DAMAGE ASSESSMENT OF RENTAL LOW-COST HOUSING FLATS IN CENTRAL SULAWESI INDONESIA AFFECTED BY PALU EARTHQUAKE

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Abstract

Several rental low-cost housing flats built under the program initiated by the Ministry of Public Works and Housing were among those affected by a strong earthquake on September 28, 2018, which was centered in the Palu Koro Fault in Central Sulawesi. One of the important characteristics of the Palu earthquake is the significant vertical earthquake acceleration. The structures of the affected housing flats were designed to be earthquake-resistant according design codes valid at the time of construction. The structural systems used on those buildings were varied including conventional reinforced concrete, precast concrete, and prestressed precast concrete. This paper presents the performance of the structure of rental housing flats in Palu area based on the results of a qualitative and quantitative survey conducted from October to December 2018 in 21 towers at 21 different locations. The study shows that the performance of the rental low-cost housing flat structures is good because design development and implementation fully complies with the requirements of design codes and construction specifications set by the Indonesian National Standard. However, in some areas where vertical earthquake is dominant, some buildings were severely damaged because the earthquake in the form of vertical waves taken place in Palu is not covered in building design codes. Nevertheless, rental low-cost housing flats built by the Ministry of Public Works and Housing are seen to be performing quite well compared to other buildings around them. In addition, the use of precast technology in rental low-cost housing flat structures results in better performance compared to that of conventional system because of better quality control during construction.

Keywords: palu; vertical earthquake; retrofitting; precast; damage level

1. Introduction

A series of earthquakes shook Palu and Donggala areas on September 28, 2018 with its largest recorded magnitude of 7.4 Mw and with its important characteristic of significant vertical ground motion component. These events caused many loss of life and various degrees of damages to buildings and infrastructures in the impacted areas. Among those impacted buildings are several rental low-cost housing flats built under the program initiated by the Ministry of Public Works and Housing and started in 2002.

To determine the damage severity and help the local government planning for further action on the housing flats, structural assessment needs to be carried out. As such, the Ministry of Public Works and Housing sent structural engineering experts to Palu and Donggala areas to inspect and assess structural conditions of housing flats. This study will report and discuss structural and architectural conditions of 21 housing flats surveyed and inspected on 28 – 30 October 2018.

2. Palu Earthquake

Source of Palu earthquake is located 0.18 Southern Latitude and 185 East Longitude with the distance 26 km north of Donggala, Central Sulawesi and the depth of 10 km. Based on information gathered from local people experiencing the earthquake and analysis of shake map in Fig. 1, the ground motion was felt in Donggala (VII-VIII MMI), Palu, Mapaga (VI-VII MMI), Gorontalo dan Poso (III-IV MMI), Majene dan Soroako (III MMI), Kendari, Kolaka, Konawe Utara, Bone, Sengkang (II - III MMI), Makassar, Gowa, dan Toraja (II MMI). With reference to Table 1, Intensity scale of VI-VII MMI means that standard building structures may suffer moderate damage while non-standard building may suffer major damage. On the other hand, intensity scales of III-IV MMI means that the shaking felt by all people in the affected area but no damage is expected. However, if buildings hit several times by a series of earthquake, light damage might occur.

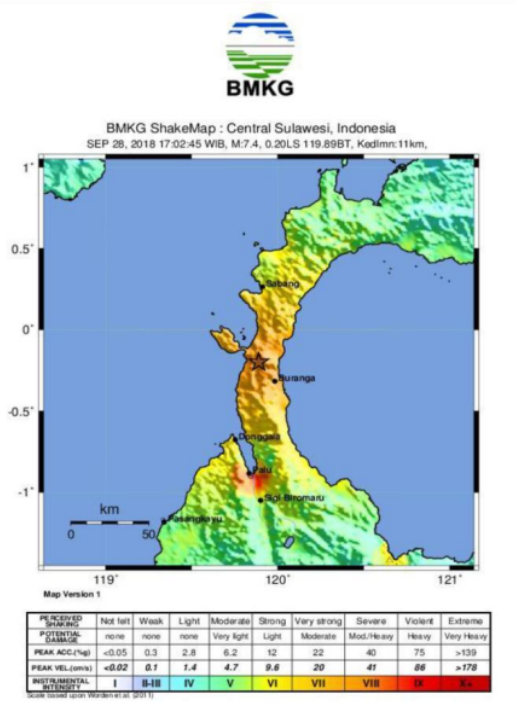

Fig. 1 – BMKG ShakeMap, Modified Mercalli Intensity Scale (MMI): Central Sulawesi, Indonesia

Table 1 – Modified Mercalli Intensity Scale (MMI) of 1931

I. Not felt	Not felt except by very few under especially favorable conditions.
II. Weak	Felt only by a few people at rest, especially on upper floors of buildings.
III. Weak	Felt quite noticeably by people indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV. Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V. Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI. Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII. Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII. Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX. Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations. Liquefaction.
X. Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
XI. Extreme	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII. Extreme	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

3. Material and Structural System of Housing Flats

Since most areas in Indonesia is at risk to earthquake, rental low-cost housing flats were designed to be structurally resistant against earthquake according to applicable Indonesian standards for building and seismic design at the time of construction. The main material used for construction is concrete. Conventional reinforced concrete, precast concrete, prestressed concrete or a combination thereof was employed in structural elements of housing flats. Any non-conventional technology used in the housing flats was first tested at Research Institute of Housing and Human Settlement, Indonesia.

