

Damage and loss probability assessment of reinforced concrete building due to Yogyakarta earthquake scenario using pushover and hazus analysis (case study: student center building, faculty of social science, UNY)

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Abstract. Yogyakarta is one of the cities in Indonesia prone to earthquake. The Student Center Building, Faculty of Social Science (FSS), Universitas Negeri Yogyakarta (UNY) was built in 2012 using the earthquake code of 2002. Seismic vulnerability assessment of the building due to the newest seismic code is essential to do as one of earthquake disaster mitigation efforts. The study aimed to determine the seismic building performance level based on ATC-40 criteria, damage probability matrix using HAZUS method, and damage loss economic value of the building based on FEMA-1999. The research begins by modelling building structures in 3D followed by performing pushover analysis then calculate the probability of building damage based on HAZUS method. The results show that the building is included in the Immediate Occupancy (IO) performance level which means that if an earthquake happens, only a little structural damage occurs. The total vulnerability value based on the HAZUS method analysis reached 48.12%, in which the probability of damage for the slight, moderate, extensive and complete level reached 22.59%, 21.60%, 3.71% and 0.23% respectively. In addition, the damage economic value obtained is 4.692% means that the building has a small damage economic probability due to the 2006 Yogyakarta earthquake scenario.

1 Introduction

Yogyakarta as one of the largest educational destination cities in Indonesia encourages educational institutions to develop and build some new educational facilities buildings from elementary schools to universities to support teaching and learning activities. New buildings, especially those located in earthquake-prone areas such as Yogyakarta must be designed with the latest earthquake resistance design code. The Student Center Building, Faculty of Social Science (FSS), Universitas Negeri Yogyakarta (UNY) completed in 2014 was designed using the seismic design code of 2002 (SNI 1726-2002). The earthquake hazard map of Indonesia in 2010 used in [1] shows an increase of peak ground acceleration (PGA) value from [2] earthquake map for Yogyakarta area (from 0.15g to range of 0.2-0.25g). Damage and loss probability study of the building due to the earthquake is essential as one of the disaster mitigation efforts.

Reference [3] states that the safety of building depends not only on the level of strength but also on the level of deformation and measurable energy on the

performance of the structure. Pushover analysis method is an appropriate method to conduct the evaluation of building performance. The previous research related to pushover analysis was done in [4] and [5], but the results do not explain the building damage probability in each level of damage. While research on Damage and Loss Assessment has been done by [6] using the form of RC Frame Buildings. They used the different method to calculate the building damage and loss using FEMA P-58 which was written in [6].

This study is a combination and development of previous research [7], [8], and [9] using pushover analysis with performance level determination based on ATC-40 followed by building damage analysis using HAZUS method to get the probability value of building damage, then measure the damage loss estimation using FEMA-1999. The study aimed to obtain the performance level, damage probability matrix, and damage loss economic value of the building.

2 Research method

The method used in this research is pushover analysis or commonly known as nonlinear static analysis to

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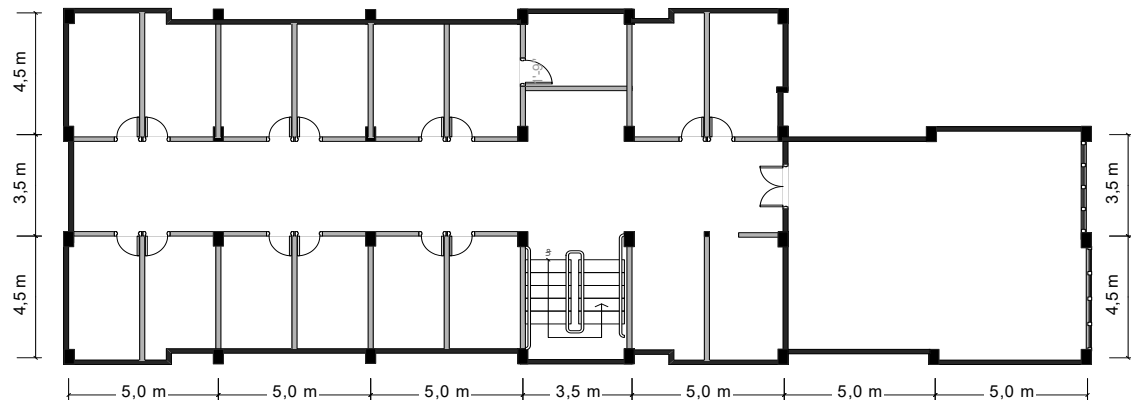


