VOL. 12, NO. 17, SEPTEMBER2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

THE PERFORMANCE OF A TEN-STORY IRREGULAR APARTMENT BUILDING MODEL UNDER SEISMIC LOAD IN PURBALINGGA REGENCY INDONESIA

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ABSTRACT

Purbalingga, Indonesia, is regency with moderately high seismicity potential requiring compliance with planning and implementation rules for earthquake-resistant structural systems. We evaluate the performance of a ten-story irregular apartment building model in Purbalingga due to the seismic load. It is necessarily conducted in order to provide information on impacts and mitigation strategies that should be implemented. The evaluation is 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 linear static analysis, the drift ratio decreases 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 decreases 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 apartment 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, and although some minor structural repairs may be appropriate, these would generally not be required prior to re-occupancy.

Keywords: apartment, immediate occupancy, performance, purbalingga, seismic load.

INTRODUCTION

Buildings have numerous functions for human activities including both general and particular residential, religious, business, social, and cultural activities. Article 8 of The Law of Republic of Indonesia No. 28 of 2002 on Building Construction states that each building construction is required to meet the administrative requirements including status of land rights, building ownership, and building permits [1]. Furthermore, the need for a Building Construction Permit stipulated in Government Regulation No. 36 of 2005 concerning Implementing Regulation of Law No. 28 of 2002 on Building Construction [2], Regulation of the Minister of Public Works No. 24 of 2007 on Technical Guidelines of Building Construction Permit [3], and Regulation of the Minister of Home Affairs No. 32 of 2010 on Guidelines of the Issuance of Building Construction Permit [4].

An apartment is a building whose functions meet the requirements for residential activities. Nowadays, due to economic and population growth, the need for apartments is increasing rapidly. An apartment building actually needs a greater area of land. In facts, the area of land provided is very limited. One way to utilize a small area of land optimally is by vertically constructing a multistory building. There are many aspects to consider in designing a multistory building, such as function, security, convenience, efficiency, and economic factors. Security is the main aspect in constructing a multistory building. The calculation of designs and structures of a multistory building is generally done to maintain the vertical gravitational forces (dead and live loads) as well as the horizontal forces of winds and earthquakes.

Due to its seismicity, Indonesia has made regulatory changes on earthquake of Indonesian National Standards, SNI 03-1726-2002 [5] to SNI 1726:2012 [6], which may change the building's structural behaviors. Based on details of the Indonesian earthquake hazard map of 2010, Purbalingga regency has a short period (0.2 s) Spectral Acceleration (Sa) response of 0.792 g and a long-period (1.0 s) Sa of 0.323 g, as shown in Figure-1.

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Figure-1. Short period (0.2 s) spectral acceleration (Sa) and long period Sa in Purbalingga regency Indonesia [6].

An area with a short-period (0.2 s) Sa response greater than or equal to 0.500 g but less than 1.000 g and a long-period (1.0 s) Sa greater than or equal to 0.200 g but less than 0.400 g is categorized as an area with moderately high seismicity potential [7]. Thus, Purbalingga is a region with moderately high seismicity potential which requires compliance with planning rules and implementation of an earthquake-resistant structural system in each building structure established in Purbalingga. In fact, the planning rules and the earthquake-resistant building structure implementation have not been completely applied.

An earthquake is a disaster that humans must be aware of [8]. Based on statistics of the frequency and magnitude of earthquakes, more than 200 large magnitude earthquakes occur each decade [9, 10]. Generally, the high level of the damage and casualties caused by the occurrence of earthquakes, especially in the areas directly adjacent to the epicenter, a high danger zone, indicates that the mitigation efforts by both the government and society were still low [11]. The aim of this study is to evaluate the performance of a ten-story irregular apartment building model in Purbalingga due to the seismic load. This must be done in order to provide information on impacts and mitigation strategies that should be applied.

