Correlation of geological conditions and levels of damage in Palu earthquake

R Hidayat*
Balai Sabo, Puslitbang Sumber Daya Air, Badan Litbang, Kementerian PU Sopalan, Maguwoharjo, Yogyakarta-55282

* rokhmathidayat33@yahoo.com

Abstract. The earthquake was occurred in Palu with magnitude 7.4 SR on September 28, 2018. The earthquake caused damage in infrastructure, settlements and casualties. The earthquake also caused liquefaction in Petobo and Balaroa. One of the factors that influence to the level of damage is geological conditions such as geological structures (faults) and rock types. The presence of faults determines the earthquake zone, so that it greatly affects the level of damage. The type of rock in Palu generally consists of alluvial deposits and sedimentary rocks, make the level of damage that occurs has different levels. The results from survey showed that the level of damage to buildings was strongly related to the earthquake zone and rock conditions. Earthquake induce damage more intensively in locations with rocks in the form of soft alluvial deposits and close to the earthquake zone. This condition can be taken into consideration in earthquake disaster mitigation actions. The arrangement of the city of Palu must be carried out with careful planning because the Palu area is on a high tectonic route. To reduce the risk of disasters, structuring and development need to consider a map of earthquake-prone zones of damage.

1. Introduction
An earthquake with magnitude 7.4 SR had occurred on September 28 2018 at 18.01 WITA. The epicenter was 26 km north of Donggala and 80 km northwest of the city of Palu with a depth of 10 km. Earthquake shocks were felt in Donggala Regency, Palu City, Parigi Moutong Regency, Sigi Regency, Poso Regency [1]. Disasters caused by earthquakes often result in many damage of property and casualties, so that mitigation efforts related to the disaster are needed. Mitigation is all actions in order to minimize disaster risk. The potential of geological resources as part of natural resources plays a role in mitigation efforts. Analysis of horizontal displacement and profile across the Palu fault shows the complexity of the fault zone, an average displacement of 3-5 meters, the total length of the fault zone is more than 140 km. The earthquake mechanism shows the direction of fault is north-south [2].

According to Pakpahan et al. 2015 [3], the Palu-Koro Fault is a very active fault. This fault has a location and source mechanism which is divided into several segments. In spatial planning, to reduce casualties due to earthquakes it is necessary to map vulnerable zones damaged by earthquakes. Geological and geotechnical studies and analyzes need to be carried out that will direct suitability for settlement and land use [4]. The success of the damage reduction after the earthquake is proportional to the accuracy
of land use decisions. Geological data that allows reduction of earthquake damage and analyzed in each section separately. Geological data that needs to be examined include soil conditions, rocks and geological structures, especially rock layers and faults [5].

Sulawesi island is located at the colission of three Australian, Philippine and Sundanese plates (the Sunda plate is the eastern part of Eurasia). The Australian and Philippine plates move down the Sunda plate with speeds of 75 and 90 mm/year. In the south of Sulawesi, the fault zone extends from eastern Indonesia accommodates relative movements between the Australian and Pacific plates with transresive faults and block rotations [6]. The Australian plate subduction under the Sunda plate takes place in the Sunda-Banda Arc where it transitions to the Java Trench. Ada gerakan 42mm/tahun blok relative pada zona patahan Palu-Koro [7].

Based on Minister of Public Works Regulation No. 21 of 2007 [8] concerning spatial planning guidelines for areas prone to volcanic and earthquake eruptions, stated that the level of vulnerability of an area to earthquakes is influenced by the type of rock, the slope, presence of fault structures, and earthquake strength. Various geological factors become land control that affect the level of damage, and can be developed into a micro zoning map of earthquake vulnerability. The micro zoning map is very important to support the improvement of the building code (building code) and land use management in earthquake-prone areas [9].

During 2000-2015, every year in the world there was an earthquake with magnitude 7.0 or more amounting to 11-28 times [10]. The area along Palu Bay is an area prone to earthquakes, caused by its geological condition which is in the front arc part of the subduction/collision zone, between the Continent plate in the north, and the Ocean plate in the south; (Hamilton, W., 1979) [11,12].

