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Pushover analysis for seven Storey building in an earthquake risk area

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Abstract
West Sumatra Province, especially Padang City, is one of the earthquake-prone areas because it is located on the west coast of Sumatra, which is tectonically close to the subduction zone, namely the meeting zone or boundary between two tectonic plates where the movement of these two plates results in a large earthquake. As an area that is prone to earthquakes, knowledge about earthquake-resistant structures is very important. One method that is commonly used today is to carry out analysis to obtain the performance level of the structure. A 7-story government building located in an earthquake-prone area will be the object of this research. The building is made of concrete material, with a frame concept and is used for public purposes, so this structure's level of importance is high. This study examines the condition of a government building's resistance to seismic behavior. The method used is to look at the structural behavior of the 7-story building with pushover analysis. The pushover method is one method of the performance-based design concept. With the ATC-4o standard as a reference, the building is analyzed using the pushover method to understand its seismic behaviour. The results obtained indicate that the building is experiencing immediate occupancy conditions.

Keywords:
Building;
Earthquake;
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INTRODUCTION

As a country located in the Pacific Ring of Fire, Indonesia will not be free from the threat of earthquakes. The cause of earthquakes can be due to the movement of the Earth's crust (earth plates). An earthquake is a vibration or shake that occurs on the surface of the Earth as a result of a sudden release of energy from within and creates seismic waves. Earthquakes usually occur at plate boundaries. The most severe earthquakes occur at the boundaries of compressional and translational plates. Apart from that, earthquakes can occur due to the movement of magma in volcanoes [1][2].

Earthquakes can occur at any time without knowing the season. However, earthquake concentrations tend to occur in certain places, such as in areas where two tectonic plates meet. Earthquakes can occur anywhere on Earth but generally occur around the boundaries between tectonic plates. The comparison of the number of losses due to earthquakes with other natural disasters can vary depending on various factors, including the magnitude of the earthquake, geographical location, level of community preparedness, and other types of natural disasters. However, earthquakes can generally cause significant losses, especially if they occur in densely populated areas or are followed by additional disasters such as tsunamis or volcanic eruptions. Earthquakes can often cause structural damage to buildings, bridges, and highways. These losses can involve large repair costs.

Compared with other natural disasters, earthquakes occupy a fairly high position regarding material and non-material losses. This can be seen from the following image obtained from the source ourworldindata.org. Compared with other natural disasters, earthquakes occupy a fairly high position regarding material and non-material losses. This can be seen from the following image obtained from the source ourworldindata.org. Figure 1 explains the loss of life suffered by humans when experiencing natural disasters. This figure shows that earthquake disasters are in third place after drought and floods in terms of the disasters that cause the most victims. Compared with other natural disasters, earthquakes occupy a fairly high position regarding material and non-material losses [1, 3, 4, 5, 6]. This can be seen from the following image obtained from the source ourworldindata.org. Figure 1 explains the loss of life suffered by humans when experiencing natural disasters. From this figure, it can be seen that earthquakes are in third place after drought and floods in terms of the disasters that cause the most victims. Therefore, ensuring the resilience of the built infrastructure when facing earthquake loads is very important.

