Large deformation of building frame structure due to December 7, 2016 Pidie Jaya earthquake

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Abstract. Pidie Jaya earthquake on December 7, 2016 caused the damage of many buildings. This paper presents the case study on a building frame structure that has undergone large deformation during Pidie Jaya earthquake without structural damage. The building has 3 stories. The permanent lateral displacement and inter-story drift of the structure in Y direction at the third story after the earthquake is 420 mm and 4.2%, respectively, which exceed the requirement of Indonesian standard for design building and other structures under earthquake load (SNI 1726:2012). The building structure was modeled as a space frame. A response spectral analysis with design response spectral provided in SNI 1726:2012 was conducted. For comparison, a time history analysis based on real time ground acceleration during Pidie Jaya earthquake was also conducted. The maximum lateral displacement based on response spectral analysis is 469 mm with maximum inter-story drift of 4.79%. Based on time history analysis, the maximum lateral displacement and inter-story drifts are 550 mm and 5.81%, respectively. Based on those results, it is necessary to revise the design response spectrum in SNI 1726:2012.

1. Introduction

Indonesia is known as the ring of fire because it is located at the confluence of three world tectonic plates, namely the Indo-Australian plate which moves northward, the Pacific plate which moves northwest and the Eurasian plate. The existence of the interaction between those plates makes Indonesia as a region that is very vulnerable to earthquakes [1]. Ring of fire is a series of active volcanoes in the world that causes Indonesia to experience the frequency of earthquakes quite often.

Aceh Province, as one of the most west provinces in Indonesia, occupies a very active tectonic zone, because in addition to the three large plates of the world, there are also nine other small plates that meet each other and form a complex meeting point of the plates [2]. Earthquakes have occurred in Aceh both in vertical and horizontal directions, such as in December 2004 with 9.2 SR which is followed by huge tsunami, in April 2012 with 8.6 SR, in July 2013 centered in Bener Meriah District with 6.2 SR and on December 7, 2016, centered in Pidie Jaya District with 6.5 SR. For the purpose of seismic vulnerability assessment, the spectral displacement and spectral acceleration of those earthquake events have been developed [3-6].

The principal reasons for building failure during the earthquake are due to soft storeys, floating columns, mass irregularities, poor quality of construction materials and faulty construction practices, inconsistent earthquake response, soil and foundation effect and pounding of adjacent structures due to large lateral deformation [7]. This large deformation also initiates cracks and under the subsequent load, the crack propagates and causes the structural damages [8]. Types of structural failure due to earthquake can be in the form of shear failure on reinforced concrete beams, destruction of one floor due to
insufficient strength between floors and very large inter-storey drift during an earthquake, failures related to strong beam-weak column, beam-column joint failures and failures related to structural system selection errors during design [9-11].

According to the National Disaster Management Agency (BNPB), the Pidie Jaya earthquake caused 104 deaths, 700 injured, 16,238 buildings damaged and 85,161 people displaced [12]. Damage to the building structures has different levels depending on the magnitude of the earthquake that occurred, the distance of the location to the epicenter, the foundation system, the quality of the building, the mass and geometry of the building and the type of soil at the building site. The behavior of building structures to retain earthquake loads needs to be known to evaluate the strength of structural elements under earthquake loads. With the occurrence of major earthquakes, the Indonesian Government through the National Standardization Agency (BSN) has issued the design code of building and other structures under earthquake load (SNI 1726:2012) [13].

In this paper, the analysis of building frame structure that has undergone large deformation during December 7, 2016 Pidie Jaya earthquake is presented. The building structure is modelled as a space frame and response spectral analysis based on SNI 1726:2012 is conducted. In addition, the time history analysis based on ground acceleration during Pidie Jaya earthquake is also conducted. The lateral displacement and inter-storey drift of structure is presented and compared with that was measured on the site.

2. Methodology
The analytical model used in this study is the frame structure of the Multipurpose Hall Building of Pidie Jaya. The building has 3 stories with the height of the first, second and third story is 4 m, 4 m and 2 m, respectively. The plan of the building is shown in figure 1. In the second floor, there is a cantilever slab and beam with the span of 2 m, as shown in figure 1. The columns and beams of the structure are steel-concrete composites, except cantilever beam which is reinforced concrete. The columns and beams cross sections are shown in figure 2. The slab of the building is reinforced concrete. During the Pidie Jaya earthquake, the structure has undergone a large permanent deformation. The lateral displacements in Y direction of first, second and third stories are 150 mm, 330 mm and 420 mm, respectively. The inter-story drift ratio in Y direction of first, second and third stories are 3.75%, 4.50% and 4.50%. This drift ratio has exceeded the requirement in SNI 1726:2012 which allows the maximum drift ratio of 2%. In X direction there is no permanent deformation was found.

