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# PALU EARTHQUAKE CASE STUDY: INDUCING AND PRINCIPLE OF ITS COUNTERMEASURES

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## ABSTRACT

The Palu Earthquake disaster on Friday 28th September 2018 in Central Sulawesi of Indonesia with the scale magnitude 7.5 of Richter Scales impacted to the huge damages area with a lot of victim and other construction damages either infrastructures or irrigation channel facilities. The earthquake induced the number of disasters such as tsunami, liquefaction, landslide and subsidence and damages the human settlement, plantation and rice field. Based on geology condition which state that the earthquake location laid on the Palu-koro active Fault therefore the soil layer conditions are dominating by the sediment deposit consist of the material molasse with the loose of sandy silty clay within un-experienced depression yet or un-confined pressures. In the saturated condition will influence increasing pore water pressures due to the soils are confined by the excessively water during earthquake and probably tsunami impact. Impacting of the pore water will affect to the liquefying soil and automatically will be decreasingly the soil shear strength parameters. Based on the morphology as a gently slope with the gradient is less than 1%, the excessive pore water pressures can intensively increase and push the soil layers on above troughing the cracks or on the weak places of the molasse soils and developing the boiled sand. If the gradient slope is less than 1% will affect to the land movement or transversal landslide such as in Sibalaya and Jonooge villages, whilst in Balaroa and Petobo villages with the gradient of slope less than 1% the bearing capacity will decrease and affect to land subsidence. Therefore, based on the analysis from investigation and soil characteristics of soils which are sensible to the liquefaction potential, the countermeasure recommendations prefer with the technology for

protecting the increasingly pore water pressures, such as an arrangement of drainage pattern system and stone column or Vibro compaction.

## INTRODUCTION

Indonesia is a country with many natural disasters that cause huge losses. The Jogjakarta earthquake [1] and the Palu earthquake are some of them. Palu earthquake that occurred in the evening of Friday, September 28 2018 with a magnitude of 7.5 on the Richter scale caused such a large damage impact due to a shift in the active fault "Palu Koro" as a result of the tectonic process. As a result of the influence of the movement of the "Palu Koro" fault, the sediment in the form of this scrap material has not undergone a lithification process or has not experienced depression and has not been fully consolidated. This cleavage material is in the form of young volcanic deposits and is known as the "Molasses" layer with loose characteristics and a uniform grade and is not completely sedimented. Thus the "molasses" layer is prone to external force disturbances such as sudden loads, especially repetitive loads due to earthquakes and an increase in soil pore water stress. The increase in soil pore water stress is due to the increase in groundwater discharge due to the increase in ground pressure load (confining pressures) when the earthquake occurs and the additional volume of water that seeps into the soil layer from the "Tsunami" event. Thus it causes an imbalance of the "Molasses" layer so that the value of its shear strength decreases and due to its sloping geography it makes it easier to move to find a new balance resulting in "Liquifaction" and landslides covering a large area.

The impact of the earthquake disaster was immediately felt in the cities of Palu, Sigli and Donggala and several surrounding areas. The occurrence of landslides and liquefaction is related to one another because the morphological conditions of the Palu area have a fairly gentle slope and vary, namely alternating, both sloping and slightly steep. The earthquake that occurs is felt with a frequency of occurrences up to many times to reach a level of stability, resulting in ground movement in the form of creeping landslides and liquefaction.

The occurrence of an earthquake accompanied by its effects, such as: Tsunami, liquefaction and landslides resulted in a very terrible impact so that many victims died and were injured and were displaced in several shelters because hundreds of houses and even thousands of people were damaged.