Fig. 1. Typical Floor Plan of Building.

determine the building performance level, followed by damage probability analysis using HAZUS method and calculation of damage loss based on FEMA-1999.

The initial step of this study is modeling the structure in 3-dimensional structure, performing load, pushover, and damage probability analysis, followed by calculating the damage losses due to earthquake using Yogyakarta earthquake scenario year 2006. The detailed description of research stages is presented in subchapters below.

2.1 Data and structural modeling

The building under study is a 3-story reinforced concrete building that functions as the center of student activities located in Yogyakarta. The typical floor plan of the building is shown in Fig. 1.

The quality of the material used is as follows:

- a. Quality of concrete: K300 (eq.to 25 MPa)
- b. Quality of steel:
 - deformed bar with the diameter of >10 mm, f_y value of 320 MPa.
 - plain round bar with the diameter of <10mm, f_y value of 240 MPa.

The structure is modelled in the 3-dimensional open frame structure according to As-Built Drawing data as shown in Fig. 2.

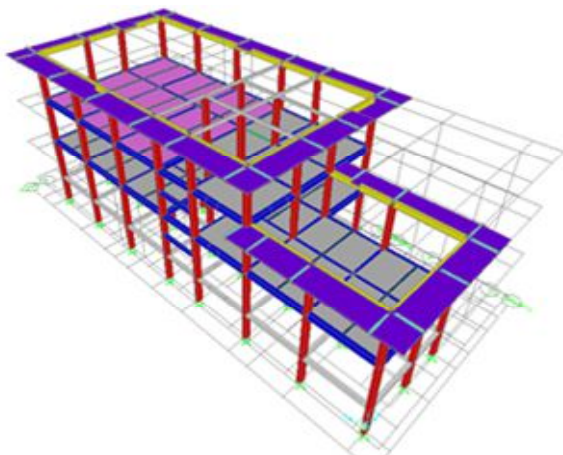


Fig. 2. The 3-D view of the building modeled in SAP2000.

The structural data based on the document of structure, as follows:

- a. Plates: 120 mm (floors, stairs, and borders); 100 mm (rooftop)
- b. Beams and Columns: each type of beam and column size is presented in Table 1.

Table 1. Beam and column size.

Structural type		Size (mm)
Beam	B1	300/450
	B2	250/350
	B3	250/400
	Sloof	300/400
	Ring balk	250/450
Column	K1	300/500
	Kp	120/120

The codes used in this study are as follows:

- 1) SNI 1726-2012 – Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Non-Gedung [1],
- 2) SKBI 1987 – Pedoman Perencanaan Pembebanan Untuk Rumah dan Gedung [10],
- 3) Applied Technology Council (ATC-40), 1996, Seismic Evaluation and Retrofit of Concrete Buildings [11],
- 4) HAZUS (Hazard US), 1999: Building Damage probability [12],
- 5) FEMA, (1999), Earthquake Loss Estimation Methodology of HAZUS 99 [13].

2.2 Pushover analysis

Pushover analysis is a nonlinear static analysis in which the design earthquake load effect on the building structure is considered as static loads that are given at the centre of mass in each storey, which value is gradually increased to exceed the loading that causes the first plastic hinge in the structure of the building, then with a

gradual increase of load resulted in the building undergoing major post-elastic form changes until it reached the plastic condition [14].

Capacity Spectrum Method (CSM) is the method which is most commonly used to compare the capacity and demand on pushover analysis. The CSM is basically focused on the reduction of elastic spectrum intersecting the capacity curve at the spectrum coordinate to obtain performance point.

