |
| All other structural systems                        | 0.0488  | 0.75 |

2.3. Seismic base shear force

The final value of the building's dynamic response to nominal earthquake loading due to the influence of the earthquake plan in a certain direction, should not be taken less than 85% of the first variance response value. If the dynamic response of the building structure is stated in a nominal shear force, the requirements can be expressed according to the following equation:

$$V_{dynamic} \geq 0.85 \% V_{static}$$  \hspace{1cm} (12)

Seismic base shear force, $V$, must be determined according to the following equation:

$$V = C_s \times W$$ \hspace{1cm} (13)

$$C_s = \frac{S_{DS}}{(R/I_e)}$$ \hspace{1cm} (14)

The seismic response coefficient, $C_s$ calculated according to the above equation does not need to exceed the following values:

$$C_{s\, min} = 0.044 \times S_{DS} \times I_e \geq 0.01$$ \hspace{1cm} (15)

$$C_{s\, max} = \frac{S_{DL}}{(R/I_e)}$$ \hspace{1cm} (16)

Where:

- $C_s$ = seismic response coefficient.
- $W$ = effective seismic weight.
- $S_{DS}$ = parameter design acceleration spectrum in the short period range.
- $R$ = response modification factor.
- $I_e$ = earthquake priority factor.

2.4. Displacement between levels

SNI 1726-2012 article 7.8.6 regulating the displacement between levels due to earthquake design ($\Delta$) must be calculated as the difference in deflection at the center of mass at the top and bottom level that is reviewed. The center deflection at $x$ ($\delta x$) level must be determined according to the following equation:

$$\delta x = \frac{C_d \times \delta xe}{I_e}$$ \hspace{1cm} (17)
Where:
- \( \text{Cd} \) = Deflection enlargement factor.
- \( \delta_{xe} \) = Deflection in the required location determined by analysis elastic.
- \( Ie \) = Factor of priority of earthquake.

2.5. Structure performance method ATC-40

The amount of horizontal drift must be considered in accordance with the applicable regulations, namely service performance limits and ultimate limit performance. According to the ATC-40 structure drift can be calculated using the following equation [5]:

\[
\text{Maximum drift} = \frac{D_t}{H} \\
\text{Maximum In – elastic drift} = \frac{D_t - D_1}{H}
\]

Information:
- \( D_t \) = displacement roof.
- \( D_1 \) = displacement on the ground floor.
- \( H \) = height of the portal structure.

### Table 5. Limitation of roof drift ratio according to ATC-40.

| Parameter                  | Performance Level |
|----------------------------|-------------------|
|                            | IO Damage Control | LS Structural Stability |
| Maksimum Total Drift       | 0.01 s/d 0.02     | 0.02 0.33Vi/Pi          |
| Maksimum Total In-elastic Drift | 0.005 s/d 0.015 | No limit No limit       |

2.6. ETABS

The ETABS program (Extended Three Dimensional Analysis of Building System) is a program that is used to model building, analysis and design of buildings quickly and accurately. CSI Berkeley software is widely used with high-level building planning in conducting dynamic analysis. Structure modeling using ETABS is made with mathematical data that is appropriate and represents the original structure used as computer data input, so the model will represent the conditions and behavior of the structure.

3. Research methods

The research design used in this study is comparative with the aim of finding similarities and differences about two or more things. In this study, researchers will compare the structure performance of the Rancacili Silinder II building by using two variations of column form type, circular columns and square columns using of ETABS V.16.2.0 software which is expected to determine which column shape has the best structural performance. The case study used in this study was the Rancacili Silinder II building located at Jalan Rancacili, Kelurahan Derwati, District Rancasari, Bandung. Based on the location, it is included in the earthquake zone 4 area.

3.1. Data analysis stages

3.1.1. Data collection. The collection of data and information on the Rancacili Silinder II building in the form of shop drawings consisting of structural drawings and architectural drawings are used as a reference for 3D structure modeling which is then analyzed using the ETABS V.16.2.0 program. Non-structural buildings are not modeled because they have no significant influence.

3.1.2. Structural modeling. The dimensions of the structure model for circular and square cross section columns are obtained by trial and error in ETABS V.16.2.0, so that the structural dimensions can be obtained that meet the capacity requirements. Furthermore, the modeling of building structures with 3D
modeling with data and information from Rancacili Silinder II shop drawing. Modeling is carried out with the help of ETABS V.16.2.0.

The structure is modelled into 3 structural models. The first structure is a structure with an existing column which in this final project is called type I structure. The second structure is a structure using circular columns, hereinafter referred to as type II structures and structures with square columns, hereinafter referred to as type III structures.

Figure 3. Structure plan with existing column (Type I structure).

