Structural Assessment of Rental Housing Flat Lere in Palu Affected by Palu Earthquake on September 28, 2018

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Abstract. Rental Housing flat Lere in Palu, Central Sulawesi is one of rental housing flats built by Directorate General Cipta Karya, Department Public Works and Housing in cooperation with local government of Palu during fiscal year of 2010-2011. It is one of buildings damaged by Palu earthquake. To assess the severity of building damage induced by earthquake, building structural engineering experts were conducting engineering investigation. Data from field investigation were used to develop computer model employed in simulating damage mechanism. By running structural model, one can explain damage mechanism in building during the earthquake. From this study, the building is considered severely damage and need to be destroyed. To rebuilt in the area, it is necessary to use structural system that highly resistance against vertical earthquake and to use updated building design codes.

INTRODUCTION

A series of earthquakes shook Palu and Donggala on Friday, September 28, 2018. According to the analysis from Meteorological, Climatological, and Geophysical Agency in Indonesia (BMKG), the largest earthquake with magnitude of 7.4 took place with source located 26 km north of Donggala-Cental Sulawesi and at the depth of 11 km [1]. Considering the epicenter location and the depth of hypocenter, the earthquake was caused by activity at Palu Koro Fault and could be classified as shallow earthquake. From source mechanism analysis, the earthquake was generated by deformation due to movement mechanism from horizontal fault structure (Slide-Slip). The earthquake caused damages to the houses, building and other infrastructures in the affected areas.

Rental Housing flat Lere in Palu flat is one of buildings affected by Palu earthquake taken place on September 28, 2018. This building was built by Directorate General Cipta Karya, Department Public Works and Housing in cooperation with local government of Palu during fiscal year of 2010-2011. Currently this housing flat has been fully donated to local government of Palu. Due to the damage, this housing flat had to be inspected, evaluated and assessed by building structural engineering experts to determine whether structures were safe or not. These steps are required by local government of Palu to be used as an input for on how to handle the damaged building

After an earthquake event, the post-earthquake safety inspection, evaluation and assessment of houses, buildings and infrastructures in affected area is in order. This is to identify whether structures are safe or not.

This study is carried out by assessing housing flat condition using visual method and simple tools based on practical criteria and secondary earthquake data according to available guidelines [2-6] and previous work [7-9]. It is then followed by detailed structural evaluation of housing flat. To be able to describe the damage mechanism occurred in the building, the building structure was modeled and analyzed using structural analysis software ETABS.

ANALYSIS AND DISCUSSION

Visual Investigation of Building

Survey of building condition assessment post-earthquake taken place on September 28, 2018 at rental low-cost housing flat Lere in Palu conducted on October 13, 2018. Based on visual observation and analysis show that this housing flat suffered major damage in both structure and architectural components as can be seen in Figure 1.a and 1.b, respectively.

(a) (b)

FIGURE 1. Pictures of damaged rental low-cost housing flat Lere: (a) major architectural damage, (b) major structrural damage concentrated on base columns undergone compression failure and combined shear and tensile failure

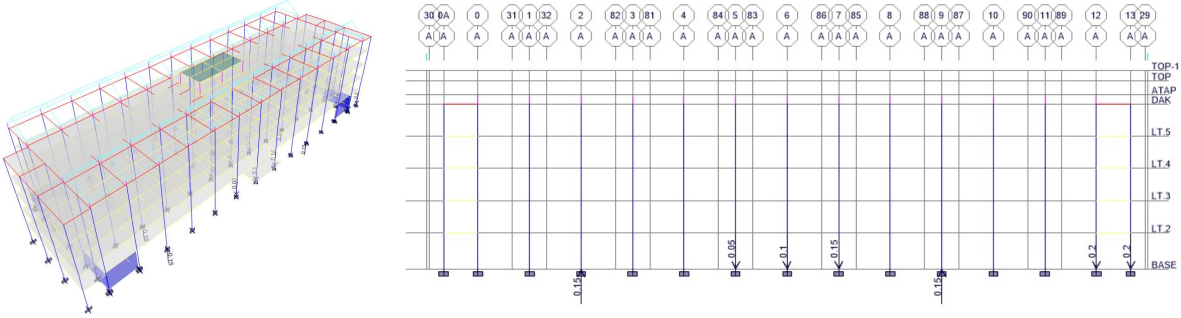
Quantitative Investigation

Failure mechanism of structure occured at rental low-cost housing flat Lere was triggered by vertical earthquake load that was dominant load in this earthquake. The wave of vertical load led to significant soil deformation and thus caused one point of structure deforming down and the other point up (forming wave-like vertical deformation along length of building). This failure mechanism can be described using Figure 2.