Buildings with structures that are either horizontally or vertically irregular have higher vulnerability than those with regular ones. An example of a building with horizontally irregular structures is one with re-entrant corner irregularity, as both projections on structural plans of the re-entrant corner are greater than 15% of the structural plan dimensions with a specified direction, as shown in Figure-2. An example of buildings with vertically irregular structures is those with in-plane discontinuity irregularity, as there is an offset of the retaining elements that is greater than the width (d) or there exists a reduction in the stiffness of thestory below, as shown in Figure-3.

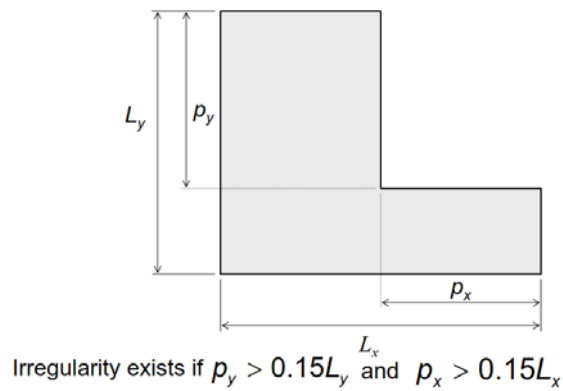


Figure-2. Re-entrant corner irregularity [12].

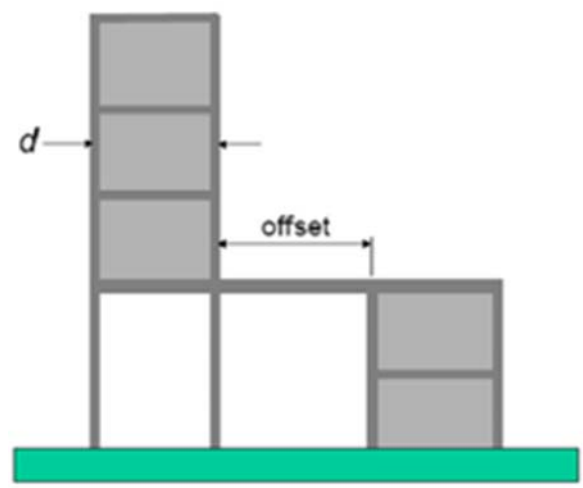


Figure-3. In-plane discontinuity irregularity [12].

Satyarno [13] states that the level of seismicity is determined by two main factors: the hazard and the vulnerability. The hazard cannot be decreased since it is a natural phenomenon. In this way, the level of seismicity can only be decreased by lowering the vulnerability. In relation to the study of earthquake engineering, nowadays there are two important terms: *performance-based evaluation* and *performance-based design.* Performance-based evaluation deals with a constructed structural analysis [14-20], while performance-based design deals with structural design [21, 22].

METHODOLOGY

Apartment Building Model

The apartment building model was adjusted based on the criteria of irregular structures, in this case, horizontally irregular structures in which the dimension of the X and Y axes differed, with the soil conditionwas determined in moderate state. Simplification is carried out in the design; for example the stiffness levels of the positive and negative axis X and of the positive and negative axis Y are made equal. The dead loads considered include the structures' self weight, consisting of beams, columns, walls, and floor plate profile. It is used a distributed load on the beamto include load-bearing walls. Meanwhile, the plate loads are modeled based on plate dimensional properties. The live loads for an apartment building type of 250 kg/m^2 are modeled as equal loads distributed on plates. To determine the structures' self weight, an analysis is conducted based on the concept of equilibrium forces. The structure plan is shown in Figure-4, while the evaluated three-dimensional apartment building model is shown in Figure-5.

