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Seismic performance of a high-rise residential building model in Purwokerto, Indonesia

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Abstract. We evaluated the performance of a high-rise residential building model in Purwokerto, Indonesia due to the seismic load. The evaluation was performed based on seismic loads given in the 2002 and 2012 Indonesian National Standard (SNI) using linear static analysis, dynamic response analysis and pushover analysis. Based on the linear static analysis, the drift ratio decreased by an average of 34.42 and 32.61% for the X and Y directions respectively. Meanwhile, based on the dynamic response analysis, the drift ratio also decreased by an average of 30.74 and 27.33% for the X and Y directions respectively. In addition, the pushover analysis indicates that the performance of this high-rise residential building model is still at Immediate Occupancy (IO) level. The post-earthquake damage state in which the building remains safe to occupy, essentially retaining the pre-earthquake design strength and stiffness of the structure. The risk of life-threatening injury as a result of structural damage is very low. Although some minor structural repairs may be appropriate, these would generally not be required prior to re-occupancy.

1 Introduction

These days, the demand for housing has increased because of the economic development and increase in population. One approach to fully use a limited size of land is by vertically developing a high-rise residential building. There are numerous perspectives to consider in constructing a high-rise residential building such as safety, effectiveness and feasibility components. Safety is the major factor to be considered in developing a tall housing. The high-rise residential building is designed in such a way to maintain the vertical gravitational forces and withstand natural disaster such as an earthquake.

Because of its seismicity, Indonesia has made major changes on the earthquake of Indonesian National Standards: SNI 03-1726-2002 [1] to SNI 1726:2012 [2]. These changes will change the building's structural behaviors. Purwokerto has a site-particular estimation of spectral acceleration response for short-period (S_s) is 0.5g and one-second (S_1) is 0.2g. Table 1 demonstrates that a locale with a site-particular estimation of spectral acceleration response for S_s larger than or equivalent to 0.5g but smaller than 1.0g and S_1 larger than or equivalent to 0.2g but smaller than 0.4g can be considered as a region with modestly high seismicity potential [3]. In this manner, Purwokerto is a locale with modestly high seismicity potential which needs to follow earthquake-resistant structural framework in every housing structure built up in Purwokerto. The purpose of

the current study is to assess the performance of the high-rise residential building model in Purwokerto, Indonesia because of the seismic load. This will create awareness in the society or any parties.

Table 1. Typical seismicity region [3].

Seismicity Region	Spectral Acceleration Response, S_s (short-period, or 0.2 seconds)	Spectral Acceleration Response, S_1 (long-period, or 1.0 second)
Low	less than 0.250g	less than 0.100g
Moderate	greater than or equal to 0.250g but less than 0.500g	greater than or equal to 0.100g but less than 0.200g
Moderately High	greater than or equal to 0.500g but less than 1.000g	greater than or equal to 0.200g but less than 0.400g
High	greater than or equal to 1.000g but less than 1.500g	greater than or equal to 0.400g but less than 0.600g
Very High	greater than or equal to 1.500g	greater than or equal to 0.600g

The seismic hazard relies on the danger level as well as the susceptibility to know plausible seismic impact [4]. The hazard level cannot diminish since it is an environmental occurrence. Thusly, the seismic hazard can be diminished by bringing down the susceptibility. Earthquake engineering comprises two critical terms: performance-based design and performance-based evaluation. The performance-based design focuses on structural design [5-8] while performance-based evaluation focuses on a constructed structural analysis [9-11].

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2 Methodology

2.1. Building model

The building model was based on the horizontally irregular structures. The dimension of the X and Y axes varied. The soil condition was determined in the moderate state. An improvement was done in the design as well. For instance, the stiffness levels of the positive

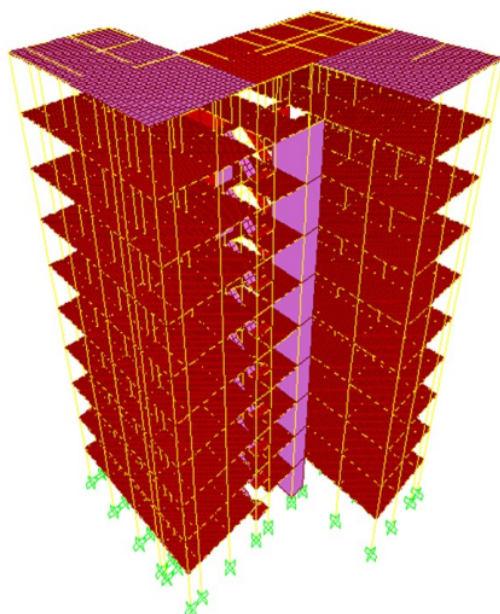


Fig. 1. Three-dimensional (3D) building model.

2.2 Structure details

The beams utilized profile I of 600 x 300 x 12 x 17 with 64 shear connectors. Every pair of shear connectors was attached to a floor with a separation of 18.75 cm between them on floors 1-9. In the meantime, the columns utilized profile I of 600 x 300 x 12 x 17 for floors 1-5 and profile I of 250 x 250 x 11 x 11 for floors 6-10. The roof utilized profile I of 500 x 300 x 11 x 15 with 52 shear connectors. Every pair of shear connectors was attached 23.10 cm separated.