FIGURE 2. Soil deformation pattern due to vertical earthquake (pictures continuous along the length of building)

Damage Modeling and Analysis

To take into account the effect of vertical earthquake causing damage in building in the form of vertical deformation, the developed structural model includes the vertical deformation at the base (ground displacement) based on deformation observed on the field as shown Fig. 3. The structural model was prepared using structural analysis software ETABS as as tool (computer aided design).



(a) (b)

FIGURE 3. ETABS Structural model for rental low-cost housing flat Lere with input ground displacement according to measurements from the field: (a) 3D model building, (b) model section along the length of building

After running the structural analysis using software ETABS, the outputs of the analysis in terms of deformation and axial forces are shown in Fig. 4.

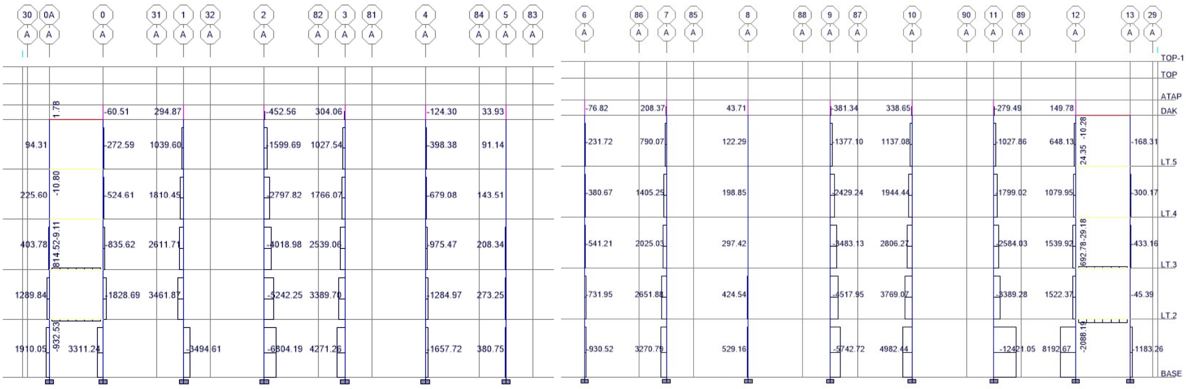


FIGURE 4. Output axial force due to ground displacement

From Fig. 4, it can be seen that vertical movement of ground surface can result in large axial forces in columns. These axial forces have different direction between two adjacent columns. For example, at column 2-A in which ground surface move up 15 cm, there is compression force of 6304.2 kN and at adjacent column (column 3-A) in which ground surface displace down 15 cm, the column has tensile force of 4271.3 kN. On another example, at column 12-A where the ground surface beneath it move down 20 cm, the column has axial compression force of 8192.7 kN and at column 11-A where the gorund surface beneath it move up 20 cm, the column has axial tensile force of 12421.1 kN. Meanwhile, based on theoretical formula, the compressive and tensile capacity of reinforced concrete column can be evaluated as follows: compressive capacity = 0,85 fc' Ag= 0.85 x 29.05 (350x500) = 4.321.187 N = 4321.2 kN and tensile capacity = 0.5 $\sqrt{fc'}$ Ag = 0.60 x $\sqrt{29.05}$ (350x500) =3.050.250 N = 404.23 kN.

From above discussion, it is clear that both in tension or in compression the axial forces occurred in columns exceed their capacities. As can be seen in Fig. 5.a, column 2-A underwent compression failure. On the other hand, Fig. 5.b shows that column 3-A suffered a combination of tensile and shear failure. Since the tensile capacity of column is much lower than the axial tensile force in column, the column was separated into two parts and then displaced to the side due lateral force as shown in Fig. 5.b. Thus, from data and computer model simulation and considering that the large vertical earthquake load coming earlier than that of horizontal earthquake load, it can explain the damage mechanism taken place on building under investigation.