Pushover analysis obtains a capacity curve that illustrates the relationship between base shear (V) and the roof displacement (Δ). The capacity curve is then converted into ADRs (Acceleration Displacement Response Spectrum) into a capacity spectrum curve that describes the relationship between Spectral Acceleration (S_a) and Spectral Displacement (S_d) which is shown in Fig. 3. while the spectrum response in the ADRS format is shown in Fig. 4.

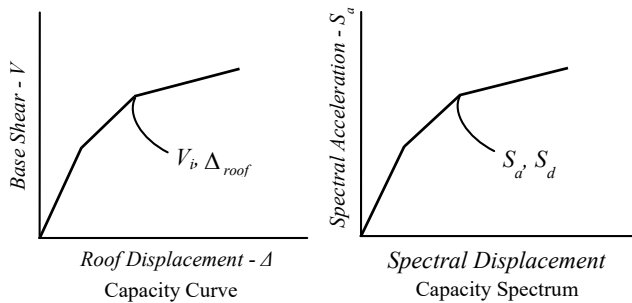


Fig. 3. Modification of capacity curve to capacity spectrum.

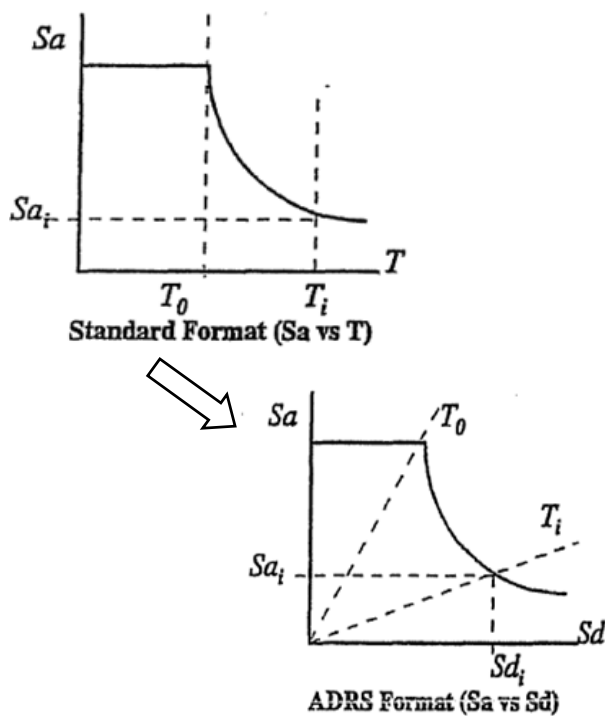


Fig. 4. Modification of standard format response spectrum to ADRS format.

2.3 Structural performance level

The determination of the performance level is based on the Applied Technology Council (ATC) 40. Reference [11] provides the limits of the roof drift ratio evaluated on the performance points in order to evaluate the performance of ductile structures with nonlinear static analysis. The parameters used are maximum total drift and maximum inelastic drift. The limit of roof drift ratio according to ATC-40 is presented in Table 2.

Table 2. The roof drifts ratio limit according to ATC-40.

Parameter	Performance Level			
	IO	Damage Control	LS	Structural Stability
Maximum Total Drift	0.01	0.01 to 0.02	0.02	$0.33 \frac{V_i}{P_i}$
Maximum Inelastic Drift	0.005	0.005 to 0.015	no limit	no limit

The value of drift ratio can be calculated using the equation as follows:

$$\text{Maximum total drift ratio} = \frac{\delta_t}{H} \quad (1)$$

$$\text{Maximum inelastic drift ratio} = \frac{\delta_t - \delta_1}{H} \quad (2)$$

Where:

δ_t = displacement obtained on performance point (m)

δ_1 = first yield displacement (m)

H = building total height (m)

V_i = total shear force of i-story

P_i = total gravitation force of i-storey

The explanation of the performance level based on ATC-40 document as follows:

- 1) Immediate Occupancy (IO): the post-earthquake damage state in which only very limited structural damage has occurred.
- 2) Damage Control (DC): a range of post-earthquake damage states that could vary from Immediate Occupancy to Life Safety.
- 3) Life Safety (LS): the post-earthquake damage state in which significant damage to the structure may have occurred but in which some margin against either total or partial structural collapse remains.
- 4) Structural Stability (SS): this level is the limiting post-earthquake structural damage state in which the building's structural system is on the verge of experiencing partial or total collapse.

