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Fragility Assesment of Mid-Rise Reinforced Concrete Building using HAZUS Method in High Seismic Zone

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ABSTRAK

Earthquake is a pounding that caused by a released energy of ground motion. The earthquake in high seismic zone caused damages and loss of live. Thus, there was important to evaluate the seismic vulnerability of structure before an earthquake was occurred to prevent the damage and safe of lives. The seismic vulnerability can be described by using fragility curves. These fragility curves was developed by HAZUS method that present the probability of the structure damage due to various ground shaking or lateral displacement of the building. This paper addresses the performance based design method to consider the building capacity due to Padang ground motion. Therefore, the damage probability was calculated by using the lognormal distribution with the probabilistic parameter was acquired by HAZUS engineering building module. Then, the fragility assesment of the building was compared in transverse and longitudinal direction. The result reveals that the building is vulnerable to collapse due to Padang ground motion.

Kata kunci : Fragility curves, PBD, HAZUS

1. INTRODUCTION

Indonesia is one of the most country that have a high risk for an earthquake motion. In 2009, an earthquake with a magnitude of 7.6 Mw was killed the lives of 1.100 people in Padang (Armouti, 2008). The earthquake caused widespread building damage from shaking, as well as from earthquake-induced landslides, liquefaction, and lateral spreading. The overwhelming majority of the buildings that were damaged or destroyed in Padang city had reinforced concrete frames with unreinforced brick infill panels, some were unreinforced masonry, and a few were steel building structures (Armouti, 2008). For mitigation of hazard on of the case is earthquake, HAZUS develop the manual to consider the estimation of the damage probability of the structure and prevent the loss of lives. This method was convenient to determine the damage in typical motion. Fragility curves can be developed

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from either analytical or empirical or combination of them based on source of the data and type of analysis (Nasution, Masrilayanti, & Kurniawan, 2020). There are several method to simulate the earthquake load and develop it into the fragility curves; static nonlinear analysis; nonlinear dynamic analysis; performance based design (Nasution, Masrilayanti, & Kurniawan, 2020). The fragility curves are established to provide a prediction of potential damage during an earthquake. These curves represent the seismic risk assessment and are used as an indicator to identify the physical damage in the strongest mainshock. To calculate the fragility, three main variability is so important to consider. There are capacity curve (β_C), the variability associated with the demand spectrum (β_D), and the variability associated with the discrete threshold of each damage state ($\beta_{T,ds}$) (V R. Patel & Vasavada, 2016). For development of fragility curves the nonlinear static analysis was performed to 5-storeys of RC building. The performance of the building was evaluated and compared to fragility assessment.

2. RESEARCH METHODOLOGY

2.1. HAZUS Methodology

HAZUS (Hazard United States) is a manual that describes the procedures for developing building-spesific damage. Hazus are developed by FEMA and provide damage and loss function under agreements between National Institutes of Building Sciences (NIBS) and Federal Emergency Management Agency (FEMA). Building fragility curves are lognormal distribution functions that describe the probability of reaching, or exceeding, structural and non-structural damage states, given median estimates of spectral response, for example spectral displacement (V R. Patel & Vasavada, 2016). These curves describe variability and uncertainty associated with capacity curve properties, damage states and ground shaking (V R. Patel & Vasavada, 2016). For a given damage state, slight, P[S|Sd], moderate, P [M|Sd], extensive, P[E|Sd], complete P[C|Sd] a fragility curve is well described by the following lognormal probability density function :

$$P(ds|sd) = \phi\ [\frac{1}{\beta_{ds}} \ln\left(\frac{sd}{sd, ds}\right)] \quad (1)$$

Where,
P (ds|sd) is Probability of exceeding damage (slight, moderate, extensive, complete)
Sd is Spectral displacement of the structure
Sd,ds is Threshold spectral displacement
βds is Standard deviation of damage state
ϕ is Cumulative distribution function

Table 1. Damage State Threshold

Damage States	Spectral Displacement (Sd,ds)
Slight	0.7 Dy
Moderate	Dy
Extensive	Dy + 0.25 (Du – Dy)
Complete	Du