The strength of the Palu earthquake, which is above 7 in Richter's, has had a huge traumatic impact. The long time of the earthquake and the damage caused caused a great trauma. These natural disasters cause damage in all things. In fact the level of damage caused by the earthquake is not evenly distributed. Many buildings are had little cracks, but in other places there were buildings that were severely damaged and even collapsed. The earthquake also caused landslides, such as the 2006 Yogyakarta earthquake, which triggered landslides (Figure 1).

**Figure 1.** Point of Location of Mass Movement of Rocks due to Yogyakarta Earthquake 2006 [13]

2. **Methods**

This research was conducted through field surveys in several area in the city of Palu and its surroundings. Observe some field phenomena, namely the level of damage to buildings and soil cracks that occur,
then connected with local geological conditions. Observation and examination of field conditions is carried out with a descriptive approach, through measurement and recording of the level of damage in infrastructure.

To be able to properly identify and analyze the relationship of geological conditions and the level of damage at the research site, an investigation was conducted which included several activities in the form of interpretations and studies of regional geological data (previous studies). Based on this data it can be seen a description of the condition of the distribution of rocks and their geological structure. Based on field investigations, we can determine the level of damage of each survey location. The level of damage is grouped into three classes. That’s mild, moderate and severe damage. The location of the survey must spread according to the geological conditions of the field.

Furthermore, geological analysis was carried out, correlation the level of damage caused by the earthquake and the geological conditions. So we got an overview of the geological factors dominant with the level of damage occurred. From the results of this investigation and analysis, expected to be able to recommend anticipatory steps in the development at the time of data collection, especially in regional spatial planning.

3. Results and discussion

Rock Condition

Based observations on the Geological Map Review of the Palu Sheet Scale 1: 250,000 (Rab Sukamto, et al., 1973) the study area generally consists of two rock formations, Aluvium-sediment beach and Molasa Celebes-Serasin.

a. Alluvium -sediment beach (Qap)

This unit consists of sedimentary material including gravel, sand, mud, and coral limestone. Formed in a river, delta and shallow sea environment, is the youngest sediment in this area. The deposits are of Holocene age. The rock conditions in this formation are generally material that has not undergone compacting (loose material). The rock structure generally consists of sand at the top, silt and clay at the bottom. Groundwater depth ranges from 0.5-16m below the surface of the ground.

b. Molasa Celebes and Sarasin (QTms)

This rock is spread in high altitudes, on the sides of mountains in the east and west of Palu City. This formation contains races derived from older rock formations, consisting of conglomerates, sandstones, mudstone, coral limestone, and marl, all of which are compacted. The rocks towards the sea turn to become finer grained clastic rocks.

Geological Structure

Based on the results of studies conducted by the Indonesian earthquake map revision team (Irsyam et al., 2010) active geological structures (fault) that pass through Palu City is Palu Koro Fault and Matano Fault, both of them are active faults, found in the valley of Palu. The main Palu-Koro fault is in the North-South direction while some of them (fractured section) are Southwest-Northeast-oriented. The active fault, which has a North-South direction, is an active fault due to the rejuvenation of an old reactivated structure, while the fracture trending Southwest-Northeast is a very active fault structure today. (Figure 2).

From the geological conditions, the physiography of the City of Palu is closely related to the condition of the fault structures that occur as well as the types of rocks that make up the City of Palu. The left and right sides of the city of Palu are the main fault zone (Palu-koro fault) and consist of rock that is harder than the constituent material.
Figure 2. Regional tectonic system of Sulawesi Island and its surroundings [14] (left), Distribution of earthquake clusters around Palu Koro [3] (right).

The geological and topographic conditions of the Palu area really control the distribution of damage caused by earthquakes. In valleys area which is consisting of soft sediments, there is an increase in earthquake vibrations which results in increased levels of damage. Strengthening earthquakes or earthquake vibrations due to geological conditions have an important impact on the level of damage to buildings that occur. Field observations indicate that the level of damage to the building was caused not only by the level of earthquake strength, but also by the low community’s understanding of the risk earthquake. The majority of buildings which is damaged do not follow regional regulations or standards for earthquake-prone areas. The majority of building structures are not designed to be earthquake resistant, so that was damaged.