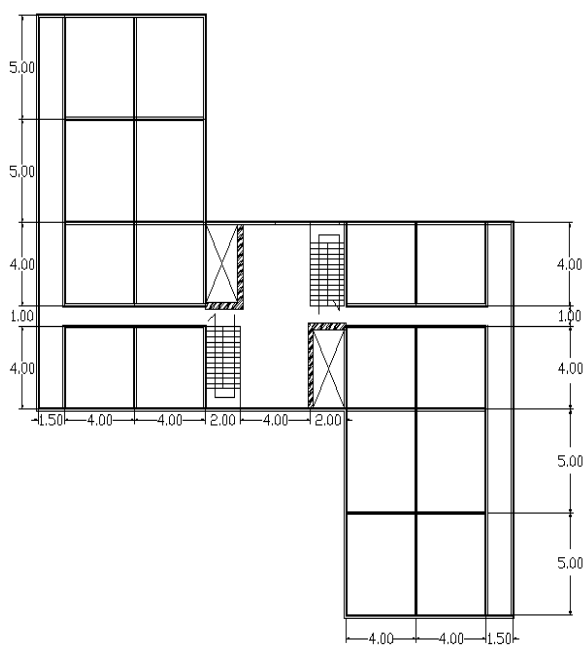


Figure-4. The structure plan.

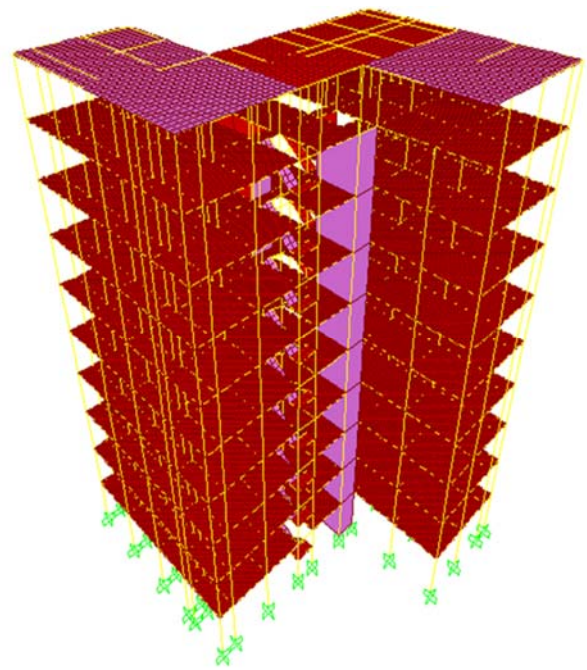


Figure-5. Three-dimensional apartment building model.

Structure details

The columns use profile I of 600.300.12.17 for floors 1-5 and profile I of 250.250.11.11 for floors 6-10. Meanwhile, the beam uses profile I of 600.300.12.17 with 64 shear connectors. Each pair of shear connectors is mounted on a floor with a distance of 18.75 cm between them on floors 1-9. The roof beams use profile I of 500.300.11.15 with 52 shear connectors. Pairs of shear connectors are mounted 23.10 cm apart. The stair planning results in an *optrede* calculation of 20 and 25 cm and an angle of 38º with a staircase of 19 steps. The stair plan and front view are shown in Figure-6, while the side view is shown in Figure-7.

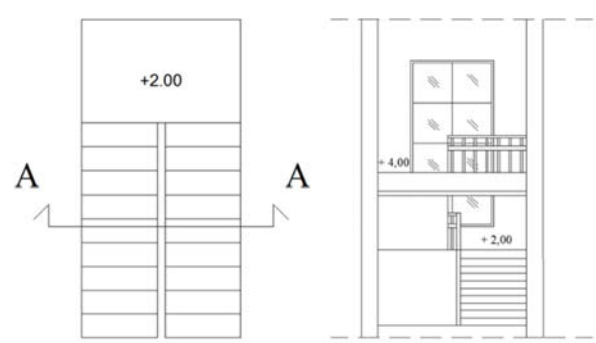


Figure-6. Stair plan and front view.