(a) (b)

FIGURE 5. Structural damage: (a) compression failure in column, (b) tensile-shear failure in column

Investigation on Precast System

Structural component of rental low-cost housing flat Lere in Palu uses precast system that has been tested at structural laboratory of the Research Institute of Human Settlement and Institute of Road Engineering Ministry of Public Works and Housing. Reduction factor *R* of 4.35 – 5.05 means that this system fall into structural category moderate moment resisting frame as shown in Fig. 6.

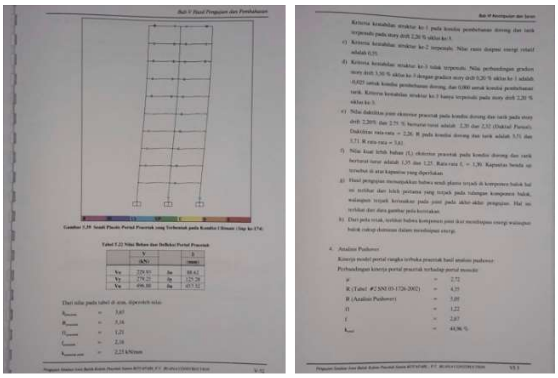


FIGURE 6. Lateral resistance system category of precast system yang digunakan

According to Indonesian seismic design code (SNI 03-1726-2002) and concrete building code (SNI 03-2843-2002), moderate moment resisting frame structure can still be used for region medium earthquake risk (zone 3,4,5), without using shear wall. Shear wall in this building is only provided in the first floor to prevent soft story effect. Damage mode of sway mechanism that was employed based on the assumption the earthquake would not occur in this building with the dominant vertical earthquake load. Random column failure in the first-floor results in random failure mode on structure above the first floor. There is no clear damage pattern on every component of the structure. However, if one compares damage evolution from several components with those crack pattern from testing shown in Fig. 7, one can see similarity in pattern. Cracks started from beam and then go into the joint as can be seen in Fig. 8. Stirrups in column and joint were properly installed, but dominant vertical earthquake load led to concrete crushing as shown in Fig. 9.

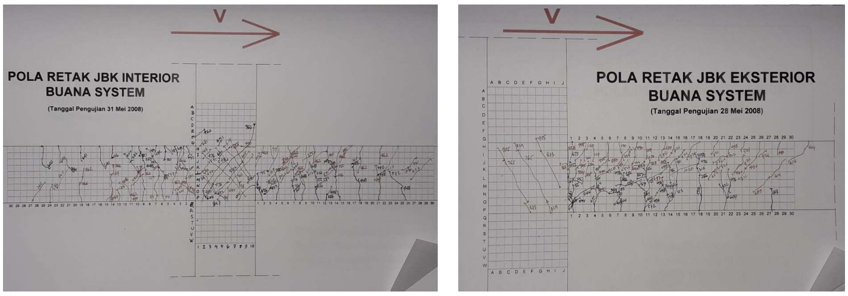


FIGURE 7. Crack pattern at interior and exterior beam-column joints during testing in Laboratory

FIGURE 8. Damage of beam-column joint due to earthquake

FIGURE 9. Stirrups installed properly in column, beam and joint, concrete crushing because of tension

CONCLUSION

The building under investigation suffered major damage in both structure and architecture parts as well as its foundation. The damage of building was mainly caused by column failures at first floor due to high vertical earthquake load that was arriving earlier than horizontal earthquake load. The phenomenon was able to be verified numerically using structural analysis software named ETABS. In addition, the behavior of damage modes occurred in precast system beam-column have been confirmed during testing at the Research Institute of Human Settlement and Institute of Road Engineering Ministry of Public Works and Housing.

Based on the detailed evaluation conducted in this study, the building is determined to be unrepairable and thus needs to be destroyed. If the building is to be rebuilt, it is better to be relocated, built using high performance earthquake resistance structural system that is able to resist vertical earthquake and use recent design building codes.

ACKNOWLEDGMENTS

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