Design of Earthquake Resistant Building by Using Shear Wall and High Damping Rubber Bearing Base Isolator

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Abstract. A Shear wall is a vertical stiffening element that functions as a retaining lateral load on the building. Meanwhile, a high damping rubber bearing is a type of base isolator that is a lateral load resisting element by reduces earthquake acceleration. In this study, three 8-story student dormitory buildings located in Yogyakarta with moderate soil conditions have been modeled, namely: fix based (FB), shear wall (SW), and high damping rubber bearing base isolator (BI). Modeling and analysis are conducted using a structural analysis program. This research aims to find out the most effective damping structural elements. Results show that BI has the highest period meanwhile BI has the smallest unity check compared to FB and SW. In terms of displacement, BI and SW have 25% and 21% smaller than FB. These are the evidence that high damping rubber bearing is the most effective structural element in resisting lateral load.

Keywords: Base isolator, high damping rubber bearing, shear wall, story displacement, unity check.

1 Introduction

In Indonesia, there have been 6000 earthquakes in one year. Earthquakes are caused by underground explosions, the impact of large objects on the ground, and the movement of magma. Indonesia is located between The Pacific Ocean Plate, Eurasia Plate, and India – Australia Plate. The movement of the plate can cause an earthquake. An earthquake causes heavy economic loss in large areas. Earthquakes cannot be predicted by time, infrastructure must be designed to resist earthquake incidents in the future.

Earthquake-resistant buildings must be optimized to make a sustainable seismic design. Sustainable seismic design (SSD) is a relatively new field of study that promises improved human welfare and innovative developments in structural engineering, the difference between conventional seismic design and SSD is the expected behavior during and after earthquakes [1]. During this time, earthquake-resistant buildings have been improved. Shear wall and base isolator can minimize earthquake effects.

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A base isolator is the component isolation structure that can improve the natural period of the structure. Base isolators can reduce the damping of structure, minimize story displacement, and reduce lateral force. A base isolator is installed between the foundation and tie beam. The basic principle of a base isolation system is to provide flexibility in the base of the building and at the same time provide damping to prevent amplification caused by the earthquake [2].

A shear wall is an earthquake-resistant element that can improve the stiffness of the structure. A shear wall can minimize the lateral force, reduce story displacement and reduce the internal force of the structure. A shear wall is installed vertically from the bottom of the structure until the roof. Due to small drift between floors and good stability in buildings, which will make the buildings more rigid, shear walls offer good performance in resisting lateral loads. Although the internal base shear force in this type of construction is generally more than other resisting systems, the capacity of the shear wall system can accept this large force induced by earthquakes [3].

This study will discuss shear walls and base isolators to reduce earthquake force. The function of the building is 8-story dormitory students located in Yogyakarta with moderate soil conditions. Shear wall, fixed based, and base isolator have been modeled and analyzed of base shear, displacement, lateral force, period, participating mass ratio, and unity check. Every model of structure has been analyzed and optimized to find out the most effective damping element structure.

2 Method

In structural design, a structure must optimally withstand the applied load and force. The structure can be said to be optimum if it has a minimum value of the components of cost, weight, construction time, and maximum benefit throughout its service life. In this research, the structures have been modeled and analyzed with the finite element method. The optimization of a structure with the maximum unity check criteria is 0.5 and has a minimum internal force, shear force, and displacement.

The design of earthquake-resistant buildings is very important so that the building has sustainable properties and has a maximum service life according to its design. The design of this earthquake-resistant building follows the reference or standard, namely: SNI 2847: 2019 (Design of Reinforced Concrete Structures), SNI 1726: 2019 (Procedures for Planning Earthquake Resistance for Building and Non-Building Structures), and Regulation of the Loading of Indonesia for Buildings (PPIUG) 1983

2.1 Period of structure

The period of the structure based on SNI 1726:2019 article 7.8.2 must be reviewed based on the nature of the structure and the deformation of the bearing elements being reviewed. The minimum structural period should be calculated with the approximate fundamental period based on the type of structure.

In modeling with dynamic linear analysis, based on SNI 1726:2019 article 7.9.1.1, the amount of variance must be sufficient to obtain combined mass participation of 100% of the structural mass. The analysis is permitted to include a combined minimum variance of at least 90% of the actual mass in each of the orthogonal directions under consideration.

2.2 Scaling control of earthquake

Earthquake force scaling control needs to be done to get the optimum seismic force according to the designed earthquake load. The combined shear force response from the modeling results (Vt) must be 100% of the shear force (V) calculated using the static equivalent method. Based on SNI 1726:2019 article 7.9.1.4, if the combined shear force response from the modeling is less than 10% of the static shear force, then the force must be multiplied by V/Vt.

