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The Influence of Base Isolator on The Reinforced Concrete Structures at Sapadia Mataram Hotel Earthquake-Induced

(Pengaruh Penggunaan Base Isolator terhadap Perilaku Struktur Beton Bertulang Pada Gedung Sapadia Hotel Mataram Akibat Gempa)

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ABSTRACT

Ring of Fire and at the intersection of three tectonic plates. Efforts are needed to minimize earthquake damage, one of which is the use of a base isolator system. This study aims to determine the effect of using High Damping Rubber Bearing (HDRB) with a diameter of 800 mm on the behavior of reinforced concrete structures in tall buildings under seismic loads. The research location is the 7-story Sapadia Hotel building in the city of Mataram. The research is conducted by analyzing a 3D model of the fixed base structure and the base isolator structure using numerical analysis. The results show an increase in the base displacement of the base isolator structure by 59% in the x-direction and 44% in the y-direction, while the inter-story displacement decreases by 36% in the x-direction and 69% in the y-direction. The use of base isolators can reduce the shear force by 35% in the x-direction and 15% in the y-direction. Based on the pushover analysis, the roof displacement values for the fixed base and base isolator structures are 0.159 m and 0.129 m respectively. These values can be used to determine the structural performance level according to ATC-40. The maximum drift value for the fixed base structure is 0.0055 m. For the base isolator structure, the maximum drift value is 0.0044 m, categorized as Immediate Occupancy (IO). This value can be used to determine the performance level of the structure based on ATC-40. The maximum drift value of the fixed base structure is 0.0055m. While in the base isolator structure, the maximum drift value is 0.0044 m which is included in Immediate Occupancy (IO). Thus, the use of base isolators in high-level buildings is able to reduce post-earthquake damage and the building is still safe to continue using.

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1. INTRODUCTION

Lombok Island is one of the islands in Indonesia that has a history of earthquakes with a large enough magnitude. On July 29, 2018, there was an earthquake with a magnitude of 6.4 followed by a magnitude of 7.0 on August 5, 2018 [1]. These earthquakes caused damage to buildings, public facilities, and many casualties. One of the areas that suffered damage due to the earthquake was Mataram City, which is located in the seismic risk area 4, so it has a very large risk of infrastructure damage due to the earthquake.

The occurrence of earthquakes certainly cannot be prevented, but endeavors are needed to minimize damage due to earthquakes. Endeavors that can be undertaken are the form of strengthening the building in various ways. The basic concept of reinforcement is to increase the lateral strength and ductility of the structure [2]. Reinforcement methods can be viewed from two aspects, namely global and local reinforcement [3]. Several types of reinforcement are often used such as shear walls and bracing. Reinforcement with shear walls is strong enough to withstand the nominal shear force design that occurs [4]. The natural vibration time of structures using shear walls and bracing can be reduced [5].

In addition, there is a type of reinforcement that can be given to the bottom of the structure, namely the base isolator. Base isolators have the concept of separating the upper structure from the lower structure which works by keeping the structure above it as a unit, the direction of earthquake vibrations that occur randomly will only affect the base isolator because of its elastic nature. While the structure above it will vibrate or move as a unified structure [6].

The base isolator can reduce the earthquake force that occurs from the lower structure to the upper structure of the building [7]. In addition, the base isolator is also able to minimize the displacement and drift values on each floor of the building structure [8]. There are many isolator systems used in base isolators, but in this study, a base isolator with the High Dumping Rubber Bearing (HDRB) type will be used (Figure 1). HDRB has a better vertical isolation effect, better environmental protection, and greater bearing capacity than other types of rubber bearings [9].

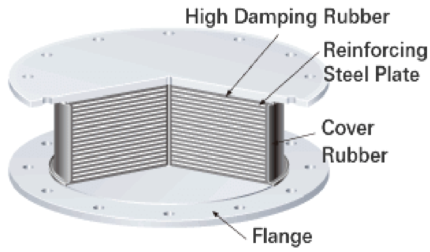


Figure 1. High Dumping Rubber Bearing

(source: Bridgestone, 2020)

The behavior of structures using HDRB-type base isolators shows that axial force has a significant influence on horizontal performance [10]. HDRB constructions with higher damping and yielding characteristics separate and dissipate seismic energy transmitted to the superstructure and have better seismic effects on the structure during an earthquake [11]. The behavior of HDRBs that have been studied previously is a reference in using this construction to reduce seismic energy in high-rise buildings. The Sapadia hotel building is one of the hotels in Mataram City, NTB which needs to be given a seismic energy-dampening construction due to the high number of floors. Therefore, this research will analyze the effect of providing HDRB construction on the Sapadia Mataram Hotel building.

