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Evaluation and Strengthening Recommendations of Rectorate Building Muhammadiyah University of Sumatra Barat Due to Earthquake

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Abstract
The UM Sumbar Rectorate building suffered structural damage after 33 years. During service life, earthquakes have frequently occurred, the largest was 7.6 magnitude earthquake 2009 in Padang. The structural components have never been handled. This study aims to identify the existing condition as a basis for handling structural damage. Research activities are structure inspection, structural analysis, and determining structural improvements. The building has been deflected by >1° (± 10cm). The majority of structural elements are cracked due to overcapacity. Based on ATC 40 pushover analysis results, it found that 10 steps on x-direction and 11 steps on y-direction of push loads on the structure until it collapsed. Structure performance level is Life Safety, which is in a plastic condition. Strengthening are suggested to increasing column, building ductility, and implementing a dilation system. Evaluation the foundation structure and soil investigation are necessary before planning the strengthening.

INTRODUCTION

The Rectorate Building of Muhammadiyah University of Sumatra Barat, located on Campus I, Padang City, was built in 1990 with 3 (three) floors. The building functions as office space on the 1st floor and lecture rooms on the 2nd and 3rd floors. Throughout its service life there have been many earthquakes in the period 1990 - 2023, one of which was the large earthquake in Padang City on September 30 2009 with a magnitude of 7.6 on the Richter Scale which caused many incidents shear failure to the building structure (Ismail et al., 2011). During its operating period of more than 30 years, the building has never been renovated or inspected for structural conditions. Visually, the building has tilted/deflected from its original upright position. Several columns on the 1st floor experienced wide cracks, this caused the reinforcement to be exposed. The majority of cracks occur in the column supports area. Some beams experience plastic deformation and experience cracks in the support area. The exposed reinforcement has corroded considering the location of the building is ± 1 km from the sea. The location of a building in an earthquake-prone area has a big chance of accelerating the growth of building damage, such as failure to draw (the building collapses suddenly) or an increase in the slope of the building triggered by ground movement so that the building falls backwards.

Many researchers investigate the condition of existing structures using Non-Destructive Test (NDT) methods on building and bridge structures(Apriani et al., 2016; Habirun, 2021b, 2023; Hakiki, 2023; Hutagalung et al., 2021; K. Kurniawan et al., 2024). Apriani et al. (2016) have tested the reliability of column structures using the NDT method by using a Hammer Test tool to test the uniformity of concrete quality, a Rebar Locator to determine the properties of cross-sections installed on structural elements and Ultrasonic Pulse Velocity. Apart from that, Habirun (2021) in her research carried out visual inspections and applied NDT methods including the Hammer Test and Crack Width as well as the Destructive Test (DT) method, namely Core Drill, on 40-year-old building structures. Several beams experienced cracks in 1/3 of the span with a width of up to 0.876 mm greater than 0.7 mm (classified as structural cracks). The floor covering has been added 3 times without removing the original layer. Core concrete quality is below the requirements ranging from 14.8 MPa – 18.8 MPa. Yanto et al., (2019) evaluated a pulmonary hospital in West Sumatra using the Pushover Analysis method based on FEMA 356. The structure is evaluated against earthquake forces at a certain level so that if it experiences collapse the building must behave nonlinearly in post- elastic. This simulation also can be carried out to analyze the capacity of the structure where additional floors are planned and also a buildings with irregular plans (D. Kurniawan et al., 2024; Sumpena et al., 2023).

Based on problems and previous research has been done, this research is carried out to inspect the existing condition of the structure deeply accompanied by field testing of the building structure based on several methods that have been applied by Apriani et al. (2016) and Habirun (2021). The results of field observations are used to analyze and evaluate the performance of building structures based on method Yanto et al. (2019). It is then used as a reference for recommending repairs and strengthening the structure so that the building can still be used. The method used to solve the problem is direct testing in the field visually and Non-Destructive testing, then the results are analyzed using software and discussed based on the results of other researchers. Several stages are carried out, including visual inspection, field testing, structural analysis, and recommendations for building structure improvements.