The damage states of the building that classified by HAZUS is shown in **Table 1**. The Spectral displacement show the level of damage of the structure. Furthermore, the variable of damage states are developed into the fragility curves using the three primary compenent variability of statistic assesment. The capacity of the building can be shown by the capacity curves of the structures. These curves are obtained from the pushover analysis in X-dir and Y-dir that showing the base shear-displacement curves. This method are then developed into the performance of the structure that following the FEMA codes. The intersection between capacity spectrum and response spectrum are considered as the performance point of the structure. The point shows the behavior of the structure and describes about the period of the structure, effective damping, and the stiffness (Muntafi, 2012). Performance level of the building are classified as immediate occupancy, damage control, life safety, limited safety, and collapse as shown in **Figure 1.** Yield capacity control point (Dy, Ay) is selected as the point where significant yielding is just beginning to occur (HAZUS, 2001). Ultimate capacity control acceleration, Au, is selected as the point maximum acceleration from ADRS format.

$$Du = 2\,.Dy\,\frac{Au}{Ay} \qquad (2)$$

While, the ultimate capacity control point displacement, Du, is selected as the greater of either the spectral displacement at the point of maximum spectral acceleration or the spectral displacement corresponding to **Equation 2.**

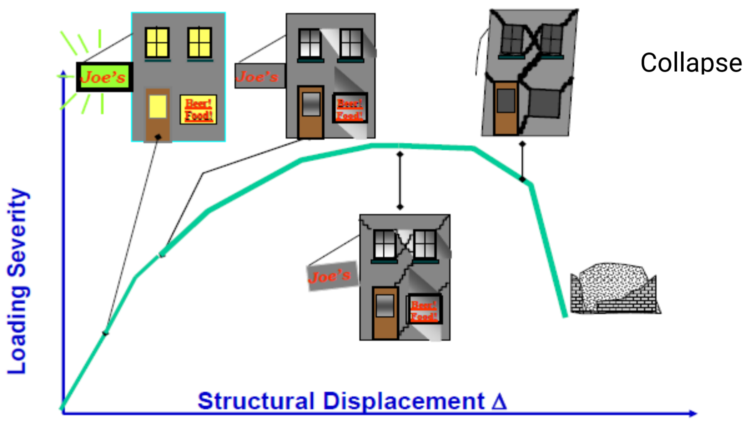

Figure 1. Illustration of Earthquake Performance Level (ATC-58)

The simulation of this method can be developed to fragility curves using the damage of the structure given of spectral response. To develop the fragility curves using HAZUS manual, Three primary variable contribute to the total variability of any given state, namely, the variability associated with the capacity curve (β_C), the variability associated with the demand spectrum (β_D), and the variability associated with the discrete threshold of each damage state ($\beta_{T,ds}$) (HAZUS, 2001), as shown in Equation (2).

$$\beta_{ds} = \sqrt{(CONV\ [\beta_C, \beta_D])^2 + \left(\beta_{T,ds}\right)^2} \qquad (2)$$

where,

β_c is capacity curves variability
β_D is demand spectrum variability (β_D = 0.45 at short periods, β_D = 0.50 at long periods)
$\beta_{T,ds}$ is threshold of damage state variability
β_{ds} is total variability of damage states

These values can be obtained from the tables (table 6.5, 6.6 and 6.7) of HAZUS manual (MH 2.1).

2.2. Modeling of the Building

In this study, a buiding is an existing building of Andalas University dormitory in Padang, West Sumatera. It is a typical 5 storeys of reinforced concrete building with the total height of 16.20 meters. The building is 38.25 m by 12.75 m in plan, and consist of 3 bays in Y-dir and 9 bays in X-dir. Building was designed by using the special moment frame and special wall system. The column was connected with the beam and slab rigidly. L-shape Shearwall located in the corner of the building as the defense of lateral force. The material of the building made of RC with the compression, fc', strength of 25 Mpa and the rebar yield strength, fy, is 390 Mpa for diameter up to 10 mm, and 240 Mpa below 10 mm as shown in **Figure 2**. In According to SNI code the risk chatagorized of this building is II. The live load for each bays is 3.83 kN/m2, with the superimposed deadload of 1.4 kN/m2.