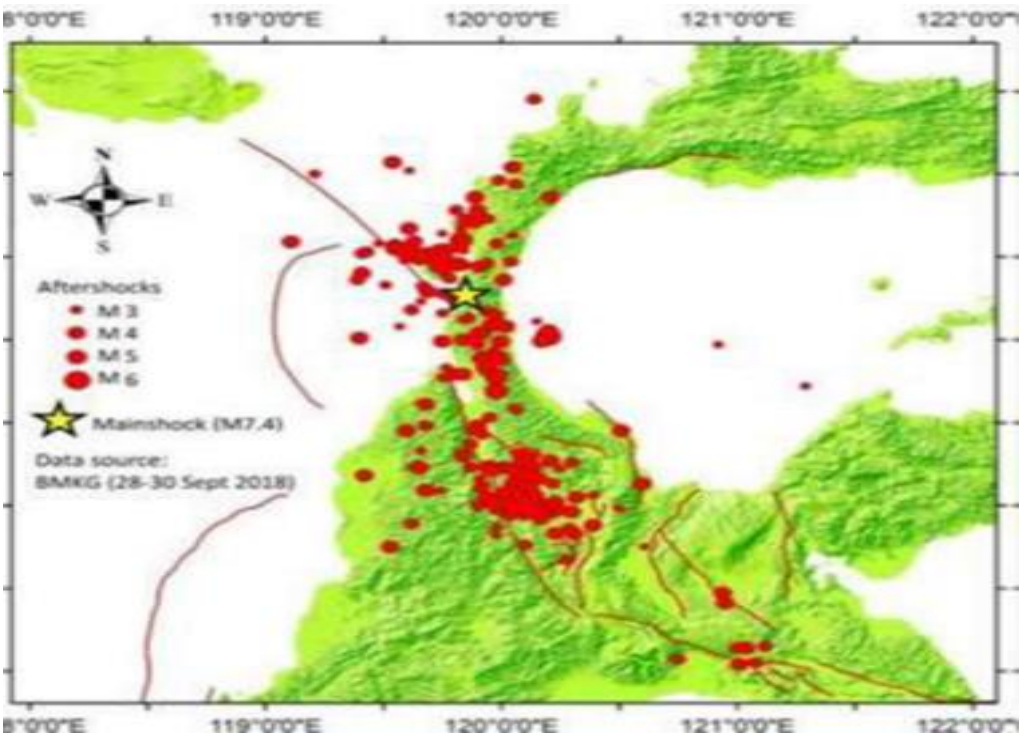
## METHOD OF INVESTIGATION

The Ministry of PUPR (Public Works and Public Housing) through the Directorate General of Highways and the Road and Bridge Research and Development Center (Pusjatan) - the R & D Agency and the related PUPR Office work together to find solutions to overcome them. This activity was initiated by collecting secondary data and field investigations for evaluation and analysis purposes in order to find appropriate and appropriate handling solutions because many infrastructure conditions were damaged and needed to be repaired immediately, such as several roads / bridges and heavily damaged irrigation channels. Handling damage to infrastructure buildings that needs to be done is by studying the mechanism of the Earthquake event and its impact on the occurrence of other disasters which are also important factors and need to be evaluated first with data from field and laboratory investigations, especially in determining the soil shear strength parameter as a design parameter.

## GEOLOGY AND PALU KORO FAULT

Based on regional geology, the Palu area consists of alluvium deposits and Holocene coastal deposits (Qap). These deposits consist of gravel, sand, mud, and coral limestone. These deposits form in shallow rivers, deltas, and marine environments. Because these deposits are young sediments, the existing layers have not undergone the entire lithification process or cementation processes and have not fully consolidated so they are prone to disturbances.

The Palu-Koro Fault in Central Sulawesi, in terms of geological maps, is in an active tectonic fault zone and field conditions can be identified in materials containing uniformly graded material content and a combination / mixed with clay rock that was previously degraded and deposited in the location. Most of the material encountered can mostly be indicated as "Molasses", namely the degraded rock to form unsemented material which is a mixture of tuff volcanic breccia debris. The location of the Palu-koro Fault which stretches in the form of a "Flowing Horizontal Fault" with the direction NNW - SSE and the intensity of the earthquake in Palu, the Geological Map and the location of the Palu Earthquake Source are shown on Figure 1.