RESEARCH METHODS

a. Visual Inspection and Field Testing

Visual inspection is carried out by taking inventory of the existing condition of the building and physical damage that occurs to structural elements as a database for repair activities. The building structure is then subjected to field testing to obtain the latest building straightness. Testing of materials installed on structures can be carried out using methods that do not damage the structure, namely Non-destructive Test (NDT).

b. Structure Element Capacity

Analysis is carried out on the building structure using SAP2000 v.21 software based on data obtained in the field. The results of the analysis are then used as a basis for action to improve the building structure. Analysis of building structures uses the latest regulations, including SNI 1727:2020 concerning loading, SNI 1726:2019 concerning earthquake loads, and SNI 2847:2019 concerning concrete structures. The cross-sectional capacity of structural elements is reviewed against the internal forces. The cross-section must meet the requirements where the corrected design strength must be greater than or equal to the external design force.

c. Structure Performance Evaluation

The current structural condition is subjected to non-linear static analysis (Pushover analysis) which is an analytical procedure to determine the performance level of the structure (Batara, 2021). The level of structural performance can be determined based on the Applied Technology Council Seismic Evaluation and Retrofit of Concrete Buildings (ATC-40, 1996). The performance point of the structure is determined from the intersection between the capacity spectrum method and the reduced spectral response curve to overcome the maximum displacement (Figure 1).

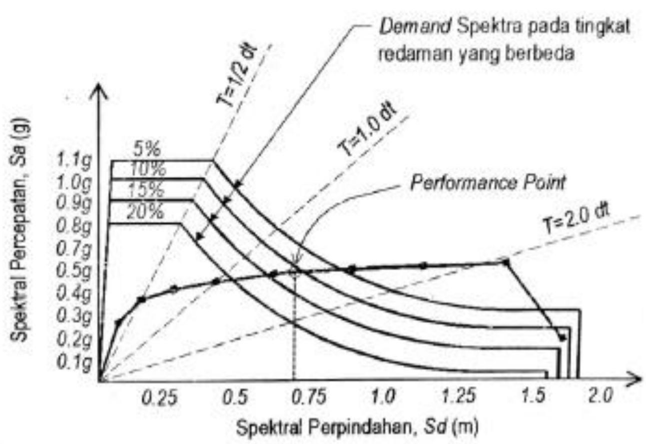

Figure 1. Structural performance points at the level of structural damping. (ATC-40, 1996)

The level of plastification conditions in the plastic hinges of structural elements (Figure 2) is determined starting from the condition of the absence of loading A, the condition of first yielding B, the ultimate capacity of the element C, the remaining collapse of element D, to the limit of elements that have experienced collapse E. Between ultimate conditions B and C there are yield stages with performance levels on Immediatelly Ocupancy (IO) elements, Life Safety LS (plastic conditions) and Collapse Prevention CP (almost collapse conditions).

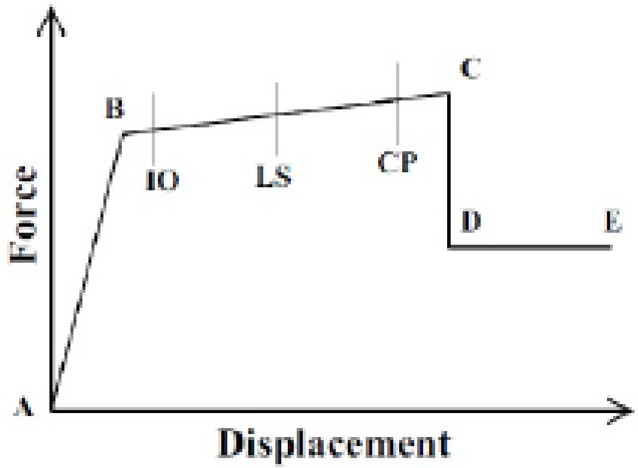

Figure 2. Plastic Joint Level of Element (Batara, 2021)

The structural performance level is determined based on Table 5.5.4 ATC-40. Globally, it can be determined based on the ratio of the roof displacement value at the performance point to the total height of the building. The performance level of the structure is outlined in Table 1.

Table 1. Deviation Limits at Structural Performance Levels (ATC-40, 1996; Batara, 2021)

	Performance level			
Interstory Drift Limit	Immediate Occupancy	Damage Control	Life Safety	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

d. Building Structure Strengthening

Structural strengthening is carried out on each element that is damaged as well as the entire building structure. Structural elements with low capacities can be strengthened by adding shear walls as was done by Fauzan et al., 2010 in their investigation of post-earthquake buildings. Besides that, structural elements that experience shear damage can be strengthened with steel concrete jacketing (Monikha Sari et al., 2013). Structural cracks can be injected with Epoxy Concresive 2525 while beams experience a weakening capacity reinforced with 2 layers of Mbrace CF 230/4900 material (Habirun, 2021a). The number of CFRP layers that can increase bending capacity is 1 – 3 layers (Sumargo et al., 2014).