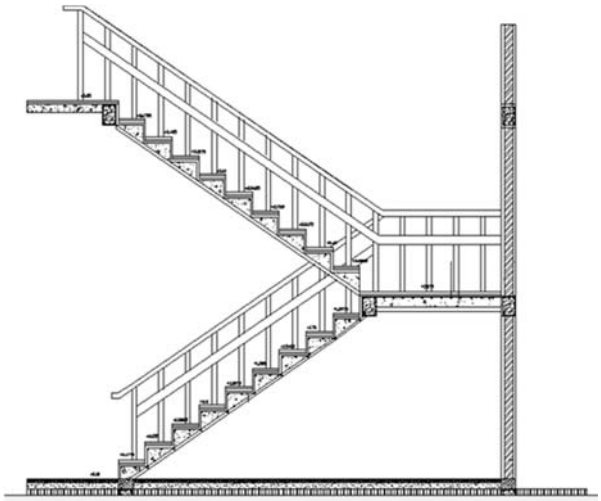


Figure-7. Stair side view.

Analysis of seismic evaluation

Static linear analysis

Static linear analysis is conducted using equivalent static load analysis. The analysis is conducted on the Non-Masonry Model. The base shear (V) occurring at the structural basic level is calculated using an equation based on SNI 03-1726-2002 and SNI 1726:2012. The base shear (V) is then distributed to the whole building structure to become the nominal equivalent static seismic load (F_i) through joints on each floor. The base shear (V) and equivalent static seismic load (F_i) based on SNI 03-1726-2002 are shown by Equations (1) and (2), respectively, while those based on SNI 1726:2012 are shown by Equations (3) and (4), respectively.

$$V = \frac{C_1 I}{R} Wt \tag{1}$$

$$F_i = \frac{W_i Z_i}{\sum_{i=1}^{n} W_i Z_i} V \tag{2}$$

$$V = Cs \times W \tag{3}$$

$$C_S = \frac{S_{DS}}{\frac{R}{I_e}} \tag{4}$$

Dynamic response analysis

The spectrum dynamic response seismic loads based on SNI 03-1726-2002 and SNI 1726:2012 are used in dynamic response analysis by adjusting the site classification and seismicity level in Purbalingga regency. Dynamic response analysis uses damping of 0.05. The dynamic response analysis is conducted using a three-dimensional model. So that the spectrum response can be modeled using SAP2000 software [23], the function of the response spectrum is defined in a dialog box of Spectrum Response Function Definition. The definition is conducted by inputting data of the fundamental period of the structure (T) and those of spectral response accelerations (Sa). To simulate the planned earthquake arbitrary load toward the building structure model, influence of the seismic loading on the major directions is considered to be 100% effective at the same time as the influence of the seismic loading in the direction perpendicular to the main direction is only 30% effective. Based on SNI 03-1726-2002, the response spectrum is developed as follows:

$$A_m = 2.5 A_0 \tag{5}$$

for $T < T_c$:

$$C = A_m \tag{6}$$

for $T > T_c$:

$$C = \frac{A_r}{T} \tag{7}$$

where

$$A_r = A_m T_c \tag{8}$$

In addition, based on SNI 1726:2012, the response spectrum is developed as follows:

For periods less than or equal to T_0, Sa is taken as given by Equation (9).

$$Sa = S_{DS}\left(0,4 + 0,6\frac{T}{T_0}\right) \tag{9}$$

For periods greater than or equal to T_0 and less than or equal to T_S, Sa is taken as equal to S_{DS}.

For periods greater than $T_S$and less than or equal toT_L, Sa is taken as given by Equation (10).

$$Sa = \frac{S_{D1}}{T} \tag{10}$$

Pushover analysis

Pushover analysis is a static, nonlinear procedure in which the magnitude of the structural loading is incrementally increased in accordance with a certain predefined pattern [24, 25]. With the increase in magnitude of the loading, weak links and failure modes of the structure are found. The loading is monotonic with the effects of the cyclic behavior and load reversals being estimated by using a modified monotonic force-deformation criterion and damping approximations. The following steps [24] are included in the pushover analysis. Steps 1 through 4 discuss the creation of the computer model, step 5 runs the analysis, and steps 6 to 10 review the pushover analysis results.