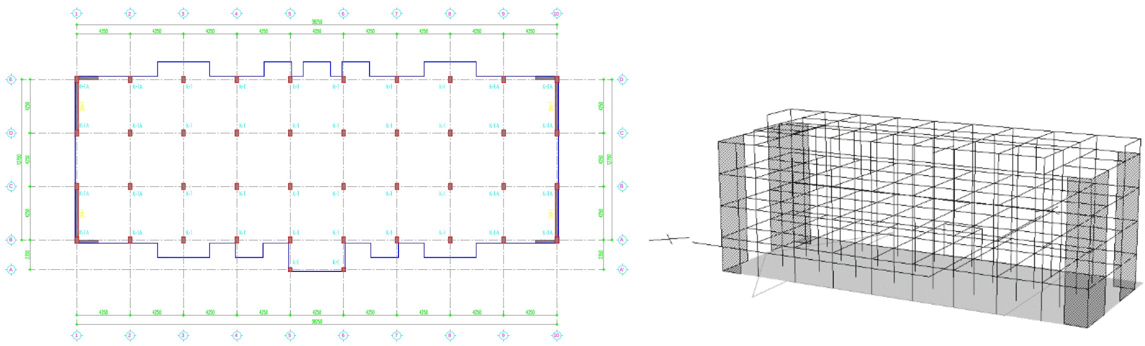

Figure 2. Modeling of the building; (a) typical plan; (b) STERA 3D model

The 3D modeling of the building was performed using STERA 3D program. Beam and column was input the rebar as the **Table 1** and **Table 2** with the open frame model. The pushover analysis was performed in the X-dir and Y-dir with the distribution model is UBC and the target drift of 1/50. The pushover is conducted to show the non-linear behavior of the building as the capacity curves (Shear vs Displacement). Displacement was observed at the top floor as the point control of the structure. The capacity curves then converted to the Acceleration Displacement Response Spectrum (ADRS) format that conducted by program automaticly. The weight of the story was input manually at the program. The calculation is obtained by calculating the volume (m3) x density (kN/m3) of the RC. The beam and column was modeled as the straight frame and the hinge plastic is input automaticly by the program.

Table 2. Properties of the Beam (mm)

Beam		Support		Midspan	
		Main	Shear	Main	Shear
	Top	4 D16		2 D16	
B250x450	Mid	2 D10	D10 – 100	2 D10	D10 – 150
	Buttom	2 D16		3 D16	
	Top	3 D16		2 D16	
B250x450	Mid	2 D10	D10 – 100	2 D10	D10 – 150
	Buttom	3 D16		3 D16	
	Top	3 D16		2 D16	
B200x350	Mid	-	D10 - 125	-	D10 - 150
	Buttom	2 D16		2 D16	

Table 3. Properties of the Column (mm)

Column	Support		Midspan	
	Main	Shear	Main	Shear
C300x500	10 D16	D10 - 100	10 D16	D10 - 150
C300x500	8 D16	D10 - 100	8 D16	D10 - 150
C300x300	8 D16	D10 - 100	8 D16	D10 - 150

Table 4. Properties of Wall (mm)

Shearwall	Dimension	Main	Shear
L-Shape	200	D16-150	D16-150

The ground motion is calculated using SNI code and the ground parameter, spectral in short period, SDS = 0.96, and spectral in one period, SD1 = 0.60. The response spectrum are then calculated to the ADRS can be seen in **Figure 2**. The ground motion used is located in Padang, West Sumatera where have a high risk for earthquake motion.