2. RESEARCH METHODS

2.1 Preliminary building data

Building name : Sapadia Mataram Hotel
Number of floors : 7 floors
Subgrade : Medium Soil (SD)
Location : Latitude (8°35'39.4 "S), Longitude (116°05'50.2 "E)
The initial design of the Sapadia Hotel Building structure refers to SNI 2847: 2019.

2.2 Loading analysis

The loading analysis on this building structure uses a reference based on the SNI 1727: 2020 regulations.

Table 1. Load data

No.	Category	Description
1	The dead load is obtained from the automatic calculation of the numerical method for the weight of all components of the building structure.	Concrete weight: 24 kN/m^3 Steel weight: 78,50 kN/m^3.
2	Additional Dead Load	
	1. Additional dead load on floor slab (Ceramics, Ceiling, MEP Inst.)	Total load: 1,93 kN/m^2
	2. Additional dead load on the roof slab (Water Proofing, Ceiling, MEP Inst.)	Total load: 1,01 kN/m^2
	3. Additional dead load on stairs (Species, Ceramics, wall handrail)	Total load: 2,09 kN/m^2
	4. Half-brick masonry wall load of 1st floor 5 m high	Total load: 12,50 kN/m^2
	5. Half-brick masonry wall load of 2nd - 7th floors 4 m high 5.	Total load: 10,00 kN/m^2
	6. Additional dead load due to elevator	Total load: 32.58 kN/m^2
3	Live Load a. Room = 1,92 kN/m^2 b. Corridor = 3,83 kN/m^2 c. Roof = 0,96 kN/m^2 + Hujan (0,1 kN/m^2) d. Stairs = 4,79 kN/m^2	
4	Earthquake Load a. Building function = Hotel b. Building risk category = Risiko II c. Primacy factor = 1 d. Soil type = Medium (SD)	

2.3 Structure Analysis with Numerical Method

Structural analysis is carried out based on the provisions in SNI 1726: 2019. In the beginning, numerical modeling and analysis of the fixed base structure will be carried out then carry out design controls in the form of vibration period control, mass ratio, and story drift. If all aspects of the design control have been fulfilled, then the base isolator design is carried out then modeling and analysis based on SNI 1726: 2019.

2.4 Pushover Analysis

Pushover analysis will be carried out when the results of the analysis and control on the design of all elements have been fulfilled, which will determine the collapse behavior of the building by providing a thrust load that is gradually increased until the building collapses.

3. RESULTS AND DISCUSSION

3.1 Earthquake Load Analysis

Table 2. Earthquake Load Parameters and Structural System Parameters

Parameters of Ground Acceleration (PGA, S_s, S_1)		
PGA = 0.4595 g	S_s = 1.0418 g	S_1 = 0.4058 g
Site Coefficient (Fa, Fv)		
F_a = 1.0833 g		F_v = 1.8942 g

Parameters of short-period spectrum response	Parameters of 1 second period spectrum response
S_{MS} = F_a x S_s = 1.1286 g	SM1 = Fv x S1 = 0.7687 g
S_{DS} = 2/3 x S_{MS} = 0.7524 g	SD1 = 2/3 x SM1 = 0.5124 g
T_0 = 0.136 detik	T_s = 0.681 detik
0.50 ≤ SDS = 0.7524, then it included in the seismic category D	0.20 ≤ SD1 = 0.5124, then it included in the seismic category D
The seismic design category belongs to category "D", so with the special moment bearing reinforced concrete frame system (SRPMK) the parameters used include the modification coefficient factor, R= 8, the system overpower factor, Ω_0= 3, dan the deflection magnification factor, Cd= 5,5	

3.2 Fixed Base Structure Analysis

Control of the fundamental period of the structure

The fundamental period values based on the numerical analysis results are as follows:

T_{cx} = 1.670 seconds

T_{cy} = 1.960 seconds

since $T_{cx} \geq T_{max}$, then T_{max} = 0.854 seconds is used

since $T_{cy} \geq T_{max}$, T_{max} = 0.854 seconds is used.