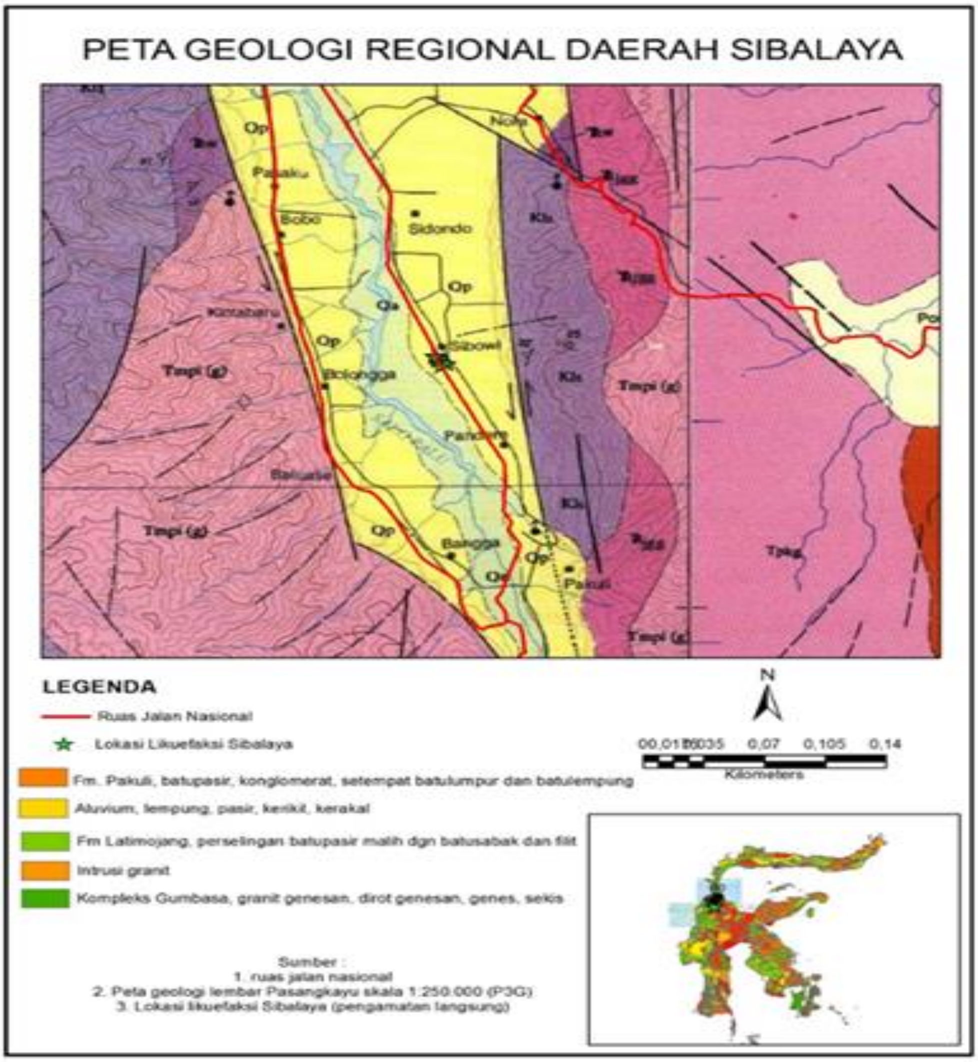



**Figure 1** Geological Map of Palu area, Position of Active Palu-Koro Fault and Earthquake Source [2]

RESULTS

***Disaster area distribution***

Areas affected by the earthquake resulting in the Tsunami, Liquifaksi and Longsoran disasters include: Jonooge, Sibalaya, Petobo and Sigi. The location of the disaster in the Sibalaya location is located 30 km to the south of the city of Palu so that in brief the locations that have an impact on echoes and other disaster impacts such as Tsunami and Liquifaksi as well as locations due to landslides are shown in Figure 4. The movement of land due to confined pressures is dominated by translational landslides such as in the Sibalaya, Jonooge and Petobo areas. Meanwhile, at the Balaroa location, subsidence occurred in a certain area because the submerged soils would try to find a balance between the bars and the surrounding area. Therefore, the disaster-impacted location in Sibalaya is in the Palu valley and is an imperfectly depressed zone due to regional tectonic processes (continuous with the effects of other earthquakes, especially those near and around it) which impact the movement of the Palu Koro Fault. The location of Donggala and its surroundings on the Palu - Tawaeli road and Airport is more dominated by the earthquake and tsunami as well as some liquefaction.

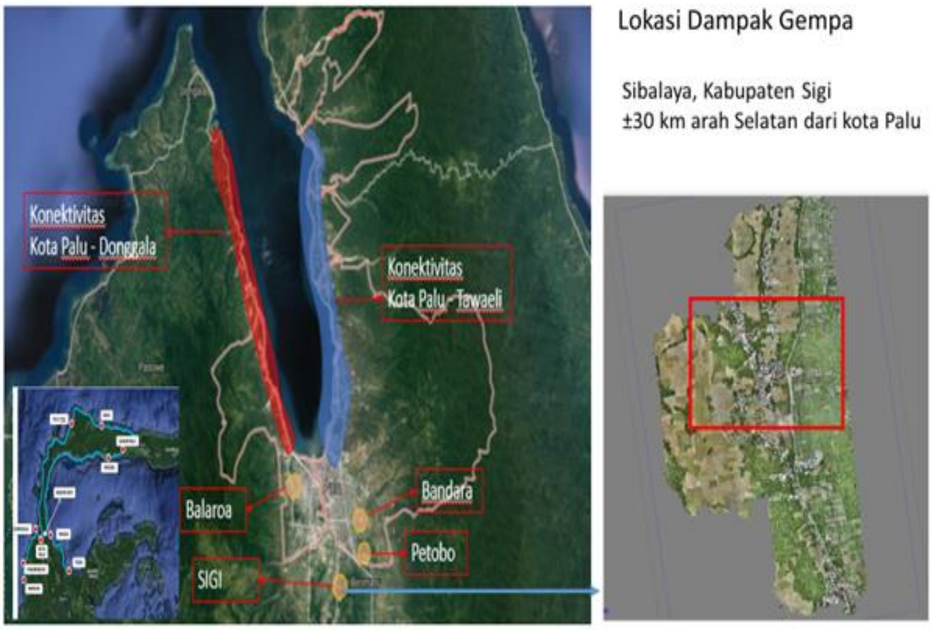



**Figure 2** Location of Disaster due to Palu Earthquake 7.5 Richter Scale (Pusjatan, 2018)

***Assessment on the potential of earthquakes, Liqufactions and tsunami***

Analysis of the study of the Palu Earthquake disaster based on a geological study based on the Palu Geological map (Figure 3) proves that the earthquake event was caused by several conditions that showed the following symptoms:

***Potential earthquake***

a) There is a major geological structure in the form of the Palu Koro fault in the form of a "Flowing Horizontal Fault" with the direction NNW - SSE, characterized by the straightness of the hills that have shown movement symptoms at the time of their formation by showing a triangular facet with details in the western part of the hammer valley and hills with a steep slope in the east.

b) At the location there are several minor fault structures, characterized by lines and several locations where the morphology is a hilly area due to previous tectonic processes which impacted and were detected in local subsidence events.

***Potential tsunami***

a) The existence of horizontal faults, it is possible to have some potential instability of the location so that it will have an impact on the balance of the molasses sediment layer in saturated conditions so that its stability includes the sea.

b) The high intensity of the earthquake, MMI VIII - X, has the impact of increasing water tension that is not constant and increasing the saturation of both groundwater and sea water. In seawater, it will increase tidal waves with a large frequency and amplitude so that the tidal waves of sea water can reach the land repeatedly.

