Analysis of the performance of the Achmad Yani University Rectorate Building due to dynamic earthquake loads

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Abstract
The Rectorate Building of Universitas Jenderal Achmad Yani (Unjani) is located in Cimahi City, an area near several active faults, including the Lembang, Cimandiri, and Garsela faults. As a vital administrative facility, ensuring the building's seismic resilience is essential. The building's architectural design incorporates inclined columns, which may impact its dynamic behavior, especially under lateral seismic loads. This study uses ETABS software to perform a numerical analysis employing dynamic analysis methods, including response spectrum and time history analysis. These methods are in accordance with the seismic code SNI 1726:2019 and performance evaluation criteria based on ATC-40. The response spectrum analysis results show that the maximum inter-story drift occurs on the sixth floor in the x-direction at 21.149 mm and on the fifth floor in the y-direction at 27.958 mm. The maximum displacement is 42.292 mm in the x-direction and 50.367 mm in the y-direction at the roof level. The time history analysis using the Miyagi earthquake record shows that the maximum inter-story drift occurs on the sixth floor at 26.28 mm in the x-direction and on the fifth floor at 29.59 mm in the y-direction. Maximum displacement reaches 50.528 mm and 53.004 mm, respectively, at the roof level in the x- and y-directions. The performance evaluation categorizes the building as Immediate Occupancy (IO), indicating that the structure remains functional and does not experience significant damage after a major earthquake.
Keywords: ATC-40, earthquake, response spectrum, time history

1. INTRODUCTION

Indonesian is known as the largest archipelagic country in the world with a total number of islands that reach17.508. Geologically, Indonesia is located at the confluence of three major tectonic plates, namely the Indo-Australian plate, Eurasian plate, and Pacific plate. In addition, Indonesia is also located within the Pacific Ring of Fire, a seismically active zone surrounding the Pacific Ocean. These geotectonic conditions make Indonesia one of the countries with a high level of natural disaster vulnerability, especially to earthquakes and other seismic phenomena. (Prasetio et al., 2023).

Along with the development of technology and information, the concept of earthquake-resistant building structures can be applied to infrastructure to ensure its safety. Performance-Based Seismic Design (PBSD) is an approach used in new and existing buildings to evaluate earthquake risk more realistically. This method considers three main aspects: life safety, post-earthquake building function and potential economic losses. With PBSD, planners can set the level of structural performance according to acceptable damage limits, so that planning is more adaptive to variations in earthquake intensity and characteristics. (Sofyan et al., 2017)

The General Achmad Yani University (Unjani) Rectorate Building in Cimahi is a vital administrative center for campus operations. Given its location in an earthquake-prone area with the presence of the Garsela, Cimandiri, and Lembang faults, its structural planning must prioritize earthquake resistance. The building has a unique design with sloping columns that support aesthetic value, but also affect the behavior of the structure against lateral loads. Based on SNI 1726:2019, there is a dynamic analysis method in evaluating structural performance. In the dynamic analysis of the response spectrum, the dynamic analysis of the history and plan response spectrum is required to obtain the maximum response of each vibration variety that occurs. (Silaban et al., 2023). In dynamic analysis, there are two analysis methods that can be used, namely the response spectrum and time history methods.

Response Spectrum Analysis is a method to calculate the maximum response of a structure to an earthquake based on the Plan Response Spectrum (Rendra et al., 2015). This method is used to analyze building structures that have many degrees of freedom and irregular shapes. The main principle is that the total response of the structure is the sum of the responses of each vibrating mode.

Time history analysis is a method in civil engineering used to simulate how a building reacts to earthquakes in detail. It does this by feeding an actual "earthquake record" to a computer model of the building. This earthquake recording, called the earthquake time history, will make our virtual building "move" and vibrate just like when a real earthquake occurs. In the time history method, the selected input earthquake acceleration (accelerogram) must take a record of ground motion due to the earthquake under review similar to the location where the building structure under review is located, taking into account the scaling of the input earthquake acceleration and base shear scaling. (Rifai, 2022).

