Performance of High-Damping Rubber Bearings for Seismic Isolation – Case Study of Nayumi Sam Tower Malang Apartment

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***Abstract*— The base-isolation system is a highly effective earthquake-resistance technique. Especially when the building is under soft soil, however, it is detrimental to the horizontal displacement control of the isolation layer and less effective in decreasing the seismic response of the superstructure. Rubber bearings with high damping can produce substantial hysteretic damping and exhibit a hardening effect at high-shear strains. The research investigates the Nayumi Sam Tower Malang apartment as a case study with 10 stories of reinforced concrete with a double system structure which is in a soft soil location. High-damping rubber bearings (HDRBs) is used as a parameter study to understand the alteration and give a recommendation. The seismic response of the building is evaluated, and the HRDB alternative systems is confirmed using ETABS. It is pointed out that the HRDBs system can reduce the impact of earthquakes by close to 25% with the smallest section of structural dimension. According to new regulation building in Indonesia, the precise values of test circumstances, such as compressive force, shear displacement, and frequency, are developed. The findings are thoroughly discussed, the applicability of HRDBs for seismic isolation of residential buildings is concluded. Building with HRDBs isolation implied to have lower base shear and inter-storey drift which improved the performance of the structure with less damage.**

***Keywords*—High-damping rubber bearing, Numerical modelling, Residential building, Seismic isolation, Seismic provision**

I. Introduction

Indonesia is one of the countries in the world's highly active seismic zones. Various earthquakes followed by many casualties hit various urban areas with loss in social and economic aspects [1-2]. These activities recorded in the last 10 years, such as in Sumatera and Java that was occurred recently in 2022 with a magnitude over 6 M_w, the modified Mercalli intensity scale coming to the level VIII [3-4]. Most of the lives and economic losses caused by these earthquakes were attributable to the destruction of buildings and infrastructure. Most structural issues discovered were attributable to inadequate adherence to standards/codes. Considering the potential seismic risk in the region, it is essential to assure the structural quality and earthquake resilience of both existing and newly constructed structures in Indonesia [5-6].

The isolated system in Indonesia is technically not coming as an option to strengthen the structural system under seismic activities since it needs experts, and the process of the structural system is quite difficult [7]. Various issues also come within the material implications followed by the design management. In fact, when those problems can be solved, isolation can offer the best benefits to structural building performance. Not only to the structural capacity of the building in total but also to the total cost of the building. The isolated Elazig City Hospital in Turkey came as the outstanding example when it was spotted to the 6.8 M_w. While many old buildings collapsed adjacent to the earthquake in the vicinity, the isolated buildings still survived and stayed operate immediately after [7-8]. This remarkable accomplishment captured the national engineer's attention to do many studies under the isolation system in Indonesia, and innovative/effective seismic protection systems are once again a national priority. When we consider the building damage caused by past earthquakes in Indonesia, it is normal to anticipate an increase in the use of the standard in residential structures.

High-damping rubber bearings (HDRBs) are a frequently utilized type of seismic isolator that is used over the globe. They are composed of layers of elastomeric pads that provide horizontal flexibility and steel shims that provide vertical rigidity [7], [9]. Typically, the rubber is filled with carbon black, oils, or resins for energy dissipation. HDRBs have characteristics that make them particularly attractive for earthquake protection. The bearings exhibit various positive aspects as (1) high stiffness and damping at low shear strains, minimizing the response to service loads and wind; (2) low shear stiffness with adequate damping capacity at the design displacement level; and (3) An increase in stiffness and damping at higher displacement amplitudes, which is useful for limiting displacements during major earthquakes [8], [10].

