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Performance Analysis of Structure with Variation in the Cross-sectional Shapes of RC Columns Using Base Isolation

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ABSTRACT

Earthquakes are natural disasters that occur suddenly and pose significant risks to buildings. One of the most critical structural components in withstanding earthquake loads is the column. The shape of a column's cross-section can significantly affect its moment of inertia and the overall strength of the building structure. One effective method to enhance the seismic performance of a structure is through base isolation. This study aims to analyze columns with and without base isolation, utilizing both square and circular column designs. The objective is to determine how much the isolator can reduce earthquake forces by comparing the moment forces, displacements, base shear forces, and drift ratios within the structure. The building model used in this analysis is a four-story structure with a height of 20.95 meters, a length of 100 meters, and a width of 45.50 meters. The isolator employed is a high-damping rubber bearing (HDRB). HDRBs are seismic materials characterized by high stiffness before yielding. The earthquake force analysis was conducted using a static earthquake method based on a response spectrum. The results indicate that the shear force is reduced by 49.3% for square columns and 50.4% for circular columns. The average drift ratio on each floor of the structure using base isolation is 16.5% for square columns and 18.5% for circular columns. Overall, the research findings demonstrate that circular columns equipped with base isolators can more effectively reduce displacement, base shear force, and drift ratio compared to square columns.

Keywords: Square column; circular column; base isolation; SAP2000

INTRODUCTION

Column is a vertical member in building whose primary function is to support structural load and transfer superstructure load to the foundation. There are several types of column cross-sections, such as rectangular, square, and circular. The difference in cross-sectional shape can have a different effect on the moment of inertia value and the strength of the building structure. The section of shape column had a significant influence on the reinforcement effect of the axial compression. The carrying load capacity and ductility coefficient of different columns follow this order: square column-oval shape column-circular column (Niu et al. 2021). Along with the many and varied high-rise buildings, an innovation of column has been developed to reduce the risk of earthquake damage to buildings, and to maintain the integrity of structural and non-structural components (Saloma, 2015). One technique used in the construction of earthquake-resistant buildings is the implementation of a base isolator system. The principle of this system is to separate the lower structure from the upper structure so that the earthquake received by the lower structure does not enter the upper structure of the building (Muliadi et al. 2014).

Base isolation extends the natural period of the structure, reducing the structural displacement during a seismic event (Diyyah et al. 2023). When an earthquake occurs, this system is to increase the structure period so that vibrations can be minimized and to reduce the basic shear forces that occur in the structure. This is possible by installing isolators with sufficient vertical and bending stiffness and high horizontal flexibility (Sierra et al. 2020). There are various types of base isolators, including High Damping Rubber Bearings (HDRB) (Clemente et al. 2019; Ghrewati et al. 2023), Lead Rubber Bearing (LRB) (Shoaei et al, 2018; Shinozuka et al. 2015; Govardhan et al. 2016), steel versus carbon (FREI) / Nylon (FREI) (C. Niel and V Engelen, 2019; Cilento at al. 2022; Moon et al. 2003; Mordini et al. 2008; Calabrese et al. 2020), Geotechnical Seismic Isolation (GSI) (Dhanya et al. 2020; Tsang et al. 2019), Recycled rubber - Fiber Reinforced Bearings (RR-FRBS) (Calabrese et al. 2020) , Scrap Tire Rubber Pads (STRP) (Raj et al. 2022; Kumar et al. 2019; Mishra et al. 2013; Zisan et al. 2022) and Recycle Tire Isolator (RTI) (Tong et al. 2020; Jie et al. 2016). High-damping rubber isolation bearing (HDRB) is one of the most popular seismic isolation devices used for engineering seismic isolation (Murota, 2020). HDRB is a system seismic material developed from natural rubber which has a relatively small horizontal stiffness and is mixed with extra fine carbon blocks, oil or resin, and other filling materials to increase damping between 10% - 20% (Larasati D, 2019). High damping rubber bearing not only depend on matrix material, but also on the use of vulcanization and filler-reinforced systems (Chen et al. 2022). HDRB has plentiful advantages, such as a simple structure, stable mechanical performance, strong energy dissipation capacity, large stiffness before yielding, environmental protection, that make it an excellent choice for base-isolation structures (Gu et al. 2021). Therefore, the use of HDRB in base isolation is expected to reduce the horizontal seismic acceleration response, increase shear force, and drift ratio of the buildings.