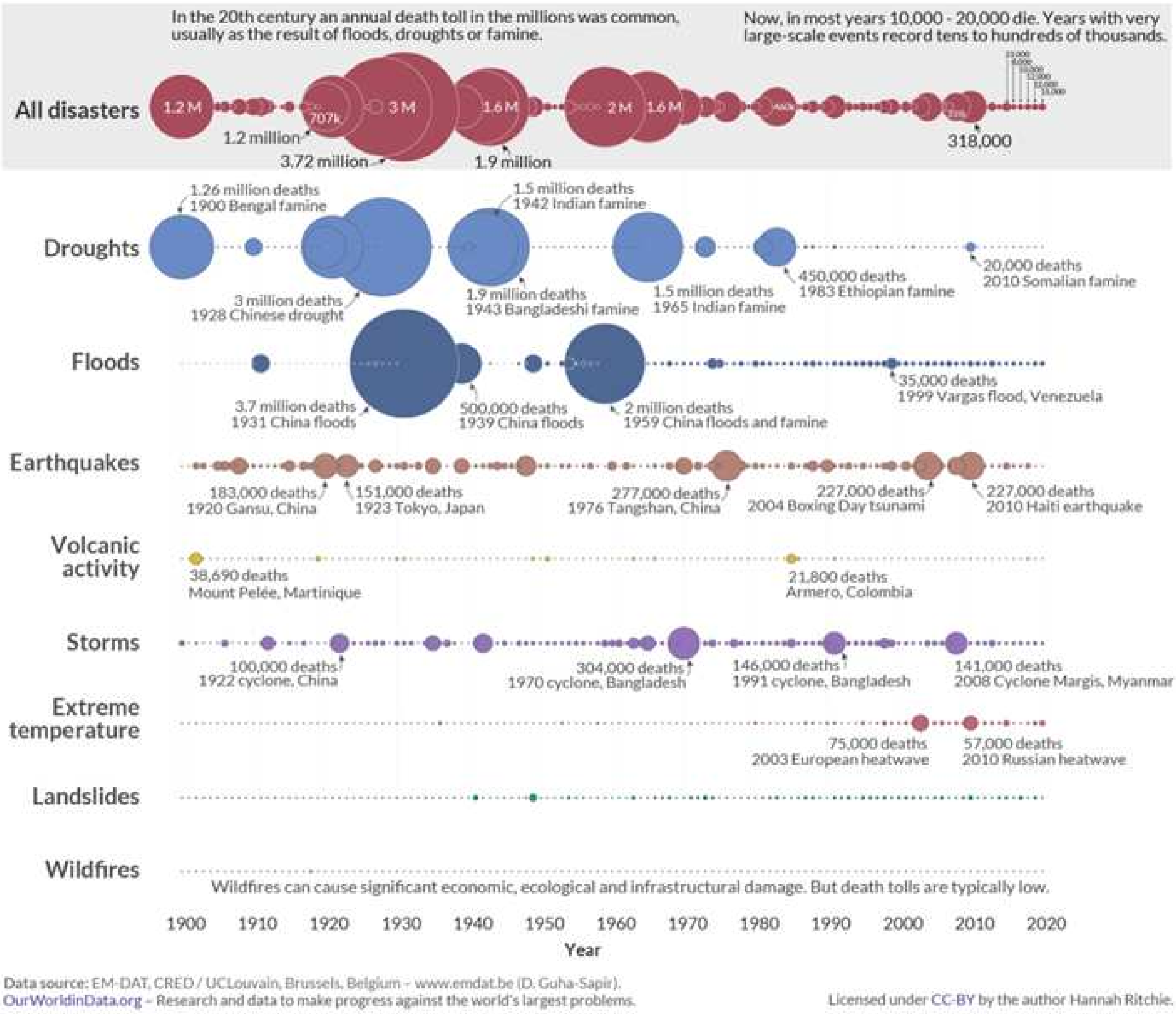


Figure 1. Global death from disasters over more than a century [7]

In general, buildings are designed to be able to continue to function well throughout the life of the building's planned use. However, in reality, in the field, before reaching the end of its useful life, buildings have experienced damage either due to age factors or damage factors due to disasters, the type of damage which was previously unforeseen during planning. It would be better if the damage was discovered early to avoid the impact of other damage.

Basically, existing buildings can be divided into two categories based on the planning and implementation process: engineered and non-engineered. Engineered construction is a building that is planned based on structural calculations and carried out or built under the supervision of building experts. Engineered construction includes multi-storey building structures, bridge and flyover structures, electric or nuclear power generating facilities, and dams. These buildings generally use modern materials and structural systems, such as reinforced concrete and steel [6][8].

Earthquake resistant structures are generally planned by applying the concept of ductility, a concept where structures are considered to no longer need to be planned to remain in an elastic condition when carrying the largest earthquake loads predicted to occur. Practically, structural analysis of earthquakes still uses force-based design methods. In the force-based design method, earthquake force calculations are carried out using linear (elastic) analysis. After the internal forces are obtained, a design is carried out to obtain the capacity of each structural element that must be provided. Each element's capacity can be calculated using the equations available in several planning standards in Indonesia [9, 10, 11].