In this study, seismic isolation system using HRDBs for residential buildings in Indonesia is evaluated in accordance with the SNI 1726-2019 [11]. The Nayumi Tower Apartment building in Malang, East Java, is used as an identification study since the location is in soft soil condition, becoming suitable for the investigation. The building supported under a double system structure with a special moment-resistant system. This structure elevated in 10-story which were actually designed as fixed base systems for the modeling database. The building is constructed in sites medium to soft soil location, S_D to S_E, one of the active seismic segments respectively. Site-specific response spectra in order, maximum considered earthquake geometric mean, PGA MCEG 0.3948, Spectral Response Acceleration maps, SS MCEr 0.8533 with Risk-Targeted Maximum Considered Earthquake 0.4. The

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spectral response is in accordance with the Direktorat bina Teknik permukiman dan perumahan direktorat jenderal cipta karya, kementrian pekerjaan umum dan perumahan rakyat which has been recognize widely in Indonesia [12].

In terms of modeling, an equivalent lateral force procedure is carried out, and the isolator system is designed. Subsequently, nonlinear response spectrum analysis is conducted. Various past numerical models of HRDBs under response spectrum and time history analyses have been investigated. The link property used for modeling HRDBs followed the default availability in ETABS. These isolators (bearings) provide independent axial force and rate of deformation linked to two-dimensional hysteretic damping in the shear degrees of freedom of the connection. If non-zero, the axial behavior is linearly elastic, as are the torsional and bending degrees of freedom [13].

II. Literature Review

Seismic isolation applies to a system that separates the building structure from horizontal components, such as soil movement, by inserting insulator material. In buildings that use a base insulator, vibrations that occur in the foundation due to the earthquake force will pass through the rubber pads before entering the upper structure. Rubber material has elastic properties, so the direction of vibration that occurs randomly will only affect the base insulator, while the upper structure of the building will vibrate as a unified structure [14]. The first variety of vibrations the building receives will cause lateral deformation of the insulator system, while the upper part of the building structure only behaves in rigid body motion. A higher variety of vibrations will cause orthogonal deformation of the first vibrational variety and vibrations on the ground so that this variety of vibrations does not participate in the response of the structure, or it can be said that the working earthquake is not transmitted into the building structure [15].

In addition, HRDBs, one of the most common isolation systems, is an anti-Seismic material developed with high damping capacity, horizontal flexibility, and high vertical rigidity. The illustration of conventional structure and isolated structure can be seen in Figure 1. The damping constant of the system varies significantly with the bearing strain rate in general in the order of 10% [16]. HDRBs are developed from natural rubber mixed with extra fine carbon block, oil, or resin and other filling materials to increase damping between 10 - 15% in shear strains 100%. The changing shear modulus value – change to the shear strain that occurs, causing a fat hysteretic loop resulting in a high equivalent damping ratio value. When a quake strikes, a high-damping rubber bearing will increase horizontal displacement via rubber shear deformation and decrease the friction coefficient. Large displacements can dampen vibrations from all directions and reduce building and bridge damage. There are two types of damping structures: fixed and sliding (see Figure 2 - 3).