This research aims to analyze the performance of structures both with and without base isolators, utilizing square and circular columns. The focus is on evaluating the effectiveness of base isolators in reducing earthquake forces by comparing key parameters such as moment force, displacement, base shear force, and drift ratio in the structures. Two building models will be designed: one with a fixed base and the other with base isolation, using software SAP2000. The analysis of earthquake forces will be performed using the static earthquake method with response spectrum analysis. Current seismic codes will provide acceleration response spectra, representing earthquake actions as a spectrum of absolute acceleration. The results will be compared in terms of internal forces, displacement, and drift for the two models. Base isolation is particularly recommended for buildings classified as risk category IV. The implementation of a base isolator is expected to significantly reduce the impact of earthquake forces on the column structure, thereby minimizing potential damage to the building during an earthquake.

METHODOLOGY

MODELLING OF STRUCTURE

Data of the building is height 20.95 m (4 floors), width 40.50 m. Main structure using reinforced concrete with concrete strength (f_c') 25 MPa and steel yield strength (f_y) is 400 MPa. Planning of structural elements in accordance with existing drawings in the form of main beams, beams, columns, slanted column, and floor plate dimensions in accordance with SNI 2847:2013. The dimension of each element of structures are shown in Table 1. In this research, the building structure is designed using the SAP2000 software with element dimensions according to existing drawings. The structure model is designed with 2 types, the structure without using isolator (fixed base) and with base isolator with 2 types of columns, square and circular. Base isolation with high damping rubber bearing isolator was defined with effective periods of 2.9 seconds, which covers the usual range of isolation system period. The analysis results are taken from the output of SAP2000 software. The drawing of the building structure shown in Figure1, and 3D images of buildings plan shown in Figure 2.

TABLE 1. Dimension of Structural Element

Structural Element	Height (m)	Width (m)
Main Beam (B1)	0.40	0.70
Secondary Beam (B2)	0.25	0.55
Column (K1)	0.60	0.60
Slanted Column (K2)	0.80	0.80