***Potential liquidity and mudflow (sand boild),***

a) As a result of earthquake shocks, it causes liquefaction of the soil (liquefaction) which is caused by water pressure whose intensity is quite large with the strength along with the magnitude of the earthquake.

b) The liquefaction process occurs due to:

i. The soil layer in the form of material sediment that is formed has almost various gradations [3] and the soil has the potential for liquefaction if it is composed of 2 types of silt sand, namely unconfined soil and confined soil. Soil [4]. According to the results of the investigation it characterizes as a layer of silt sand (sandy-silt) which has the potential to experience soil liquefaction or liquefaction.

ii. The earthquake that occurred resulted in the activation of cracks on the surface of the ground in the fault zone / minor fractures (fault lineations), so that gaps with varying widths were formed, between 10 mm - 100 mm.

iii. The finer silt and clay material mixes with subsurface water which experiences additional pressure due to increased water pressure so that it is pressed to the top and out through the cracks as a result of which it appears to the surface in the form of mud (sand boiled) which can be found in several places around the fault or fracture location.

iv. The next consequence is that below the soil layer that has experienced mudflows, a cavity is formed or closes and the soil layer above has the potential to collapse (soil subsidence).

v. There is an increased lateral stress due to the increase in pore water tension with a large earthquake intensity (MMI between VII - 10) which is spreading and gushing upward, especially in the fracture area.

vi. The loose silt sand material around the bursts which is very loose / decomposed will descend and be above the clay rock base rock with a slope that is not steep / sloping [4].

### *Potential for subsidence and landslides*

a) Based on the results of field measurements both manually and by DTM (Digital Elevation Modeling) and GCP (Ground Control Point), it shows that landslides occurred on gentle slopes with unconfined soils, and are shown in Fig. 3.

b) The study and evaluation of the Sibalaya location shows that the landslide location was caused by the accumulation of water with great pressure and was stuck on the hills formed during the tectonic process that had taken place before.

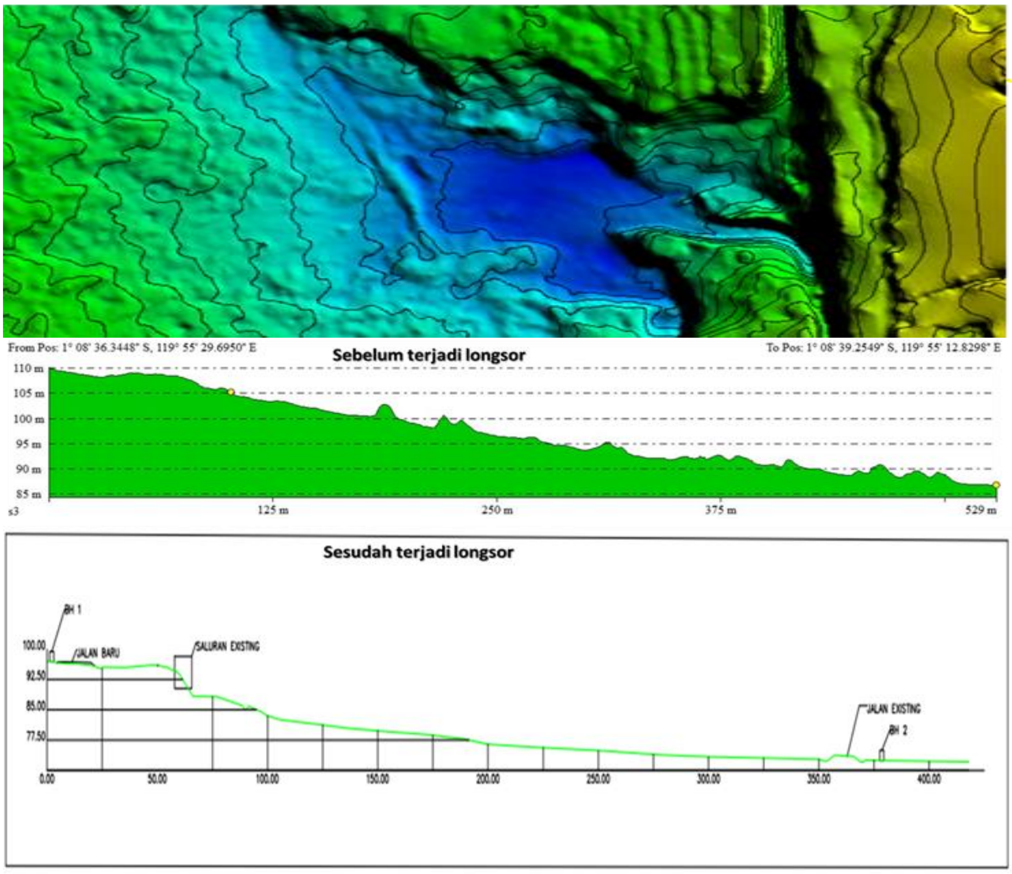



**Figure 3** Cross sections at the Sibalaya location (before and after landslides) due to the Palu earthquake [2]

### *Field investigation results*

The results of field investigations obtained are very helpful for evaluating the mechanism of the earthquake, which has the impact of causing other disasters. Field investigations carried out include: Sondir Testing, Geoelectric Estimation, Geoseismic Estimation and Technical Drilling. In addition to the gradation of the material and identifying its semented level (unconfined or confined) as identification of the potential for liquefaction, drill data (N-SPT values) and sondir data (qc and JHP values from CPT results) are also used which are one way to determine the resistance / strength of the layer land against potential liquefaction.