![Figure 1. Plan of analytical model.](image-url)
The building structure is modelled as space frame as shown in figure 3 using structural analysis software, namely SAP 2000. The material properties used in the analysis are shown in table 1.

| Material property                                      | Value       |
|-------------------------------------------------------|-------------|
| Concrete compressive strength ($f_{c'}$)              | 25 MPa      |
| Steel yield strength ($f_y$)                          | 240 MPa     |
| Steel ultimate strength ($f_u$)                       | 370 MPa     |
| Concrete elastic modulus ($E_c$)                      | 23.5 GPa    |
| Steel elastic modulus ($E_s$)                         | 200 GPa     |
| Reinforced concrete density                           | 2400 kg/m$^3$ |
| Concrete density                                      | 2200 kg/m$^3$ |
| Steel density                                         | 7850 kg/m$^3$ |
The loads considered in this study are dead load, live load, wind load and earthquake load. Dead load, live load and wind load are calculated based on minimum load requirement as specified in Indonesian standard [14]. For earthquake load analysis, a response spectral analysis with design response spectral specified in SNI 1726:2012 [13] was conducted. In addition, a time history analysis based on ground acceleration during December 7, 2016 Pidie Jaya earthquake was also conducted. The ground acceleration of Pidie Jaya earthquake can be found in the reference [15]. The data for earthquake load analysis is shown in table 2. The following load combinations (LC) were calculated:

| LC  | Expression       |
|-----|------------------|
| 1   | 1.4 D            |
| 2   | 1.2 D + 1.6 L    |
| 3   | 1.2 D + 0.5 W_x |
| 4   | 1.2 D + 0.5 W_y |
| 5   | 1.2 D + 1.0 W_x + L |
| 6   | 1.2 D + 1.0 W_y + L |
| 7   | 1.2 D + 1.0 L + 1.0 E_x |
| 8   | 1.2 D + 1.0 L + 1.0 E_y |
| 9   | 0.9 D + 1.0 W_x |
| 10  | 0.9 D + 1.0 W_y |
| 11  | 0.9 D + 1.0 E_x |
| 12  | 0.9 D + 1.0 E_y |

Where D = dead load, L = live load, W_x = wind load in X direction, W_y = wind load in Y direction, E_x = earthquake load in X direction and E_y = earthquake load in Y direction.

| Building location | Mayang Lancok, Pidie Jaya |
|-------------------|---------------------------|
| Coordinate        | 5.229 NL; 96.245 EL       |
| Soil classification| Soft soil                 |
| Seismic design category | D                       |
| Seismic importance factor (I) | 1.25                  |
| Response modification coefficient (R) | 8                        |
| Bedrock acceleration at short period (S_S) | 0.802 g             |
| Bedrock acceleration at period of 1 second (S_L) | 0.398 g             |
| Design spectra acceleration parameter at short period (S_DS) | 0.639 g             |
| Design spectra acceleration parameter at period of 1 second (S_D1) | 0.608 g             |

3. Results and discussion

3.1. Lateral displacement

The lateral displacement in X and Y directions obtained from response spectral analysis for all load combinations are shown in figures 4 and 5, respectively. For comparison, the real lateral displacement in Y direction measured in the site is also plotted in figure 5. The displacements in X direction meet the requirement of SNI 1726:2012. However, the displacement in Y direction exceeds the SNI 1726:2012 requirement. The higher displacement in Y direction compared to in X direction is presumably due to the presence of cantilever plate and beam. The presence of cantilever plate results in high bending moments in the columns which cause the large displacement. Another reason for high lateral displacement in Y direction is the stiffness of the structure in Y direction because there is only one raw of columns in the front of the building.
Figure 4. Lateral displacement in X direction obtained from response spectral analysis.

Figure 5. Lateral displacement in Y direction obtained from response spectral analysis.

Figure 6. Lateral displacement in X direction obtained from time history analysis.
The lateral displacement in X and Y directions obtained from time history analysis are shown in figures 6 and 7, respectively. Since the difference from the response spectral analysis is only for load combination with earthquake load, the lateral displacement shown in figures 6 and 7 is only for load combination with earthquake load (LC 7, LC 8, LC 11 and LC 12). The real lateral displacement in Y direction measured in the site is also plotted in figure 7. The lateral displacements obtained from time history analysis are higher than those obtained from response spectral analysis.

3.2. Inter-story drift
The inter-story in X and Y directions obtained from response spectral analysis for all load combinations are shown in figures 8 and 9, respectively. For comparison, the real inter-story drift in Y direction measured in the site is also plotted in figure 9. The inter-story drifts in X direction meet the requirement of SNI 1726:2012. However, the inter-story drifts in Y direction exceed the SNI 1726:2012 requirement.
Figure 9. Inter-story drift in Y direction obtained from response spectrum analysis.

The inter-story in X and Y directions obtained from time history analysis are shown in figures 10 and 11, respectively. Since the difference from the response spectral analysis is only for load combination with earthquake load, the inter-story drifts shown in figures 10 and 11 are only for load combination with earthquake load (LC 7, LC 8, LC 11 and LC 12). The real inter-story drift in Y direction measured in the site is also plotted in figure 11. The inter-story drift obtained from time history analysis is higher than that obtained from response spectral analysis. The higher lateral displacements and inter-story drift obtained from time history analysis and what found in the real structure at the site compared to those obtained from response spectral analysis confirms that the design response spectral in SNI 1726:2012 cannot result in the safe structures in the earthquake-prone areas. Therefore, to have the safe structures in the future, the revision of design response spectral in SNI 1726:2012 is needed.

Figure 10. Inter-story drift in X direction obtained from time history analysis.
4. Conclusion
The response spectral and time history analysis was conducted to study the deformation of building structure due to December 7, 2016 Pidie Jaya earthquake. Based on the analysis, the following conclusions can be drawn:
1. The deformation of structure in X direction meets the requirement of SNI 1726:2012. In the site, there is no permanent deformation in X direction.
2. The deformation of structure in Y direction exceeds the requirement of SNI 1726:2012. The large deformation in Y direction is presumably due to the presence of cantilever in the front row of the column.
3. The deformation of the structure obtained from time history analysis using real time ground acceleration during December 7, 2016 Pidie Jaya earthquake is higher than that obtained from response spectral analysis using the design response spectral provided in SNI 1726:2012. Therefore, the design response spectral in SNI 1726:2012 needs to be revised.

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