2.3 Story displacement

Based on SNI 1726:2019 article 7.8.6, the determination of the displacement between floors must be calculated as the difference in the deviation on each floor at the center of mass above and below the floor under consideration. The magnitude of the displacement between levels is as follows:

$$\delta_x = \frac{C_d\,\delta_{xe}}{I_e} \tag{1}$$

Information:
δ_{xe} = deviation on x-floor
C_d = enlargement factor of lateral deviation
I_e = earthquake priority factor that is determined

The displacement between floors in the structure must be less than the deviation between the permitted floors based on article 7.12 of SNI 1726:2019. For seismic categories of D, E, and F the deviation between permit floors may not exceed (Δ)/ρ.

2.4 Design optimization

Structural design must produce structures with optimum finishes. The criteria for assessing the optimum structure are as follows: minimum fee, minimum weight, minimum construction time, minimum labor, and minimum operating efficiency.

In this research, optimization of the structural design is carried out in terms of unity check, base shear force, displacement, and minimum lateral force. Unity check is the ratio between the load and the capacity of the structure. The unity check has a value in the range of 0 – 1. The smaller the unity check, the stronger the structure can withstand the received force. A structure with a unity check below 0.5 is a structure with an ineffective design, construction will require very large costs. For structures with a range of 0.5 to 1, it has a value that is quite effective in terms of the strength to withstand the designed force. In this modeling, the unity check criteria used is 0.5 [4]. Design optimization is carried out on the shear wall structure and the base isolator.

The shear wall structure and the base isolator must meet the design criteria according to the established standards. Both modelings are carried out by controlling the period, basic shear force, the combination of variations, multiple system control, displacement, and unity check. The optimum shear wall structure if it meets the controls and the structure has an average unity check value of 0.5.

2.5 Base isolator

Base Isolator is an earthquake-resistant component located under the column. The basic concept of the base isolator is to separate the building structure from the soil or foundation so that the earthquake force is not transmitted to the building structure. The advantage of a base isolation system is the ability to significantly reduce the damage to structural and non-structural elements to improve the security of buildings, building components, and architecture to reduce seismic design acceleration [2].

In this study, a base isolator of the HDRB type was carried out. The HDRB type has advantages over Lead Rubber Bearing. HDRB is better at reducing structural deviation[6]. In order for the building it supports to stand when an earthquake occurs, the HDRB must be designed properly. The stages of designing an HDRB include: determining the weight of the structure for each column of the building (W) and the total weight of the structure (WT), and analyzing the building reactions that occur in the structural analysis aid program.

2.6 Shear wall

Shear Wall is a vertical stiffening component designed to withstand lateral forces due to earthquakes acting on the structure. Lateral resisting systems are used to increase the stiffness capacity, this system has many forms depending on the position and function of walls like core walls, coupled walls, and planar walls [3]. Shear walls are usually used in elevators or stairs. Based on their geometry, shear walls can be categorized as flexural walls (slender walls), squat walls (short walls), and coupled shear walls.

Shear walls can increase the effect of lateral stiffness significantly on the amount of lateral deviation between 19% to 37%. Variations in the location of the shear wall in the structure can also affect the effect by 9% to 14% [5].

3 Result and discussion

3.1 Preliminary design

Preliminary design purpose is to define the material, element, and load before modeling of structure. Standards used for this step are SNI 1726:2019 and SNI 2847:2019.

Table 1. Type of Beam

Beam	Height (h) (mm)	Wide (b) (mm)

BI	550	350
B2	400	250
BA	450	300
BK 1	450	300
BK 2	400	250
BK 3	300	200
BA 2	300	200
K1	500	500

Table 2. Type of Slab

Name of Slab	Slab type	Height (mm)
Slab 1	Two way slab	130
Slab 2	Two way slab	130
Slab 3	Two way slab	130
Slab 4	Two way slab	130
Slab 5	Two way slab	130
Slab 6	One way slab	130
Slab 7	One way slab	130
Slab 8	Two way slab	130
Slab 9	Two way slab	130
Slab 10	Two way slab	130
Slab 11	Two way slab	130
Slab 12	Two way slab	130
Slab 13	Two way slab	130

Table 3. Super Dead Load

Type Room	Load (Kg/m^2)	Load (Kg/m)
Floor 1 -8	133	-
Roof floor	90	-
Bathroom	143	-
Wall load floor 1	-	980
Wall load floor 2 -8	-	780
Wall load roof deck	-	700
Wall load balcony	-	100