2.3 Analysis of seismic evaluation

The static linear analysis was done by using the equivalent static load analysis based on the Non-Masonry Model. The base shear (V) happening at the structural basic level was computed based on equations in SNI 1726:2012 and SNI 03-1726-2002. The base shear (V) was then allocated to all the building structures to form the equivalent static seismic load (F_i) through all the joints on every floor.

The spectrum dynamic response seismic loads were utilized in dynamic response analysis by altering the

and negative X and Y axes were made equivalently. The dead loads were the structures' self-weight, comprised columns, floor plate profile, beams and walls. It was utilized as a distributed load on the beam to involve the load-bearing walls. The plate loads were formed based on the plate dimensional features. The live loads for a housing building type of 250 kg/m² were formed as equal loads distributed on the plates. The assessed three-dimensional (3D) building model was displayed in Figure 1 and the resulting structure plan was displayed in Figure 2.

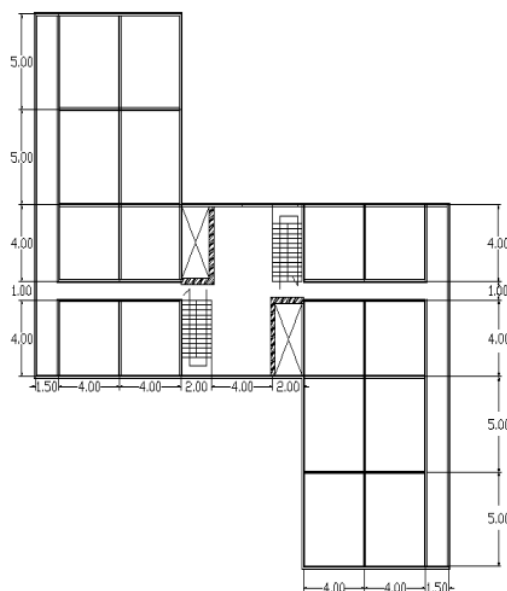


Fig. 2. The structure plan.

location categorization and seismicity level in Purwokerto, Indonesia. The spectrum response was modeled using SAP2000 software while dynamic response analysis utilizes the damping of 0.05 [12]. The function of the response spectrum was defined clearly in *Spectrum Response Function Definition*. Next, data were inputted into the spectral response accelerations (S_a) and fundamental period of the structure (T). In order to simulate the earthquake arbitrary load towards the building structure model, the effect of the seismic loading on the main directions were set to be 100% effective. This is because the effect of the seismic loading is in the direction perpendicular to the main direction (30% effective only).

Pushover analysis [13, 14] is a static and nonlinear procedure whereby the value of the structural loading was increased based on the predefined pattern. The relationship between the weak links and failure modes of the structure were found after increasing the magnitude of the loading. The loading is categorized to be monotonic. The effects of the cyclic behavior and load reversals were estimated by using the altered monotonic force-deformation criterion with damping approximations [15].

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3 Result and discussions

3.1. Linear static analysis

The base shear (V) on the moderate soil type occurring in the structure's basic level calculated base on SNI 03-1726-2002 is 4929.53 kN in the X direction and 6433.04

kN in the Y direction. Meanwhile, the base shear referring to SNI 1726: 2012 is 3426.77 kN in the X direction and 4471.94 kN in the Y direction. The base shear is reduced by 30.48%. The drift ratio experiences average decreases of 34.42 and 32.61% respectively in the X and Y directions, as displayed in Figure 5.

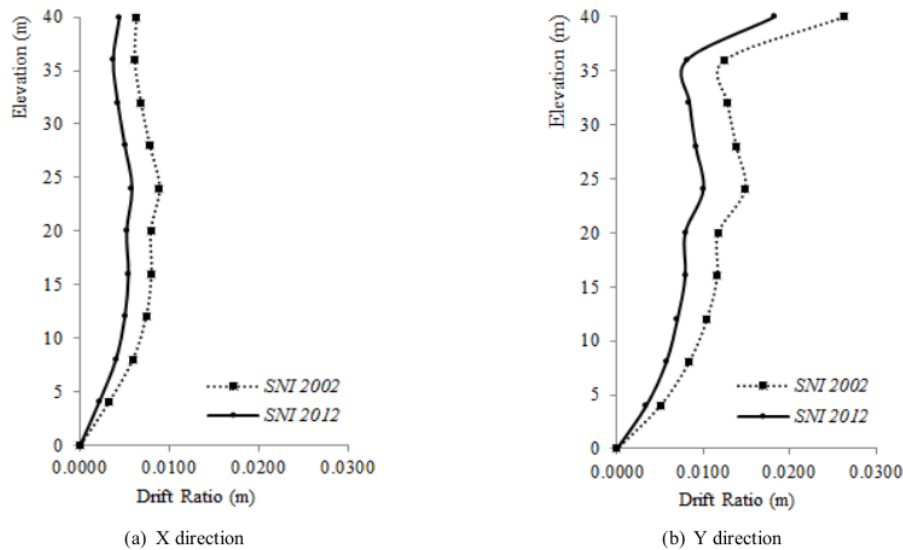


Fig. 5. Drift ratio resulting from the linear static analysis

3.2. Dynamic response analysis

In general, the response spectrum based on SNI 03-1726-2002 was larger than SNI 1726:2012. In other words, the high-rise residential building model in

Purwokerto, Indonesia still met the requirements of SNI 1726:2012 even SNI 03-1726-2002 was used. The drift ratio reduced by 30.74 and 27.33% in the X and Y direction respectively as displayed in Figure 6.