2.4 Vulnerability analysis on HAZUS method

The Hazard-US (HAZUS) method is a method developed by the National Institute of Building Sciences (NIBS) [12] for risk assessment due to various disasters. This method was issued by The Federal Emergency Management Agency (FEMA) in 1997 to assess the losses caused by the earthquake in the US. The HAZUS earthquake method is one of the analysis model used to determine the level of building vulnerability in an area due to earthquake disaster.

The HAZUS method produces vulnerability curves with a high degree of accuracy that can be applied in analyzing the building vulnerability level. The conditional probability of being in, or exceeding, a particular damage state, ds , given the spectral displacement, S_d , is defined by the function:

$$P[ds / S_d] = \Phi \left[\frac{1}{\beta_{ds}} \ln \left(\frac{S_d}{\bar{S}_{d.ds}} \right) \right] \quad (3)$$

where:

$P[ds/S_d]$ = damage probability value, ds

S_d = inelastic spectral displacement (inches)

$\bar{S}_{d.ds}$ = the median value of spectral displacement at which the building reaches the threshold of damage state, ds

β_{ds} = the standard deviation of the natural logarithm of spectral displacement for damage state, ds

Φ = the standard normal cumulative distribution function

2.5 Building damage economic value

According to [13], the economic value of the damage is the value of building losses due to earthquakes that include structural and non-structural damage. The value of the loss is measured by the percentage value of the building value itself. The relationship between the level of damage, the percentage of damage, and the economic value of the damage follow the research developed in the USA (FEMA, 1999) as presented in Table 3.

Table 3. The relationship between the damage level, percentage, and economic value due to the earthquake (FEMA-1999).

Damage level	Damage ratio	Loss of economic value
<i>Slight</i>	1% - 15%	2%
<i>Moderate</i>	15% < damage ≤ 40%	10%
<i>Extensive</i>	40% < damage ≤ 80%	50%
<i>Complete</i>	80% < damage ≤ 100%	100%

3 Result and discussion

3.1 Lateral earthquake load

Evaluation of building structures using pushover shows the structure of the building is considered fully elastic so that reduction factor (R) = 1 is used in that calculation. Calculation of the lateral earthquake loads according to SNI 1726-2012 [1] using the equation below:

$$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^n w_i h_i^k} \quad (5)$$

Where:

C_{vx} = vertical distribution factor

w_x and w_i = total effective seismic weight of structure in x or i level (ton)

h_x and h_i = floor height from ground level to i or x level (m)

k = structural period exponent

The result of lateral earthquake load distribution in each story is presented in Table 4.

3.2 Pushover analysis result

Pushover analysis result shows the capacity curve of x and y -direction. The relationship between the base shear (ton) with displacement (m) is presented in Fig. 5.

Based on the result, the x -direction capacity curve is higher and tend to be upright than the y -direction capacity curve. The slope of the capacity curve shows the stiffness of the structure building. The Curve that tends to be upright shows that the building has a higher stiffness value than the sloping capacity curve.

Table 4. The distribution of lateral earthquake load.

Storey	Weight (Ton)	H (m)	h^k	$W \times h^k$	C_{vx}	F (Ton)
1 st	169,9834	2,4	2,922	496,644	0,0309	33,209
2 nd	447,7623	6,4	9,712	4348,746	0,2705	290,789
3 rd	421,2626	10,4	17,601	7414,781	0,4612	495,807
Roof	144,1218	14,515	26,476	3815,835	0,2374	255,155
Total	1183,130			16076,007	1	1074,961

After knowing the percentage of each level of damage, then calculated the Mean Damage Probability (MDP) to determine the average ratio value of the damage. The MDP calculation is done by the following equation:

$$MDP = \sum_{i=1} \{PDS_i * LEV_i\} \quad (4)$$

Where:

MDP = Mean damage probability

PDS_i = Probability damage state i

LEV_i = Loss economic value i

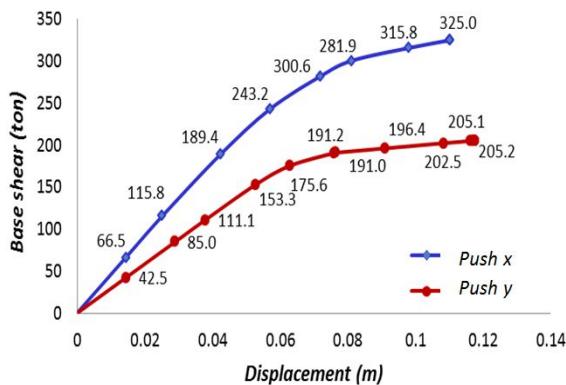


Fig. 5. The capacity curve in x and y-direction.

Fig. 5. shows that the x-axis direction structure is more rigid than the y-axis direction because the larger column dimension is in the x-axis direction so that the column inertia moment is greater toward the x-axis than the y-axis.

3.3 Performance level

The intersection result of the capacity curve and spectrum demand is obtained performance point value. Performance point values, effective natural vibration time and effective viscous damping based on the ATC-40 method in x and y-direction is presented in Figure 6 and Fig. 7.

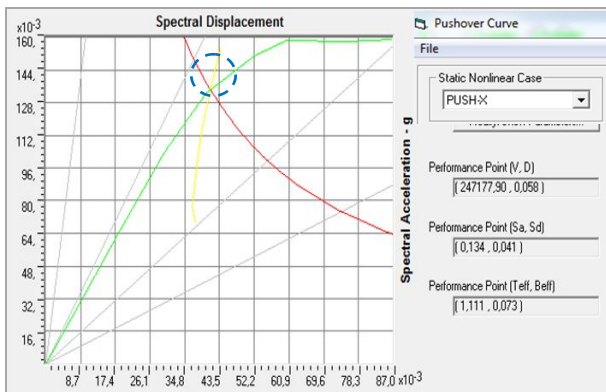


Fig. 6. The capacity curve in the x-direction.

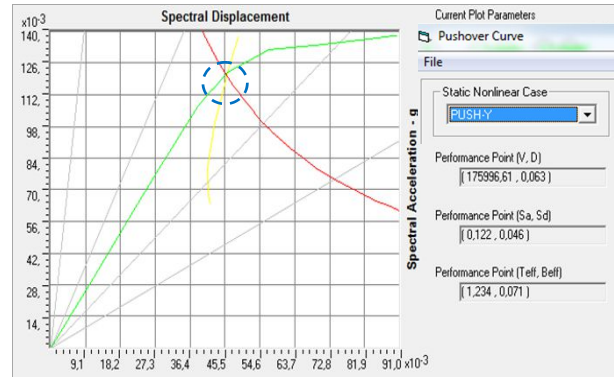


Fig. 7. The capacity curve in y-direction.

Performance levels can be determined based on the drift ratio criteria obtained when the performance point is reached. The calculation of drift ratio on x and y direction of pushover analysis using the equation (1) and (2) as follows:

1) x-direction

Maximum total drift ratio:

$$\frac{\delta_t}{H} = \frac{0,058}{14,515} = 0,0040 < 0,01$$

Maximum inelastic drift ratio:

$$\frac{\delta_t - \delta_i}{H} = \frac{0,058 - 0,0143}{14,515} = 0,00301 < 0,005$$

2) y-direction

Maximum total drift ratio:

$$\frac{\delta_t}{H} = \frac{0,063}{14,515} = 0,00434 < 0,01$$

Maximum inelastic drift ratio:

$$\frac{\delta_t - \delta_i}{H} = \frac{0,063 - 0,0144}{14,515} = 0,00335 < 0,005$$

Based on the calculation of the drift ratio, both maximum total drift and maximum inelastic drift ratio show that the performance level of the structure building is Immediate Occupancy, which means that only very limited structural damage has occurred, so the building is safe and can be directly used.