To find out the spread, other field test data is needed, such as estimation from non-destructive tests both Geoelectric and Geoseismic [5]. Furthermore, it was stated that from SPT and CPT data, parameters of soil strength withstand earthquake liquefaction (CRR), ground shear stress due to earthquakes (CSR) and safety factor were also conveyed. Types of soil layers that are potential for Liqufaction and landslides [4].

***Cone penetration test***

Based on several results of field investigations conducted, some data were obtained which were used for seismic analysis and other impacts such as Tsunamis, Liquefaction, Landslides and Land subsidence. The results of the investigation by CPT (Cone Penetrometer Test) or sondir showed that the depth of the hard soil layer was obtained at a depth of 10 m from the local soil surface. The result of the end resistance value (qc)> 1500 kPa is quite shallow and this shows that the unsaturated state has a large bearing capacity. When further observed the gradation as shown in Figure 4, this material has various grains and is very sensitive to the potential for liquefaction, especially due to changes in the saturation process accompanied by increased pressure (confined pressures).

By paying attention to its nature that the layer of Molasse material is not perfectly confined so that it easily absorbs water and when this absorbed water has a large hydrostatic pressure it will become saturated and try to find a partial escape through the cracks and cause a burst of loose sand (Boiled Sands).

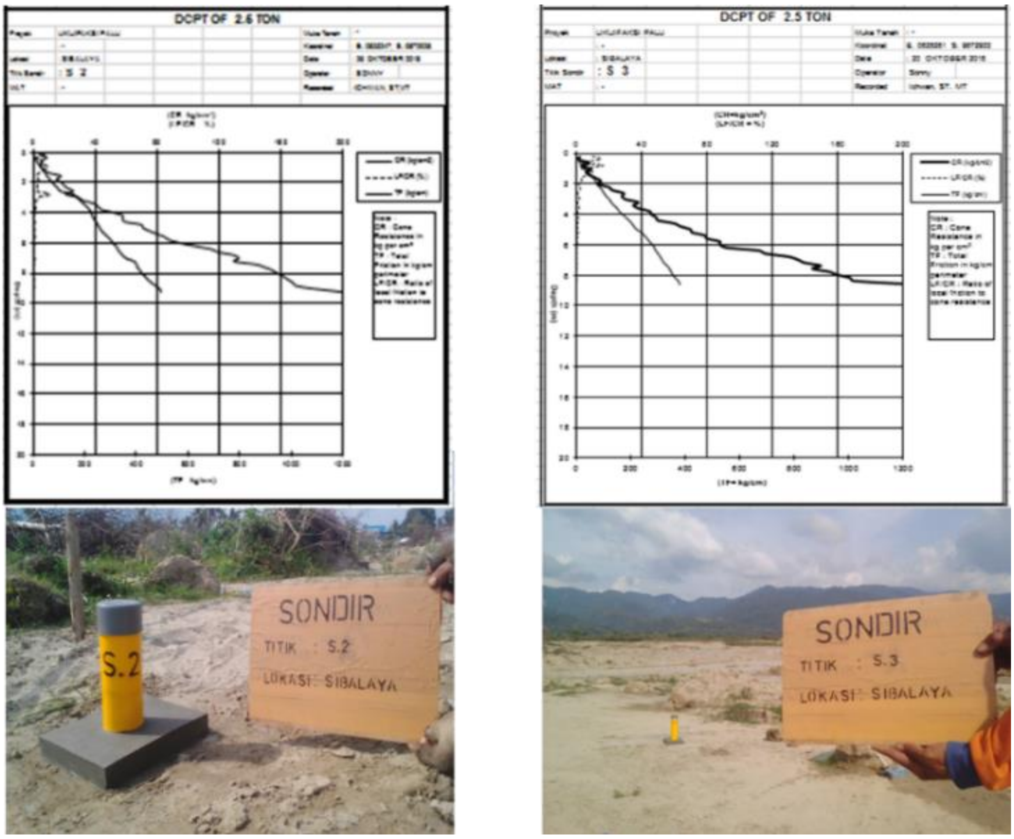



**Figure 4** CPT values from site

***Geoelectrical resistivity tests***

From the geoelectric test of GL1 (Figure 5), the upper part is adjacent to a secondary irrigation canal whose presence is suspected to be in the minor fault area of the Palu-Koro major fault. This layer provides information on the presence of an unfettered and easily intrusive layer that originates underneath. This condition is indicated by the existence of springs that pass through the fracture and partially saturate and melt the unconfined sand layer of Molasse to find a way out, resulting in liquefaction of the soil (liquefaction process).

From the geoelectric test of GL3 at the bottom, it is found that a layer of loose, saturated sand is spread out with a relatively shallow depth with loose and saturated conditions because it is no longer confined so that it experiences movement (landslide), there are 3 main layers of GL:

1) Layer 1 ± 5 meters - 25 meters with a resistivity value of 1038 Ωm - 6081 Ωm is a layer of molasses and stockpile soil (Unconfined and Confined Molasse layers)

2) Layer 2 with a resistivity of 177 Ωm - 429 Ωm at a depth of ± (25 meters - 32 meters): the sandy mud layer with its constituent lithology is silt with a mixture of sand in it (impermeable layers as Film Layers

3) Depth ± (32 meters - 39.6 meters) with a resistivity value of 12.5 Ωm - 73.3 Ωm: The lithology of this layer is thought to be mud or mud rock having a higher moisture content than other lithologies (the presence of claystone / clay-shale layers).