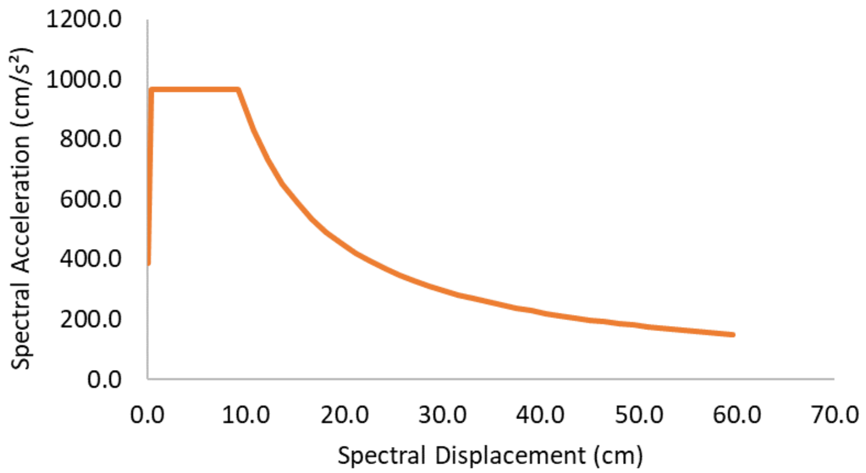

Figure 2. Acceleration Displacement Response Spectrum of Padang

3. RESULTS AND DISCUSSION

To generate the fragility curves for critical response of the building, the pushover analysis is conducted to obtain the capacity curves. This method was performed using STERA 3D. The building is push till the structure collapse and from this process the performance point of the building can be obtain and observed as the building capacity at the typical ground motion. To acquire the performance point, the ground motion and the capacity curves are plotted in one graph as shown in **figure 3**.

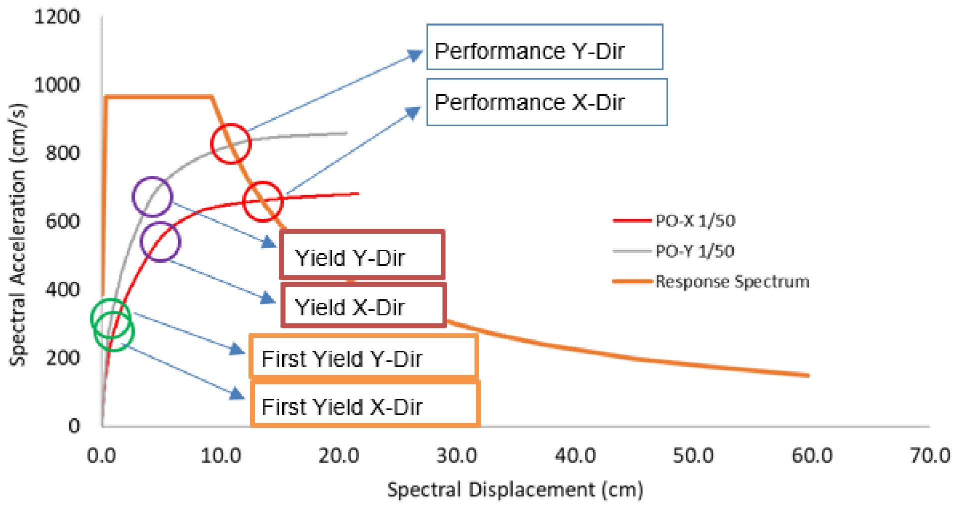

Figure 3. Performance Point of the Building in ADRS format

Using the lateral deformation of the structure, performance point of the building have to check towards the deformation limit as the ATC-40 codes (Tavio & Wijaya, 2018). The defermation limit in various performance level can be seen in **table 2**.

In this case the performance use the maximum total drift of the structure. Maximum total drift of the structure is interstory drift at performance point at the top floor divided by total height of the builing. In new building, the performance level of the structure is recommended in life safety level, when the maximum total drift is 0.02 (Tavio & Wijaya, 2018).

Table 5 Drift Level at Performance Point of the Structure (ATC-40)

Drift limit	Performance level			
	Immediate Occupancy	**Damage Control**	**Life Safety**	**Structural Stability**
Maximum total drift	0.01	0.01-0.02	0.02	0.33Vi/Pi
Maximum inelastic drift	0.005	0.005-0.015	No limit	No limit

In this study, the performance point of the building obtained are 130.74 mm and 100.76 mm in X-dir and Y-dir. Thus, the performance level of the building can be obtained by divided the performance point with the total height of the structure, that is 16.20 meter. In X-dir the performance level is 0.13/16.2 = 0.008, Immediate Occupancy, while in Y-dir the performance level is 0.10/16.2 = 0.006, Immediate Occupancy. The simulation damage of the earthquake using PBD method can be discribed by fragility assesment using lognormal distribution.