Table 4. Live Load

Type Room	Load (Kg/m^2)
Floor 1 -8	250
Roof floor	120

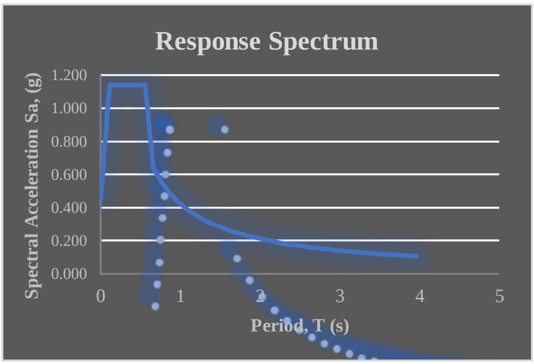

Fig. 1. Yogyakarta Response Spectrum

3.2 Fixed-based structure

Fixed-based structure (FI) is modeled using a structural analysis program. The materials definition, beams, and columns are modeled on the software according to the structural working drawings. In the modeling, input loading is also carried out according to what has been planned. Loading input is based on loading data on the preliminary design in Table 1 – Table 4 that has been carried out based on the function of the building space.

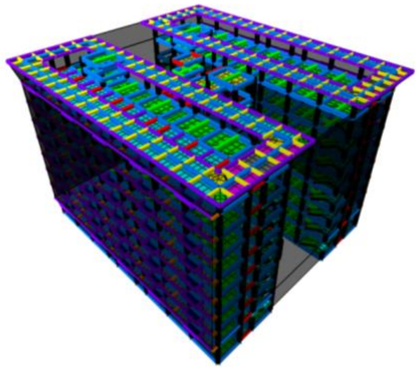

Fig. 2. Fixed-Based Modeling

Weight control in FI modeling is to verify between manual calculation and software calculation.

Manual calculation	= 2471,516 ton
Software calculation	= 25623,950 ton
Deviation	= 2,93%.

3.3 Shear wall (sw) structure

Shear wall used in the structure is located in the elevator room. Shear walls are planned based on the height of the building and the length of the room span. The building height is 35.7 meters and the span length is 4.55 meters and 3 m. The quality of the concrete used is 40 MPa. There are 3 shear wall elements in the structure, the 1st shear wall is located in the lift room between columns 8F and 9F. the 2nd shear wall is located between columns 9G to 9F. The 3rd shear wall is located between the 8G to 9G columns as shown in Fig.3. The structure is designed with a double system with special moment resisting frames capable of withstanding a minimum of 25% of seismic forces. The shear wall that has been used is a special reinforced concrete shear wall. The value of the response modification coefficient (R) is 7 with a system strength factor (Ω) of 2.5 and Cd of 5.5.

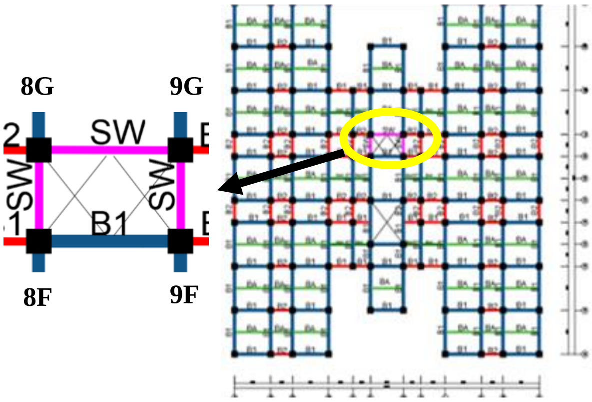

Fig. 3. Shear Wall

3.4 Base isolator (bi) structure

Base isolator that has been used in this study is a high damping rubber bearing. Base isolator placed between column and foundation. The analysis of the base isolator must accommodate the shear modulus and strength of the base isolator.

Table 5. Base Isolator Specifications

Characteristic	Unit	Value
Outer diameter	mm	850
Inner diameter	mm	20
Effective plane area	x10^2 mm^2	5671
Thixness of one rubber layer	mm	5,25
Total thickness rubber	mm	168
Total height	mm	368,4
Total weight	kN	12,1
Critical stress	N/ mm^2	51
Compressive stiffness	x 10^3 kN/m	4760
Allowable tensile stress	N/ mm^2	1
Initial stifness	x 10^3 kN/m	12,4
Post yield stiffness	x 10^3 kN/m	1,24
Characteristic strength	kN	143
Equivalent shear stiffness	x 10^3 kN/m	2,09
Equivalent damping ratio		0,240