In some region of Palu, there are large cracks and landslides. Landslides occur as a result of shear stresses that occur when vibrations from earthquakes exceed the maximum shear stress that can be received by the mass of rock / soil on the slope. While liquefaction is the process of changing the saturated granular soil from solid conditions to a liquid state due to the decrease in the effective stress of the soil. The decrease in effective stress causes the soil to lose its shear strength, so that the soil behaves like a liquid [15].

Figure 3 shows the surface displacement in the earthquake area of Palu. The main horizontal displacement process is north and south direction. West block moves to the south, while east block has a northward shift. Horizontal displacement is greater than 4 m along the fault zone. While the right picture shows the epicenter centers during earthquake peering occurred during the period 28 Sep - 12 October 2018.
Overall the damage caused by the Palu earthquake was quite severe. Field observations at several locations showed that many buildings were damaged, such as fractures and land subsidence. Many earthquakes cause mass movements. In some areas there are many damage in road bodies. In Petobo and Balaroa there is liquefaction or "dissolution" of rock / soil masses. The change in rock mass that is not compact (not consolidated), saturated with water into a melting state. Liquefaction occur mainly in alluvium regions. Earthquake waves cause ground shocks under certain conditions and one of them can cause liquefaction.

**Liquefaction in Petobo and Balaroa**

The liquefaction event is the behavior of the soil under a cyclic load that occurs due to a short cyclic load, the soil mass suddenly experiences a transition from a solid state to a liquid state or has a main consistency such as a liquid. Liquefaction in earthquake can be marked by the presence of ground movement in the horizontal direction, seepage of water out of the fracture of the ground, the movement of sloping or descending buildings, land subsidence, and the occurrence of landslides on dikes and slopes. Buildings that are in a simulated area can result in collapse, tilting or moving sideways.
or even resulting in the collapse of the building. From a number of records of past events, it is known
that liquefaction events have the potential to occur in the consistency of saturated granular soils that
are detached from drainage properties in poor soil. If cyclic loads occur as during an earthquake,
loose sand tends to decrease in volume, this results in an increase in pore water pressure and a
decrease in the effective shear strength of the soil. The Palu earthquake caused liquefaction in Petobo
and Balaroa (Figure 4).

The amplification factor in earthquakes is the ratio of maximum acceleration at ground level to
bedrock. The frequency and amplitude that radiates from the bedrock to the surface of the earth will
change as it passes through the soil sediment layer. This process causes severe damage to the structure
of the building. Earthquake waves that spread on the ground will reflect and spread on the border of
the soil layer which has different characteristics. Zones with thick soft sedimentary layers have
vibration amplification / amplification 4-5 times [16]. The petobo area is quite far from the earthquake
zone but experiences liquefaction due to the thick soft soil layer.

The potential of liquefaction in a soil deposit will be determined by a combination of several
components, including the value of the soil properties index, such as dynamic modulus, humidity,
fill weight, grain gradation, relative density and soil structure. Also environmental factors such as
land formations, earthquake characteristics, geological conditions, groundwater position and effective
soil stress [17]. Based field survey, the level of damage is grouped into three classes. That’s mild,
moderate and severe damage (table 1).

![Figure 4. Liquefaction in Petobo (upper) and Balaroa (bottom)](image)

| No | Building Damage                                      | Damage Level |
|----|------------------------------------------------------|--------------|
| 1  | Thin crack, still decent for residence               | 3            |
| 2  | Large cracks (more than 2cm), not decent for residence | 2            |
| 3  | Severely damaged, not decent for residence           | 1            |
Figure 5. Plot the Location of Field Survey in Geological Map.