Seismic base shear force control

Based on the results of the numerical analysis, the dynamic seismic base shear force values are shown in Table 3.

Table 3. Static force and dynamic force

Force direction	Static earthquake, V_s (kN)	V_s 100%	Static earthquake, V_d (kN)	Control $V_d \geq V_s$ 100%
X	4473,186	4473,19	4473,197	OK
Y	4473,186	4473,19	4473,197	OK

Control of building motion mode requirements

Based on the results of the numerical analysis, the values and descriptions of the building motion modes are shown in Table 4.

Table 4. Modal direction factor

Case	Mode	Period	Description
Modal	1	1,96	Translation
Modal	2	1,67	Translation
Modal	3	1,53	Rotation

Inter-story deviation control

Based on the results of the numerical analysis, the value of the deviation between floors can be seen in Table 5. The X-direction and Y-direction deviation graphs are shown in Figure 2.

Table 5. Deviation between floors

Story	*h* (mm)	Location	δe_x (mm)	δe_y (mm)
Roof	4000	Top	38.098	38.944
6th story	4000	Top	34.002	36.846
5th story	4000	Top	28.928	32.875
4th story	4000	Top	22.798	27.246
3rd story	4000	Top	16.037	20.567
2nd story	4000	Top	9.240	13.011
1st story	5000	Top	3.450	5.466

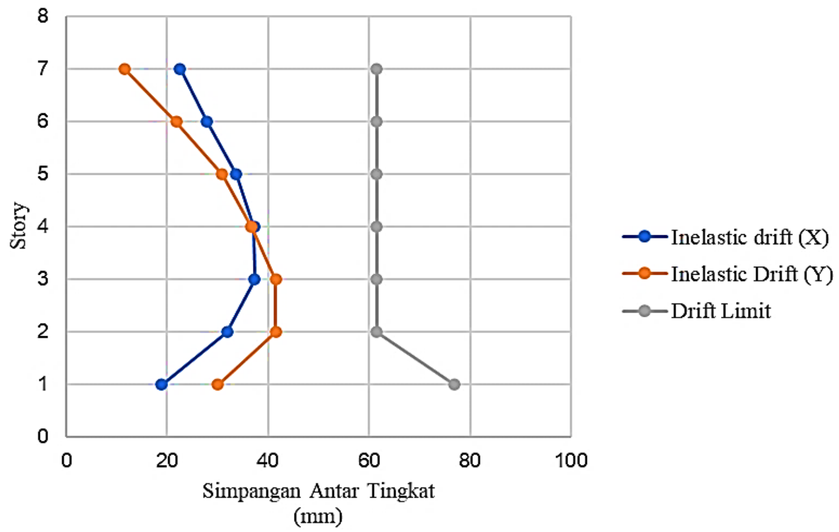


Figure 2. Inter-story deviation graph

Based on the results of numerical analysis, the deviation of this structure is still safe from damage to structural elements and non-structural elements.

3.3 Base Isolator Analysis

The selection of base isolator specifications used is based on the axial force of the lowest floor column. Based on the axial force (P_u) value of 4,878.41 kN, the HH080X6R type base isolator is used with a nominal long-term column load of 6,050 kN. The base isolator modeling was performed by inputting the design properties data in the numerical analysis which is shown in Table 6 and the modeling is shown in Figure 3.

Table 6. Base isolator properties data

No	Properties	Value	Unit
1	D_M	0,36	m
2	$u_{(\gamma)}$	0,33	
3	$G_{(\gamma)}$	0,47	
4	K_{eff}	1178,55	kN/m
5	K_2	787,52	kN/m
6	K_1	7.875,23	kN/m
7	Q_d	78,21	kN
8	D_y	0,11	m
9	F_y	86,89	kN
10	$\beta_{eff\ (\gamma)}$	0,19	