3.5 FI, SW, and BI analysis

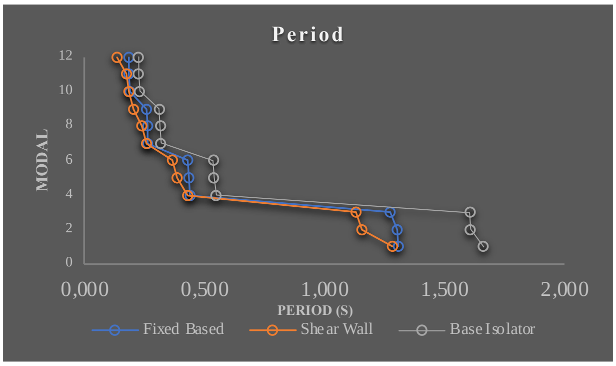

Fig. 4. Period of Fixed-Based, Shear Wall and Base Isolator

Based on the graph in the picture above, the comparison of the period of structure in the three models shows that the period of the structure with shear walls has the smallest period compared to the period of fixed structure and base isolator. The shear wall structure has a more rigid structure than fixed based structure and base isolator structure. The shear wall structure has the largest period of 1.305 seconds on modal 1 and the base isolator structure has a period of 1.672 seconds on modal 1. Each model meets the combined mass participation with the mass participation value in each model being more than 90%.

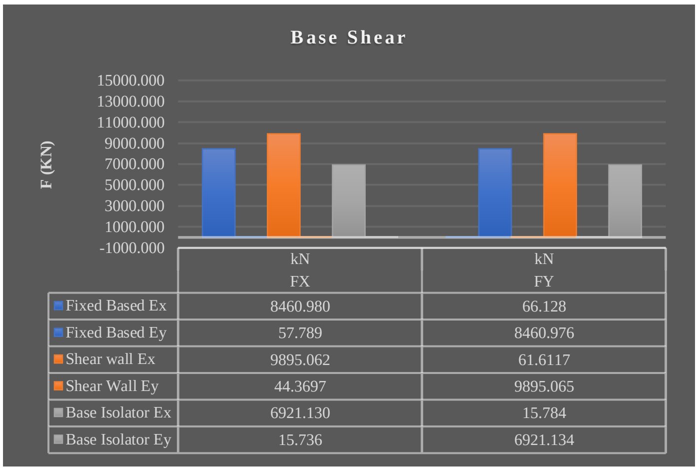

Fig. 5. Base Shear of Fixed Based, Shear Wall and Base Isolator

Based on the comparison of shear forces from three models that have been carried out, the x-way and y-way shear forces in the shear wall structure have the largest shear force compared to the fixed-based structure and base isolator structure as shown in Fig. 5. The shear wall structure is heavier than the base isolator structure and fixed-based structure. The addition of the structure's super dead load makes the shear wall element force scale larger than fixed based structure and based isolator structure. In the shear wall structure, the magnitude of earthquake force is damped by the shear wall elements. The beam and column elements in SW structure do not fully affected the earthquake loads. In a fixed-based structure, the seismic forces are fully accepted by the beam and column components, in the base isolator the seismic forces are attenuated by reducing the drift between floors that occurs in the structure. The shear wall structure has an earthquake shear force of 17% greater than a fixed-based structure. The base isolator structure has an earthquake shear force of 18% smaller than the fixed-based structure.

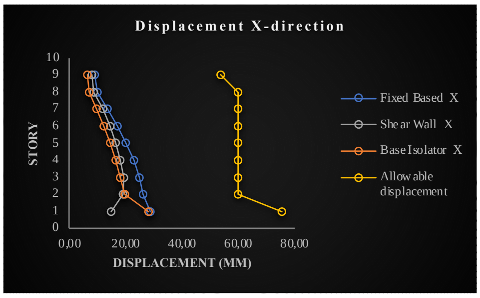

Fig. 6. Displacement Structure X- direction

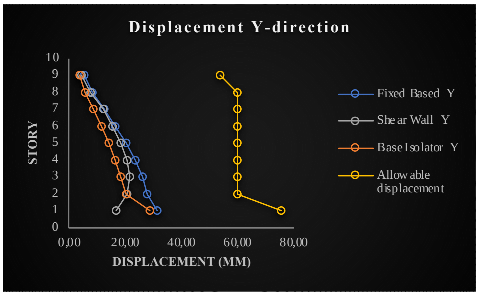

Fig. 7. Displacement Structure Y-direction

Based on the comparison of floor displacements from three models that have been carried out, the structure with a base isolator has the smallest floor displacement in the x-way with a displacement of 6.11 mm at a height of 35.7 meters as shown in Figure 6. Fixed-based structures have the largest displacemenet compared to structures with shear wall and base isolator. Structural modeling with earthquake-resistant elements in the form of shear walls and base isolators is effective in reducing the displacemenet between floors for an earthquake in the x-way. The shear wall structure effectively reduces the displacement between floors in the x-way by 21% more than a fixed based structure. The structure with a base isolator effectively reduces the displacement between floors in the x-way by 25% compared to a structure with a fixed base.