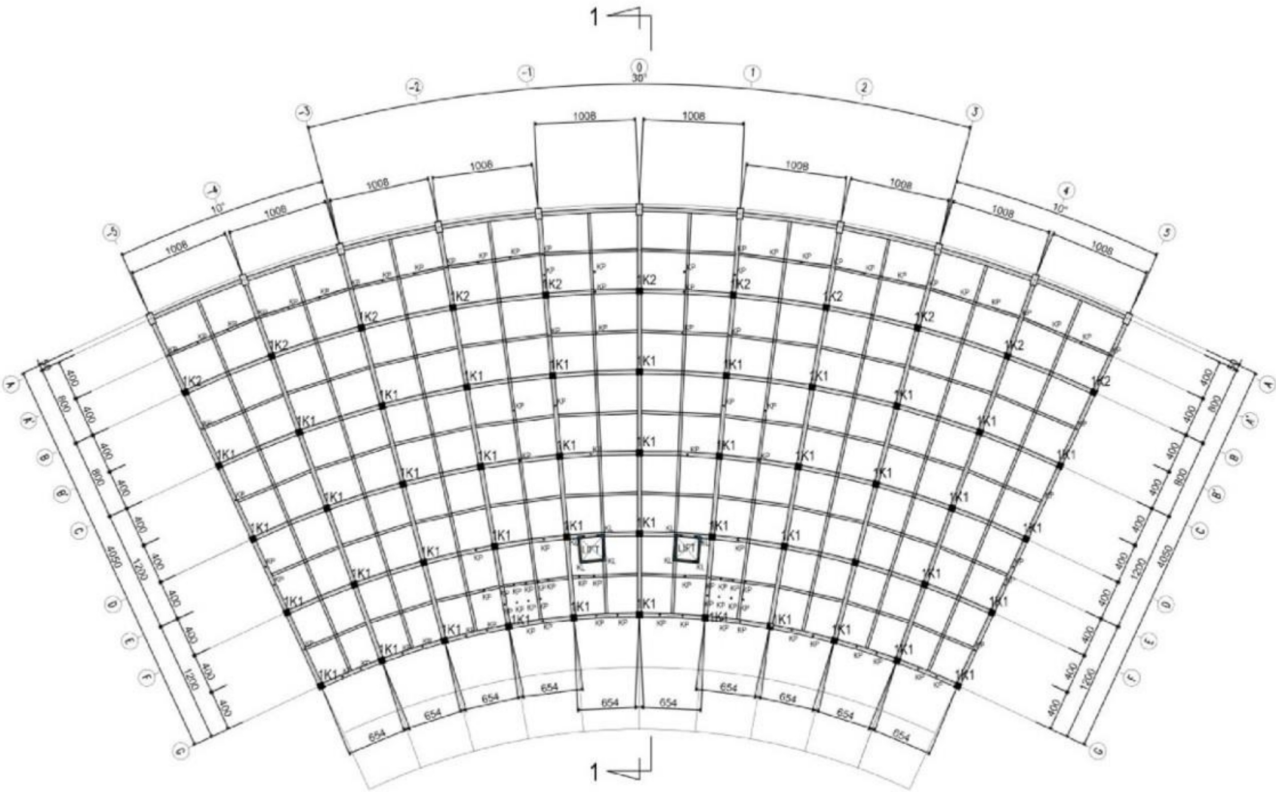

FIGURE 1. Site plan of columns used for output results.

a) Square Column b) Circular Column

FIGURE 2. Structure of Buildings

BASE ISOLATION

The following steps are used as a basis for choosing the dimension of base isolator to be used (Ismail, 2012).

1. Determine the building axial force of the structure for each column based on the planned load.
2. Determine the type of seismic base isolator to be used based on the axial force of each column axial force.

This research use HDRB with type elastomer MVBR 0514/MVBR 0520 X0.6R. G is 0.62 MPa, equivalent damping ratio is 0.24. T_D is 2.9 s. B_D is 1.58. Some of the equations used to design base isolation in building structures are as follows (Naem, 1999).

1. Horizontal stiffness of the structure

$$KH = \left(\frac{W}{g} \times \frac{2\pi}{T}\right)^2 \quad (1)$$

where, KH is horizontal stiffness of the structure, W is weight per column structure, T is planning vibration period, and g is acceleration of gravity.

2. Deviation

$$DD = \frac{g \, x \, SM1 \, x \, TD}{4\pi^2 x \, BD} \quad (2)$$

where, DD is deviation (mm), SM1 is Spectrum acceleration parameter at 1 s period, g is acceleration of gravity, T_D is period, and B_D is reducing coefficient.

3. Diameter of HDRB

$$D = \sqrt{\frac{4 \, xA}{\pi}}$$

$$\text{With, } A = \frac{1}{4} x \, \pi \, x \, d^2 \quad (3)$$

Where, D is diameter of HDRB (mm), and A is area HDRB.

4. Estimated Area of HDRB

$$A = \frac{W \, x \, 2\pi/T^2 xtr}{G \, x \, A} \quad (4)$$

Where, A is elastomer area (mm^2), W is weight of elastomer, G is shear modulus, tr is total thickness of area, and T is period.

RESUL TS AND DISCUSSION

The results of the comparative analysis will be presented in terms of internal forces, displacements, and base shear forces experienced by fixed-base structures and structures with base isolators. This analysis will follow the calculation of the force output for each structure. Figure 3 illustrates the varying displacements observed in square columns and circular columns for both (a) fixed-base structures and (b) base-isolated structures.

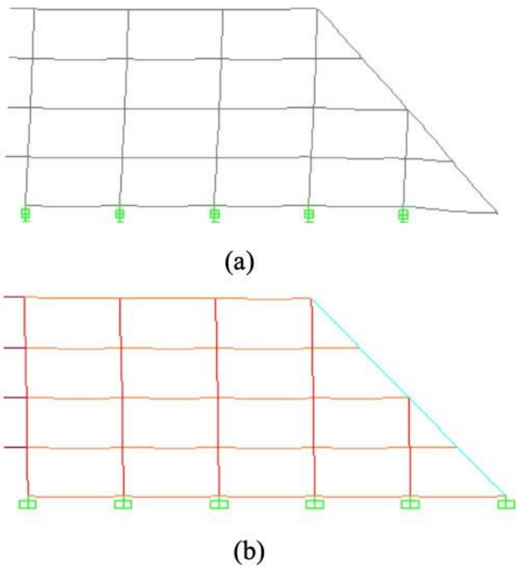

FIGURE 3. Displacement of Portal (a) Fixed Base, (b) Base Isolation

The comparison of a fixed base building with a building using base isolation on the values of axial force, shear force, and moment of the building's structural components is shown in Table 2.