a) Create the basic computer model (without the pushover data) using SAP2000.
b) Define properties and acceptance criteria for the pushover hinges. The program includes several built-

in default hinge properties that are based on average values from ATC-40 [26] for concrete members and average values from FEMA 273 [27] for steel members. These built-in properties can be useful for preliminary analysis, but user-defined properties are recommended for the final analysis.

c) Locate the pushover hinges on the model by selecting one or more frame members and assigning them one or more hinge properties and hinge locations.

d) Define the pushover load cases. In SAP2000, more than one pushover load case can be run using the same analysis. Also a pushover load case can start from the final conditions of another pushover load case that was previously run in the same analysis. Typically the first pushover load case is used to apply the gravity load and then subsequent lateral pushover load cases are specified to start from the final conditions of the gravity pushover. Pushover load cases can be force controlled, that is, pushed to a certain defined force level, or they can be displacement controlled, that is, pushed to a specified displacement. Typically a gravity load pushover is force controlled and lateral pushovers are displacement controlled. SAP2000 allows the distribution of lateral force used in the pushover to be based on a uniform acceleration in a specified direction, a specified mode shape, or a user-defined static load case.

e) Run the basic static analysis and, if desired, dynamic analysis. Then run the static nonlinear pushover analysis.

f) Display the pushover curve. The file menu allows us to view and if desired, print to either a printer or an ASCII file, a table which gives the coordinates of each step of the pushover curve and summarizes the number of hinges in each state.

g) Display the capacity spectrum curve. Note that we can interactively modify the magnitude of the earthquake and the damping information on this form and immediately see the new capacity spectrum plot. The performance point for a given set of values is defined by the intersection of the capacity curve and the single demand spectrum curve. Also, the file menu in this display allows us to print the coordinates of the capacity curve and the demand curve as well as other information used to convert the pushover curve to Acceleration-Displacement Response Spectrum (ADRS) format.

h) Review the pushover displaced shape and sequence of hinge formation on a step-by-step basis. Hinges appear when they yield.

i) Review member forces on a step-by-step basis.

j) Output for the pushover analysis can be printed in a tabular form for the entire model or for selected elements of the model. The types of outputs available in this form include joint displacements at each step of the pushover, frame member forces at each step of the pushover, and hinge force, displacement, and state at each step of the pushover.

RESULT AND DISCUSSIONS

Results of linear static analysis

The base shear (V) on the moderate soil type occurring in the structure's basic level calculated based 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 shown in Figure-8.

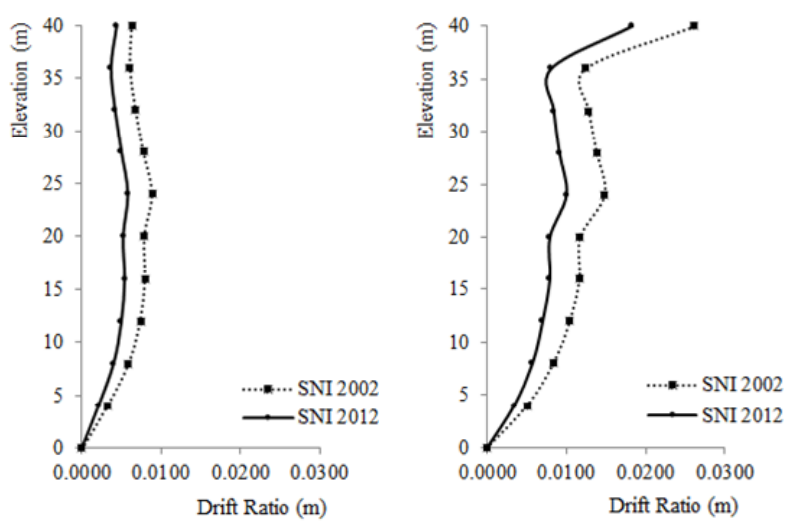


Figure-8. Drift ratio resulting from the linear static analysis: (a) X direction, (b) Y direction.