Table 6. Damage State Threshold in X-dir (mm)

Damage States	Spectral Displacement (Sd,ds)
Slight	31.5
Moderate	45.0
Extensive	87.9
Complete	216.4

Table 7. Damage State Threshold in Y-dir (mm)

Damage States	Spectral Displacement (Sd,ds)
Slight	40.6
Moderate	58.0
Extensive	95.3
Complete	207.0

The damage states threshold in table 4 and table 5, is considered as the variable factor to develop the fragility curves. From the spectral displacement of the building, the variable of the capacity curve (β_C), the variability associated with the demand spectrum (β_D), and the variability associated with the discrete threshold of each damage state ($\beta_{T,ds}$) is obtained by taking in table 6.5, 6.6 and 6.7 of HAZUS MH 2.1 as shown in **table 5**.

Table 8. Variability Values of 5-storeys Building

Damage State	Kappa Factor (k)	Degradation Values		
		Damage ($\beta_{T,ds}$)	Capacity Curves (β_c)	Total (β_{ds})
Slight	Minor Degradation (0.9)	Moderate (0.4)	Moderate (0.2)	0.75
Moderate	Major Degradation (0.5)	Moderate (0.4)	Moderate (0.2)	0.85
Extensive	Extreme Degradation (0.1)	Moderate (0.4)	Moderate (0.2)	1.00
Complete	Extreme Degradation (0.1)	Moderate (0.4)	Moderate (0.2)	1.00

To generate the fragility function subtitute the damage states variable into the **Equation 1**. The fragility curves are obtained for each damage states, and show the continous distribution of damage state at performance point of the structure. Degradation (Kappa) factors are a function of the expected amplitude and duration (HAZUS, 2001). These parameter depend on the level of ground motion, thus it is different for each building location and earthquake typical. To obtain the kappa factor HAZUS was proposed how to calculate the Kappa Factor from the capacity curves. Slight damage corresponds to response between ½ yield and full yield; Moderate damage to response at or just beyond yield; and Extensive and Complete damage correspond to post-yield response for the duration of scenario earthquake shaking. Beta values are given in Tables 6-5 through 6-7 for $\kappa \geq 0.9$ (minor degradation), $\kappa = 0.5$ (major degradation) and $\kappa \leq 0.1$ (extreme degradation) of the structural system; and linear interpolation may used to establish Beta's for other values of the Kappa factor (HAZUS, 2001).

