Comparison of Structural Performance of Fixbase and Base Isolation in KAI Boutique Hotel Building with Response Spectrum

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Abstract — This study compares the seismic performance of fixed-base and base-isolated structures for the KAI Boutique Hotel Building in Bandung, a region prone to earthquakes due to active faults such as the Lembang, and Baribis Faults. This study aims to analyze the differences in base shear, displacement, and inter-story drift between the two structural systems using response spectrum analysis, and evaluate the seismic performance level based on ATC-40 guidelines. The research methodology involved modeling an 11-story hotel building in ETABS v.18.1.0 with two scenarios: fixed-base and base-isolated models analyzed by response spectra. The base isolation system uses High Damping Rubber Bearings (HDRB). The main parameters analyzed include base shear, and inter-story deviation. The results show that base isolation significantly reduces base shear. For example, by response spectrum analysis, the base shear is reduced by 54.5% in the X direction and 56.3% in the Y direction compared to the fixed-base system. Base isolation effectively reduced the average inter-storey deviation by 68% in the X direction and 73% in the Y direction. Based on ATC-40, both fixed-base and base-isolated structures achieved the "Immediate Occupancy (IO)" performance level in all analyses, showing minimal structural and non-structural damage, allowing the building to continue functioning after the earthquake.
Keywords: base isolation; seismic performance; response spectrum analysis; High Damping Rubber Bearings (HDRB); ATC-40 Performance Evaluation.

I. INTRODUCTION

Indonesia is highly prone to earthquake disasters, mainly because it is located in the convergence zone of the world's three major tectonic plates: Eurasia, Indo-Australia, and the Pacific. Active fault activities such as the Lembang, Cimandiri and Baribis Faults in West Java, particularly in Bandung City, pose a significant earthquake risk. Strong earthquakes, including megathrust earthquakes with the potential to generate tsunamis, pose a serious threat to infrastructure and human safety.

To address this risk, the development and implementation of earthquake-resistant buildings is crucial. Earthquake-resistant buildings are designed to withstand or adapt to earthquake-induced ground movements without suffering significant structural damage, so they remain safe and functional after an earthquake. In Indonesia, mitigation efforts have been carried out through the application of reinforced concrete methods, Moment-Reinforcing Frame Systems (SRPM), and shear walls. However, cases of building collapse such as the Roa-Roa Hotel in Palu in 2018 show that further innovation is needed.

One promising innovation is the base isolation system. This system is designed to protect buildings from the horizontal forces of an earthquake by separating the structure from the ground motion, thus preventing the transfer of forces to the upper structure. The application of base isolation in Indonesia is still limited, with some examples such as the Head Office of PT Bridgestone Tire Indonesia in Karawang and Anatapura Palu Hospital.

Based on this description, the author raised this research with the aim of comparing the performance levels of fixbase and base isolation building structures, which in this case is the KAI Boutique Hotel Building, Bandung. The analysis was conducted using the response spectrum analysis method. This method simulates the dynamic response of the structure to earthquake loads based on the ground motion characteristics during an earthquake, providing a detailed description of internal forces, displacements and accelerations. This allows a realistic comparison between conventional fixed-base and base isolation systems.

II. LITERATURE REVIEW

The concept of a base isolation system aims to separate the upper part of the building structure from the foundation directly connected to the ground, so as to dampen the impact of seismic motion transferred from the ground to the upper structure. In this way, the earthquake energy reaching the building can be minimized to avoid structural damage. The system works by inserting rubberized isolator elements, known as base isolators that have low horizontal stiffness, between the foundation and the upper structure of the building. This isolator serves to reduce lateral displacement caused by earthquakes. A comparison between a conventional structure without a fixed-base isolation system and a structure equipped with a base isolation system is shown in Figure 1.

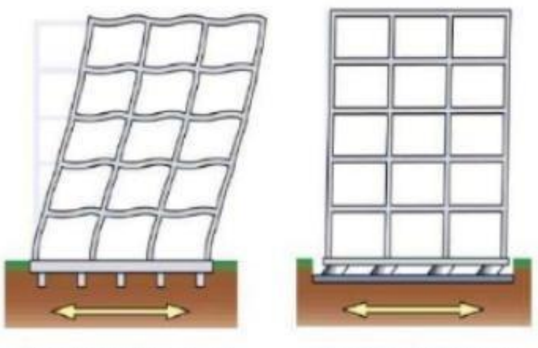

Figure 1. Comparison of conventional structures (fixed base) with Base Isolation Structures
Source: Andrian et al. (2017)

The design of building structures capable of withstanding earthquake loads is based on the provisions listed in SNI 1726: 2019 (National Standardization Agency, 2019). In this research, a seismic analysis approach is used, namely the dynamic spectrum response method. This method aims to evaluate the behavior of structures against earthquake loads. The main parameters analyzed include the base shear force due to seismic loads, floor displacement, and inter-story drift that occur in the structure.