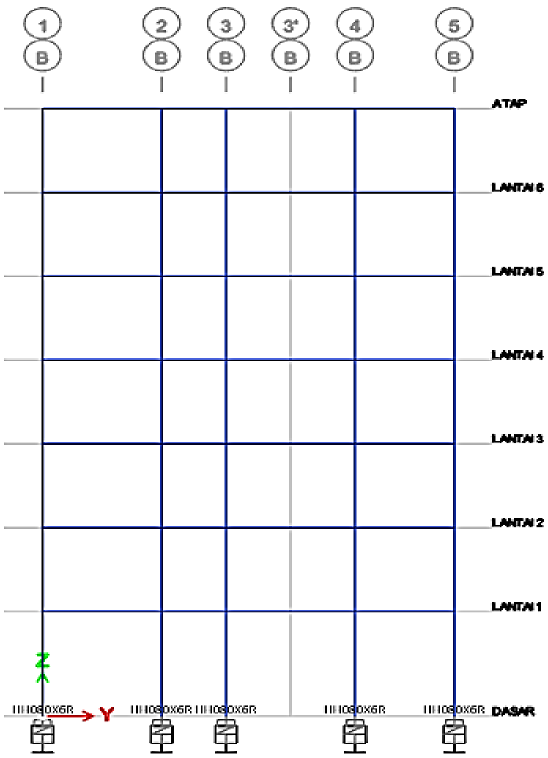


Figure 3. Modeling of the base isolator with numerical method

3.4 Analysis Result of HDRB type Base Isolator

Natural vibration time control

Based on SNI 1726:2019 states that structures that have a natural vibration time of less than 15% must use the complete quadratic combination *(CQC*) method, and if the natural vibration time is more than 15% use *SRSS*. From the results of the numerical analysis, the value of the natural vibration time of the structure is obtained as in Table 7.

Table 7. Natural vibration time

Mode	Period (seconds)
1	3,204
2	2,991
3	2,664
4	0,861
5	0,766
6	0,694
7	0,433
8	0,349
9	0,341
10	0,273
11	0,222
12	0,198

Control of translation requirements

Based on SNI 1726:2019 standard, modes 1 and 2 will have translations in the X and Y directions, and mode 3 will have rotations. Based on the results of numerical analysis, the value and description of translation and rotation can be seen in Table 8.

Table 8. Modal direction factor

Case	Mode	Period	UX	UY	RZ	Value	Description
Modal	1	3,22	0,00	0,85	0,09	0,87	Translation
Modal	2	3,026	0,94	0,00	0,00	0,95	Translation
Modal	3	2,705	0,00	0,10	0,86	0,86	Rotation

Deviation control between floors

Based on the results of the numerical analysis, the deviation value for each level can be seen in Table 9. The X direction and Y direction deviation graphs are shown in Figure 6.

Table 9. Deviation between story

Story	*h* (mm)	Location	δe_x (mm)	δe_y (mm)
Roof	4000	Top	60.45	55.94
6th story	4000	Top	57.82	55.29
5th story	4000	Top	54.42	53.05
4th story	4000	Top	50.05	49.58
3rd story	4000	Top	44.69	45.13
2nd story	4000	Top	38.31	39.38
1st story	5000	Top	30.58	31.43
Base	0	Top	23.09	22.47

