Performance assessment of building structures due to Pidie Jaya earthquake using pushover analysis

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Abstract. Pidie Jaya earthquake occurred on December 7, 2016 caused the damage of many building structures. Therefore, it is important to assess the performance of building structures in resisting the earthquake load. In this paper, the performance assessment of two building structures, which were the Multipurpose Hall Building that has been deformed permanently and Prosecutor’s Office Buildings that have been experienced some flexural and shear cracks was conducted. The study was started by performing site, design document, and as built drawing assessment. The building structures were modelled as space frames using ETABS software and the data obtained from the site was inputted. The design response spectrum recommended by SNI 1726:2019 was used as spectrum demand. The performance of building structures was assessed by conducting a non-linear push over analysis in two X and Y directions until the structures near to collapse and capacity curves were obtained. By comparing the capacity and demand spectrums in Acceleration-Displacement Response Spectrum (ADRS) format, then the performance points of the structures were obtained based on ATC-40. Based on the inter-story drift at the performance point, then the performance levels of the structures were determined. The assessment results showed that the performance level of the Multipurpose Hall Building structure is Life Safety, while the Prosecutor’s Office Building structure is Damage Control.

1. Introduction
According to the National Disaster Management Agency (BNPB), the 6.5 Mw magnitude earthquake experienced in Pidie Jaya Regency with the epicentre at coordinates of 5.25 latitude north, 96.24 east longitude, and a depth of 15 km at 05:03:36 am in West Indonesia Time on Wednesday, 7th December 2016 resulted in 112 people killed by building collapse, more than 600 people wounded and 85,161 people displaced [1-3]. The earthquake also caused the structural failure of 16,238 buildings in Pidie Jaya, Bireuen, and Pidie Regencies [1,2]. It is reported that the most common construction damage due to Pidie Jaya earthquake was failures of reinforced concrete, confined masonry, and timber structures [3]. Therefore, it is necessary to assess the performance of building structures that have been experienced the earthquake.

Performance assessment of building structures can be performed by conducting dynamic time history analysis so that the deformation of the building structures at any time during an earthquake can be obtained [4-7]. However, to perform the time history analysis, it is necessary to have a ground acceleration data during the earthquake. Another simpler method to determine the performance of the structures is to perform a non-linear static pushover analysis [8-14]. This analysis is carried out by
gradually applying lateral loads to the structures until the structures is on the verge of collapse [15, 16].
In this study, pushover analysis has been used for performance assessment of building structures that have experienced the Pidie Jaya earthquake. Two building structures were used as cases in this study, namely the Multipurpose Hall Building and the Prosecutor's Office Building. Those building structures was chosen as the cases in this study because the Multipurpose Hall Building structure has experienced a very large lateral displacement, while the Prosecutor's Building structure has experienced shear and flexural cracks in its floor beams. And what's interesting is that the two buildings have not collapsed yet. Therefore, the purpose of this study is to determine the performance of the structures of the two buildings so that further structural strengthening efforts can be performed.

Table 1. Structural performance level.

| Performance Level   | Description                                                                                                                                 |
|---------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Immediate Occupancy | The post-earthquake damage state in which only very limited structural damage has occurred. The basic vertical and lateral force-resisting systems of the building retain nearly all of their pre-earthquake characteristics and capacities. The risk of life-threatening injury from structural failure is negligible. |
| Damage Control      | This term is actually not a specific level, but a range of post-earthquake damage states that could vary from Immediate Occupancy and Life Safety.                                                   |
| Life Safety         | The post-earthquake damage state in which significant damage to the structure may have occurred but in which some margin against either total and partial structural collapse remain. Major structural components have not become dislodged and fallen, threatening life safety either within or outside the building. While injuries during the earthquake may occur, the risk of life-threatening injury from structural failure is very low. |
| Structural Stability| This level is the limited post-earthquake structural damage state in which the building's structural system is on the verge of experiencing partial or total collapse. Substantial damage to the structure has occurred, potentially including significant degradation in the stiffness and strength of the lateral force-resisting system. However, all significant components of the gravity load resisting system continue to carry their gravity demands. Although the building retains its overall stability, a significant risk of injury may exist and significant aftershocks may lead to collapse.                                                                 |