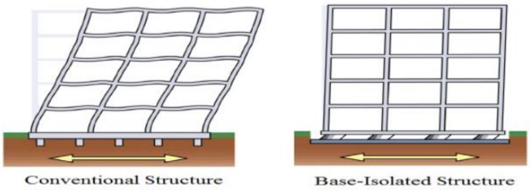


Figure 1. Illustration of Conventional Structure vs Isolated Structure

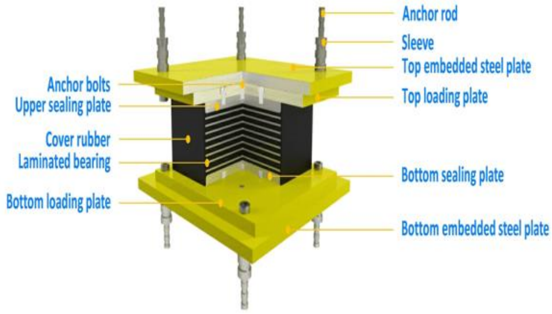


Figure 2. High Damping Rubber Bearing – Fixed Type

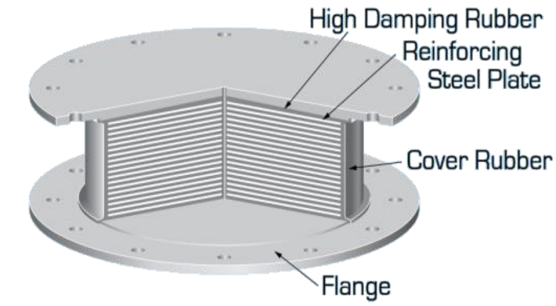


Figure 3. High Damping Rubber Bearing – Sliding Type

The fixed type has a high damping rubber has good horizontal shear performance, enabling it to withstand horizontal forces. It is able to absorb vibration by horizontal displacement and hysteretic energy [7], [8], [10], [17]. Where the sliding type considered the displacement utilizing sliding friction. The top plate of stainless steel and the sliding plate of PTFE can lower the friction coefficient and achieve a large displacement for shock absorption. The research in this study will focus on the behavior of HRDBs under sliding type. With a working temperature of -40 °C to + 60 °C followed by the 0.006 rad and damping ration 10%.

III. Method

This analysis uses ETABS to evaluate the structural capacity as specified in SNI 1726-2019. The preliminary analysis of the structure - The Nayumi Tower Apartment building is adapted to see the ratio capacity of structure. Then, the property of the damper, including manufacturing tolerance, is considered by Jingtong (bearing pad company – rubber Co.Ltd.) [14], [15]. Illustration of the rubber bearing pad – round sliding in accordance with Figure 4. The item dimension used in the model is HDR-D900-H/8 with embedded part 445 kg. Detail of section dimension of damping is illustrated in Figure 4.

Two models were investigated as existing building approaches as model control compared to the isolated building using BRDBs. The building is designed for residential usage as public apartment which were constructed from 2000 to 2015. The structure implied to the building is reinforced concrete in the fixed base system. The building information is presented in Table 1.

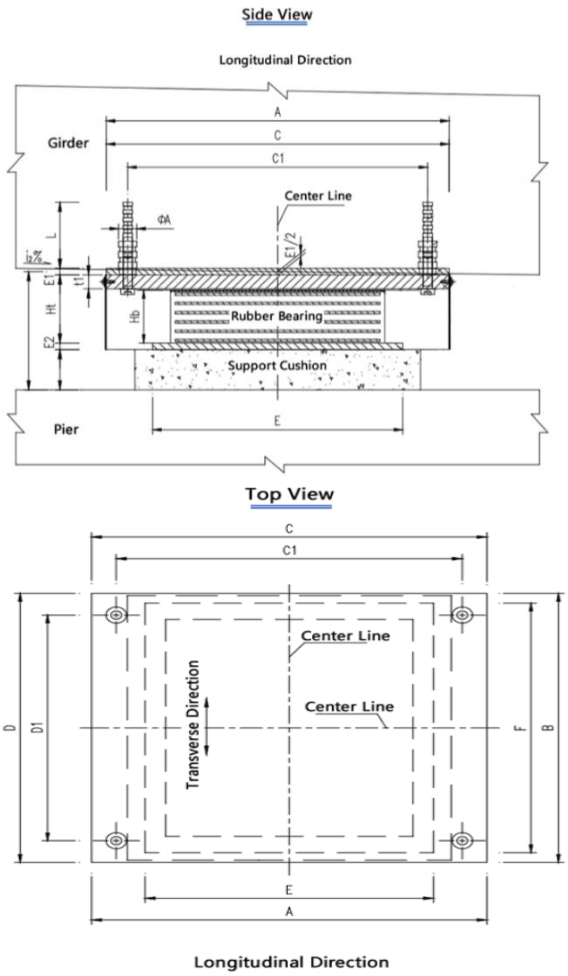
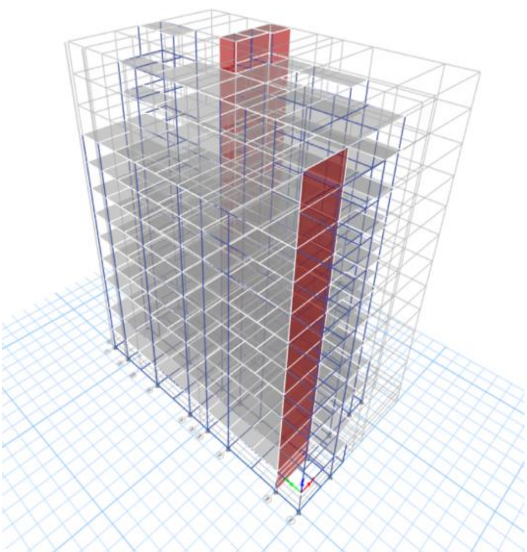


