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Performance Evaluation of the Structure of the Klaten DPRD Building When Affected by a 7.0 Magnitude Earthquake

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Abstract— Evaluation of structural performance in Indonesia has been carried out for several high-rise buildings as part of the owner's demands for safety guarantees to determine the level of security that the building has. A simple but accurate nonlinear analysis is needed to determine the structure's performance under earthquake loads. The capacity spectrum method (pushover analysis) documented in ATC 40 is a form of equivalent linearization based on two basic assumptions: secant period and equivalent damping. The performance point estimates where the capacity of the structure can withstand a given (demand) load; In terms of performance, the level of damage to the structure category based on lateral displacement can be seen. It is simulated that an earthquake will shake the Klaten DPRD building with a magnitude of 7.0 and 20 km from the epicenter. The amount of PGA(g) will be calculated based on the equation of Cornell et al. Building structure modeling was carried out with the help of ETABS v9.7.4.

Keywords: Nonlinear pushover analysis, ATC 40, ETABS v9.7.4, Magnitude, PGA(g).

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1. Introduction

The earthquake that claimed many lives led to essential mitigation measures being taken. Building performance inspection is carried out to determine how big the collapse is. Testing the structure's seismic performance using the concept of performance-based design is one of several existing methods to analyze the failure pattern of a building structure. Structural performance evaluation in Indonesia has been carried out for several high-rise buildings as part of the owner's safety guarantee demands to determine the extent of the building's security level [1]–[4]. A simple but entirely accurate nonlinear analysis is needed to determine the performance of a structure when it receives earthquake loads [5]–[10]. One method of nonlinear analysis that can be used is the capacity spectrum method which utilizes nonlinear dynamic pushover analysis, which uses structural performance as a design objective. The performance-based design has two main elements: structural capacity (capacity) and load (demand). The load (demand) is the ground motion due to the earthquake, described as a spectral response curve.

Structural capacity is the ability of a structure to withstand or overcome earthquake forces without being damaged. Pushover analysis is one of the analyses that can describe the structure's capacity as a whole. The pushover analysis obtains the performance point, which intersects the demand and capacity curves. The performance point is the estimate at which the capacity of the structure can withstand a given (demand) load; In terms of this performance, the level of damage to the structural category can be seen based on the lateral displacement [11]. According to FEMA 2004 [12],[13] the criteria for earthquake-resistant structures are as follows:

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a. Immediate Occupancy (IO)
When an earthquake occurs, the structure can withstand the earthquake; the structure does not experience structural damage and does not experience non-structural damage. So it can be used immediately.
b. Life Safety (LS)
When an earthquake occurs, the structure can withstand earthquakes with minor structural damage, and the people who live or are in the building are kept safe from earthquakes.
c. Collapse Prevention (CP)
When an earthquake occurs, the structure suffers heavy structural damage but has not yet collapsed.
d. Structural Stability (SS)
In conditions where the structure has experienced partial or total damage, the damage has caused a degradation of the strength and stiffness of the lateral force-resisting drift system.

Determine the performance level of the structure based on the performance points obtained from the intersection of the spectrum capacity and the demand reduction curve. Nonlinear analysis pushovers can show which structural elements are failing. In determining the performance level of the structure, it is necessary to calculate the maximum total drift by dividing the value of the structural deviation by the full height of the frame. The performance limits for structural deformation levels according to ATC 1996 can be seen in Table 1. ASCE 2017 states the acceptance criteria used in nonlinear procedures as seismic performance level limits (IO, LS, and CP) on the force-deformation component relationships can be seen in Figure 2. Seismic performance levels (IO, LS, and CP) as described in points a), b), c), and d). The P and S in Figure 1 represent the primary and secondary structural members. The intersection of the magnitudes to determine the value of the spectral displacement and acceleration is shown in Figure 1.