The level of damage caused by the Palu earthquake-based survey results, then plotted on a GIS-based geological map (Figure 5). Although there is no real correlation in the level of damage to buildings, most of the buildings that were severely damaged (damage classified as three levels) were concentrated in the central plains of Palu and around the fault line. The level of damage to buildings is greatly affected by the position of the building. In addition to being influenced by the distance to the earthquake zone, the level of damage also affected by soil / rock conditions. Lowland areas with geological conditions in the form of sediment deposits or loose land are severely damaged, while areas are rather high with geological conditions in the form of more compact sedimentary rocks experiencing minor damage. Balaroa and Petobo, although a little far from the earthquake zone but have loose soil conditions, experience the most severe levels of damage. While the Watusampu and West Ova regions with positions in hard rock zones, suffered minor damage.
Table 2. Damage level of each observation location

| No | Location, Damage Level                                                                 | Damage Class |
|----|----------------------------------------------------------------------------------------|--------------|
| 1  | Watusampu, the level of light damage, the building has a thin crack, it can still be inhabited | 3            |
| 2  | Balaroa, the level of damage is very heavy, experiencing liquefaction, destroyed buildings, some buried | 1            |
| 3  | Pengawu, the level of damage is moderate, the road has a crack of 5 cm, the cracked building can still be inhabited | 2            |
| 4  | Baliasih, the level of damage is moderate, the ground has a crack of 10 cm, light cracked buildings can still be inhabited | 2            |
| 5  | Gumbasa, the level of damage was very heavy, irrigation canals were cracked up to 25 cm, irrigation buildings were severely damaged | 1            |
| 6  | Petobo, the level of damage is very heavy, experiencing liquefaction, buildings destroyed, some buried | 1            |
| 7  | Horse racing, moderate damage, cracked soil, light cracked buildings can still be inhabited | 3            |
| 8  | Ova Barat, the level of damage is mild, light cracked buildings can still be inhabited    | 3            |

4. Conclusions
Based on the results of the study of the influence of geological conditions to the level of damage to buildings is very significant, especially fault zones and rock conditions. Development in Palu city of Palu must be done immediately so the communities activities can normal immediately as usual. Development in Palu city requires careful planning because the Palu area is on a high tectonic track. To reduce the risk of disasters due to population growth and increasing settlement needs, structuring and development need to consider a map of earthquake-prone zones of damage. The geological conditions, especially the distribution of rock types and fault zones, must be taken into consideration in the development of the development of Palu City in the future. Socialization is needed for the community to raise awareness that the Palu area and its surroundings are earthquake-prone areas. For this reason, efforts are needed to improve human quality / increase human resources, with knowledge about earth and earthquake. The level of damage to buildings is closely related to the structure of the building, so it is necessary to socialize earthquake resistant buildings.

References
[1] Arnani M 2018 Gempa 7,7 Guncang Donggala Sulteng, Berpotensi Tsunami ed B Galih https://nasional.kompas.com/read/2018/09/28/17173901/gempa-77-guncang-donggala-sulteng-berpotensi-tsunami
[2] Valkaniotis S, Ganas A, Tsironi V and Barberopoulos A 2018 A preliminary report on the M7.5 Palu earthquake co-seismic ruptures and landslides using image correlation techniques on optical satellite data, Report submitted to EMSC on 19 October 2018 12:00 UTC, https://www.researchgate.net/publication/328414705
[3] Pakpahan S, Ngadmanto D and Masturyono 2015 Analisis Kegepmaan di Zona Patahan Palu Koro,Sulawesi Tengah, Seismicity Analysis in Palu Koro Fault Zone, Central Sulawesi Journal of Environment and Geological HazardsJurnal Lingkungan dan Bencana Geologi 6 No.3 Desember 2015
[4] Westra P 2010 Kontribusi Geologi Dalam Pembangunan Kota Wilayah Bengkulu Paska Gempa Bumi *Jurnal Penelitian UNIB XVI* No.1 Januari 2010 pp 21-27 21

[5] Tudes S 2012 *Correlation Between Geology, Earthquake and Urban Planning* (https://www.intechopen.com/books/earthquake-research-and-analysis-statistical-studies-observations-and-planning/correlation-between-geology-earthquake-and-urban-planning)