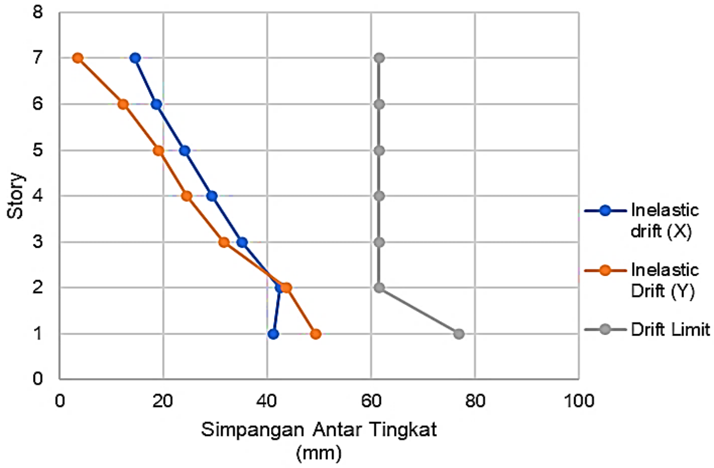


Figure 4. Inter-story deviation graph

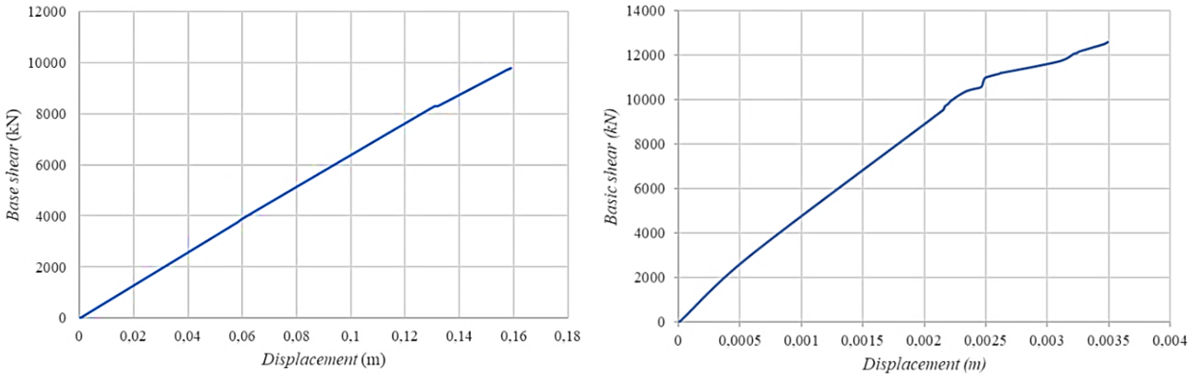
Based on the graph and table above, the largest deviation in the X direction is 60.45 mm and the Y direction deviation is 55.94 mm. These deviations are smaller than the maximum planned deviations $D_M > D_E$ (363 mm > 60.449 mm and 363 mm > 55.943 mm), so both deviations are considered safe.

3.5 Pushover analysis

The capacity spectrum method is based on an equivalent linearization approach as in Applied Technology Council (ATC-40) and Federal Emergency Management Agency (FEMA) 440-EL. In this method, the pushover curve is converted to a capacity spectrum that converts each point on the curve to a spectral acceleration (S_a) and spectral displacement (S_d).

Pushover analysis of fixed base structure

Based on the results of the numerical analysis, the pushover analysis results for the base shear and displacement values in the x direction can be seen in Figure 5(a) and for the y direction in Figure 5(b).



(a) (b)

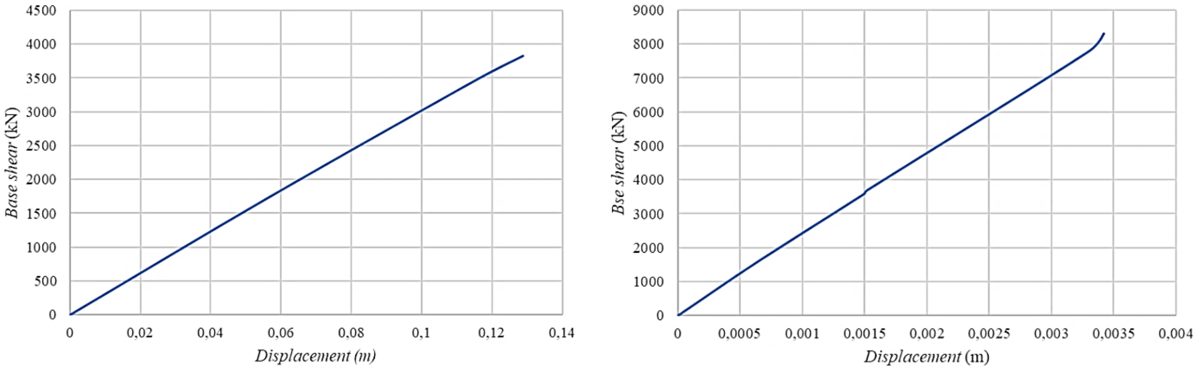
Figure 5. Graph of the relationship between base shear and displacement of the fixed base structure in *x* direction (a) and *y* direction (b).

Based on Figure 5 (a), there is a change in structural response from linear to non-linear conditions in the form of a slight decrease in stiffness as indicated by a small decrease in the slope of the curve due to plastic joints in columns and beams. Plastic joints caused by bending moments occur in beams and columns when the applied load exceeds the bending moment capacity under review.