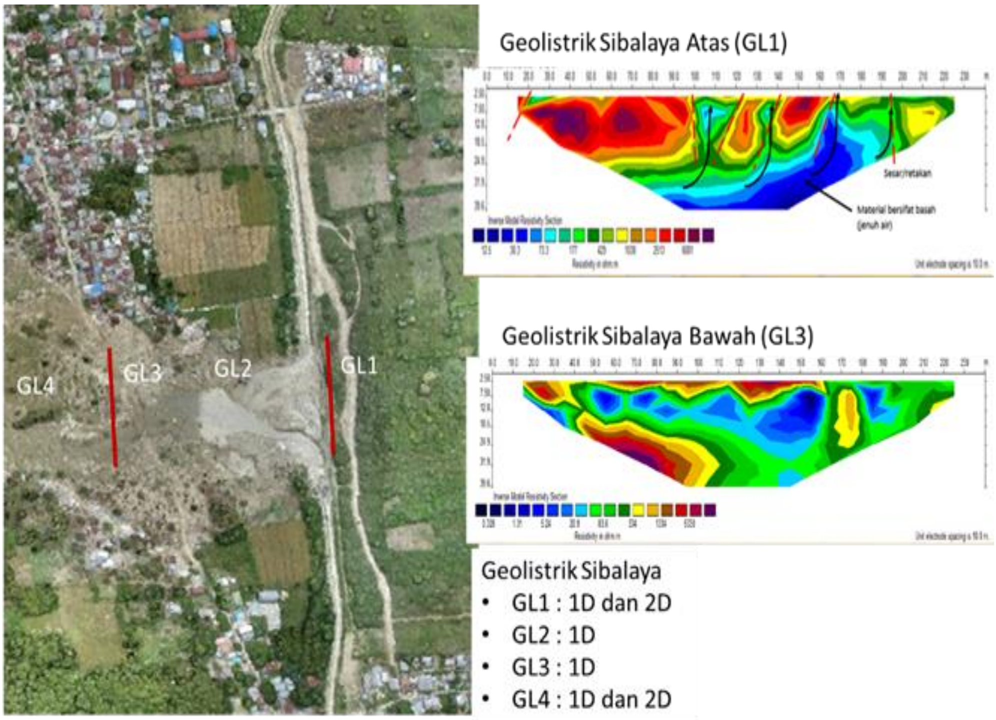
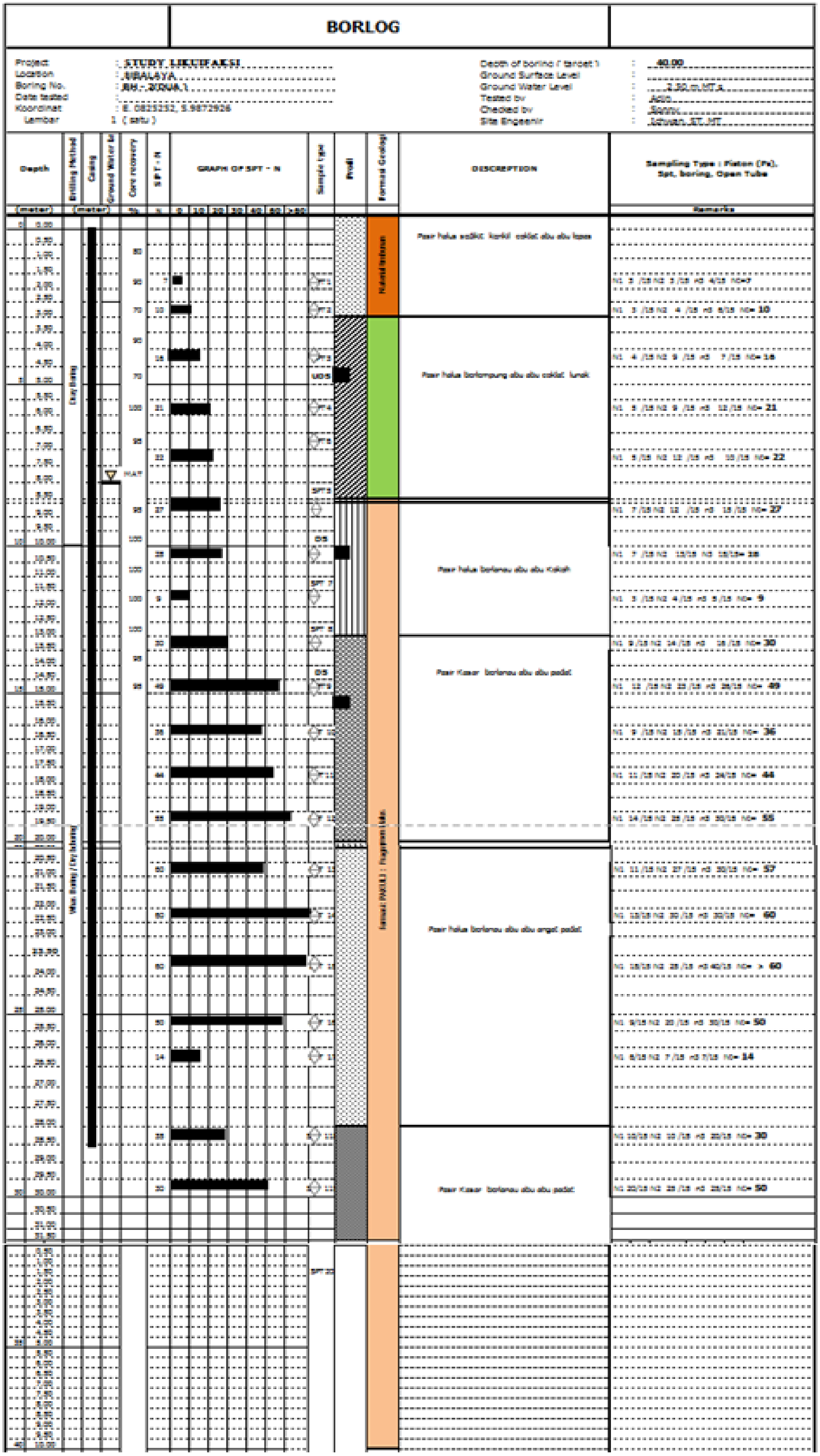



