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Potential for Liquefaction After The 2018 Pasigala Earthquake Due to Changes in Hydraulic Conductivity Characteristics and Soil Properties in the Gumbasa Irrigation Rice Field Area

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ABSTRACT: On September 28, 2018, an earthquake shook Palu-Sigi-Donggala (Pasigala), resulting in the destruction of several buildings. Another disaster that came at that time was like liquefaction. Liquefaction itself is a process in which non-cohesive materials from solid properties turn into liquid properties due to increased air pressure and pore water in the soil. In the rice field area, liquefaction occurs, so this study aims to determine the potential for liquefaction in the rice field area and to find out how the infiltration of soil after the earthquake is caused by changes in soil characteristics after the earthquake.

For this study, the researcher used a liquefaction potential analysis method based on soil grains and liquefaction safety factors and for hydraulic conductivity using the horton method. From the results of field and laboratory research that has been carried out, the results of this study show that in Petobo and Jono-Oge villages, Sibowo and Sidondo villages and Sidera villages have the lowest change in conductivity values so that in laboratory tests it was found that in the area of the two villages there is a type of clay soil and when the liquefaction potential in the village is analyzed it is stated that there is no liquefaction potential due to the soil density in the village Included in the dense category. Then in the village of Pandere-West Sibalaya and Maranata village has a high hydraulic conductivity value and when laboratory testing is carried out it is identified that the soil type of the two villages is sandy soil, then when the liquefaction potential analysis is carried out the two soils have the potential for liquefaction and the density of the soil is not solid..

KEYWORDS: Liquefaction Potential, hydraulic conductivity, physical properties, safety factors, infiltration

I. INTRODUCTION

On September 28, 2018, an earthquake measuring 7.4 SR occurred in the cities of Palu, Sigi and Donggala. The epicenter was 26 km north of Donggala Regency and 80 km northwest of Palu City with a depth of 10 km (Sains et al., 2022). Other disasters that accompanied the earthquake at that time were soil liquefaction and tsunamis which caused major damage to buildings in Palu City. Liquefaction itself is a process in which non-cohesive material from solid properties changes to liquid properties due to increased air pressure and pore water in the soil (Azizah 2022).

The physical properties of the soil are one of the factors that affect the input of water into the soil. The physical properties of the soil that affect the process of water into the soil include soil hydraulic conductivity, porosity, texture, and structure. In addition, bulk density and soil density are other factors that affect the process of water into the soil. The saturated hydraulic conductivity of a soil is defined as a measure of the movement of water in a porous medium in a saturated state. Determining the value of saturated hydraulic conductivity is very important because the availability of groundwater depends on the movement of water in the soil (Annisa & Prijono, 2023).

Hydraulic conductivity is one of the important indicator parameters in generation and represents the contribution of excess pore water pressure in mixed sand-silt soil deposits during earthquakes (Belkhatir, 2013), which could cause changes in water needs in water-saturated areas such as rice fields in Indonesia, especially rice fields in the Gumbasa Irrigation Area.

It is important to evaluate the systematic influence of heterogeneity in soil properties, especially the hydraulic conductivity that is expected to vary in natural granular soil deposits, and also to evaluate the influence on net pore pressure and acceleration for a wide range of soil conditions and ground movements reliably (Beber & Dashti S, 2017).

Infiltration is the process of surface water entering the soil. Infiltration itself has an effect when the flow on the surface or run off begins. Infiltration can also mark the transition of water from fast and slow moving surfaces into groundwater. Soil infiltration capacity is influenced by physical properties, degree of compression, content in surface water and soil permeability to water and soil microclimate. Water that penetrates the soil surface is influenced by gravity, capillary force or rainwater pressure that hits the soil.

The highest infiltration rate can be achieved when water first enters the soil and decreases with time (Philip, J. R. 1969). At the beginning of infiltration, water entering the soil fills the lack of water content in the soil. After the water content in the soil reaches capacity, the excess water will flow down to become water reserves in the soil (ground water) (Soil Physics, 2004).