TABLE 2. Results of Axial Force, Shear, and Moment Values on Fixed Base and Base Isolation Columns

	Fixed Base		Base Isolator		Increase (%)	
	square	circular	square	circular	square	circular
Axial (kN)	6198.8	6211.2	8888.1	8885.9	43.4%	43.1%
Shear (kN)	475.5	470.6	241.1	233.6	49.3%	50.4%
Moment (kN/m)	889.6	880.4	854.1	840.7	4.0%	4.5%

Based on the Table 2, the shear force that occurs in the fixed base structure against the base isolator building is reduced by 49.3% of square columns, and 50.4% of circular columns.

BASE SHEAR

The difference between a fixed base structure and one that utilizes base isolation with two-column cross sections, specifically, model 1 with a square column and model 2 with a circular column can be observed in Table 3. This table presents a comparison between the fixed base structure and the base isolated structure using the High Damping Rubber Bearing type.

TABLE 3. Base shear of the fixed base and base isolation

Structure	base shear		(%)
	Fixed base (kN)	Base Isolation (kN)	
Model 1	8348.4	6137.4	26.4%
Model 2	8392.2	6278.8	25.2%

Based on the Table 3, the shear force of the structure without the square column isolator is 8348.4 kN, and the circular column is 8392.2 kN. When an isolator is installed, the base shear value that occurs in the square column becomes 6137.4 kN and the circular column is 6278.8 kN. The shear force that occurs in the fixed base structure against the base isolator building has decreased by 26.4% for the square column, and 25.1% for the circular column. This means that the base isolation can reduce the earthquake forces that occur against the planned shear forces in accordance with the isolated structural system.

DISPLACEMENT

Based on the results of the previous calculation, the displacement value of each building with the review of the dynamic earthquake in the x-direction and y-direction is obtained. The ordinate x and y direction correspond to the direction of the ordinate from SAP2000. Then the comparative value of the displacement that occurs in the two columns of the fixed base structure and the base isolation structure is in Table 4 and Table 5.

TABLE 4. Displacement in X direction

Floor	Fixed base (mm)		Base isolator (mm)		(%)	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Roof	21.3	21.4	72.7	81.1	24.1	27.8
4	19.2	18.6	72.0	80.2	27.5	33.2
3	12.6	12.7	70.5	78.4	45.9	51.4
2	7.7	7.8	68.4	75.9	78.5	86.7
1	0.0	0.0	65.8	72.9	100	100
Mean					54.7	59.8

TABLE 5. Displacement in Y direction

Floor	Fixed base (mm)		Base isolator (mm)		(%)	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Roof	17.9	18.1	67.1	76.5	27.3	32.2
4	15.8	16.0	66.5	75.8	31.8	37.2
3	11.2	11.4	65.1	76.7	47.8	57.1
2	6.2	6.3	63.2	71.7	91.2	91.1
1	0.0	0.0	60.7	68.9	100	100
Mean					54.0	59.6

Based on the Table 4 and 5, the displacement of the base isolator building structure tends to increase when compared to the fixed base structure. Displacement in the base isolator building structure tends to increase when compared to the fixed base structure, which is an average of 54.7% of square columns, and 59.8% of circular columns in the X direction, decrease of 54.0% square column and 59.6% circular column in the Y-direction. In the fixed base structure, the upper structure with the foundation part becomes one so that the structure tends to be rigid. Whereas by inserting the base isolator system between the lower structure and the upper structure, it has a low stiffness between the upper structural components and the foundation so that the displacement generated by the building tends to be greater than the fixed base structure.

STORY DRIFT RATIO

The drift ratio is defined as the ratio of maximum lateral drift to total height of the specimen. Based on the calculation of drift ratio for each structure for both earthquake direction as follows.