Results of dynamic response analysis

In Purbalingga, Indonesia, the response spectrum referring to SNI 03-1726-2002 is greater than that referring to SNI 1726:2012, as shown in Figure-9. Thus, if the apartment building model was made earlier, referring to SNI 03-1726-2002, it is obvious that it will also meet the requirements of SNI 1726:2012. The results of dynamic response analysis show that the drift ratio decreases by 30.74 and 27.33% on average in the X and Y directions, respectively, as shown in Figure-10.

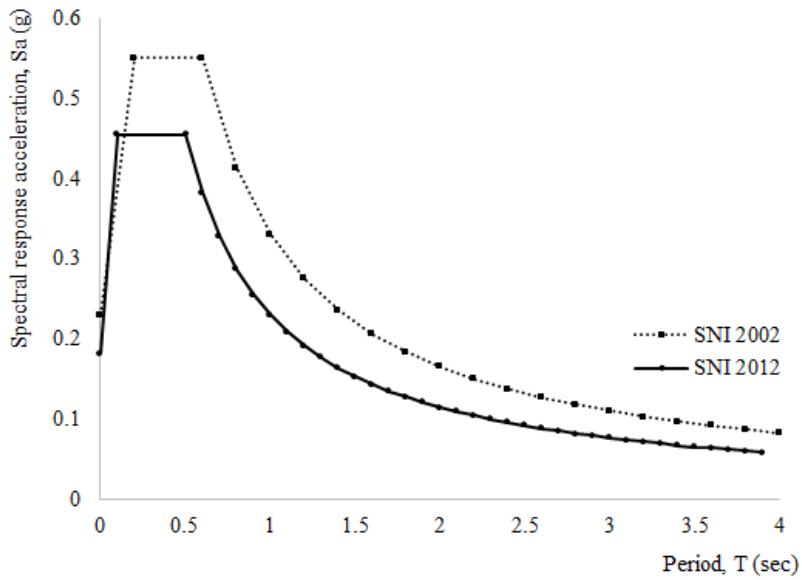
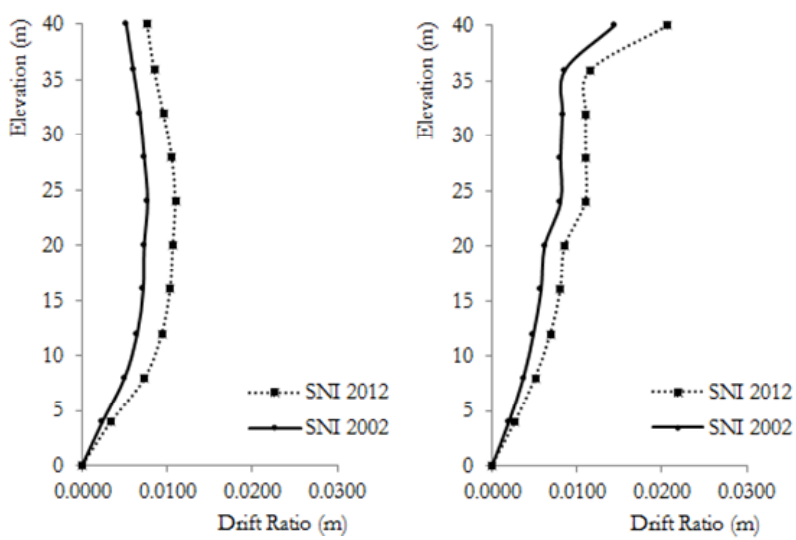


Figure-9. The response spectrum for moderate soils in Purbalingga, Indonesia.



(a (b

Figure-10. Drift ratio resulting from the dynamic response analysis:
(a) X direction, (b) Y direction.