This study was conducted to analyze the potential for liquefaction that can occur in the Gumbasa irrigated rice field area. This study was conducted due to changes in the characteristics of hydraulic conductivity and soil properties that could cause liquefaction disasters in the future. To investigate the potential for liquefaction and changes in characteristics that occur in the soil, this study will use a combination of testing, field testing and laboratory testing. Based on the background of this problem, the author made a paper as a final assignment with the title "Potential Study of Liquefaction After the 2018 PASIGALA Earthquake Due to Changes in Hydraulic Conductivity Characteristics and Soil Properties Case Study in the Gumbasa Irrigated Rice Field Area (Segment 3)"

II. ANALYSIS RESULT

The results of this study are based on laboratory and field tests conducted in August 2024, using both disturbed and undisturbed soil samples collected from several predetermined locations. The study area comprises five villages located within the Gumbasa irrigation paddy field region.

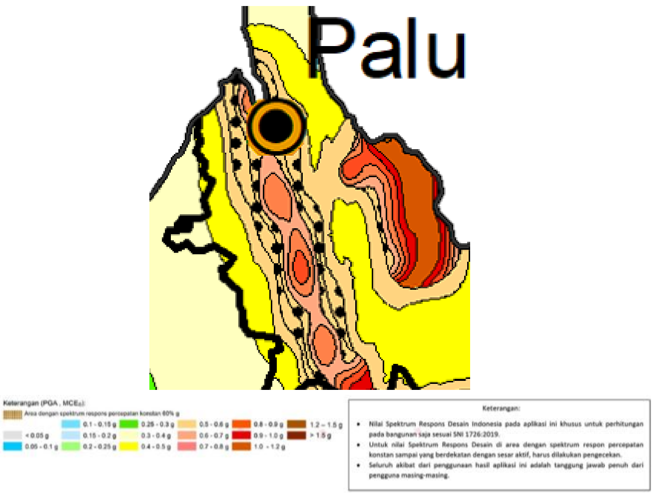

Figure 1. Seismic Zoning MapThe earthquake and subsequent

liquefaction that occurred on 28 September 2018 significantly altered subsurface soil stratification and water requirements in paddy field areas. Liquefaction-induced ground deformation affected soil structure and irrigation demand, prompting this study to investigate the Gumbasa irrigation paddy fields. The study area was divided into five segments to evaluate spatial variations and to identify post-earthquake changes associated with liquefaction.

A. Hydraulic Conductivity of Soil

Based on the field test results, infiltration measurements indicate spatial variability in the average infiltration rates among the villages during the 20-minute observation period.

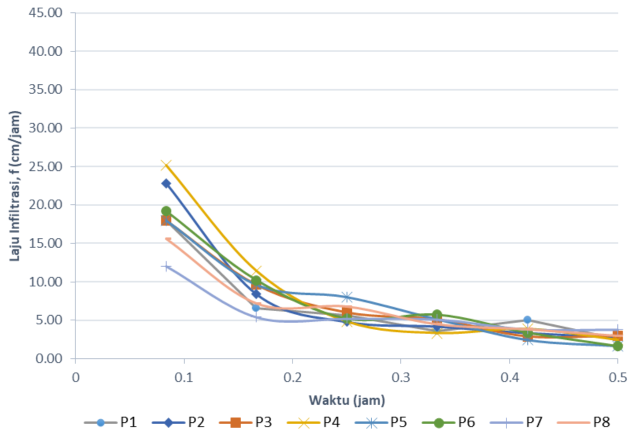

Figure 2. Example of Infiltration Rate Graph (Pandere–Sibalaya Barat Village)

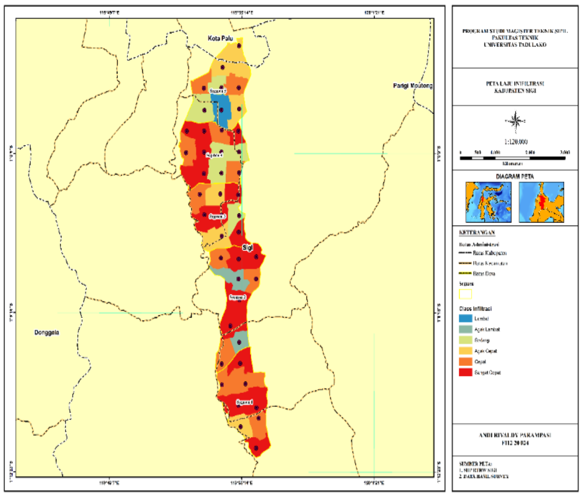

Figure 3. Infiltration Rate Classification Map

Based on the infiltration graphs and data recapitulation for each village, the highest water level reduction between the 5th and 10th minute was observed in Maranata Village. Consequently, this area is predominantly classified as rapid infiltration (red zone). In contrast, the lowest water level reduction during the same time interval occurred in Petobo and Jono-Oge Villages, which are therefore dominantly classified as moderately rapid infiltration (yellow zone). Furthermore, by the 30th minute, the rate of water level reduction at all observation points tended to stabilize, indicating the attainment of near steady-state infiltration conditions. However, at observation point 4 in Petobo and Jono-Oge Villages, a consistently stable water level reduction was observed from the beginning until the end of the testing period.