This study aims to evaluate the structural performance of the Unjani Rectorate Building against earthquake loads by analyzing the behavior of *base shear*, *displacement*, and the influence of the P-Delta effect. The evaluation is carried out through simulation using ETABS structural analysis software version 21, with a dynamic analysis approach in the form of response spectra and *time history analysis.*

2. RESEARCH METHOD

The methods used in this research are quantitative analysis and simulation methods with a linear dynamic analysis approach, namely spectrum response analysis and linear time history analysis due to earthquakes in the Unjani Rectorate Building located in Cimahi City, using ETABS software version 21.

Table 1. Building Description

Building Description	Information
Building Name	Rectorate Building
Building Location	Jl. Terusan Jend. Sudirman, Cibeber, Cimahi Sel. District, Cimahi City, West Java is a project owned by the Kartika Eka Paksi Foundation, Rectorate Building of General Achmad Yani University, Cimahi.
Building Structure System	SRPMK+ Shear Wall
Building Function	Education Facility
Number of Floors	8 floors+ 1 Roof
Material Quality	
Concrete	Fc' 30 Mpa dan Fc' 35 Mpa
Steel Reinforcement BJ 420B	Fy 420Mpa, Fu 525 Mpa
Soil Site Class	Medium Soil (SD)
Earthquake Risk Category	(IV)

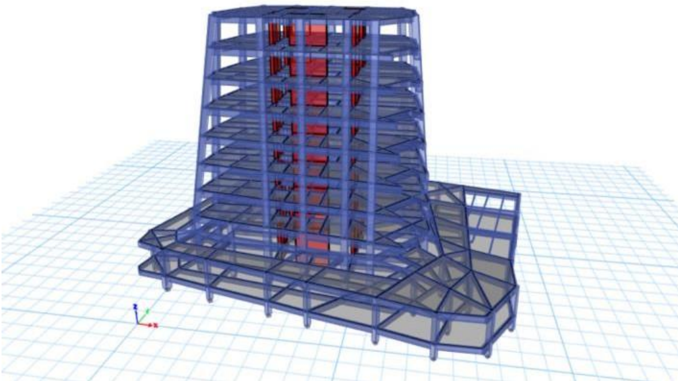

Figure 1. 3D modeling of Unjani Rectorate Building structure using Etabs v.21

2.1 Loading Input

a) Dead Load,

The dead load of the structure is the load that comes from permanent structural elements, such as columns, beams, plates, and shear walls.

b) *Additional Dead Load (SIDL)*

1. Floor Plate SIDL (SNI, 2020)

- Ceramic Load (roman) = 0.57 kN/m2
- Mortar = 0.48 kN/m2
- MEP = 0.39 kN/m2
- Ceiling (Gypsum 9 mm) = 0.07 kN/m2
- Hanging = 0.10 kN/m2
- Total = 1.61 kN/m2

2. Roof Plate SIDL
   - Mortar = 0.48 kN/m2
   - MEP = 0.39 kN/m2
   - Ceiling (Gypsum 9 mm) = 0.07 kN/m2
   - Hanging = 0.10 kN/m2
   - Water Proofing = 0.28 kN/m2
   - Total = 1.32 kN/m2
3. Wall and Glass SIDL
   - Wall (Tinggi 4.3 m) = 4.3 kN/m
   - Glass (Tinggi 4.3 m) = 1.634 kN/m

c) *Live*
- Floor Plate = 1.92 kN/m^2
- Roof Plate = 0.96 kN/m^2

d) *Rainwater Load*

In this Unjani Rectorate Building, it is planned that the rainwater on the roof has a maximum height of 5 cm. Rainwater Load (R) = 10 kN/m^2 x 0.05 m
= 0.5 kN/m^2

e) *Spektrum Response Earthquake Load*

Based on the results of soil investigation at the construction site of the Unjani Rectorate Building, it is known that the soil type belongs to the SD site class (medium soil) according to the classification in SNI 1726: 2019. This building is included in earthquake risk category IV because it is an educational facility, with an earthquake primacy factor (Ie) of 1.5. The bedrock earthquake acceleration values for the location in Cimahi City are SS= 1.1732 and S1= 0.5102, obtained from the official website of the national seismic information system. Based on the value of the amplification coefficient Fa = 1.03072 and Fv = 1.7898, the spectral response parameters SMS= 1.2092 and SM1= 0.9132 are obtained. Furthermore, the design acceleration parameter determined as SDS= 0.8062 g and SD1= 0.6088 g. With values of SDS≥ 0.50 and SD1≥ 0.20, the structure is included in Seismic Design Category D. The structural system used is a Special Moment Bearing Frame System (SRPMK) combined with shear walls, forming a double structural system with values of R = 7, Cd = 5.5, and Ω_0 = 2.5. The characteristic values of the design spectrum response curve include T_0 = 0.151 seconds, Ts = 0.7551 seconds, and TL = 6 seconds. (SNI, 2019)