Results of pushover analysis

The results of the pushover analysis show that the values of basic shear (V) and displacement (D) occur when the apartment building model nearly collapses. The values of Sa, Sd, the effective natural period (T_{eff}), and effective viscous damping (β_{eff}) may also be determined. The results are based on SNI 03-1726-2002 and SNI 1726:2012, as presented in Table-1, showing that the base shear decreases by 30.57% in the X direction and by 18.27% in the Y direction due to the apartment building models in Purbalingga regency, Indonesia, when the performance point is already reached. The ductility of the structure is obtained by comparing the ultimate

displacement value (δ_u) and the yield displacement (δ_y) as presented in Table-2.

Table-1. Comparison of pushover analytical results.

Parameter	SNI			
	2002		2012	
	Direction X	Direction Y	Direction X	Direction Y
V (kg)	7571.40	7420.61	5256.80	6064.94
D (m)	0.077	0.061	0.053	0.050
S_a	0.545	0.550	0.379	0.045
S_d	0.050	0.036	0.035	0.290
T_{eff}	0.607	0.511	0.067	0.511
β_{eff}	0.05	0.05	0.05	0.05

Table-2. 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 apartment building model is determined by story drift, that is, the ratio of the drift of the control point to its height. The pushover analysis results show that the story drift that occurs is 0.193% in the X direction and 0.153% in the Y direction for the seismic load of SNI 03-1726-2002 while for the seismic load of SNI 1726:2012, the story drift is 0.133% in the X direction and 0.125% in the Y direction. The drift levels of pushover analytical results are shown in Figure-11, while the structural performance is presented in Table-3.

Table-3. Structural performance.

SNI	Direction	Dt (m)	Elevation (m)	Story drift (%)	Performance
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*

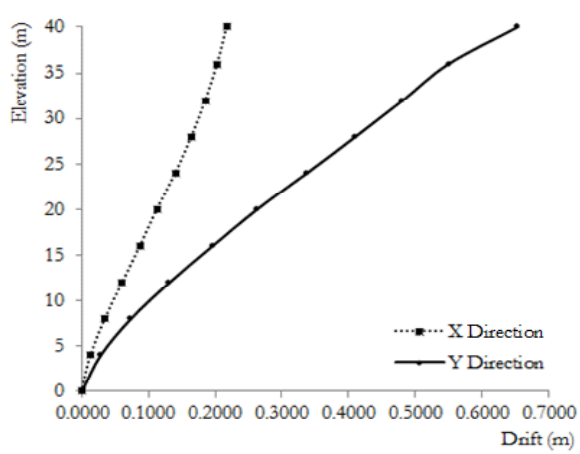


Figure-11. Drifts in the X and Y directions resulting from the pushover analysis.

The analyzed drift of the apartment building model in Purbalingga regency, Indonesia, in the Y direction is greater than that in the X direction because there is a difference in stiffness, where the X direction is stiffer than the Y direction. There are several causative factors, including the strong axis column mounting in the same direction as the X axis, the shear wall position, which is in the same direction as the X axis, and the stair structure, which is in the same position as the X axis. The value of story drift is less than 1% so the performance of the apartment building model in Purbalingga regency does not change, remaining at the level of IO.

CONCLUSIONS

Based on linear static analysis, it is found that there is a 30.48% decrease in the base shear (V). The results of the static linear analysis also show that the drift ratio experiences average decreases of 34.42 and 32.61% in the X and Y directions, respectively. The drift ratio based on dynamic response analysis shows average decreases of 30.74 and 27.33% in the X and Y directions,

respectively. The results of pushover analysis show that the performance of this apartment building model is still at Immediate Occupancy (IO) level, that is, 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, and although some minor structural repairs may be appropriate, these would generally not be required prior to re-occupancy. The plastic hinge distribution shows that the collapse initially starts at the beam elements.

ACKNOWLEDGEMENTS

The authors express their gratitude and appreciation to the Research and Public Services Institution (LPPM) of Jenderal Soedirman University (UNSOED) for funding this study through the Competence Development Research Scheme. The authors also thank Dodi Rahmawan and Fadli Faisal Putra, who provided assistance that allowed this study to be accomplished well.

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