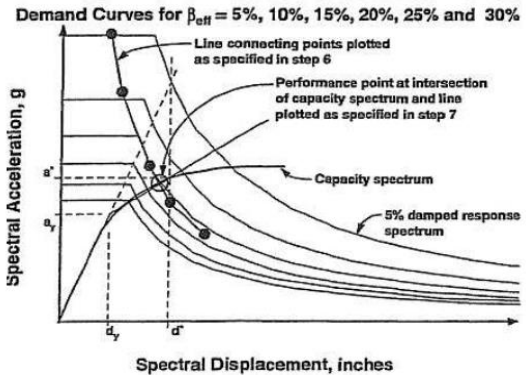


Figure 1. Power System Components

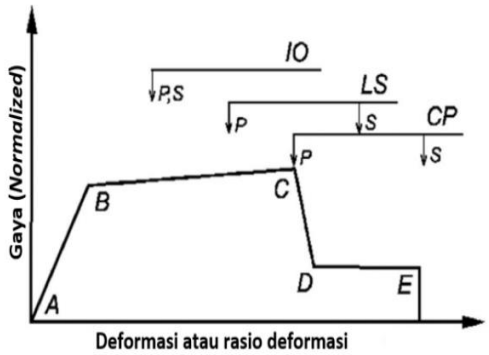


Figure 2. Illustration of acceptance criteria [14]
Table 1. Performance level

Parameter	Performance level			
	IO	DC	LS	SS
Maximum total drift ratio	0,01	0,01 sd 0,02	0,02	0,33 Vi/Pi
Maximum inelastic drift ratio	0,005	0,005 sd 0,015	Not limited	Not limited

Earthquake-Resistant Building Planning Concept Building structures designed to be earthquake resistant must have several criteria, including sufficient strength, rigidity, and stability to prevent structural failure (collapse). The basic concept of earthquake-resistant building planning is as follows:

a. When hit by a light-scale earthquake, the building structure and functions must be able to keep running (serviceable) so that the structure must be strong and there is no damage to the structural and non-structural elements of the building.
b. When hit by a medium-scale earthquake, the structure is allowed to suffer damage to non-structural elements, but damage to structural elements is not allowed.
c. When hit by a large-scale earthquake, it is permissible for damage to structural and non-structural elements to occur, but it must not cause buildings to collapse so that there are no casualties or can minimize the number of fatalities.

According to [15], The concept of an earthquake response spectrum, namely to see the characteristics of ground motion and its effect on the structure. An earthquake response spectrum plots the maximum response of all possible single-degree systems to a given ground motion. In addition, the response spectrum can also be used as a dynamic approach to structures, especially earthquake-resistant building planning and the calculation of lateral forces in planning regulations. In general, there are three types of response spectrum depending on the type of response used, namely:

a. The deformation response spectrum μ_0 plots displacement versus natural vibration time Tn for a given ζn.
b. The pseudo velocity response spectrum μ_0 plots the velocity against the natural vibration time Tn for a given ζn.
c. The pseudo-acceleration response spectrum plots the acceleration against the natural vibration time Tn for a given ζn.

The spectrum's abscissa is the system's natural vibration time and the ordinate is the maximum response. This analysis generates the maximum base shear and displacement that occurs in the X and Y directions of the analyzed building structure. The Klaten DPRD building has a height of up to 4 floors and is possibly vulnerable to damage caused by the earthquake. It is assumed that the Klaten DPRD building was hit by an earthquake with a magnitude of 7.0 and is 20 km from the epicenter. The PGA (g) amount will be calculated based on equation 1 and equation 2. This paper aims to determine the damage to the building as part of disaster mitigation.

$$Ln\begin{Bmatrix}Ap\\Vp\\Dp\end{Bmatrix} = a + bM + cLn(R+25)+\varepsilon \quad (1)$$

$$\begin{Bmatrix}Ap\\Vp\\Dp\end{Bmatrix} = [\exp(bM)](R+25)^{c} \quad (2)$$

Where: a = 6.74; b = 0.859; c = -1.80; ε = 0.57 [16] Earthquake Level The seismic hazard design gives a different earthquake load has a different earthquake return period, and predicted peak ground acceleration (PGA) [17] as shown in Table 2.

Table 2. *Seismic hazard*

Earthquake load level to intensity MMI*	**FEMA's qualitative description**	**Probability of occurrence in 50 years**	**Return period (years)**	**Effective PGA (g)**
Level 1: MMI VII Event Level	periodically	50%	72	0,12
Level 2: MMI VIII Design Intensity Level	infrequently	10%	475	0,25
Level 3: MMI IX Severity Level	Very rarely	2%	2.475	0,5

**Modified Mercalli Intensity scale*

The result of the nonlinear pushover dynamic analysis is a curve showing the relationship between the base shear and the roof displacement, as shown in Figure 3. This relationship is then mapped into the structural capacity curve, as shown in Figure 4.