f) *Time History Earthquake Load*

After determining basic parameters such as return period and target spectrum, the next step was to determine the magnitude and distance of the earthquake source based on the Indonesian earthquake hazard deaggregation map for the Cimahi area with a return period of 250 years and a response acceleration of 3 seconds. The deaggregation results show that potential earthquakes come from three types of sources: shallow crustal earthquakes with magnitudes of 5.4-5.6 Mw at a distance of 40-50 km, benioff (subduction) earthquakes with magnitudes of 7.2-7.4 Mw at a distance of 120-150 km, and megathrust earthquakes with magnitudes of 8.4-8.6 Mw at a distance of 150-200 km. The recorded ground motion data were adjusted to the magnitude range, distance, and Vs30 value of 274 m/s according to the medium soil classification (SD) based on Article 5.5 of SNI 1726:2019. Three earthquakes were used in the time history analysis, namely the San Leandro (2007), Miyagi Japan (2005), and Valdivia, South America (2010) earthquakes, as they met the magnitude and distance criteria relevant to the conditions of the study site.

g) *Load Combinations*
- Load and Resistance Factor Design (LRFD)
- 1.4D

- 1.2D + 1.6L + 0.5(Lr atau R)
- 1.2D + L + 1.6(Lr atau R)
- 1.2D + Ev + Eh + L
- 0.9D - Ev + Eh

3. RESULTS AND DISCUSSION

3.1 Effetive Seismic Weight

In SNI 1726:2019 it is stated that the calculation of effective seismic weight is obtained from fixed loads (DL) and additional dead loads (SIDL).

Table 2. Seismic Effective Weight

Floor	**Mass (kg)**
Floor 9	618442.1
8th Floor	782483.9
7th Floor	827786.5
6th Floor	883306.2
5th Floor	935513.9
4th Floor	919273.2
3rd Floor	971090
2nd Floor	882657.9
Floor Canopy	1079489
1st Floor	1793317

3.2 Variety Analysis of Respons Spectrum

The calculation of seismic base shear is carried out to obtain a comparison between the resulting shear forces. This comparison is used as the basis in the dynamic earthquake force scaling process, so that the analysis results meet the consistency and validation requirements of the static approach in accordance with the provisions in SNI 1726:2019.

Seismic response coefficient, $Cs = S_{DS}/(R/I_e)$
$= 0.81/ (7/1.5)$
$= 0.1727$
X direction Upper Limit, $C_{s\ max} = S_{D1}/T \times (R/I_e)$
$C_{s\ max}$, x $= 0.1221$
$C_{s\ max}$, y $= 0.1221$
Lower Limit $C_{s\ min} = 0.044 \times S_{DS} \times I_e$ ($C_{smin} \geq 0.01$)
$= 0.0532$
Terms of seismic response coefficient values if $C_s > C_{smax}$, then $C_s = C_{smax}$
Cs used in X direction, = 0.1727
Cs used in Y direction, = 0.1727

Base Shear Force Calculation

Effective Weight (W) = 95059 kN
X-Direction Seismic Base Force (Vx) = Cs x W
= 16421.38 kN
Y-Direction Seismic Base Force (Vy) = Cs x W
= 16421.38 kN
Etabs Output Static Shear Force Vx = 16421.3827 kN
Etabs Output Static Shear Force Vy = 16421.3827 kN

Table 3. Spectrum Response Base Shear Force

Output Case	Step Number	FX	FY
		kN	kN
Static X	1	-16421.38	0.00
Static X	2	-16421.38	0.00
Static X	3	-16421.38	0.00
Static Y	1	0.00	-16421.38
Static Y	2	0.00	-16421.38
Static Y	3	0.00	-16421.38
Spec X		16421.35	2880.67
Spec Y		2416.34	16421.33
Spec X Unscale		6081.03	1066.75
Spec Y Unscale		1066.75	7249.58

3.3 Time History Analysis

The Indonesian seismic hazard degradation map stipulates that the minimum evaluation and seismic retrofitting efforts in buildings must consider earthquakes with a return period of 250 years, as stated in SNI 1726:2019.