Figure 5 Geoelectrical resistivity test results

***Boring***

Investigations based on technical drilling (Figure 6), especially with regard to Drill -1 (detail-1) and Drill-3 (detail-3) after the earthquake occurred, showed differences in layers caused by potential faults so that Bor-1 was at depth 2-3 meters of solid rock layers are found, while in Bor-3 the soil layer has been degraded due to fault movement and saturation. This condition can be observed with the N-SPT values varying to a depth of more than 20 meters.


BORLOG
Project : STUDY LIKUIFAKSI
Boring No. : BH - 2(DUA)
Koordinat : E. 0825232, S.9872926
Lembar 1 ( satu )
Depth of boring ( target ) : 40.00
Ground Surface Level :
Ground Water Level : 2.50 m.MT.a
Tested by : Adin
Checked by : Sonny
Depth
Drilling Method
Casing
Ground Water
Core recovery
SPT - N
GRAPH OF SPT - N
Sample type
Profil
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DESCRIPTION
Sampling Type : Piston (Px), Spt, boring, Open Tube
(meter)
(meter)
%
N
0
10
20
30
40
50
>50
Remarks

**Figure 6** location with Molasses layer and Saturated silt sand Lapsan N-SPT value <40 varies to a depth of 20 m)

***Characteristics of the liquefaction potential layer***

Analysis and study of the Palu Earthquake on the impact location covers the distribution area as shown in Figure 4. At the time of the field investigation, it was found that the material encountered at the disaster location was dominated by sandstone layers and conglomerate rocks that had completely degraded and their position was under silt layer sediment. is a sediment "Molasse" and not completely confined, and shown in the identified outcrops in the field (Figure 7).

This Molasse sediment is formed from the Celebes Formation which has not been completely depressed. This condition can be proven by the appearance of old mud puddles in several locations which are thought to have come out of the crack patterns that were formed in several locations. The results of the gradation analysis of the material presented [3] that this molasses material has a homogeneous gradation and is potentially unstable to water saturation.


**Photo 1** Molase layer at Sibalaya

Based on the results of other field investigations with technical drilling, such as sondir, geoelectric and geosismic, it is known that in the Sibalaya and

Jonooge areas, an estimate of the startification of the soil layer as a loose sand layer varies in thickness between 2 to 5 meters and the N-SPT value <30 with conditions not. Unconfined sand. As a result of experiencing saturation, there will be destruction so that it experiences cracks and changes in the value of its property characteristics. According to [4], the impact of liquefaction will cause ground movement with the following conditions:

1) Stratification of the soil layer consists of a layer of sand with a low permeability value and there is an interface layer with the layer below which has a high permeability value and contains a significant change between the original and saturated state or the stress that occurs has become "residual stress"

2) Slope will affect the movement of saturated material after liquefaction and movement according to the load to gravity and the increase in water pressure is

3) The slope movement is getting steeper, the faster it is and can reach a maximum of 4 m as the lateral flow on slopes reaches 1% [4]. The more vertical the slope, the tsunami does not occur because landslides occur due to the warranty.

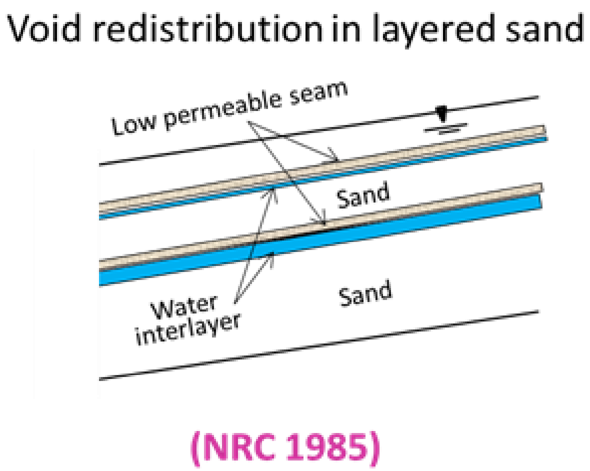


**Figure 7** Potential Soil types that have the potential for liqufaction and landslides [4]

In the locations, especially Sibalaya, the investigation was carried out that there were conglomerates and mud rocks which were characterized by several indications in the field. The results of a fairly detailed investigation were carried out in the Sibalaya locations which also reflected the conditions of other locations such as Petobo and Jonooge, although they did not fit properly (Figure 17). But when viewed from the presence of material identified on the spread of the geological map and also experienced the impact of liquefaction and landslides. The study of the Disaster area in Sibalaya based on investigation and secondary data can be described as follows:

1) At the Sibalaya location, it is dominated by graded material dominated by a sand layer with conglomerate rock deposited mixed up between tuffaan volcanic debris and sand and weathered clay rock (Figure 8).
2) At the Sibalaya location, mud material consisting of clay and silt was found around the cracks with wet mud conditions due to the presence of water which is thought to be the trigger for local abrasion which is characterized by a slippery surface area.