Several researchers concluded that linear analysis could not be used to determine the behavior of structures in large earthquakes. This is because plasticization occurs in several places when a large earthquake occurs in the structure. So, the building no longer behaves linearly but behaves nonlinearly. Thus, non-linear analysis is needed to determine the behavior of structures when experiencing a large earthquake, which is a performance-based design concept [12, 13, 14].

The main goal of performance-based design is to determine the desired level of performance of the building. Seismic performance is described by setting the maximum allowable damage level (performance level) to identify earthquake hazards. The building risk category focuses on the level of risk permitted in building structures that are planned following the purpose of the building or, in other words, the function of a building [15, 16, 17, 18].

METHOD

The building structure that will be analyzed in this research is located in Padang, with a height of seven floors and an elevation of 27.20 m, as can be seen in Figure 2. The dimensions of the main beam are 40 x 60 cm^2, while the main column is 50 x 50 cm^2. The total height is 7 x 3.5 = 24.5 mm. The quality of concrete used is f'c 30MPa and for reinforcement steel is fy 400 MPa. Abscissa coordinate (X) is longitudinal, while the ordinate is transversal.

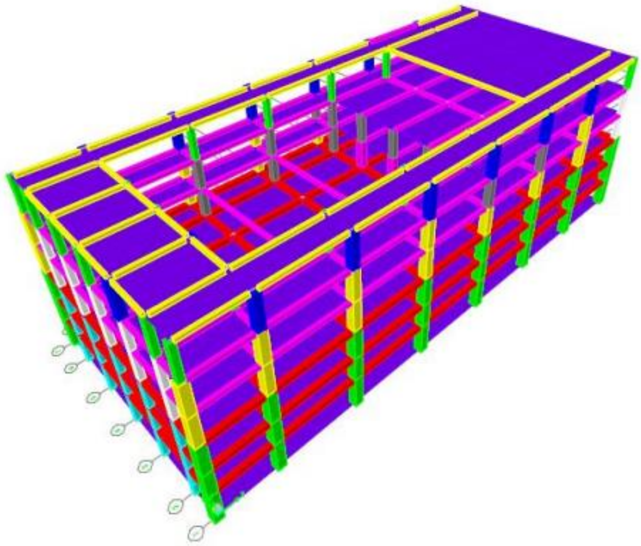


Figure 2. Modelling of the building

Pushover analysis is one of the analyses included in the performance-based planning concept. This analysis aims to find the capacity of a structure and the level of performance of a structure. This analysis is carried out by providing a static load in the lateral direction whose value is increased gradually and proportionally until it reaches the desired deviation value or reaches failure [11][19]. In other words, it is a method of two-dimensional or three-dimensional linear and non-linear static analysis, where the effect of a planned earthquake on the building structure is considered as a static load that captures the center of mass of each floor, whose value is gradually increased, until it exceeds the load which causes yielding (plastic joints) first in the building structure, then with a further increase in load it experiences deformation until it reaches a condition on the verge of collapse [20][21]. The final result is the structure's base shear and deviation (displacement). The calculation results obtained are then drawn on a graph, by inputting the values obtained and plotting the lines connecting the points obtained on the response spectrum graph. Then, the spectrum response graph obtained is used as a reference for inputting earthquake loads into the analysis software.

The response spectrum is a spectrum presented in the form of a graph or plot between the period of vibration of the structure versus the maximum responses based on the damping ratio and certain earthquakes, as shown in Figure 3. Maximum responses can be in the form of maximum deviation (spectral displacement, SD), maximum speed (spectral velocity, SV) or maximum acceleration (spectral acceleration, SA) of the single degree of freedom (SDOF) structure mass [2, 22, 23]. The earthquake response spectrum calculation refers to the SNI earthquake regulations 1726-2019, with the final result in the form of a response spectrum graph which is used for earthquake loading in building structure modeling in the analysis software. In SNI 1726-2019 concerning earthquakes, the acceleration parameters of 0.2 and 1.0 seconds are used because the intervals of 0.2 and 1.0 seconds contain the greatest earthquake energy. In addition, a period of 0.2 seconds generally represents the shortest period of vibration of a structure (2-story building) that is planned according to ASCE requirements, which have taken into account the effects of soil, rocking of the foundation and other factors that are usually ignored in structural analysis [24].