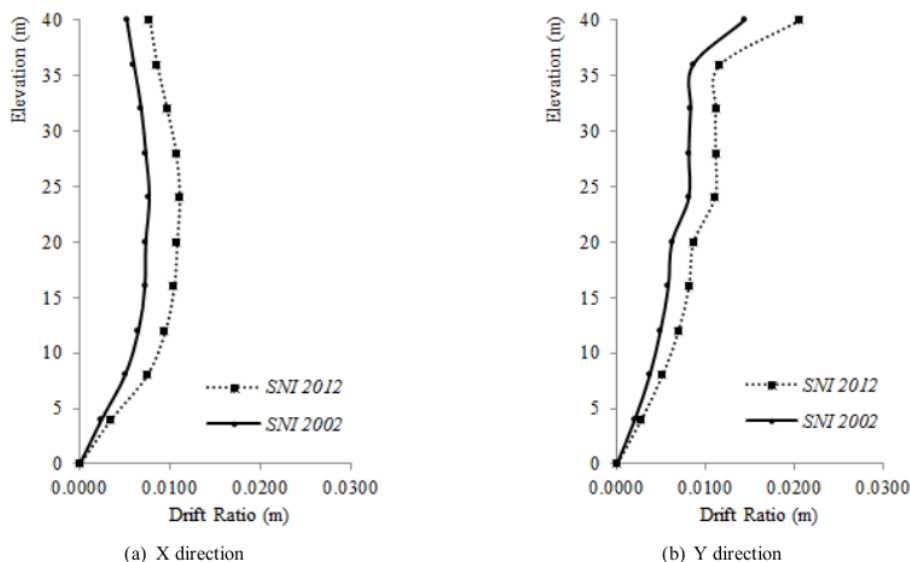


Fig. 6. Drift ratio resulting from the dynamic response analysis

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3.2. Pushover analysis

The results of the pushover analysis displayed the magnitude of displacement (D) and basic shear (V) when the high-rise residential building model nearly collapsed. As illustrated in Table 2, the base shear reduced by 30.57 and 18.27% for X and Y direction due to the high-rise residential building model in Purwokerto, Indonesia when the performance point was reached. The ductility of the structure was acquired by associating both the yield displacement (δ_y) and ultimate displacement (δ_u) as displayed in Table 3.

Table 2. Comparison of pushover analytical results.

Parameter	SNI			
	2002	2012		
	Dir. X	Dir. Y	Dir. X	Dir. Y
V (kg)	7571.40	7420.61	5256.80	6064.94
D (m)	0.077	0.061	0.053	0.050

Table 3. Ductility of the structure.

Direction	δ_y (m)	δ_u (m)	Ductility
X	0.21229	0.21714	1.02
Y	0.19704	0.64398	3.27

The structural performance of the high-rise residential building model was distinguished by drift ratio. The pushover analysis results displayed that the drift ratio was 0.193 and 0.153% for X and Y direction respectively for the seismic load of SNI 03-1726-2002. On the other hand, the drift ratio was 0.133 and 0.125% for X and Y direction respectively for the seismic load of SNI 1726:2012. The structural performance was displayed in Table 4.

Table 4. Structural performance.

SNI	Dir.	D_t (m)	Elevation (m)	Drift Ratio (%)	Performance level
2002	X	0.0770	40	0.193	IO
	Y	0.0610	40	0.153	IO
2012	X	0.0530	40	0.133	IO
	Y	0.0500	40	0.125	IO

The analyzed drift of this high-rise residential building model in the Y direction was larger than X direction as X direction was stiffer than Y direction. This phenomenon was due to the shear wall position and the stair structure. The performance of the high-rise residential building model in Purwokerto, Indonesia still remained at the level of Immediate Occupancy (IO) as the value of the drift ratio was less than 1%.

4 Conclusions

About 30.48% reduction in the base shear (V) based on the static linear analysis. Besides that, the drift ratio reduced to 34.42 and 32.61% in the X and Y direction, respectively. However, the drift ratio reduced to 30.74

and 27.33% in the X and Y direction respectively if based on the dynamic response analysis. The results of the pushover analysis displayed that the performance of this high-rise residential building model still at Immediate Occupancy (IO) level. In other words, the building still remained safe to occupy as the pre-earthquake design strength and stiffness of the structure did not alter greatly. The risk of getting injury due to minor structural damage was low and safe to stay.

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