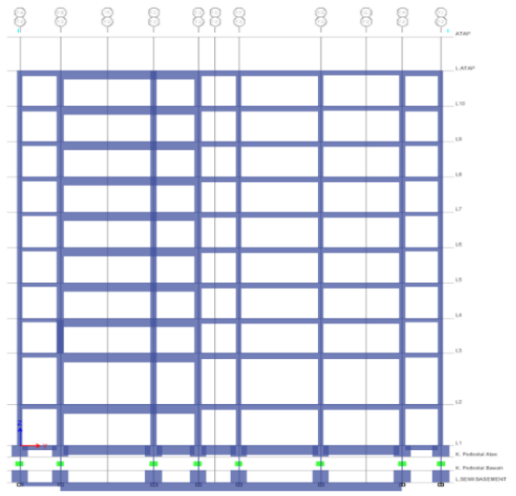
Figure 4. Detail of HRDBs – Perspective Illustration Under Manufacturer's Model Design

TABLE 1.
GENERAL DETAILS OF APARTMENT BUILDINGS MODEL

Structural member	Information
Overall plan – building size	± 4900 m^2
Storey	10-storey 1 semi basement
Type of structure	Multi – storey rigid joint
Grade of concrete	*f'c* 40 MPa
Grade of steel	BJ 41



(a)



(b)

Figure 5. Illustration of the Building; (a) 3D View Perspective, (b) Cross Section

The building model is presented in Figure 5, which is layered into a 10-storey with 1 semi-basement. The modeling developed by using ETABS by computer and structures Inc. The associated design basis for a short period, S_s, and S_1 period respectively, 0 to 0.8 s. The isolation system is located underneath the column, which total 25 bearings. It is presumed that all isolators have identical vertical loads. Using ETABS, it is sufficient to characterize the hysteretic properties of the isolators without addressing their geometric aspects. In this work, the design of the bearing is carried out in accordance with the method described by Constantinou et al.

Regarding the numerical modeling of HRDBs using ETABS, isolation modeled with link or support element with two nodes connected by six springs. This default mode available functions are linear bearings, low damping rubber bearings, lead rubber bearings, flat sliding bearings, and double and triple frictional pendulum bearings. ETABS is incapable of modeling the temperature-dependent behavior of LRBs as well. This study employs a rubber bearing-type link or support element to mimic the nonlinear behaviour of a lead rubber bearing. Bilinear force-deformation properties, comprising kI, fy, and r, must be defined in two horizontal directions for nonlinear rubber bearings, although only linear elastic properties can be defined for the axial and three rotational directions.

The damping of the superstructure can be assigned individually for direct integration analysis, which is used in this study. The damping of the first three modes (stiff body modes) must be set to zero since the inherent damping of the isolators is dictated by their hysteretic characteristics. The modal damping ratios for superstructure modes are assumed to be 0.2.

IV. RESULTS AND DISCUSSION

After identifying the model with the existing condition, running the model to find its characteristic is necessary. A mode of oscillation building defined by the associated natural period is addressed. Results of the natural period and deforestation shape are presented in Table 2 and Table 3. Natural Period *Tn* is the time required for a structure to complete one oscillation cycle. It is an inherent attribute governed by a structure's mass, *m*, and stiffness, *k*. The evaluation of the natural period is in accordance with equation (1) as follows:

$$Tn = 2\pi\sqrt{\frac{m}{k}} \quad (1)$$

Buildings with larger mass with small stiffness normally have a significant natural period compared to buildings with light mass and stiff buildings. The evaluation of the natural period of existing building models and building with isolated HRDBs is presented in Table 2 and Table 3. Regarding the decreasing model in both the *x-axis* and *y-axis*, reduction factor building with HRDBs isolation can manage to 50%.