1. Seismic base shear force

   The seismic base shear force (V) in the specified direction shall be determined in accordance with the following equation

   $$V = C_s \times W \qquad \text{... 1)}$$

   Where,

   V= Seismic base shear force (kN)
   C_s= Seismic response coefficient
   W= Effective seismic weight (kN)

2. For isolation level structural elements, it should be planned to be able to withstand the minimum shear force (V_S) with the following equation

   $$V_S = \frac{D_D \times K_{DMin}}{R} \qquad \text{... 2)}$$

   Where,
   VS = Shear force of isolation structure
   DD = Plan lateral displacement
   $KDMin$ = Effective stiffness
   R = Earthquake reduction value

   In base isolation, there is a calculation to determine the maximum displacement value (D_M) and the following is the equation

   $$D_M = \frac{g \times S_{M1} \times T_M}{4\pi^2 \times B_M} \qquad \text{... 3)}$$

   Where,
   DM = Maximum displacement (mm)
   g = Gravity acceleration
   M = Soil coefficient of spectral response
   TM = Effective period of the structure
   BM = Effective damping of the structure

3. Displacement and deviation between floors, Inter-story deviation (Δ) is defined as the difference in lateral displacement between the center of mass of the floor under review and the floor below. The value of this deviation should be controlled so as not to exceed the maximum permissible limit, i.e. the allowable inter-storey deviation (Δa). According to the provisions, for Special Moment-Practicing Frame System (SRPMK) structures with fixbase system and risk category I, the permissible value of Δa is 0.0154 hsx, while for structures with base isolation system, the limit value is set at 0.015 hsx. Here, hsx refers to the height of the floor below the floor being analyzed

Structural performance refers to how well a structure is able to respond to a planned earthquake. This level of performance can be identified through the extent of damage caused to the structure by an earthquake with a certain return period. One approach used to evaluate structural performance is the capacity spectrum method introduced in ATC-40, which categorizes structural performance levels into several categories, namely Immediate Occupancy (IO), Damage Control (DC), Life Safety (LS), and Structural Stability (SS). These performance levels can be determined based on deformation limits, as shown in Table 1.

Table 1. Structure performance based on ATC-40

Interstory Drift Limit	Performance Level			
	Immediate Occupancy	Damage Control	Life Safety	Structural Stability
Maximum total drift	0,01	0,01 - 0,02	0,02	0,33 Vi/Pi
Maximum inelastic drift	0,005	0,005 - 0,015	No limit	No limit

III. METHOD

The building structure analyzed in this study is an 11-storey regular reinforced concrete hotel building model located in Bandung City, with the function as a commercial residential building (hotel). The structural system used to resist lateral forces due to earthquakes is the Special Moment Bearing Frame System (SRPMK). Seismic analysis was conducted refers to the provisions of SNI 1726: 2019 with the dynamic response spectrum analysis method. Evaluation of the structural performance level is carried out based on ATC-40 guidelines with a non- linear analysis approach. The entire modeling and analysis process was carried out using ETABS software version 18.1.0, by comparing two types of structural systems, namely fixbase structures and structures with base isolation systems that use High Damping Rubber Bearings (HDRB) devices. Visualization of the structural model is shown in Figure 2 and figure 3.

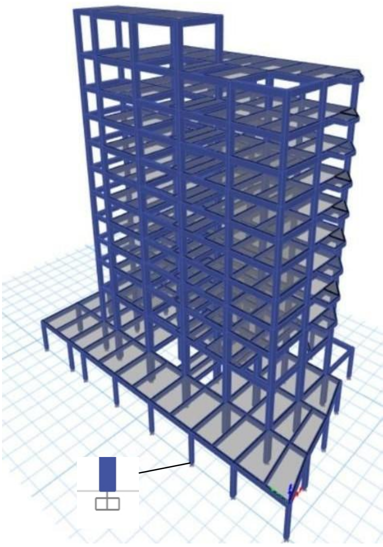

Figure 2. Fixbase structure (Etabs 18.1)

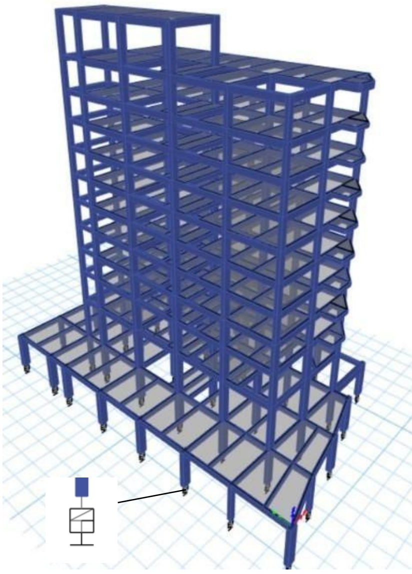

Figure 3. Base Isolation structure (Etabs 18.1)

IV. RESULTS AND DISCUSSION

Based on SNI 1726: 2019, the seismic base shear force cannot be less than 100% of the static shear force. If the seismic base shear force is less than the static shear force, it is necessary to scale the force with a scale factor multiplied by the static / dynamic V. based on the calculation of the static shear force, a force of 1208.62 kN is obtained. While based on the results of running the Fixbase structure on Etabs, the shear force results are less than the static shear force, so scaling is carried out and the following are the results of the shear force before and after scaling