Based on the two figures, the base shear value result of pushover-x is greater than pushover-y, on the contrary, the displacement obtained from the performance point of pushover-y is slightly higher than pushover-x. The displacement value of the pushover analysis results will affect both the maximum total drift ratio and the maximum inelastic drift ratio.

The larger the displacement value on the performance point, the greater the maximum total drift ratio will be. The recapitulation of performance point parameters values based on the analysis is presented in Table 5.

Table 5. Performance point based on the analysis result.

Pushover	Base Shear (ton)	Performance Point					
		V_t (ton)	δ (m)	S_a	S_d	T_{eff}	B_{eff}
Push-X	325,030	247,177	0,058	0,134	0,041	1,111	0,073
Push-Y	205,204	175,996	0,063	0,122	0,046	1,234	0,071

3.4 Seismic design level

Seismic design level of each building can be determined from the result of a field survey and structural design data used. Based on the previous research [9], the regulations applied to the seismic design of each building type are different from one another, starting from the Pre-code, Low-code, Moderate-code, to High-codes. The assumption of code classification for engineering buildings in this research which is developed from the previous research and the development of seismic building design code is presented in Fig. 8.

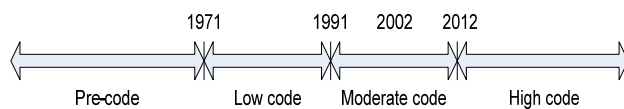


Fig. 8. Diagram of Indonesian building design code.

Where:

- Pre-code* : design of the building without considering earthquake load
- Low-code* : design of buildings using Indonesian Concrete Regulation (PBI) 1971 or SNI T-15-1991
- Moderate-code* : design of buildings using SNI 03-2847-2002
- High-code* : design of buildings using SNI 03-2847-2012 and thereafter

Based on that classification, the building belongs to moderate-code seismic design level category.

3.5. Peak spectral displacement

Peak Spectral Displacement value is obtained from the intersection of the response curve and capacity curve graph. The response curve is made based on the attenuation equation that corresponds to the Yogyakarta earthquake characteristics occurred on May 27, 2006, i.e. Joyner - Boore - Fumal attenuation, 1997. While the capacity curve obtained from the analysis of pushover that has been converted in ADRS format.

The attenuation equation is chosen because it alludes to the earthquake mechanism of the shallow crustal earthquake – strike-slip which is earthquake mechanism of Yogyakarta. In addition, Yogyakarta earthquake magnitude is included in the large magnitude quake range required at the attenuation (5,5M-7,5M). The

equation of attenuation of Joyner - Boore - Fumal, 1997 as follows:

$$\ln [Y] = b_1 + b_2(M-6) + b_3(M-6)^2 + b_5 \ln(r) + b_v \ln(V_s/V_A) \quad (6)$$

where:

- Y = ground motion parameter
- b = coefficient of attenuation
- r = epicentre (km)
- M = magnitude moment (Mw)
- V_s = shear wave velocity (m/s)

The value of inelastic spectral displacement is obtained by the following empirical formulas and the result is presented in Table 6.

$$S_d = 9,8 * S_a * T^2 \quad (7)$$

where:

- S_a = Spectral acceleration (g)
- S_d = Spectral displacement (in)
- T = Time period (s)

Table 6 shows the conversion of pushover analysis in the ADRS format based on the results of the S_a and S_d values due to the attenuation (equation (6) and (7)). In addition, the results of the intersections are presented in Fig. 9.

Table 6. The value of S_a and S_d based on attenuation equation.