4. Assessment Procedures

For this study, rapid assessment of structural and architectural condition of housing flats after Palu earthquake is conducted using visual and simple tools. Using guides [2-6] and previous studies [7-10], the conditions of buildings can be categorized into several damage levels and their corresponding required repair actions as follows:

- Minor damage of building
  a. No significant settlement of foundation
  b. No structural damage
  c. Architectural damage such as crack and spalling of skim coat cement and crack and spalling of plaster

  The required actions are to repair the damaged architectural components

- Moderate damage of building
  a. No significant settlement of foundation
  b. Cracked on structural component, but no significant change of shape
  c. Architectural damage in the form of crack on the wall and even hole on the wall on certain conditions, but no significant slope

  The required actions are to repair architectural and structural components

- Major damage of building
  a. Significant settlement of foundation

b. Spalling of structural components and even failed structural components, but no failure of overall structure
c. Architectural damage in the form of crack through the wall thickness, slope wall and even failure

There are several alternative actions that can be done on building experiencing major damage as follows:

a. If structural component damages do not cause significant change of shape on reinforcing bar and the overall building, then further investigation needs to be conducted to assess building structure
b. If there is significant settlement of foundation, then further investigation needs to be conducted to assess building structure
c. If structural component damages cause significant change of shape on reinforcing bar and the overall building, then the building can be stated as not functioning structurally.

- Failure of building
  a. Failure of foundation
  b. Fail on one or more structural components causing building failure

Several failure modes of structures that are critical and thus may cause buildings cannot function anymore are:

- Soft story effect
- Weak column strong beam
- Failure at beam-column joint
- Compressive failure

In this study, the following assessment procedure was used:

1. Conduct visual investigation to record structural and non-structural (architectural) damages
2. Compare between recorded damage data and damage criteria
3. Determine the level of damage criteria
4. Propose actions that need to be done based on the damage level

Data employed in this study:

1. Secondary earthquake data from Meteorological, Climatological, and Geophysical Agency, Indonesia.
2. Pictures taken during survey of visual examination.

Condition assessment surveys of housing flat buildings in di Central Sulawesi post-earthquake were conducted at 21 different locations during the period of 28 – 30 October 2018. From these surveys, it was found that structural and non-structural (architectural) damage conditions vary from minor to major damages.

5. Results and Discussions

From survey and analysis of conducted on housing flat structures affected by Palu earthquake, it shows that, from 21 existing housing flats being investigated, there are 18 housing flats having light structural damage, 2 having moderate damage and 1 having major structural damage. Meanwhile, from architectural investigation, there are 17 housing flats having light architectural damage, 3 housing flats having moderate architectural damage and 1 housing flat having major architectural damage.

Housing flats that suffer moderate and major structural damage are:

- Moderate damage (2 housing flats): MTs DDI Lonja and UPT Dinas PU Palu (Fig. 2)
- Major damage (1 housing flat): Univ. Tadulako – Palu (Fig. 3).

Meanwhile, housing flats that suffer moderate and major architectural damage are:

- Moderate damage (3 housing flats): Univ. Al-Khairat Palu, Rusunawa Pekerja Kota Palu dan UPT Dinas PU Palu
- Major damage (1 building): Univ. Tadulako – Palu

Fig. 2 – Front view of damage occurred on rental low-cost housing flat UPT Dinas PU Palu

Fig. 3 – Front view of damage occurred on rental low-cost housing flat Univ. Tadulako

Figure 4 shows the distribution of 21 housing flats suffering various degrees of structural damage. These are housing flats built in the period of 2007-2017. As can be seen, most housing flats have only minor damage. This shows that the seismic performance of those housing flats are good as many buildings around them are severely damaged. In other words, the housing flats perform well against designed earthquake load. One housing flat that suffer major damage is housing flat Univ. Tadulako – Palu constructed using conventional reinforced concrete.