[6] Rosa and J Taugaloidi 2004 GPS and seismological constraints on active tectonics and arc-continent collision in Papua New Guinea: Implications for mechanics of microplate rotations in a plate boundary zone *J. Geophys. Res.* 109 B05404, doi: 10.1029/2003JB002481

[7] Socquet A, W Simons, C Vigny, R McCaffrey, C Subarya, D Sarsito, B Ambrosius and W Spakman 2006 Microblock rotations and fault coupling in SE Asia triple junction (Sulawesi, Indonesia) from GPS and earthquake slip vector data *J. Geophys. Res.* 111 B08409 doi: 10.1029/2005JB003963

[8] Peraturan Menteri Nomor 21/PRT/M/2007 *Pedoman Penataan Ruang Kawasan Rawan Letusan Gempa Berani Dan Kawasan Rawan Gempa Bumi* Kementerian PU

[9] Husein S, Karnawati D, Pramunijoyo S and Ratdomopurbo A 2007 Kontrol Geologi terhadap Respon Lahan dalam Gempabumi Yogyakarta 27 Mei 2006 upaya pembuatan peta zonasi mikro di daerah Bantul *Seminar Nasional 2007 Geotechnics for Earthquake Engineering Universitas Katolik Parahyangan Bandung*

[10] USGS (United States Geological Survey) 2017 *Tectonic Summaries of Magnitude 7 and Greater Earthquakes from 2000 to 2015*, Reston, Virginia

[11] Baeda and Yasir A 2011 Seismic and Tsunami Hazard Potential in Sulawesi Island, Indonesia *Journal of International Development and Cooperation* 17 No. 1 pp 17-30

[12] Daryono M, Natawidjaya D H and Sapiie B 2013 Paleoseismology of Palukoro Fault, Historical Records of 1907 & 1909, and recently 2012 Earthquake Events in Central Sulawesi, Indonesia. *Paparan Penelitian dalam 3rd International Symposium on Earthquakes and Disaster Mitigation Yogyakarta*

[13] Karnawati D 2006 The Mechanism Of Rock Mass Movements As The Impact Of Earthquake *Geology Engineering Review And Analysis dinamika TEKNIK SIPIL 7* Nomor 2 Juli 2007 pp 179–190

[14] Hall R. 1999 Neogene history of collision in the Halmahera region, Indonesia, *Proceeding Indonesia Petroleum Association* 1999.

[15] Yeats R S, Sieh.K and Allen C R 1997 *The Geology of Earthquake* 568 pp New York; Oxford University Press

[16] Setiani N, Zaenudin A and Hidayati S 2014 Amplifikasi Gempabumi Daerah Subang Jawa Barat, Jurusan Teknik Geofisika Universitas Lampung, https://media.neliti.com/media/publications/244755-amplifikasi-gempabumi-daerah-subang-jawa-af426f73.pdf

[17] Warmun H and Jumis D Y 2013 Kajian Potensi Likuiifikasi Pasca Gempa Dalam Rangka Mitigasi Bencana Di Padang *Jurnal Rekayasa Sipil*

[18] Badan Nasional Penanggulangan Bencana (BNPB) 2012 *Perka BNPB No.2 Tahun 2012 Tentang Pedoman Umum Pengkajian Bencana*, BNPB Jakarta

[19] Kahruddin M S, Hutagalung R and Nurhamdan 2011 Perkembangan Tektonik dan Implikasinya Terhadap Potensi Gempa dan Tsunami di Kawasan Pulau Sulawesi, Proceeding JCM Makassar 2011. 1-10, Makassar: The 36th HAGI and 40th IAGI Annual Convention and Exhibition pp 26-29 September 2011.

[20] Supartoyo, Sulaiman, C and Junaedi D 2014 Kelas Tektonik Patahan Palu Koro, Sulawesi Tengah, Tectonic class of Palu Koro Fault, *Central Sulawesi Journal of Environment and Geological Hazards, Jurnal Lingkungan dan Bencana Geologi* 4 No.2 pp 111-127