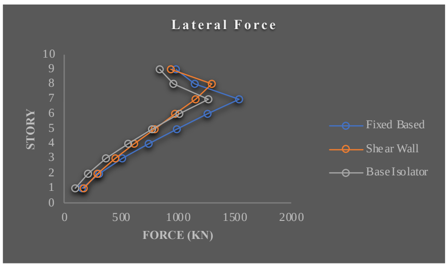

Fig. 8. Lateral Force

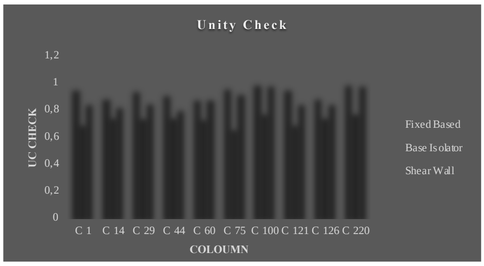

Fig. 9. Unity Check

The structure with a base isolator has the smallest floor displacements in the y-way with a displacement of 4.501 mm at a height of 35.7 meters as shown in Fig. 7. The fixed-based structure has the largest displacement compared to structures with shear wall and base isolator. Structural modeling with earthquake-resistant elements in the form of shear walls and base isolator is effective in reducing the drift between floors for earthquakes in the y-way. The shear wall structure effectively reduces the drift between floors in the y-way direction by 27% more than a fixed-based structure. The structure with a base isolator effectively reduces the drift between floors in the y-way by 28% more than a structure with a fixed base.

In the picture above, the fixed-based structure has the greatest lateral force than the structure with a base isolator and shear wall. The fixed-based structure has the largest lateral force on the 9th floor of 955.3011 kN. The structure with shear wall and base isolator components is effective in resisting earthquake forces in the x-way. The lateral force of the shear wall structure is 17% smaller than fixed based structure. The lateral force of a base isolator structure is 32% less than that of fixed based structure.

Based on Fig. 9, the base isolator structure has the smallest column UC value compared to fixed-based and shear wall structures. The base isolator structure has an average UC value of 0.743 while the shear wall structure has an average UC value of 0.889 and fixed based structure is 0.9462. The base isolator structure is the most effective in resisting the load received by the structure. The shear wall structure has a smaller unity check value of 12% than fixed based structure. The base isolator structure has a smaller unity check value of 23% than fixed based structure.

4 Conclusion

In the structure with fixed-based support, the structure has a shear force of 8460.980 kN in the X-way and 8460.976 kN in the Y-way. The fixed-based structure has a displacement between floors of 9.04 mm in the X way and 5.43 mm in the direction. Internal forces in fixed-based structures are greater than shear walls and base isolators. The biggest lateral force on the fixed base structure is on the 7th floor, which is 1543,186 kN. The average unity check value in fixed-based modeling is 0.946.

The structure with the addition of a shear wall has the smallest period value compared to the fixed-based structure and the base isolator. Shear walls withstand earthquake loads of 54.8% in the X way and 52.3% in the Y way. The deviation between floors for the shear wall structure has a smaller value of 21% in the X way and 16% in the Y way compared to the fixed-based structure. The planned shear wall structure is quite optimum with an average unity check value of 0.889. The value of the unity check structure with the shear wall is 12% smaller than the fixed-based structure.

The structure with the base isolator has the largest period compared to fixed based structures and shear walls. The placement of the base isolator is effective in reducing the earthquake load so that it has an impact on the smaller deviation between floors. The drift between floors in the base isolator has a smaller value of 25% in the X way and 28% in the Y way compared to the fixed-based structure. The average value of the unity check base isolator is 0.743. The value of the unity check structure with a base isolator is 23% smaller than that of a fixed-based structure.

Optimization of the structure design on the shear wall and base isolator modeling is carried out to determine the most optimum structure. The selection of the most optimum structure in terms of the value of unity check, story drift, and internal forces. Based on this case, the base isolator structure has the smallest unity check, smallest drift, smallest story drift, and smallest internal force compared to the fixed-based structure and shear wall structure. The result of this study may be different for other structures and could not be generalized due to some limitations.

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