Table 4. Determination of Earthquake Location Data Time History

RSN	Event	Location	Year	M	R (km)	Vs30 (m/s)
8662	40204628	San Leandro	2007	5.45	44.37	274.33
4030717	Miyagi-Eq	Japan	2005	7.22	149.0116	274.2
6001826	VALDIVIA HOSPITAL	South America	2010	8.81	185.1036	274

As per the provisions of Article 7.9.2.3.1 in SNI 1726:2019, this matching should be performed within the period range between 0.8 × T_lower to 1.2 × T_upper, where T represents the fundamental period of the structure.

T_{lower} = 0.032 sec

T_{upper} = 1.141 sec

$0.8 \times T_{lower}$ = 0.0256 sec

$1.2 \times T_{upper}$ = 1.3692 sec

Description :

T_{lower} = Vibration phase when 90% of actual mass participation has been met at each orthogonal two-way response

T_{upper} = The larger initial vibration phase between the two orthogonal direction phase values

Referring to Article 7.9.1.4.1 of SNI 1726:2019, if the dynamic analysis results in a total base shear force (Vt) that is smaller than 100% of the equivalent static method shear force (V), then the force must be calibrated with the V/Vt factor. Meanwhile, the calculation of inelastic shear force (Vi) as per Article

7.9.2.5.1 considers the lateral force distribution, response reduction factor, and primacy factor of the structure.

Table 5. Base Reaction Time History before and after scaling

Case	**Step Type**	**Unscaled**		**Scaled**	
		Vi, x	**Vi, y**	**Vi, x**	**Vi, y**
		kN	**kN**	**kN**	**kN**
San Leandro - X	Max	7070.84	991.3947	16421.36	2302.419
San Leandro - Y	Max	836.747	6633.853	2071.272	16421.34
Miyagi - X	Max	8115.27	584.9477	16421.35	1183.649
Miyagi - Y	Max	753.225	8341.645	1482.798	16421.34
Valdivia - X	Max	4647.87	1008.218	16421.35	3562.129
Valdivia - Y	Max	656.189	6193.848	1739.709	16421.33

Table 6. Earthquake scale factor Time History

Case	**Vi (kN)**	**Fx**	**SF (mm/s2)**
San Leandro - X	7070.843	2.32241	4880.37
San Leandro - Y	6633.853	2.47539	5201.85
Miyagi - X	8115.272	2.02352	4252.27
Miyagi - Y	8341.645	1.9686	4136.87
Valdivia - X	4647.867	3.5331	7424.55
Valdivia - Y	6193.848	2.65124	5571.38

Inter-story Deviation

Inter-level deviation is the difference in horizontal displacement between the centers of mass of two adjacent floors. In this study, the Unjani Rectorate Building uses a Special Moment Bearing Frame System (SRPMK) equipped with shear walls, thus forming a double structural system. Deflection analysis is performed using ETABS software to accurately calculate the displacement between floors. The analysis parameters were determined systematically so that the response of the structure to earthquake loads could be described appropriately.

Allowable Inter-Storey Deviation, Δa	$= 0.01$ h
Redundancy Aspect, ρ	$= 1.3$
Permitted Inelastic Story Drift, Δmax	$= \Delta / \rho$
	$= 0.0077$
Aspect Magnification Deflection, Cd	$= 5.5$
Earthquake Fundamental Aspect, Ie	$= 1.5$
Inelastic Story Drift, Δ	$= \delta * Cd / Ie$

Table 7. X-Direction Displacement Response Spectrum and Time History

Floor	h	Elevation Height	Displacement - X (mm)			
	mm	m	Spektrum	San Leandro	Miyagi	Valdivia
Floor 9	4300	39.10	42.292	45.937	50.528	38.63
8th Floor	4300	34.80	37.183	40.128	44.354	33.929
7thfloor	4300	30.50	32.167	34.171	37.864	29.081
6thfloor	4300	26.20	26.841	27.973	30.993	23.954