Based on Figure 8 (b), there is a change in structural response from linear to non-linear conditions in the form of a slight decrease in stiffness indicated by a small decrease in the slope of the curve due to the presence of plastic joints in columns and beams. Plastic joints caused by bending moments occur in beams and columns when the applied load exceeds the bending moment capacity under review.

Pushover analysis of base isolator structure

Based on the results of numerical analysis on the structure with base isolator, the pushover analysis results for the base shear and displacement values in the x direction can be seen in Figure 6(a) and Figure 6(b) for the y direction.



(a) (b)

Figure 6: Graph of the relationship between base shear and displacement of the base isolator structure in the x direction (a) and y direction (b).

Based on Figure 6(a) the increase in the curve does not decrease in slope, this is due to the stiffness of the base isolator so that the plastic joints caused by the bending moment that occurs in the structure do not exceed the capacity. In addition, based on Figure 6(b) the increase in the curve does not experience a decrease in slope but an increase, this is due to an increase in the stiffness of the base isolator so that the plastic joints caused by the bending moments that occur in the structure do not exceed capacity.

3.6 Discussion of Analysis Results

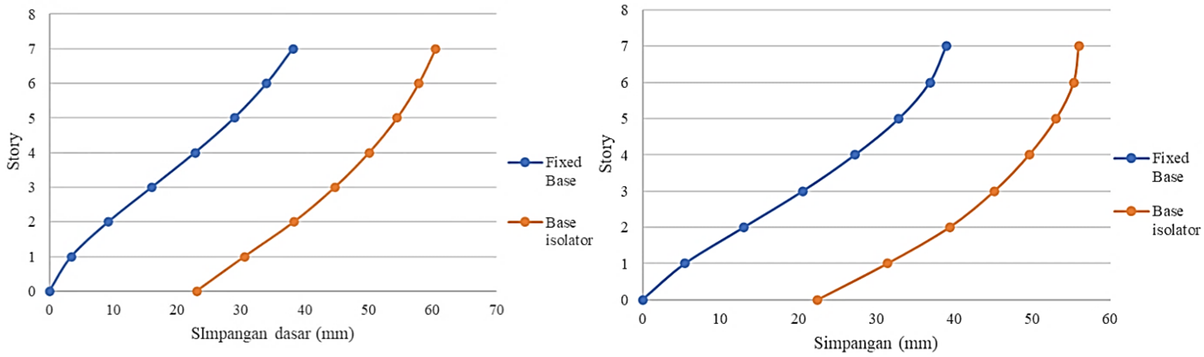
Comparison of vibration period values

Based on the results of the analysis carried out using numerical methods, the model using the base isolator structure can increase the vibration period of the structure compared to the existing structure (fixed base). In the fixed base structure, the resulting vibration period is 1.96 seconds, while in the base isolator structure, a vibration period of 3.204 seconds is obtained. The vibration period of the structure using the base isolator increased 1.64 times from the existing structure (fixed base). The vibration period of the base isolator structure is strongly influenced by the effective stiffness of the isolator. If the base isolator stiffness is smaller, the resulting structural vibration period is greater, and vice versa if the base isolator stiffness is greater, the resulting structural vibration period is smaller. So from this statement, there is a relationship between the effective stiffness of the isolator and the period of structural vibration.

Comparison of base deviation values

Based on the results of the analysis carried out using the numerical method, the model using the base isolator structure has a larger base deviation than the fixed base structure. This happens because the base isolator has flexibility in the horizontal direction so that the deviation that occurs is greater. Deviations that occur in structures that use a fixed base are generally only influenced by the stiffness and mass of the structure. Unlike structures that use base isolators, the deviation in the structure is not only influenced by the strength and mass of the structure but the structure is also influenced by the effective stiffness value and the actual damping of the base isolator.

The deviation that occurs in the base isolator must be controlled and must not exceed the calculated maximum displacement (D_M) of 425 mm. A comparison of the base deviation values of the two structures can be seen in Figure 7.