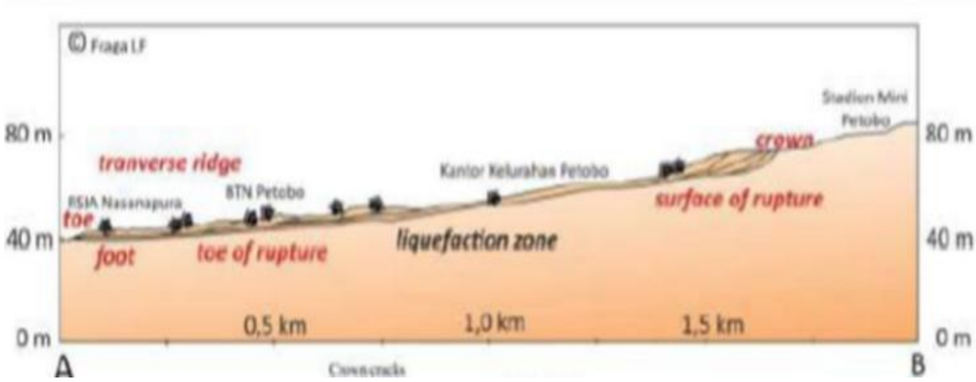


**Figure 8** Identification of the results of the study of the alleged landslide location in Sibalaya after experiencing liquefaction and translational landslides

## PRINCIPLES FOR HANDLING ROAD INFRASTRUCTURE IN THE SIBALAYA

The principle of handling road infrastructure in the Sibalaya area needs to consider the following matters in sequence:

1) Based on the geological study which described earlier that the location of this earthquake was traversed by the Palu-Koro Active Fault so that the soil layer was dominated by sediment deposits of Molasses material which was dominated by fine fraction of clay sand and had not yet been completely depressed (un-confined pressures) so that in a saturated state, it will trigger an increase in pore water stress due to being confined by the surrounding soil gravity and finally a liquefaction process or soil liquefaction is formed.

2) The material encountered in the disaster location is dominated by layers of sandstones and conglomerate rocks that have completely degraded and their position is interspersed with silt rock sediments which are part of the sediment "Molasse", which is material formed from the Celebes Formation which has not been completely depressed and has a loose characteristic. low permeability and dominated by a gradation of sandy silty soils.

3) The soil layer that dominates the surface to a depth of 8-10 meters is a layer of silt sand with a mixture of fine clay fractions commonly called Molasse. This soil layer has low permeability and is described into an unconfined layer which is above the confined soil layer.

4) Due to the slope morphology of the slope is quite flat it will easily become saturated so it also greatly affects the level of stability when the level of saturation has increased to an extreme and fluctuates due to the intensity of the earthquake that occurred, then according to Archimedes' legal theory the flow of water moves according to gravity and is a function of the slope of the slope.

5) As a result of being saturated, there will be destruction so that it experiences cracks and changes in the value of its property characteristics and the impact of liquefaction will cause soil movement with layers containing fine grained fragments (sandy silty soils) and has a slope. The steeper the slope movement, the faster it is and can reach a maximum of 4 m as the lateral flow on slopes reaches 1%.

6) Based on the analysis of the investigation data and soil type, it can be seen that the soil layer has the potential for liquefaction so that the recommended handling of a technology so that the pore stress does not increase and the implementation of technology that can increase the carrying capacity and stability of infrastructure, such as implementing a water control system and stone columns or vibro compacting. To better know the characteristics of layers that have the potential to liquefaction, a lab test should be carried out, such as by conducting an undrained cyclic triaxial test on samples taken from the field [6].

7) Other locations such as Sibalaya, Jonooge, Balaroa, Sigli and other locations need to be analyzed with the support of investigative data such as in Sibalaya so that the mechanism of the Palu Earthquake disaster is known and its handling principles.

## CONCLUSION

The main factor of the earthquake disaster in Palu, Central Sulawesi, was caused by the movement of the Palu-koro Active Fault as a result of a series of other dilated earthquakes which were part of a tectonic process that could not be predicted and avoided. The next triggering factor besides earthquakes and causing greater damage to public facilities including road infrastructure is the occurrence of Tsunamis, Liquefaction and Landslides as well as land subsidence which is a series of events as a cause and effect of earthquakes.

Based on the analysis of the investigative data and soil type, it can be seen that the soil layer has the potential for liquefaction so that the recommended handling of a technology so that the pore stress does not increase and the implementation of technology that can increase the carrying capacity and stability of infrastructure, such as implementing a water control system and stone columns or vibro compacting.

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