RESULTS AND DISCUSSION

Identification of Visual Observation Results

Visual observations are carried out on all building components, especially structural components. The observation results show that mostly a whole main structure components been damage. Campus I Padang area, the location where the rectorate building is located, has a poor drainage system which causes frequent rainwater stagnation in a relatively long time. In addition, there is an infiltration pond which is located adjacent to the building in the back area.

Columns on floors 1 – 3 are damaged and some of them has wide cracks which exposed the reinforcement and corroded (Figures 3 and 4). The majority of cracks occur at the column support area. So that it can be categorized as a column experiencing shear failure. Some beam elements have undergone permanent plastic deformation or deflection. Most of the beams experienced cracks in the support area. This is an indication of shear failure (Figure 5). One of the reasons for the deflection of the beam is due to the relatively long span of about 9.25-meters without any joists or columns in the middle of the span. The capacity of the beam exceeds the internal force so that cracks occur.

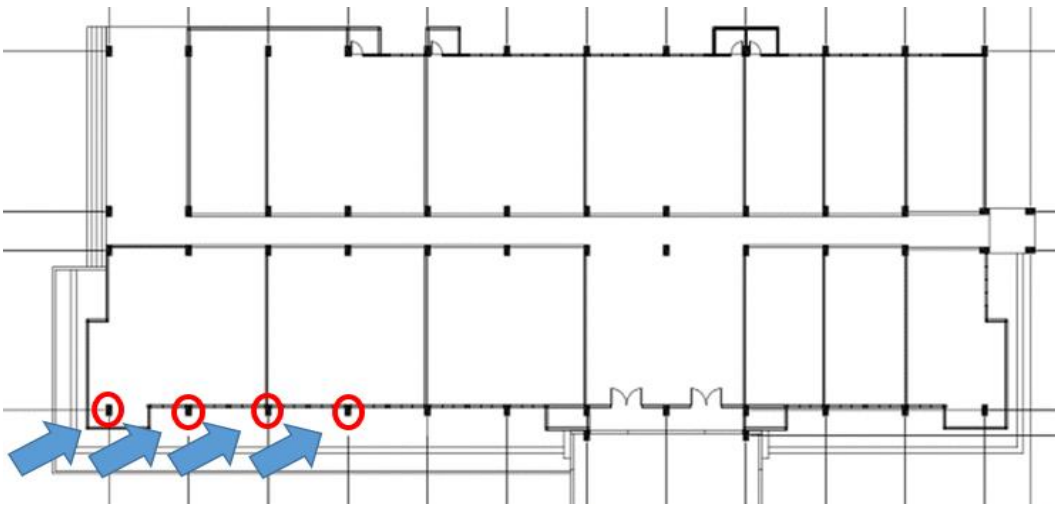

Figure 3. Map of the column locations that suffered the most severe damage.

Figure 4. The column has a crack wide enough at the supports (1/4 span) to expose the reinforcement and corrode.

Figure 5. Beam experiencing permanent deflection (left) accompanied by cracks in the support area (middle) and bending cracks (right)

Overall, the building structure is categorized as severe damage (damage IV) (Amri, 2006). Structural components have been damaged by the destruction of the concrete cover in large quantities until the steel reinforcement is exposed and most of the building frame is damaged which can cause collapse due to permanent deformation of the structure.

There are several possible causes for this damage, namely that the location of the establishment was in an earthquake area. During the 33 years of the building's existence, several earthquake phenomena with quite high magnitudes have occurred. During its lifetime, post-earthquake structural handling has never been carried out. On the other hand, the planning standards applied to buildings in 1990 do not yet apply to the latest planning standards like today. The growth of cracks in structures has become increasingly clear in the last 5 years due to a maximum magnitude 6 earthquake.

Building Slope Test Results

Due to the slope of the building, a thorough deformation is then checked using the a theodolite. The results show that almost all columns have experienced permanent deformation. The building slope is > 1° (± 10 cm) and the building settlement ranges from 5 to 10 cm. The damage category is based on the slope of the building, the building has experienced heavy damage (Amri, 2006). Other factors that cause structural cracks, tilt and subsidence of buildings are the condition of the soil structure which is often flooded and the presence of infiltration in the form of artificial ponds which are located too close to the building. This makes the soil active and gives the building deformation movements when an earthquake occurs. It is necessary to carry out soil investigations in future research to evaluate soil structure and actual foundation bearing capacity. The potential for damage growth is very large considering the location of the building is in the earthquake zone. Buildings can experience a draw failure or collapse suddenly as well as an increase in the slope of the building triggered by ground movement so that the building falls backwards.