5thfloor	4300	21.90	21.073	21.588	23.826	18.555
4thfloor	4300	17.60	15.34	15.383	16.78	13.434
3rdfloor	4300	13.30	9.802	9.675	10.362	8.516
2nd floor	2550	9.00	5.151	4.96	5.254	4.494
Canopy floor	4450	6.45	2.967	2.759	3.111	2.61
1stfloor	2000	2.0	0.371	0.343	0.392	0.32

Table 8. Y-Direction Displacement Response Spectrum and Time History

Floor	h	Elevation Height	Displacement - Y (mm)			
	mm	m	Spektrum	San Leandro	Miyagi	Valdivia
Floor 9	4300	39.10	50.367	50.521	53.004	48.374
8th Floor	4300	34.80	46.263	46.045	48.688	44.736
7thfloor	4300	30.50	41.257	40.714	43.449	40.316
6thfloor	4300	26.20	35.468	34.453	37.095	34.878
5thfloor	4300	21.90	28.911	27.327	29.621	28.403
4thfloor	4300	17.60	21.286	19.841	21.55	21.114
3rdfloor	4300	13.30	13.991	12.662	13.689	13.773
2nd floor	2550	9.00	7.25	6.493	6.948	7.23
Canopy floor	4450	6.45	4.14	3.382	3.452	3.93
1stfloor	2000	2.0	0.511	0.43	0.433	0.497