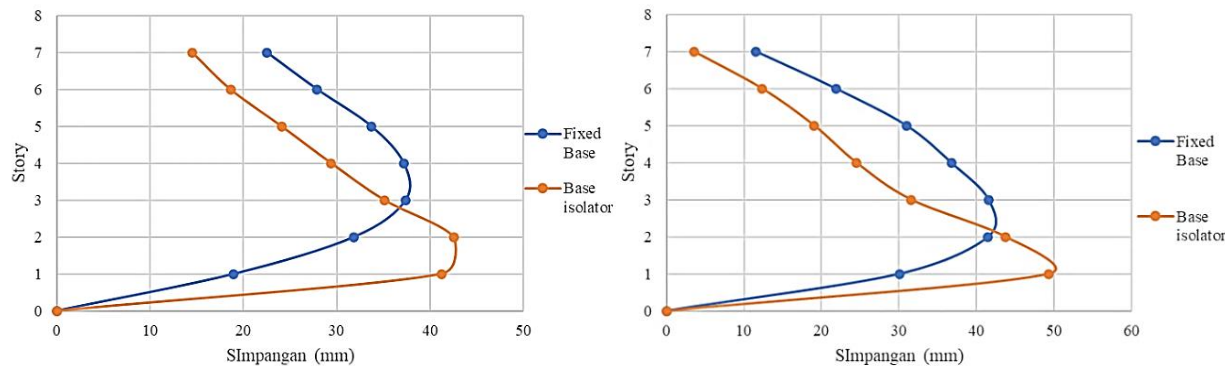
(a) (b)

Figure 7. Comparison graph of base deviation values in x direction (a) and y direction (b)

Based on Figure 7, the base deviation in the base isolator structure has increased. In the x direction it increases by 59% and in the y direction it increases by 44%, this increase occurs due to the influence of the base isolator which separates the upper structure and the base of the building in contact with the ground, so that only the upper structure moves. In the model with a fixed base structure, the largest base deviation occurs in the y-axis direction because it is influenced by the shape of the flat-shaped building, so the building can withstand lateral forces that occur from the Y-axis direction smaller than the X-axis. In models that use base isolator structures, the largest base deviation occurs in the X-axis direction because it is influenced by the presence of base isolators that make the upper building structure move together and the long shape of the building has a large mass in the x direction so that it makes buildings with base isolators when receiving lateral forces from the x direction will receive a greater push.

Comparison of deviation values between floors

Based on the results of the calculations carried out, that the model using the base isolator structure, the value of the deviation between floors is smaller than that of the fixed base structure. Comparison of deviation between floors and Figure 8.



(a) (b)

Figure 8. Comparison graph of x-direction (a) and y-direction (b) inter-story deviation values

Based on Figure 8, the deviation between floors that occurs in the fixed base structure can be reduced by the base isolator. The base isolator can reduce the deviation between floors that occurs in the X-direction building structure by 36% and Y-direction by 69%. In the model with a fixed base structure, the largest base deviation occurs in the Y-axis direction because it is influenced by the shape of the flat-shaped building, so that the building can withstand lateral forces that occur from the Y-axis direction smaller than the X-axis. In models that use base isolator structures, the largest base deviation occurs in the X-axis because it is influenced by the presence of base isolators that make the upper building structure move together and the long building shape will make buildings with base isolators when receiving lateral forces from the x direction will receive a greater push. The magnitude of the deviation between the lowest floor in the X-direction and Y-direction base isolator structures is caused by the movement of the lowest column that adjusts to the deviation of the base isolator.

Comparison of base shear force

Based on the results of the calculations carried out, the model using the base isolator structure has a smaller base shear force than the model using the fixed base structure. This is shown in Figure 9.