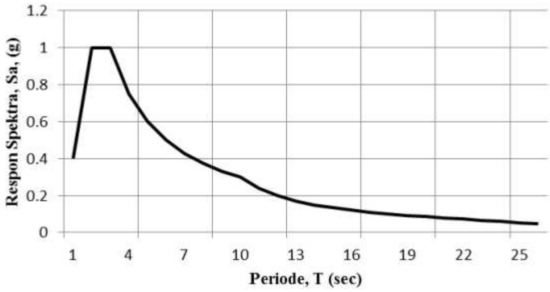
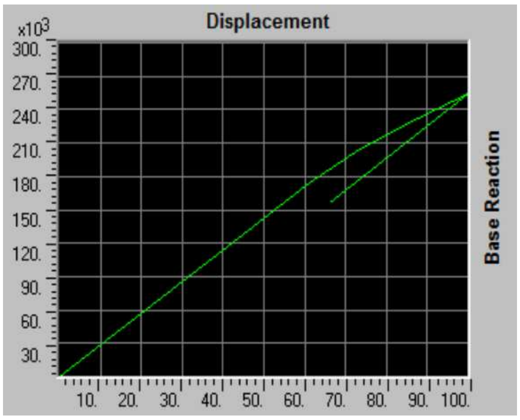


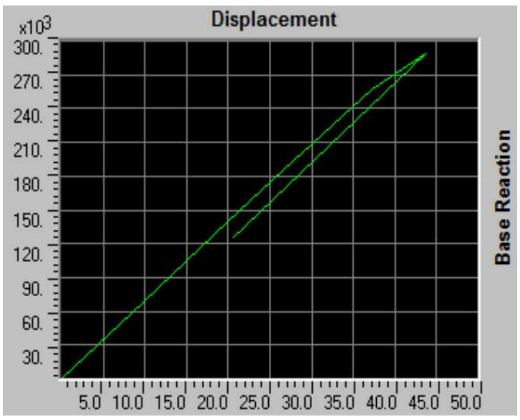
Figure 3. Respons Spectrum for Padang City

RESULTS AND DISCUSSION

Based on the results of the pushover curve in the X direction in Figure 4a, it can be concluded that the structure collapsed at step 11 with a displacement value of 100.0004 cm and a base shear force (base reaction) of 256.0 KN. This means that the structure collapsed at the 11th step in the x-x direction, which means that the elements in the structure, namely beams and columns, can no longer work optimally. Meanwhile, in Y direction, as shown in Figure 4b, based on the results of the Y direction pushover curve above, it can be concluded that the structure experienced collapse at step 6 with a displacement value of 43.3784 cm and a base shear force (base reaction) of 284.679 MN. This means that the structure collapsed at step 6 in the y-y direction, which means that the elements in the structure, namely beams and columns, can no longer work optimally.



(a). Capacity curve X direction



(b). Capacity curve Y direction

Figure 4. Capacity curve X and Y direction

According to the ATC-40 capacity spectrum method, the grouping of structural performance levels is based on the maximum total drift value and the maximum inelastic drift value. The maximum total drift is the interstory drift at the performance point, while the maximum inelastic drift is the proportion of the maximum total drift beyond the effective yield point [9][25].

Performance Point is an intersection point between the capacity spectrum obtained from the capacity curve (displacement VS base reaction) and the demand spectrum obtained from the spectrum response graph. The following are performance points in ADRS (Acceleration Displacement Response Spectra) format. The performance point for X direction is (82245;28.893) in V-D format. Meanwhile, for Y direction is (111867;16.046), as depicted in Figure 5 and Figure 6, respectively.