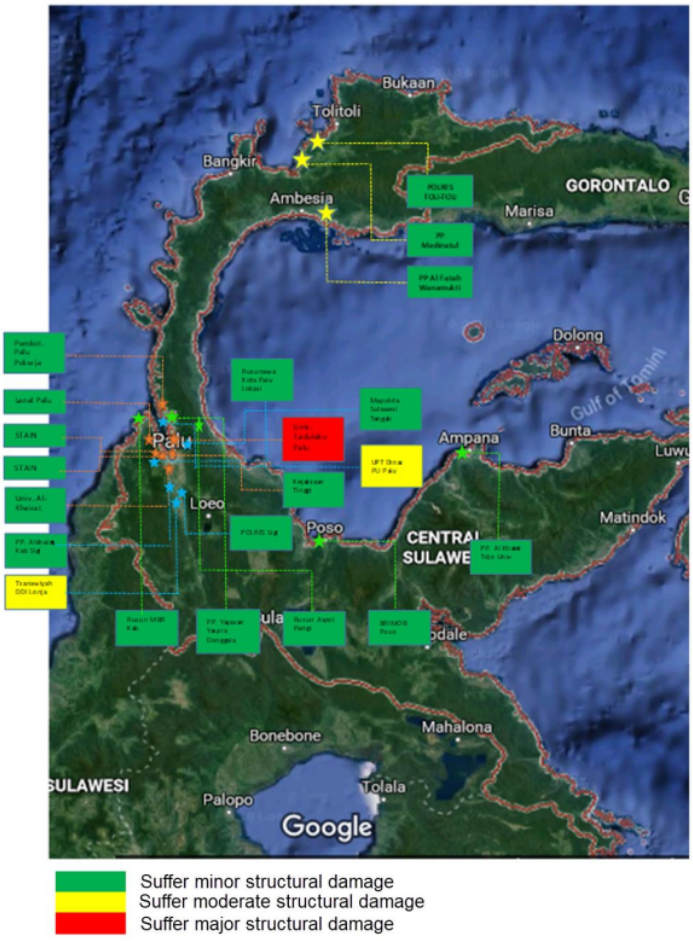

Fig. 4 – Mapping of housing flats suffering structural damage due to earthquake

Distribution of 21 housing flats suffering various degrees of architectural damage is shown in Fig. 5. As can be seen, most housing flats have only minor architectural damage.

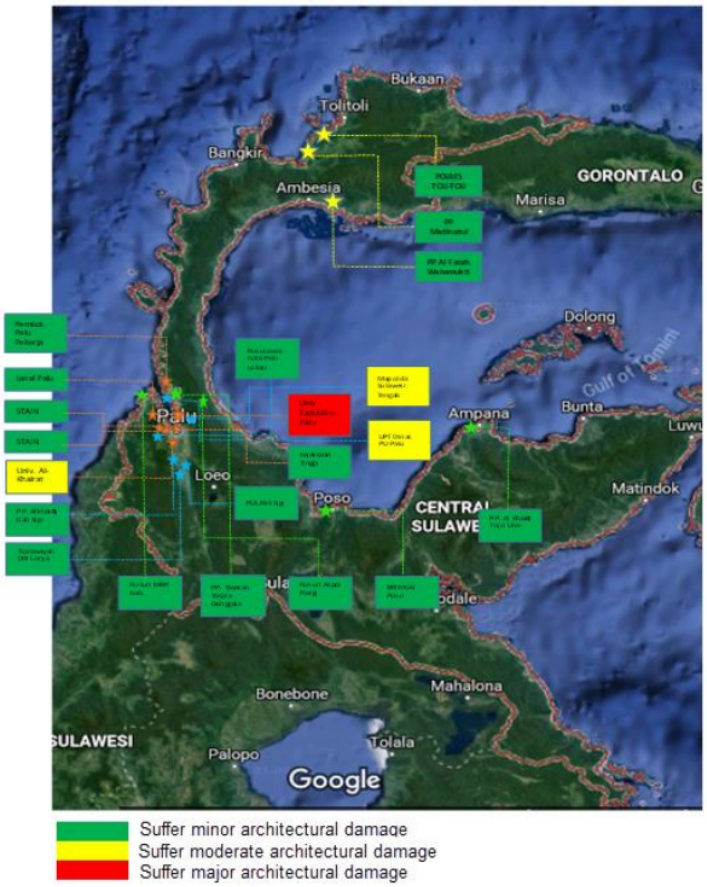

Fig. 5 – Mapping of housing flats suffering architectural damage due to earthquake

Table 2 shows summary of damage occurred on the investigated housing flats. As can be seen, the majority of housing flats perform well under earthquake load.

Table 2 – Summary of damage levels on 21 housing flats investigated in this study.

Damage Level	Structural Damage	Architectural Damage
Minor	18	17
Moderate	2	3
Major	1	1

6. Conclusion

Overall, rental low-cost housing flats in Central Sulawesi built by Ministry of Public Work and Housing of Indonesia perform well against earthquake load especially the ones using precast concrete system. It is because the precast concrete system is prefabricated in controlled environment, thus better quality. In addition, the study also shows the importance of complying with building design codes published by Indonesia National as buildings designed according to Indonesia building codes perform well against the expected seismic design loads.

7. Acknowledgements

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