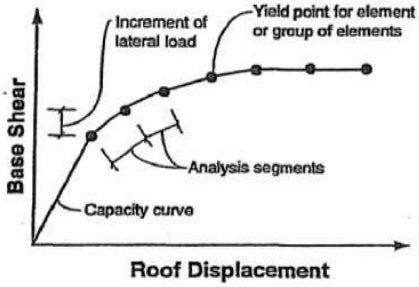
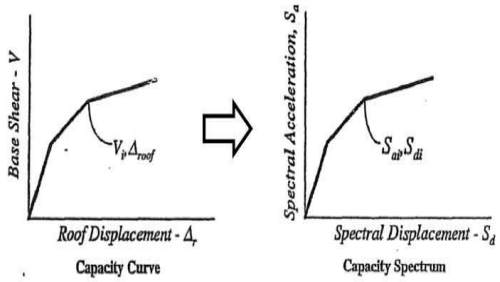


Figure 3. Capacity curve



a. Capacity Curve (standard format) b. Capacity Spectrum (SDRS format)

Figure 4. Modification of the Capacity Curve to a Capacity Spectrum

2. Method

The structural data of the analyzed Klaten DPRD Building were obtained from the practical work of UTY students, both secondary and primary data, data in the form of working drawings, and quality of materials. All modeled structures must have working drawings; non-structural buildings are not modeled but are calculated as loads. The layout of the Klaten DPRD Building can be seen in Figure 5, and the structural plan and appearance of the Klaten DPRD Building can be seen in Figures 6 and 7. Furthermore, the structural data is used for modeling the building structure with the help of ETABS v9.7.4, which can be seen in Figure 8. Working drawings used for the modeling stage must be by the existing drawings so that this analysis does not deviate from the existing drawings. Furthermore, the building structure was analyzed using nonlinear pushover analysis with a 7.0 magnitude earthquake control. According to [18], the capacity spectrum method documented in ATC 40 is a form of equivalent linearization based on two fundamental assumptions: the secant period and equivalent damping.

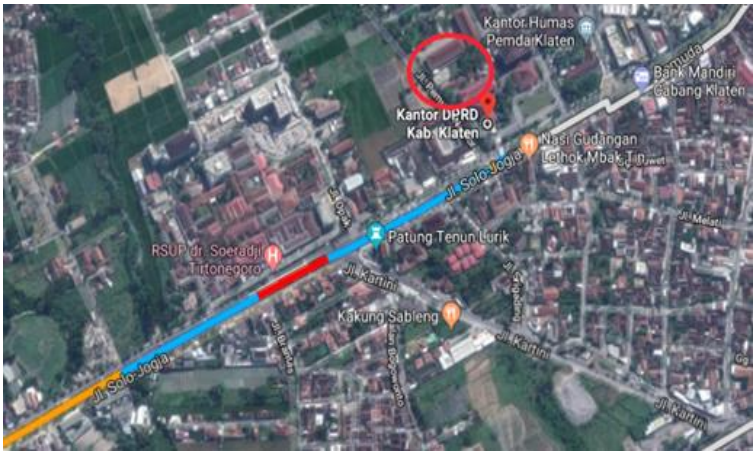


Figure 5. Location of the Klaten DPRD Building

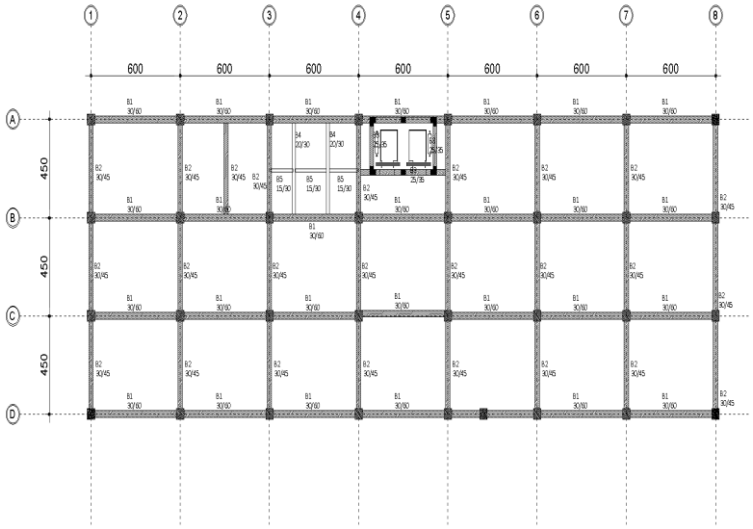


Figure 6. Structural plan of the Klaten DPRD Building



Figure 7. View of the Klaten DPRD Building

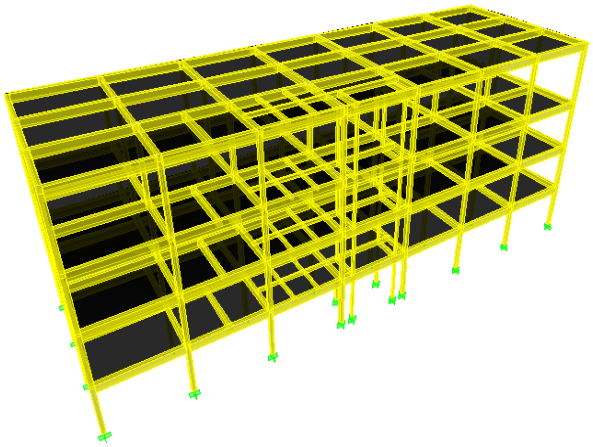
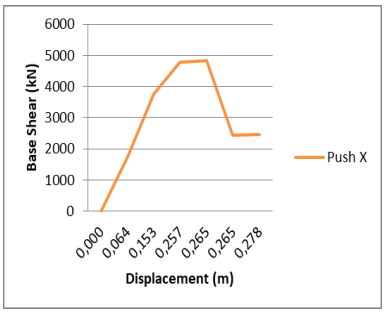