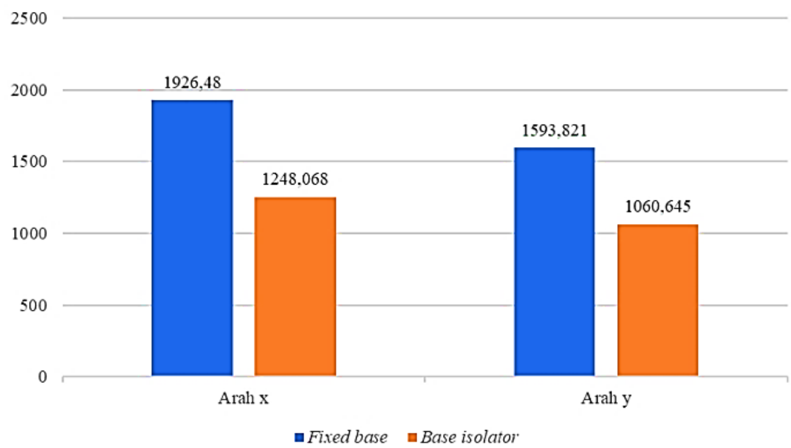


Figure 9. Comparison diagram of base shear force

Based on the review of Figure 9, there is a decrease in the x-direction base shear force from 1926.48 kN (fixed base) to 1248.068 kN (base isolator) by 35%. In the Y direction, there is a decrease in the base shear force of 1248.068 kN (fixed base) to 1060.645 kN (base isolator) or by 33%. The magnitude of the shear force reduction is due to the base isolator having a damping of up to 40% critical.

3.7 Structure Performance Level

Based on the calculation of the drift max fixed base in the x direction, a value of 0.0054 m is obtained, this value is less than the maximum value of the total drift of the Immediate Occupancy (IO) performance level of 0.01. So that the performance level is included in the Immediate Occupancy (IO) category. The calculation of the drift ratio is shown in Table 8.

Table 10. Calculation of drift ratio

Performance point	Fixed base		Base isolator	
	x	y	x	y
D (m)	0,158	0,00349	0,129	0,003
V (kN)	9768,35	12577,8	3820,41	8307,73
H (m)	29,00	29,00	29,00	29,00
Drift Max/h	0,0055	0,00012	0,0044	0,00012

Based on the calculation results in Table 10, the drift ratio calculation is then controlled by the performance level with limitations. In the fixed base structure, the x and y direction max drift values are 0.0055 m and 0.00012 m respectively so that the performance level is included in the Immediate Occupancy (IO) category.

In the base isolator structure, the x and y direction maximum drift values are 0.0044 m and 0.00012 m respectively so that the performance level is included in the Immediate Occupancy (IO) category. This means that there is very little post-earthquake damage to the structure. The risk of loss of life as a result of structural damage is very low and the building is still safe to continue using and the activities in it will not be disrupted if repairs are carried out.

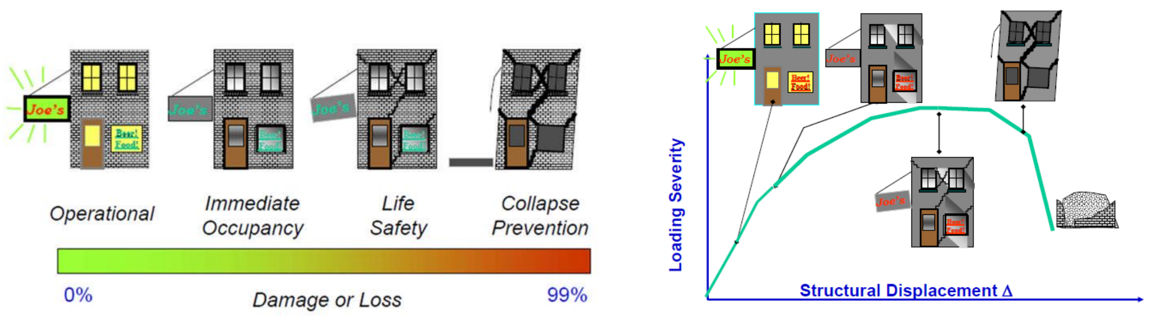


Figure 10. Global response and performance level
(source: FEMA, 2006)

4. CONCLUSION

Based on the results of the comparative analysis of the structure using a fixed base with a structure using a base isolator with a type of High Dumping Rubber Bearing (HDRB), it is concluded that the vibration period of the structure using the base isolator increases by 1.64 times from the fixed base structure. The base deviation of the base isolator structure has increased in the x direction by 59% and in the Y direction by 44%. The base isolator can reduce the deviation between floors that occurs in the X direction by 36% and y direction by 69%. The performance level of the structure with base isolator and fixed base is included in the Immediate Occupancy (IO) category. Based on this research, the effect of using base isolators can reduce post-earthquake damage where the damage to the structure is very small, the risk of casualties is very small, and the building is still safe to continue using.

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