Table 2. Unscaled and scaled static shear force

	Unscaled (kN)	Scaled (kN)	Gaya geser Statik (kN)
Arah X	1067,45	1208,63	1208,63
Arah Y	973,73	1208,63	1208,63

Meanwhile, the shear force of the base isolation structure was found to be 647.94 kN. The result of running the base isolation structure shows that the shear force of the isolation structure is greater than 647.94 kN. The following is the summary

Table 3. Static shear force static of base isolation

	Vs (kN)	Base Isolation Vs (kN)
Arah X	647,94	657,01
Arah Y	647,94	680,05

Based on the results of the two structural models above, it can be concluded that the use of base isolation can reduce the base shear force by 54.4% in the X direction and 56.3% in the Y direction.

The displacement value of the center of mass from the elastic analysis (δxe) is obtained from the output of the story displacement value from the analysis using the ETABS program as follows

Table 4. Comparison of Displacement of each floor

Story	FIXBASE Displacement (mm)		Base Isolation Displacement (mm)	
	X	Y	X	Y
Crown	63,04	68,96	352,29	358,21
LT ATAP	63,04	68,96	352,29	358,21
LT 10	61,00	64,70	352,21	357,44
LT 9	58,06	60,91	351,35	356,28
LT 8	54,20	57,20	349,67	354,62
LT 7	49,77	51,81	347,88	352,55
LT 6	44,68	46,65	345,74	349,99
LT 5	38,91	40,75	343,40	346,95
LT 4	32,39	33,06	340,19	343,36
LT 3	25,51	25,45	337,12	339,45
LT 2	15,41	16,20	320,17	332,43
LT 1	3,84	5,61	308,37	322,47

Source: Analysis Result

Based on the results above, it can be seen that the displacement of each floor has increased in the base isolation structural system, but if we examine more deeply, then we can find out that there is a very drastic decrease in the deviation between floors in the base isolation construction system, the following is a summary of the deviation between floors and its reduction.

Table 5. Inter story deviation and its reduction (X)

Respon Spectrum arah X			
Story	Fixed Base	Sistem Isolasi	Reduksi
Crown	0,00	0	
LT ATAP	11,22	0,24	98%
LT 10	16,19	2,592	84%
LT 9	21,20	5,025	76%
LT 8	24,36	5,361	78%
LT 7	28,04	6,42	77%
LT 6	31,70	7,035	78%
LT 5	35,88	9,633	73%
LT 4	37,83	9,213	76%
LT 3	55,53	50,838	8%
LT 2	63,65	35,403	44%
LT 1	21,13	0	0%

Table 6. Inter story deviation and its reduction (Y)

Respon Spectrum arah Y			
Story	Fixed Base	Sistem Isolasi	Reduksi
Crown	0,00	0	
LT ATAP	23,39	2,316	90%
LT 10	20,87	3,465	83%
LT 9	20,41	4,986	76%
LT 8	29,65	6,225	79%
LT 7	28,37	7,662	73%
LT 6	32,42	9,117	72%
LT 5	42,30	10,791	74%
LT 4	41,88	11,712	72%
LT 3	50,89	21,06	59%
LT 2	58,21	29,898	49%
LT 1	30,88	0	0%

The results of the performance evaluation based on the ATC-40 method are determined by finding the maximum total deviation value, the following is the formula

$$Maksimal\ drift = \frac{Dt}{H_{total}} \quad \text{... 3)}$$

Based on the above results, the structural performance level of the fixbase and base isolation structures can be found, namely

Table 6. Structure performance level

Parameter		Respon Spectrum
Fixbase (X)	Dt (mm)	63,04
	H (m)	44
	Level Kinerja	Immediate Occupancy (IO)
Base Isolation (X)	Dt (mm)	352,29
	H (m)	44
	Level Kinerja	Immediate Occupancy (IO)
Fixbase (Y)	Dt (mm)	68,96
	H (m)	44
	Level Kinerja	Immediate Occupancy (IO)
Base Isolation (Y)	Dt (mm)	358,21
	H (m)	44
	Level Kinerja	Immediate Occupancy (IO)

V. CONCLUSION

Comparison of the base shear value that occurs in the fixbase construction system with the spectrum response is 1208.63 kN in the X and Y directions, while the base shear in the base isolation construction system is obtained 658.42 kN in the X direction and 679.89 in the Y direction. Then there is a reduction rate of 54.5% in the X direction and 56.3% in the Y direction. There is an increase in displacement on each floor of the base isolation structure, but the deviation between floors that occurs is reduced with an average reduction rate of 64% in the X direction and 55% in the Y direction. Based on the results of the comparison analysis of base shear and deviation between floors, it can be seen that the structural performance level of the fixbase and base isolation structures is at the same performance level, namely immediate Occupancy

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