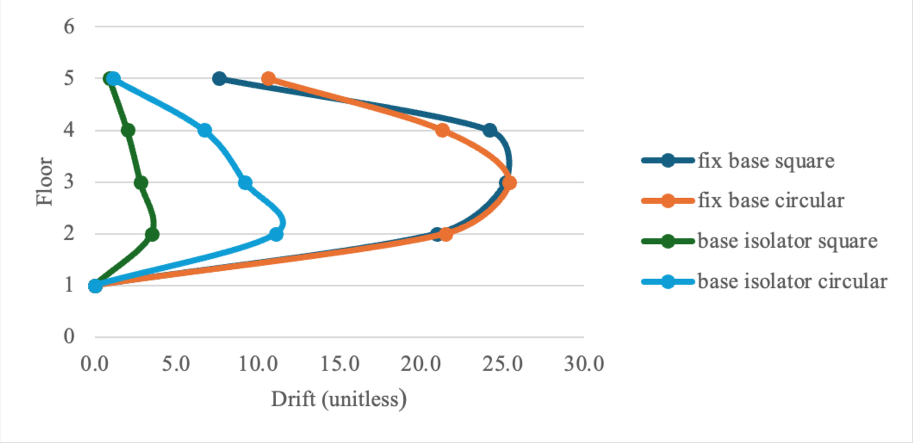

FIGURE. 4. Drift ratio in X direction

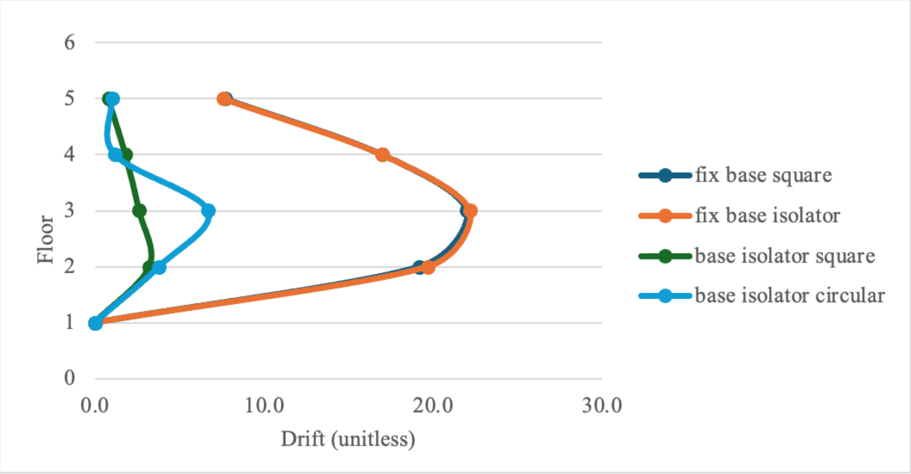

FIGURE. 5. Drift ratio in Y direction

Based on the Figure 4 and 5, it can be show that the drift value of structures that use base isolation on each floor has a smaller value. This proves that the base isolation is able to reduce the drift value that occurs. The overall average reduction value of the two columns viewed from the X direction was 71% for the square column and 54% for the circular column. The overall average reduction value of the two columns reviewed from the Y direction is 70% of the square column and 66% of the circular column.

CONCLUSIONS

The conclusions that conducted in fixed base and base isolation building structures using square columns and circular columns, the following are obtained:

1. The axial force, shear force and moment forces that occur in fixed base and base isolation structures can be reduced by 43.4%, 49.3% and

4.0% for square columns and 43,1%, 50,4%, and 4.5% for circular columns.

2. Based on the comparison of the base shear force that occurs in fixed base and base isolation structures using square and circular columns, it can be reduced by 26.1% for the structure model using square columns, while for structures using circular columns the base shear force can be reduced by 25.1%.
3. The structure under review which is inserted with base isolation has a greater displacement compared to the fixed base structure. The amount of displacement that occurs in both types of structures can be reduced on average by 54.7% for square columns, 59.8% for circular columns in the X direction and reduced on average by 54.1% for square columns, 59.6% for circular columns in the Y direction.
4. Based on a comparison of the drift values from the two column models that occur in fixed base and base isolation structures, the drift value can be reduced on average by 71% for square columns and 54% for circular columns in the X direction. In the Y direction it can be reduced on average by 70 % square columns and 66% circular columns.
5. Based on the results of the analysis that has been carried out by drift ratio and displacement of the structure, it can be concluded that circular columns have greater strength than square columns with the application of base isolation. This is because when both columns are given the greatest load, the round columns can reduce the earthquake forces that occur in the structure.

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DECLARATION OF COMPETING INTEREST

None.

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