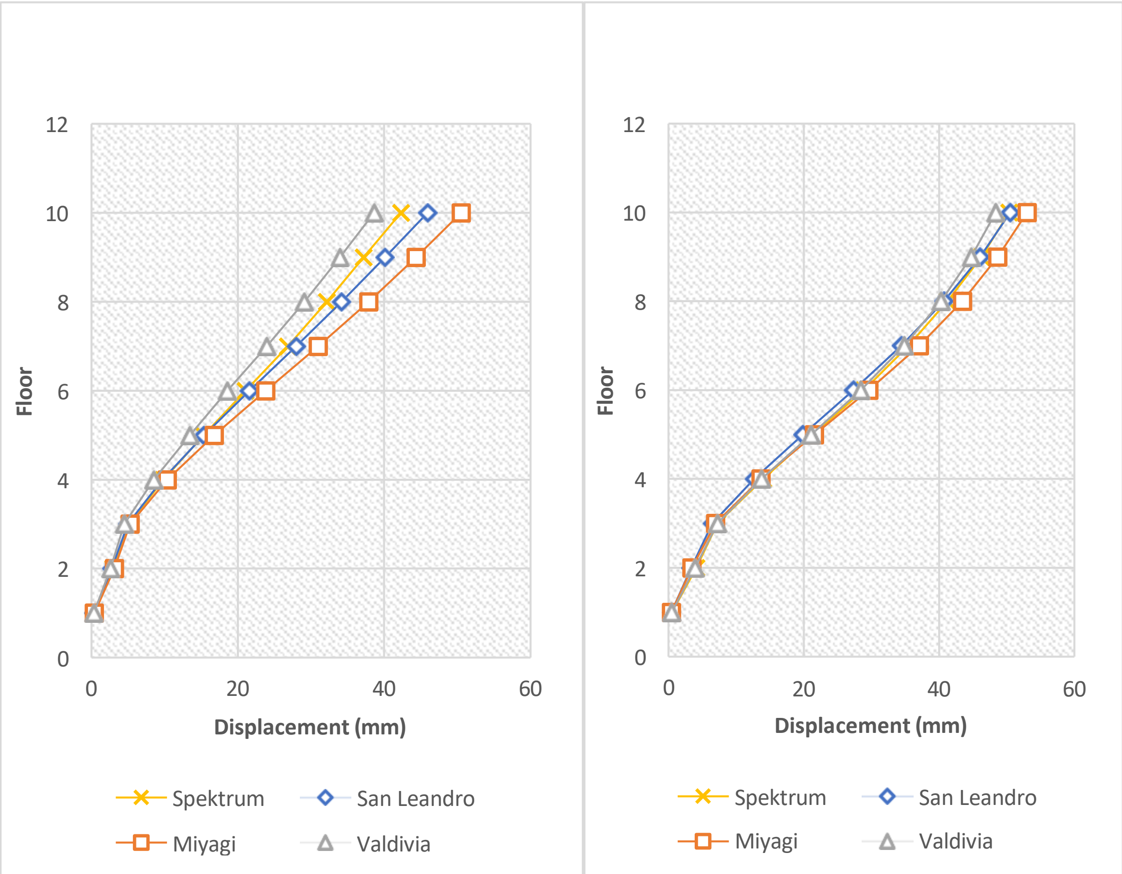

Figure 2. X-Direction Displacement (Left) and Y-Direction Displacement (Right)

Table 9. X-Direction Interlevel Deviation of Spectrum Response and Time History method

Lantai	**h**	**Hight Elevation**	**Inter Floor Deviation - X (mm)**				**Drift Limit**
	mm	**m**	**Spektrum**	**San Leandro**	**Miyagi**	**Valdivia**	**mm**
Floor 9	4300	39.10	18.733	21.300	22.638	17.237	33.08
8th Floor	4300	34.80	18.392	21.842	23.797	17.776	33.08
7thfloor	4300	30.50	19.529	22.726	25.194	18.799	33.08
6thfloor	4300	26.20	21.149	23.412	26.279	19.796	33.08
5thfloor	4300	21.90	21.021	22.752	25.835	18.777	33.08
4thfloor	4300	17.60	20.306	20.929	23.533	18.033	33.08
3rdfloor	4300	13.30	17.054	17.288	18.729	14.747	33.08
2nd floor	2550	9.00	8.008	8.070	7.858	6.908	19.62
Canopy floor	4450	6.45	9.519	8.859	9.970	8.397	34.23
1stfloor	2000	2.00	1.360	1.258	1.437	1.173	15.38

Table 10. Y-direction Interlevel Deviation of Response Spectrum and Time History method

Lantai	**h**	**Hight Elevation**	**Inter Floor Deviation - Y (mm)**				**Drift Limit**
	mm	**m**	**Spektrum**	**San Leandro**	**Miyagi**	**Valdivia**	**mm**
Floor 9	4300	39.10	15.048	16.412	15.825	13.339	33.08
8th Floor	4300	34.80	18.355	19.547	19.210	16.207	33.08
7thfloor	4300	30.50	21.226	22.957	23.298	19.939	33.08
6thfloor	4300	26.20	24.042	26.129	27.405	23.742	33.08
5thfloor	4300	21.90	27.958	27.449	29.594	26.726	33.08
4thfloor	4300	17.60	26.748	26.323	28.824	26.917	33.08
3rdfloor	4300	13.30	24.717	22.620	24.717	23.991	33.08
2nd floor	2550	9.00	11.403	11.407	12.819	12.100	19.62
Canopy floor	4450	6.45	13.306	10.824	11.070	12.588	34.23
1stfloor	2000	2.00	1.874	1.577	1.588	1.822	15.38