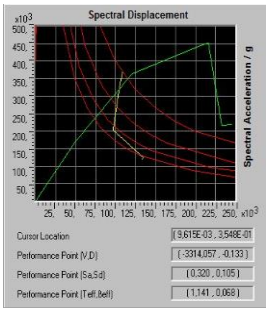
Figure 8. Modelling ETABS v9.7.4 [19]

3. Result and Discussion

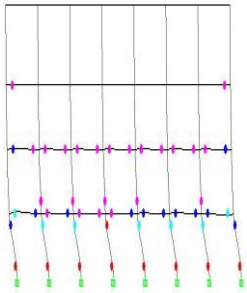
An earthquake with a magnitude of 7.0 and a distance of 20 km from the epicenter is calculated based on equations 1 and 2 to obtain a PGA of 0.43 g. Then the structure was analyzed using a controlled nonlinear pushover analysis method with a magnitude of 7.0. Then the analysis results can be seen in Figure 9 for the X direction and Figure 10 for the Y direction. Figure 9 shows that the structure collapsed on the 1st-floor column when an earthquake hit it. The maximum base shear was 4835 kN with a 0.265 m or 265 mm displacement. However, the beam only suffered minor damage and had no potential to collapse [20]. The concept of concrete columns and weak beams requires that after a structure experiences a design earthquake, plastic hinges can occur in the beams, not the columns. This is so that the system stays up and the people in it still have time to save themselves. When the design earthquake occurs, the area that bears the maximum moment on the column is still experiencing plastic hinges. The columns in the area near the supports (taking the ultimate moment) will experience a decrease in brittle strength due to the loss of the concrete cover and reduced concrete stress [21].



Base shear vs Displacement X direction

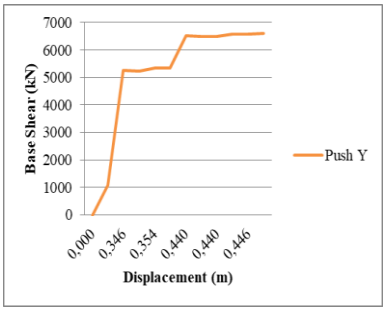


Performance point X direction

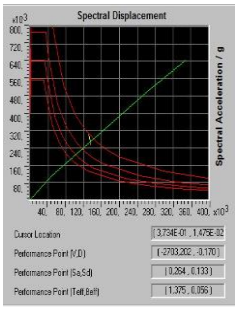


Structural view due to maximum base shear

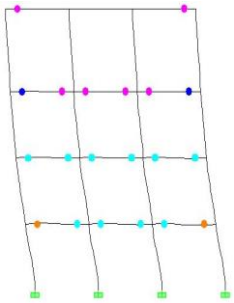
Figure 9. The results of the X direction pushover analysis



Base shear vs Displacement Y direction



Performance point Y direction



Structural view due to maximum base shear

Figure 10. The results of the Y direction pushover analysis

Figure 10. shows that when a maximum earthquake of 6611 kN occurs, it can be seen that the beams begin to experience plastic hinges and also experience minor damage to some of the beams. Furthermore, it is recapitulated for performance point values, estimates where the structural capacity can withstand a given load (demand). In terms of performance, the level of structural damage category can be seen based on the lateral displacement. The performance point results for the X and Y directions are shown in Table 3.

Table 3. Performance point result

Performance point X direction	
Story Number	4
Spectral accelaration	0,320
Spectral displacement	0,105
Damping	0,068
Base shear (kN)	3314
Time Period	1,141
Displacement (mm)	133
Performance point Y direction	
Story Number	4
Spectral accelaration	0,264
Spectral displacement	0,133
Damping	0,056
Base shear (kN)	2703
Time Period	1,375
Displacement (mm)	170

4. Conclusion

Evaluation of the seismic performance of buildings on the structure of the Klaten DPRD Building uses the concept of performance-based design. This concept obtains the performance point value, the intersection of the demand and capacity curves. Based on the deformation limit of the

maximum deviation ratio at the performance level of the structure still within the limits required in the regulations, the building being reviewed was still within the limits of life safety design.

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