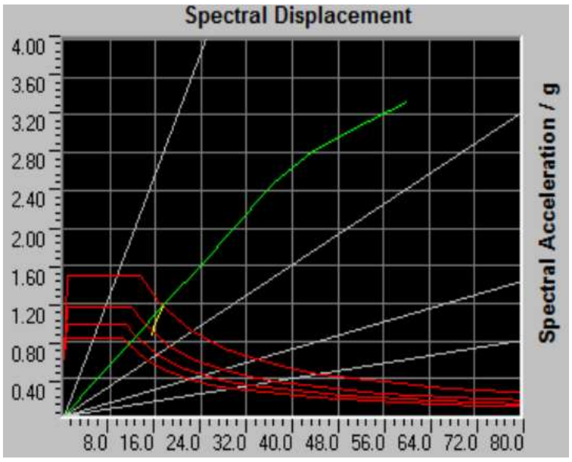


Figure 5. Performance Point for X Direction

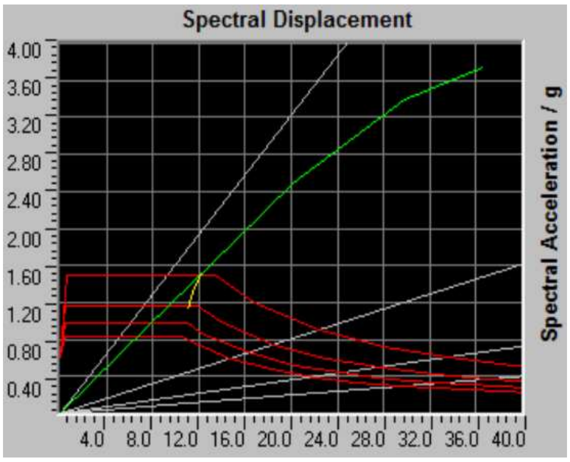


Figure 6. Performance Point for Y Direction

Pushover analysis aims to find a common point between what the structure can handle (according to the pushover curve) and what the earthquake imposes (according to the seismic response spectrum). This point is called the performance point. To determine the performance level of the structure, it is necessary to define the ratio of the drift by dividing the performance point value of the structure by the total height of the structure.

Table 1. Performance point in X level

Axis	Displacement (D)	Base Force (V)
X	6.0461	111867
Y	28.893	82245

Table 2. The requirements of the performance level of ATC 40 [26]

Parameter	Performance Level			
	Immediate Occupancy (IO)	Damage Control	Life Safety (LS)	Structural Stability
Maximum total drift	0.01	**0.01-0.02**	0.02	0.33 (Vi/Pi)
Maximum inelastic drift	0.005	0.005-0.015	No limit	No limit

Table 1 describes the value of displacement versus base force in the X and Y directions. The table shows the maximum values of each direction (bold), which are used to define the ratio of limitation to obtain the performance level of the structure. The performance level of structures against earthquakes describes limiting damage conditions that are assumed to be satisfactory for a given building and ground motion. Moreover, building damages, danger to life and safety of occupants in the building due to the damage, and post-earthquake serviceability of the building describe and control the limiting damage condition. Additionally, building performance level against earthquakes is a combination of the performance of structural and non-structural components. Lastly, the performance levels of building structures against earthquakes will be presented in Table 2, based on ATC-40.

The building structure performance level criteria are obtained based on the maximum total drift and maximum inelastic drift values.

Ratio X = 160.46/24500 = 0.006

Ratio Y = 288.93/24500 = 0.01

The results indicate that the structure is categorized as IO or Immediate Occupancy. The immediate occupancy performance level depends on the amount of structural and non-structural damage that is considered acceptable. In this case, the selected level of damage should allow the immediate occupancy of the structure.

CONCLUSION

The building has been evaluated using the ATC 40 method regarding the performance level of the structure after an earthquake. The level performance of the structure is IO, The Immediate Occupancy (IO) category is a structural condition that can withstand the structure and does not suffer structural and non-structural damage during an earthquake. In this category of IO, structures can be re-functional after the earthquake. It can be concluded that the building is sufficient enough to overcome the earthquake loads based on its region. Compared to the longitudinal axis, the transversal is weaker since it yields longer displacement than the transversal axis.

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