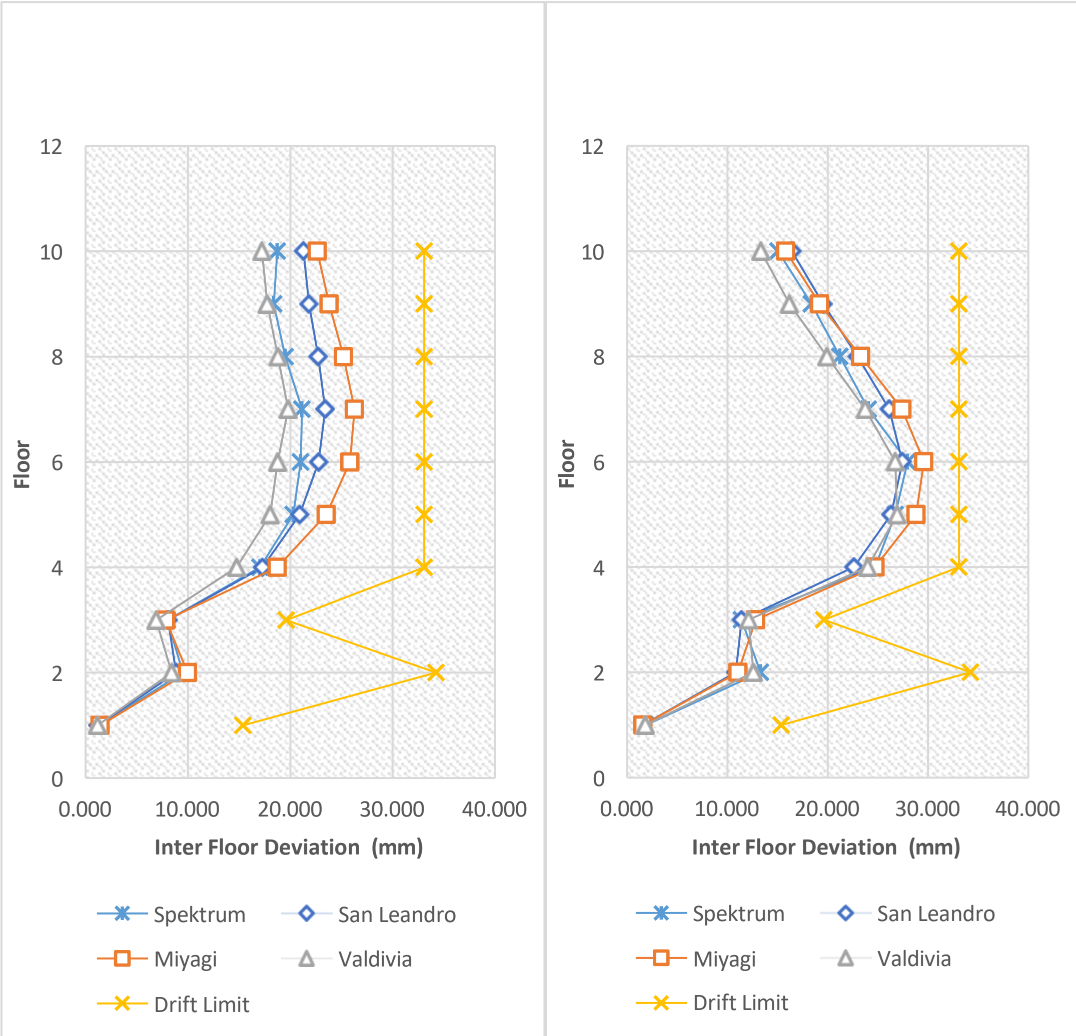

Figure 3. X-direction Interlevel Deviation (left) and Y-direction Interlevel Deviation (right)

ATC 40 STRUCTURE PERFORMANCE

The structural performance level in this analysis refers to the provisions set forth in Applied Technology Council-40 (ATC-40). This evaluation aims to determine whether the structure is included in the Immediate Occupancy (IO), Life Safety (LS), or Collapse Prevention (CP) category based on the permitted deformation criteria. The following is an example of determining the structural performance level of the Unjani Rectorate Building using the Miyagi Earthquake.

X-Direction Structure Performance Level
Target Displacement, Dt = 50.528 mm
First displacement, D1 = 0.392 mm
Building height, H = 39100 mm
Maximum total deviation, Dt/H = 0.00129 mm
Maximum inelastic deviation, (Dt-D1)/H = 0.00128 mm
Y-Direction Structure Performance Level
Target displacement, Dt = 53.004 mm
First displacement, D1 = 0.433 mm
Building height, H = 39100 mm
Maximum total deviation, Dt/H = 0.00136 mm
Maximum inelastic deviation, (Dt-D1)/H = 0.00134 mm

Table 11. Recapitulation of Determination of X-Direction Structure Performance Levels

X-Direction Structure Performance Level						
Earthquake Load	**Dt (mm)**	**D1 (mm)**	**Building Height (mm)**	**Total Deflection Maximum**	**Inelastic Deflection Maximum**	**Level Performance**
				Dt/H	**(Dt-D1)/H**	
Respon Spektrum	42.292	0.371	39100	0.00108	0.00107	IO
San Leandro	45.937	0.343		0.00117	0.00117	IO
Miyagi	50.528	0.392		0.00129	0.00128	IO
Valdivia	38.63	0.32		0.00099	0.00098	IO