Structural Element Capacity Analysis

The configuration of the building structure is quite simple and regular with a square shape with a span of 55 meters and a width of 30 meters. The building is modeled and analyzed using SAP2000 v. 21 (Figure 6). The concrete quality is assumed to be the same as when it was built at f'c 20MPa, the tensile strength of the reinforcing steel used is fy 240 MPa. For structural elements that have undergone corrosion, it is assumed that the performance has decreased by 10% (Gotami & Aswin, 2020). Structural analysis uses the latest regulations including SNI 1727:2020 concerning loading, SNI 1726:2019 regarding earthquake loads, and SNI 2847:2019 concerning concrete structures.

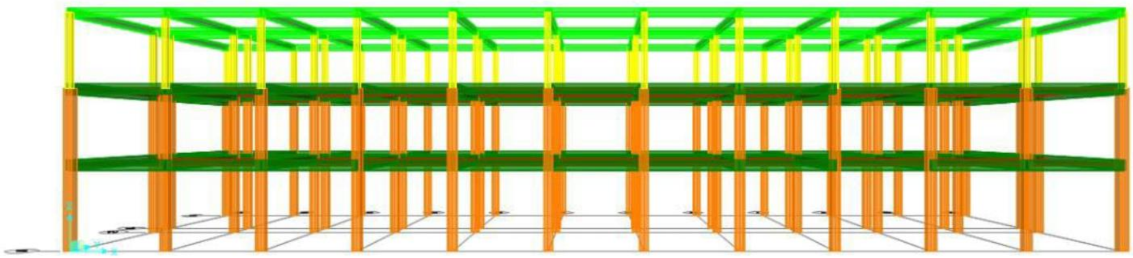

Figure 6. Building structure modeling in SAP2000 v. 21

The results of the structural analysis show that the main column K1 (45 x 45) has experienced excess capacity. The ratio of reinforcement to the cross-section of the existing column is 0.8%. This value is below the cross-sectional ratio requirement which ranges from 1% to 8%. This makes the column unable to withstand the load optimally. Some beam elements have experienced excess capacity where the capacity ratio is greater than 1.0. An indication of collapse has occurred by the presence of cracks in the beams found during visual inspection.

Pushover Analysis

Nonlinear static analysis (pushover analysis) is calculated using the SAP2000 v.21 software. The results show 10 steps and 11 steps of pushing load in the x and y directions on the building structural components until they collapse. The beginning of the plastic hinge occurs in the 1st floor column when the pushing load enters the 2nd step (Figure 7). As the push increases, more plastic joints are formed in the element. Step 8 in the y direction, the plastic joint formed has reached the ultimate capacity (C) in the column shown in yellow (Figure 8). This condition occurs in all 1st floor columns until the pushing load simulation reaches steps 10 and 11 (Figure 9).