Period (s)	S_a (g)	S_d (in)
0,00	0,104	0,000
0,10	0,180	0,018
0,20	0,243	0,095
0,30	0,228	0,201
0,40	0,196	0,307
0,50	0,165	0,403
0,60	0,138	0,488
0,75	0,109	0,603
1,00	0,080	0,787
1,50	0,065	1,427
2,00	0,050	1,954

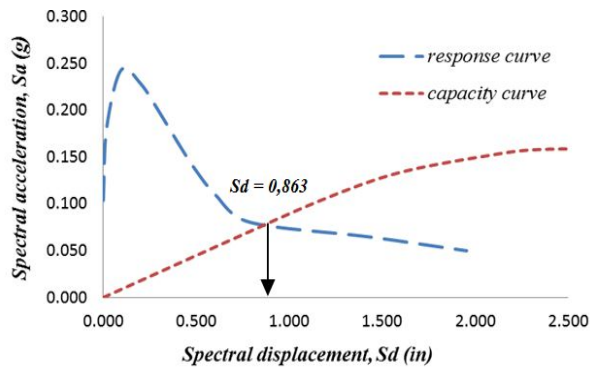


Fig. 9. The intersection of the response curve and the capacity curve.

Fig. 9. shows that based on the intersection of capacity and response curve of the building, the spectral displacement value obtained is 0.863 in.

3.6 Results of damage probability analysis

The S_d value obtained (0.863 in) used to find the parameter of fragility curve. The building type is included on C1L model (low reinforced concrete

buildings). The cumulative probability results are presented in Table 7, while the fragility curve is shown in Fig. 10.

Fig. 10. shows that the Student Center building, Yogyakarta State University designed with Moderate-code has a fairly sloping shape of its fragility curve. There is no damage at the first 0.1 in spectral displacement and just after the value of S_d above 0.1 in, the probability of damage began to appear. Furthermore, the probability of damage in each damage level is shown in Table 8, while its matrix of damage probability is presented in Fig. 11.

Fig. 11. shows the probability value of the building damage reviewed due to Yogyakarta earthquake scenario. The probability of slight damage level is 22.59%, the moderate level is 21.60%, the extensive level is 3.71%, and the complete level is 0.23%, so the total vulnerability value is 48.12%. It is evidence that the probability of building damage is not more than 50%, and in the event of damage, the greatest possible damage is a slight level of damage.

Table 7. The cumulative probability result.

<i>Slight</i>						
S_d	S_{ds}	β	S_d / S_{ds}	$\ln(S_d / S_{ds})$	$\ln(S_d / S_{ds}) / \beta$	$\Phi[\ln(S_d / S_{ds}) / \beta]$
0,863	0,9	0,89	0,958888889	-0,041980072	-0,04716862	0,4812
<i>Moderate</i>						
S_d	S_{ds}	β	S_d / S_{ds}	$\ln(S_d / S_{ds})$	$\ln(S_d / S_{ds}) / \beta$	$\Phi[\ln(S_d / S_{ds}) / \beta]$
0,863	1,56	0,9	0,553205128	-0,592026409	-0,657807121	0,2553
<i>Extensive</i>						
S_d	S_{ds}	β	S_d / S_{ds}	$\ln(S_d / S_{ds})$	$\ln(S_d / S_{ds}) / \beta$	$\Phi[\ln(S_d / S_{ds}) / \beta]$
0,863	4,2	0,9	0,20547619	-1,582425113	-1,758250126	0,0393
<i>Complete</i>						
S_d	S_{ds}	β	S_d / S_{ds}	$\ln(S_d / S_{ds})$	$\ln(S_d / S_{ds}) / \beta$	$\Phi[\ln(S_d / S_{ds}) / \beta]$
0,863	10,8	0,89	0,079907407	-2,526886722	-2,839198564	0,0023

Table 8. The damage probability in each building damage level.