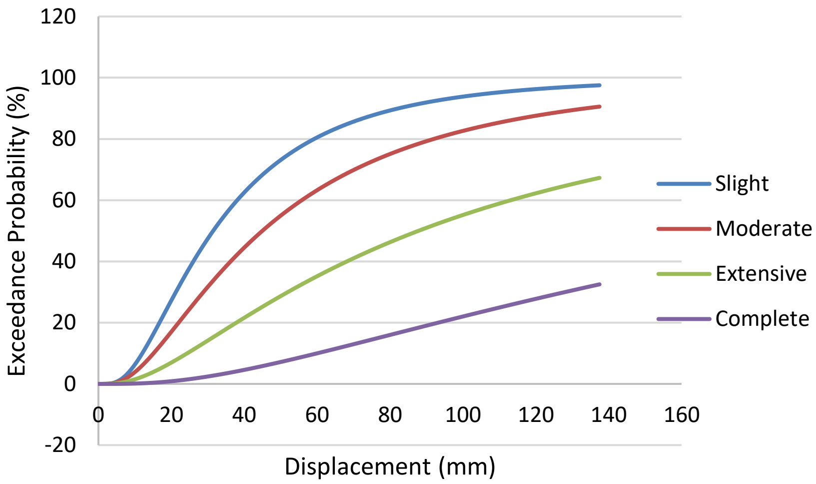

Figure 4. Fragility Curves at performance point of X-dir

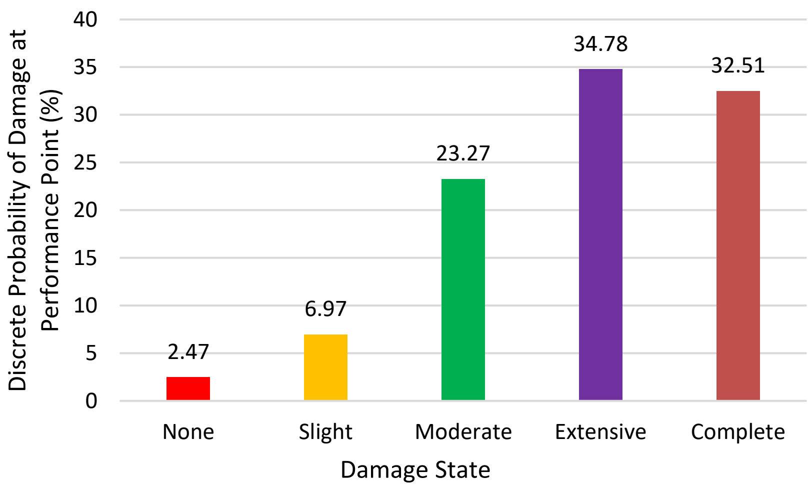

Figure 5. Discrete Probability of Damage at Perfromance Point of X-dir

Based on HAZUS manual user, the fragility curves in X-dir obtain as the **Figure 4** with the discrete probability of the structure at the performance point as shown in **Figure 5**. probability damage of the structure show that the structure experience the different exceedance of probability for each state. When the damage of the structure distributed lognormally it means that the motion of the ground are relate to the structure. More bigger the load excited to the structure more affect to the structure. The damage probability of the structure in slight, moderate, extensive, complete are 97.5%, 90.6%, 67.3% and 32.5% respectively. It show that the structure is sensitive when resist the lateral load in X-dir. The

Estimate of the structure without damage is 2.47%. The calculation must be determined carefully beacause the variable of the structure that proposed by HAZUS for typical building. The discrete chart ease to show whether the structure experience damages in each state.

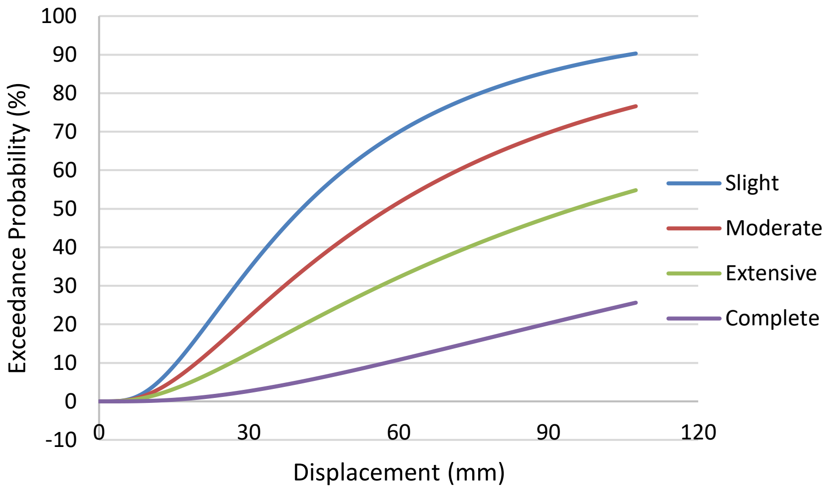

Figure 6. Fragility Curves at Performance Point of Y-dir

The fragility curves in Y-dir are calculated using lognormal distribution with the damage variable that obtained by HAZUS. In Y-dir the probability of the structure for collapse is more than smaller than X-dir. The damage probability of the building in slight, moderate, extensive, complete are 90.29%, 76.6%, 54.8%, and 25.6% respectively as shown in **Figure 6**.