Table 2. Deformation limit for the structural performance level.

| Interstory drift limit | Performance Level       |
|------------------------|-------------------------|
|                        | Immediate Occupancy     | Damage Control        | Life Safety       | Structural Stability |
| Maximum total drift    | 0.01                    | 0.01 - 0.02           | 0.02              | 0.33 V_i/P_i         |
| Maximum inelastic drift| 0.005                   | 0.005 - 0.015         | no limit          | no limit             |
2. Performance of structures
According to ATC-40 [17] the structural performance level can be classified as shown in Table 1. The deformation limit for each performance level is given in Table 2. Maximum total drift is defined as the interstory drift at the performance point displacement, while maximum inelastic drift is defined as the portion of the maximum total drift beyond the effective yield point.

3. Assessment method
The research started with the collection and studying the as-built drawings with a focus on the building size, structural members, and details. Furthermore, field assessments were also conducted, and the structural member dimension was measured by using a meter instrument, permanent structural deformation with a water pass, arrangement and diameter of the reinforcing steel bars using a profometer, while the concrete compressive strength was tested using the non-destructive method with a Schmidt hammer type N/N. Moreover, the data on the tensile strength of the reinforcing and shape steel was obtained from job specifications at the time of building construction.

The building structures were modeled as a space frame using ETABS software. The material properties were then inputted to the software, and a non-linear static pushover analysis was performed. Besides the lateral load, the dead load of the structures and other components were also considered. The lateral load was applied step by step with the control of deformation at a top level of the structures in two X and Y directions until the structures were on the verge of collapse.

The design response spectrum, as recommended in SNI 1726:2019 [17] with soft soil, was used as the demand spectrum. The soft soil was assumed based on the results of previous studies conducted in the Pidie Jaya region using microtremor analysis, which showed the soil to have a dominant period greater than 0.6 seconds [1]. Moreover, it was also supported by the value of V30 found to be between 42.51-178.73 m/s [19] as well as the classification of the SNI 1726:2019 [17]. The capacity curves resulting from the push over analysis and the demand spectrum curve were plotted together in the Acceleration-Displacement Response Spectrum (ADRS) format to obtain performance points.

4. Description of the assessed building structures

4.1 Case 1: prosecutor’s office building structure
The type of structure of the building is a reinforced concrete frame. The building was built in 2013 has 3 floors with a building length of 38.00 m, width at 33.50 m, and a total height of 14.00 m. The height of the first, second, and third-floor columns is 4 m each while the size of the columns section is 500 mm x 500 mm with a longitudinal reinforcement of 16D19 mm for each of the floors. The size of the floor beams is 350 mm x 700 mm with the reinforcement in the positive and negative moment areas A, = 10D19 mm and A’, = 5D19 mm. The size of the ring beams is 200 mm x 300 mm with the reinforcement in the positive and negative moment areas A, = 3D16 mm and A’, = 2D16 mm. The thickness of the floor slab is 12 mm.

Based on the site tests, the concrete compressive strength for the columns is 21.24 MPa, the floor beam is 12.40 MPa, the ring beam is 20.21 MPa, and the floor slab is 20.38 MPa. The yield strengths of reinforcing bars for longitudinal and transversal reinforcements are 360 MPa and 240 MPa, respectively. The structural plan of the building is shown in Figure 1. Due to the Pidie Jaya earthquake, almost all the floor beams have shear cracks, as shown in Figure 2a, as well as flexural cracks, as indicated in Figure 2b.

4.2 Case 2: multipurpose hall building
The type of structure of the building is a steel-concrete composite frame. The building was built in 2014 has 3 floors with a building length of 36.00 m, width at 23.40 m, and a total height of 10.00 m. The height of the first, second, and third-floor columns is 4 m, 4 m, and 2m, respectively. The structural plan of the building is shown in Figure 3. The columns K1’ have the size of 500 mm x 500 mm, which are steel WF 400.400.13.20 encased by concrete. The columns K2’ have a size of 400 mm
The beams BL2' have a size of 300 mm x 500 mm, which are steel WF 200.200.8.12 encased by concrete. Based on the site tests, the compressive strength of concrete was 25 MPa. Yield strength and tensile strength of steel are 240 MPa and 370 MPa, respectively, while its modulus of elasticity is 200 GPa. Due to the Pidie Jaya earthquake, the columns in the front row have undergone considerable permanent deformation, reaching 420 mm at the top of the column on the 3rd floor, as shown in Figure 4.