Table 12. Rekapitulasi Penentuan Level Kinerja Struktur Arah-Y

Y-Direction Structure Performance Level						
Earthquake Load	**Dt (mm)**	**D1 (mm)**	**Building Height (mm)**	**Total Deflection Maximum**	**Inelastic Deflection Maximum**	**Level Performance**
				Dt/H	**(Dt-D1)/H**	
Respon Spektrum	50.367	0.511	39100	0.00129	0.00128	IO
San Leandro	50.521	0.43		0.00129	0.00128	IO
Miyagi	53.004	0.433		0.00136	0.00134	IO
Valdivia	48.374	0.497		0.00124	0.00122	IO

Based on the results of the structural performance level analysis of the spectrum response earthquake load and three time history earthquake data, the maximum deviation ratio in the x and y directions is recorded to be below 0.01, while the maximum inelastic deviation ratio is below 0.005. Thus, the structure of the Unjani Rectorate Building is categorized in the Immediate Occupancy (IO) performance level, which indicates that the structure remains protected, only suffers minor damage, and can function again immediately.

4. CONCLUSION

After conducting an evaluation using the spectrum response analysis method and time history on the Unjani Rectorate Building structure, the author can draw the following conclusions.

1. The results of the spectrum response analysis show a maximum inter-level deviation of 21,149 mm (6th floor, x direction) and 27,958 mm (5th floor, y direction). The maximum displacement occurs at the roof floor, which is 42,292 mm (x) and 50,367 mm (y).
2. The maximum inter-level deviation based on the time history method due to the Miyagi earthquake was recorded as 26.28 mm (6th floor, x direction) and 29.59 mm (5th floor, y direction). The maximum displacement occurred on the roof floor, which was 50.528 mm (x) and 53.004 mm (y).
3. Evaluation of the structural performance of the Unjani Rectorate Building based on ATC-40 shows that the maximum deviation ratio due to the Miyagi earthquake is still within the Immediate Occupancy (IO) limit, so the building is declared safe and can still function after the earthquake.

REFERENCE

1. Prasetio, A., Effendi, M. M., & Dwi M, M. N. (2023). Analisis Gempa Bumi Di Indonesia Dengan Metode Clustering. *Bulletin of Information Technology (BIT)*, *4*(3), 338–343. https://doi.org/10.47065/bit.v4i3.820
2. Rendra, R., Djauhari, Z., & Kurniawandy, A. (2015). Respon Spektrum Dan Time History (Studi Kasus : Hotel SKA Pekanbaru). *Jom FTEKNIK*, *2*(2), 1–15.
3. Rifai, M. (2022). *EVALUASI KINERJA STRUKTUR GEDUNG BERTINGKAT DENGAN ANALISIS TIME HISTORY (Studi Kasus : Rumah Sakit Umum Muhammadiyah Metro)*. *9*, 356–363.
4. Silaban, G. T. N., Tampubolon, S. P., Sri Mulyani, A., & Felestin. (2023). Performance Evaluation of High-rise Buildings with Respons Spectrum Analysis and Time History Analysis. *Science Tech: Jurnal Ilmu Pengetahuan Dan Teknologi*, *9*(1), 84–95. https://jurnal.ustjogja.ac.id/index.php/sciencetech/article/view/14295
5. SNI, 1726-2019. (2019). Tata cara perencanaan ketahanan gempa untuk struktur bangunan gedung dan nongedung. *Badan Standarisasi Nasional 1726:2019*, *8*.
6. SNI, 1727-2020. (2020). Penetapan Standar Nasional Indonesia 1727 : 2020 Beban Desain Minimum dan Kriteria Terkait Untuk Bangunan Gedung dan Struktur. *Badan Standarisasi Nasional 1727:2020*, *8*, 1–336.
7. Sofyan, M., Sipil, J. T., Tinggi, S., Pln, T., & Rokhman, A. (2017). *PERILAKU BANGUNAN STRUKTUR BETON BERKOLOM MIRING TERHADAP GAYA GEMPA LATERAL*.