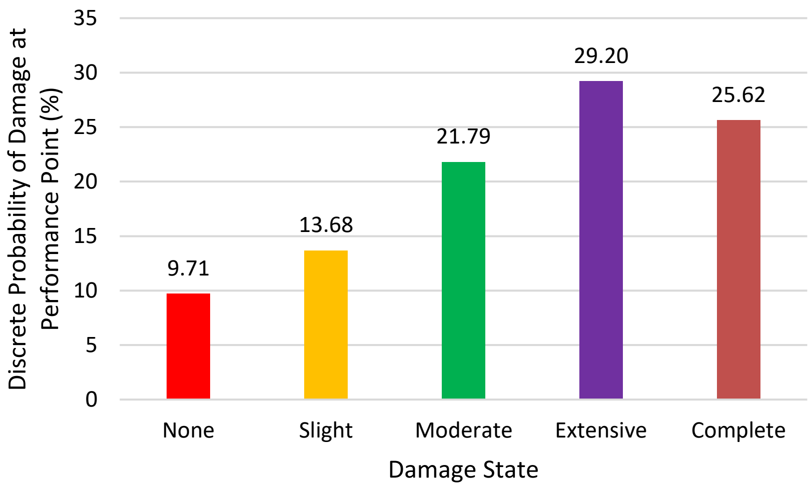

Figure 7. Discrete Probability of Damage at Performance Point of Y-dir

This mechanism can be seen in the maximum total drift of the building when experiencing the lateral load. From the plastification pattern, the structure have to check in the first yield and in the ultimate condition. The first yield is the important condition because showing the limit state of the structure in good or collapse position (Silitonga & Imran, 2019). The fragility graph is calculated in performance point of the building, so that the damage of the building can be seen clearly as shown in **Figure 7**.

Table 9. Plastic Hinge of the Structure

Type	Location	PO-X			PO-Y		
		1<U<5	U>5	Total	1<U<5	U>5	Total
Beam	Support	224	70	294	238	56	294
	%	76.2%	23.8%		81.0%	19.0%	
Column	Support	208	6	214	214	0	214
	%	97.2%	2.8%		100%	0%	
Wall	Support	28	4	32	24	8	32
	%	87.5%	12.5%		75.0%	25.0%	

The plastification observed is ultimate condition where the structure push till collapse. In **table 9**, the structure that experiencing the ductility more than five in X-dir is more bigger than Y-dir. It means that the structure in X-dir is more ductile when accepted lateral load. It can be seen in ADRS format that the ultimate curves of the X-dir is more than Y-dir. When the shearwall of the structure experience the damages, it can be affect to all of the structure. The shearwall will be collapse and the frame being the second mechanism defense for resistant the lateral force. The strength of the shearwall panel can be neglected and the defense will be conducted by the element boundary of the shearwall. The hinge of the structure can be seen in **Figure 8**.

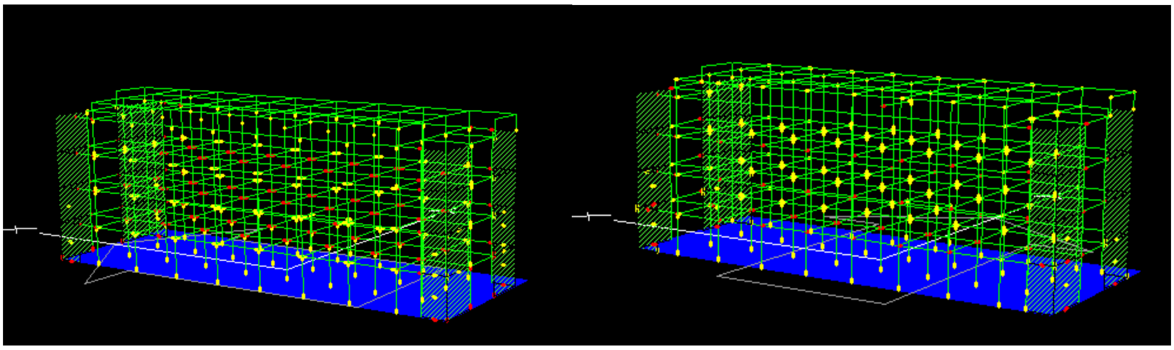

Figure 8. Plastic Hinge of the Structure at Ultimate Point ; (a) X-dir; (b) Y-dir

4. CONCLUSION

In this study the RC building with the total height of 16.20 meter was analyzed using STERA 3D to acquire the capacity curves. The capacity are then converted to the ADRS format and plot it into the ground motion. The intersection of the capacity curves and the ground motion are mentioned as the performance point. The damage of the simulation of earthquake was calculated using HAZUS method and develop it into the fragility curves. The fragility are then translated into the discrete damage of probability at performance point of the building. From these bar chart, the vulnerability of the structure can be observed. In X-dir and Y-dir the performance level of the structure is Immediate Occupancy with the maximum total drift are 0.008 and 0.006 respectively. Thus, the damage discrete of the building in X-dir are 2.47% (none), 6.97% (slight), 23.27% (moderate), 34.78% (extensive), 32.51% (collapse) and the damage discrete in Y-dir are 9.71% (none), 13.68% (moderate), 21.79% (extensive), and 25.62% (collapse). Based on the fragility assessment of the building, it is chatagorized as vulnerable.

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