**Figure 1.** Prosecutor’s Office Building structural plan.

**Figure 2.** Cracks of the floor beams: (a) shear cracks; (b) flexural cracks.

**Figure 3.** Multipurpose Hall Building structural plan.
Figure 4. Permanent deformation of the building structure.

5. Assessment results

5.1 Case 1: prosecutor’s office building structure

Pushover capacity curves in X and Y directions are shown in Figure 5. At the same base shear, the displacement in X direction is greater than in Y direction. This means the stiffness of the structure in X direction is smaller than in Y direction. The maximum base shear was 8,500 kN. The structure gets first to yield at the base shear of 7,100 kN with the displacements of 170 mm and 37 mm in X and Y directions, respectively.

Figure 5. The pushover capacity curves of Prosecutor’s Office Building structures.
Since the displacement in X direction is greater than in Y direction, then the pushover capacity curve in X direction was used as the basis to make the ADRS capacity curve. By comparing ADRS capacity curve and ADRS demand curve recommended in SNI 1727:2019 for Pidie Jaya as shown in Figure 6, the performance point was obtained at the spectral acceleration of 0.205 g and spectral displacement of 680 mm. The inter-story drift at the performance point displacement is given in Table 3, and the performance level of the structure can be categorized as Damage Control.

![Graph](image_url)

**Figure 6.** The capacity and demand ADRS curves of Prosecutor’s Office Building structure.

| Story | Displacement (mm) | Story height (mm) | Interstory drift |
|-------|-------------------|-------------------|-----------------|
| 1     | 26                | 4000              | 0.007           |
| 2     | 65                | 4000              | 0.010           |
| 3     | 105               | 4000              | 0.010           |

**Table 3.** Interstory drift of Prosecutor’s Office Building structure.

5.2 Case 2: multipurpose hall building structure

Pushover capacity curves in X and Y directions are shown in Figure 7. At the same base shear, the displacement in X direction is smaller than in Y direction. This means the stiffness of the structure in X direction is greater than in Y direction. The maximum base shear was 27,500 kN. The structure gets the first yield at the base shear of 9,500 kN with the displacements of 34 mm and 50 mm in X and Y directions, respectively.

Since the displacement in Y direction is greater than in X direction, then the pushover capacity curve in Y direction was used as the basis to make the ADRS capacity curve. By comparing ADRS capacity curve and ADRS demand curve recommended in SNI 1727:2019 for Pidie Jaya as shown in Figure 8, the performance point was obtained at the spectral acceleration of 0.742 g and spectral displacement of 54 mm. The inter-story drift at the performance point displacement is given in Table 4 and the performance level of the structure can be categorized as Life Safety.
**Figure 7.** The pushover capacity curves of Multipurpose Hall Building structure.

**Figure 8.** The capacity and demand ADRS curves of Multipurpose Hall Building structure.

**Table 4.** Interstory drift of Multipurpose Hall Building structure.

| Story | Displacement (mm) | Story height (mm) | Interstory drift |
|-------|-------------------|-------------------|-----------------|
| 1     | 113               | 4000              | 0.028           |
| 2     | 244               | 4000              | 0.033           |
| 3     | 310               | 2000              | 0.033           |

**6. Conclusions**

The performance of two building structures subjected to earthquake load was assessed. The assessment was conducted by performing non-linear pushover analysis and the ATC-40 was adopted. The following conclusions can be drawn:
1. The Prosecutor’s Office Building structure has no permanent displacement. However, their floor beams have many shear and flexural cracks due to the earthquake. The maximum inter-story drift of this building frame structure is 0.010. The performance level of this building structure is Damage Control.

2. The Multipurpose Hall Building structure has a permanent displacement of 420 mm on the third floor. However, there is no crack on the structure. The maximum inter-story drift of this building frame structure is 0.033. The performance level of this building structure is Life Safety.

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