Figure 4. Structure plan with round columns (Type II structure).
4. Results and discussion
The column is dimensioned by trial and error in the ETABS V.16.2.0 software. Variations in the column form reviewed were 2 column cross sections namely circular column section and square column cross section. The column is designed with the same cross-sectional area. The following column dimensions are obtained from trial and error.

| Structure Model | Column type | Dimensions (mm) | Floor |
|-----------------|-------------|-----------------|-------|
| Type I          | K3          | ø 800           | Base  |
|                 | K1          | 800 x 800       | Base  |
|                 | K2          | ø 800           | Base  |
|                 | KL1         | 200 x 500 x 500 | Base  |
|                 | KL2         | 200 x 500 x 500 | Base  |
|                 | KL3         | 200 x 400 x 400 | Base  |
|                 | KT1         | 200 x 400 x 600 | Base  |
|                 | KB          | 300 x 300       | Roof  |

| Structure Model | Column type | Dimensions (mm) | Floor |
|-----------------|-------------|-----------------|-------|
| Type II         | KB1         | ø 800           | Base  |
|                 | KB2         | ø 700           | 3 – 5 |
|                 | KB3         | ø 600           | 6 – 8 |

| Structure Model | Column type | Dimensions (mm) | Floor |
|-----------------|-------------|-----------------|-------|
| Type III        | KP1         | 710x710         | Base  |
|                 | KP2         | 625x625         | 3 – 5 |
|                 | KP3         | 535x535         | 6 – 8 |
4.1. Drift
Comparison of drift is done using a combination of dead load, live load, and earthquake load spectrum response. The deviation of each level of structure obtained from the analysis with ETABS V.16.2.0 for each type of structure can be seen in the deviation graph (Figure 6 and Figure 7).

![Figure 6. Comparison of drift in X direction.](image)

![Figure 7. Comparison of drift in Y direction.](image)
In figure 6 and 7 shows that the structure with a square column section (type III structure) has the highest value of the roof drift for the direction of X and Y direction of 51.865 mm and 52.777 mm. The drift value in type II structure has increased for X direction and has decreased for Y direction to type I structure which is 1.347% and 4.876%. Type III structure has increased the value of deviation in the direction of X and Y direction to type I structure which is 3,321% and 6,817%. From the comparison of the three structures drift it can be seen that structure I is the most rigid structure because it produces the smallest deviation value.

4.2. Structure performance evaluation based on ATC-40
After structural analysis using spectrum response method using ETABS V.16.2.0 software, the structure performance level based on ATC-40 is obtained. The results of the calculation and comparison of the level of structural performance of each structure type model can be seen in tables 9 and 10.

Table 9. Comparison of Structure Performance Levels in the direction of X.

| Structure Model | Maximum Total Drift | Maximum Total In-elastic Drift | Performance Level |
|-----------------|---------------------|-------------------------------|-------------------|
| Type I          | 0.00154             | 0.00146                       | IO                |
| Type II         | 0.00157             | 0.00150                       | IO                |
| Type III        | 0.00160             | 0.00153                       | IO                |

Table 10. Comparison of Performance Levels of Structure Y direction.

| Structure Model | Maximum Total Drift | Maximum Total In-elastic Drift | Performance Level |
|-----------------|---------------------|-------------------------------|-------------------|
| Type I          | 0.00152             | 0.00143                       | IO                |
| Type II         | 0.00145             | 0.00138                       | IO                |
| Type III        | 0.00162             | 0.00155                       | IO                |

From the comparison of the structure performance levels in table 9 and table 10 it can be seen that each type of structure has the same level of performance, namely immediate occupancy where the total maximum drift value is x and direction y is less than equal to 0.01.

5. Conclusion and recommendations

5.1. Conclusion
- The structure performance level (structure type I) using the combined column cross section has a maximum total drift value of 0.00154 for the X direction and 0.00152 for the Y direction, so that it is included in the immediate occupancy performance level, where an earthquake occurs only a little damage and has the strength and stiffness is almost the same as the conditions before the earthquake.
- The structure performance level (structure type II) using a circular cross section has a maximum total drift value of 0.00157 for the X direction and 0.00145 for the Y direction, so that it is included in the immediate occupancy performance level, where there is little damage and strength and stiffness are almost the same as the conditions before the earthquake.
- The structure performance level (structure type III) using a square cross section has a maximum total drift value of 0.00160 for the X direction and 0.00162 for the Y direction, so that it is included in the immediate occupancy performance level, where there is little damage and strength and stiffness are almost the same as the conditions before the earthquake.
- Performance levels of type II, and III structures have the same level of performance, namely immediate occupancy (IO), but when viewed from the value of the roof deviation produced by the structure with a square column section, the highest deviation value is 51.865 mm towards X and 52.777 mm towards Y so the collapse of a building is relatively large. On the other hand,
structures with circular crossed columns produce the smallest deviation value, i.e. 50,874 mm towards X and 46,995 mm towards Y, resulting in a rigid building structure.

5.2. Recommendations
The results of this study have implications for knowing the magnitude of the deviation that occurs based on variations in the use of column crossings in a building. Based on the results of the research recommendations for similar research are as follows:

- It is necessary to do an analysis with the variation of the other cross section shapes, such as rectangles to determine the most optimal form of column crossings in resisting earthquakes in either X direction or Y direction.
- Need to be analyzed with various forms of building structures.
- This research can be developed further by analyzing time history for the three structure models.

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