<i>Probability of Damage</i>	<i>Level of Damage</i>	<i>Damage Probability</i>	<i>Damage Probability (%)</i>
$P[C] = P[C SD]$	<i>Complete</i>	0,0023	0,23%
$P[E] = P[E SD] - P[C SD]$	<i>Extensive</i>	0,0371	3,71%
$P[M] = P[M SD] - P[E SD]$	<i>Moderate</i>	0,2160	21,60%
$P[S] = P[S SD] - P[M SD]$	<i>Slight</i>	0,2259	22,59%
<i>Total vulnerability</i>		0,4812	48,12%
$P[None] = 1 - P[S SD]$	<i>No damage</i>	0,5188	51,88%

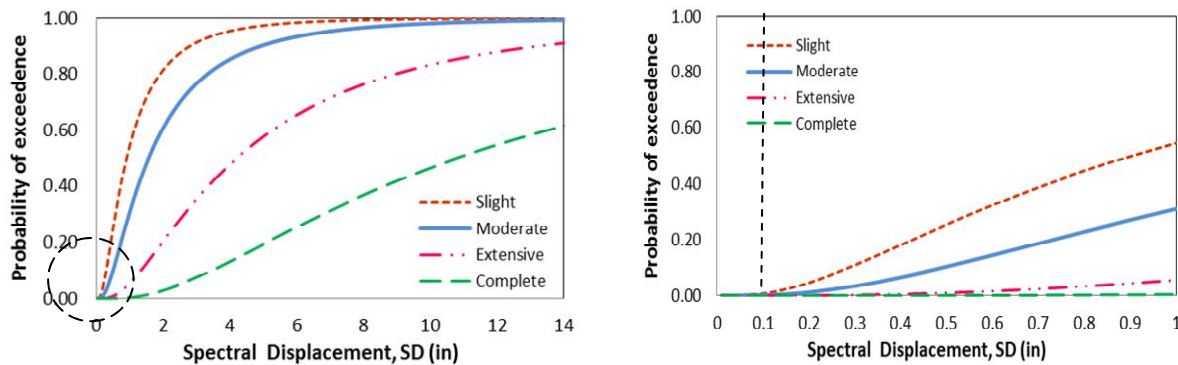


Fig. 10. The fragility curve of the building.

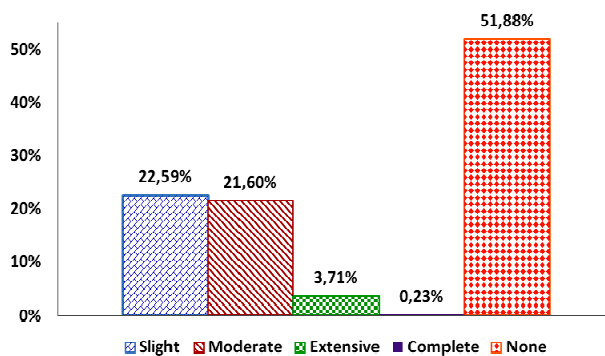


Fig. 11. Damage probability matrix of each damage level.

3.7 Damage loss analysis (FEMA, 1999)

The value of the economic loss is calculated based on the probability analysis of the building damage for each level of damage. Calculation of Mean Damage Probability (MDP) of the Student Center building is calculated based on equation (4) and the following results are obtained:

$$\text{MDP} = (0,0023 \times 1) + (0,0371 \times 0,5) + (0,2160 \times 0,1) + (0,2259 \times 0,02) = 4,6921$$

Table 9. The mean damage probability.

Level of damage	Damage probability	Loss Ec.value	Mean damage probability
Complete	0.0023	100%	0.2261
Extensive	0.0371	50%	1.8545
Moderate	0.2160	10%	2.1597
Slight	0.2259	2%	0.4517
Total MDP			4.6921

4 Conclusions

The conclusions obtained from this study are as follows:

1. The performance level of the building based on pushover analysis is at Immediate Occupancy level, either at x-axis direction or in the y-axis direction. This means that if an earthquake occurs, the structure is able to withstand the earthquake. There is no

significant damage to the structure, so it can be directly used without having to be repaired.

2. The vulnerability of buildings at each level of building damage obtained due to earthquakes for the level of slight, moderate, extensive, and complete are 22.59%, 21.60%, 3.71%, and 0.23% respectively. This means that total building vulnerability is 48.12% and the possibility of no-damage is 51.88%.
3. The estimated value of economic losses based on the method of FEMA-1999 approach obtained by MDP value of 4,692. This means that the building has a small damage economic loss probability of 4.692% due to the 2006 Yogyakarta earthquake scenario.

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