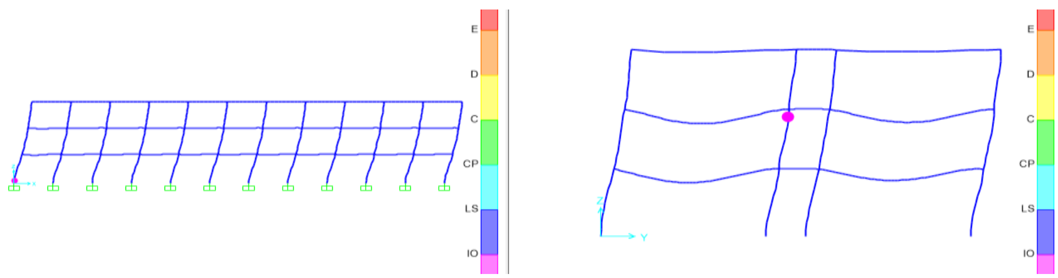

Figure 7. Deformation of push x (left) and push y (right) in step 2

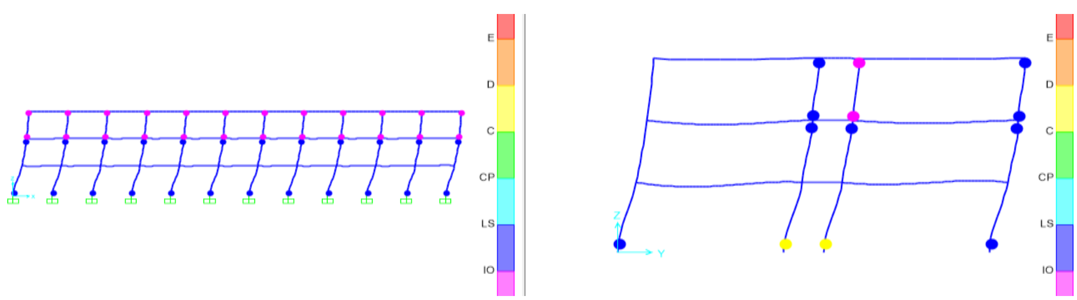

Figure 8. Deformation of push x (left) and push y (right) in step 8

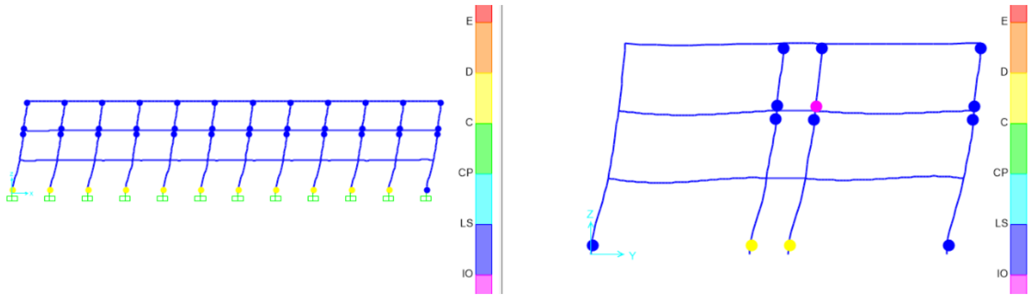

Figure 9. Deformation of push x (left) in step 10 and push y (right) in step 11

Achieving the ultimate capacity in the column structure is in accordance with the cracks that have occurred in the current building. It can be said that the location of the column structure with plastic hinges the results of the analysis results are the same as the cracked or broken condition of the column support at the same location in the building. Collapse is caused by a working load greater than the column cross-sectional capacity. The total deviation obtained is 0.02 for the x and y directions. Meanwhile, the maximum inelastic deviation obtained is 0.016 for the x direction and 0.018 for the y direction. Based on table 5.5.4 ATC-40, the structural performance level of the rectorate building is at Life Safety. This means that the structural components are in a plastic condition. If an earthquake occurs, buildings will collapse and there is a significant risk of loss of life. In connection with the conditions that have occurred and seen in the field, the building structure has displayed indications of structural damage and failure.

Recommendations for Structural Improvements

Based on the results of the analysis, it is necessary to re-plan to reduce the risk of a balance failure. But there are some suggestions to apply the strengthening of the building. Cracks and failures in the column structure are strengthened by increasing the cross-sectional capacity of the structural elements using the concrete jacketing method, so that the cracks in the exposed columns and reinforcement can be closed again. Reinforcement of beam elements is not recommended using Carbon Fiber Reinforced Polymer (CFRP). Under actual conditions, beams require more than 3 layers of CFRP to increase structural capacity. However, the addition of CFRP above 3 layers provides less optimal performance (Sumargo et al., 2014). The ductility of the building needs to be improved by adding columns and joists to reduce the deformation that occurs. The building has a fairly long span of 55 meters. It is necessary to apply a dilation system by dividing the building into 2 (two) parts in the middle of the span. So that it has a separate center of mass of the building and reduces the risk of shear failure. The results of the upper-structure strengthening plan need to be retained by the substructure. So that further investigation is needed on the capacity of the foundation and soil conditions. The investigation will simultaneously answer the cause of the decline in the building.

CONCLUSION

The rectorate building is in a plastic condition where if an earthquake occurs the building will collapse/balance failure/collapse suddenly. The cracked column elements of the support areas found in the field have reached their ultimate capacity due to the low installed column cross-sectional capacity and unable to withstand the overall load of the building when an earthquake occurs. Structural repair and strengthening actions are recommended to maintain the building so that it remains standing, including increasing column capacity with the concrete jacketing method, increasing building ductility, and applying a dilatation system. Suggested follow-up before carrying out structural strengthening include investigation of the substructure, investigation of soil conditions, then proceed with planning the strengthening of the entire building.

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