TABLE 2.
NATURAL PERIOD OF EXISTING BUILDINGS WITH NO ISOLATION

Case	Mode	Period Sec	Frequency cyc/sec	CircFreq rad/sec	Eigenvalue rad²/sec²
Capital	1	1.5	0.667	4.191	17.56
Capital	2	0.9	1.117	7.017	49.24
Capital	3	0.86	1.17	7.351	54.04
Capital	4	0.43	2.326	14.62	213.7
Capital	5	0.22	4.495	28.24	797.6

TABLE 3.
NATURAL PERIOD OF EXISTING BUILDINGS WITH HRDBS ISOLATION

Case	Mode	Period Sec	Frequency cyc/sec	CircFreq rad/sec	Eigenvalue rad²/sec²
Capital	1	3.83	0.261	1.643	2.699
Capital	2	3.48	0.287	1.806	3.261
Capital	3	2.96	0.338	2.121	4.498
Capital	4	1.11	0.9	5.652	31.94
Capital	5	0.99	1.01	6.344	40.25

TABLE 4.
BASE SHEAR REACTION DUE TO SEISMIC ACTIVITY; EXISTING BUILDING WITH NO ISOLATION VS BUILDING WITH HRDBS ISOLATION

Base reaction	Existing building with no isolation		Building with HRDBs isolation	
	x – axis	y – axis	x – axis	y – axis
Eqx	7928.12	188.39	9313	4724
Eqy	266.3367	7510.844	4724	10262

It can be pointed out that building with an isolation system implies a higher natural period, which is considered to have higher flexibility. Nevertheless, since the building is isolated using the HRDBs system, the structure's natural frequency is relatively smaller compared to the structure with no isolation. In addition, the base shear reaction also comes with a relatively small impact on the structure with HRDBs isolation. The result is presented in Table 4.

Inter-story drift was also compared to fully understand the isolated structure's behavior. The drift of a structure with no isolation system apparently appears to have 172 mm different when it compared to a structure with HRDBs isolation with only informed 17 mm. Inter-story drift can be seen in Figure 6. From the illustrated Figure 6, it is approved that structure with HRDBs isolation offer remarkable results with all conditions in each story fill the required limit design.

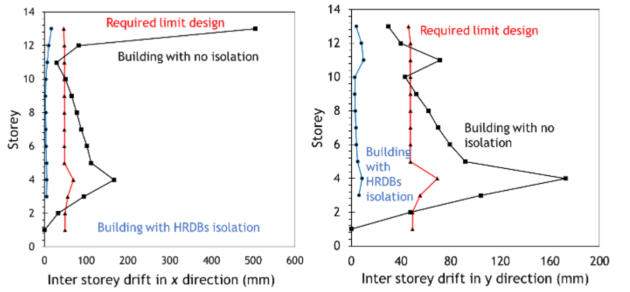


Figure 6. Inter Storey Drift In *x* - Direction vs. *y* - Direction

V. CONCLUSION

This study investigated the applicability of seismic isolation with HRDBs by numerical analysis using ETABS. Two identified model with 10-storey was selected from the actual Nayumi Sam Tower Malang apartment building. Conclusion are listed as follows:

1. Natural period of building with HRDBs isolation resulted to have a higher value compared to buildings with no isolation. In fact, natural frequency shows opposite reactions. This can be stated in the building with HRDBs having high flexibility with no less effect on the failure of the structure.
2. The result clearly demonstrated the effective performance of building with HRDBs isolation. It is confirmed to have a 25% lessened impact on the earthquake. In addition, it is also informed to have a small base shear reaction and small inter-storey drift effect. The base shear coefficient and maximum displacement of the building with no isolation exceed the required limit design, which needed.

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