The changes in water demand are also influenced by the post-earthquake physical properties of the soil. Therefore, laboratory tests were conducted to evaluate the physical characteristics of soils in the affected villages following the earthquake-induced liquefaction.

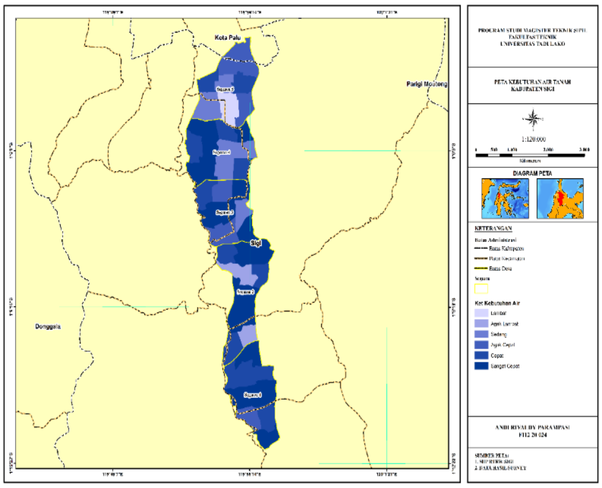

Figure 4. Groundwater Requirement Map

Based on the laboratory test results, the physical properties of soils in each village were identified and subsequently visualized in a soil type map according to the study area.

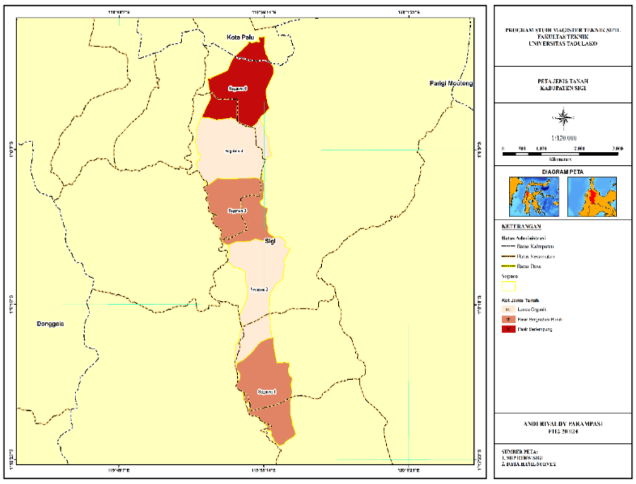

Figure 5. Soil Type Classification Map

Laboratory analyses indicate that soils in the study area are dominated by poorly graded sands (SW) and silty soils with low plasticity (ML), with localized occurrences of silty sand and clayey sand (SM–SC, SM, and SC). Uniform sand-dominated soils exhibit low density and high permeability, resulting in higher agricultural water demand and increased liquefaction susceptibility. In contrast, silty and well-graded soils demonstrate improved compaction and reduced permeability, leading to lower water demand and generally lower liquefaction potential. Due to spatial variability in soil characteristics, a post-earthquake liquefaction safety factor analysis was performed to evaluate site-specific liquefaction risk.

B. Evaluation of Liquefaction Potential

Based on laboratory grain size analyses conducted using sieve and hydrometer tests, soil liquefaction potential was evaluated using the Tsuchida (1970) criteria, which define zones of potential and high liquefaction susceptibility. The results indicate that soils in Pandere–Sibalaya Barat and Maranata Villages are classified as potentially liquefiable, as most data points fall within the liquefaction-prone zones and exhibit uniform grain size distributions. In contrast, soils from Sibowi–Sidondo, Sidera, and Jono-Oge–Petobo Villages show relatively low liquefaction potential, as the data points are distributed both inside and outside the liquefaction zones due to non-uniform grain size characteristics.

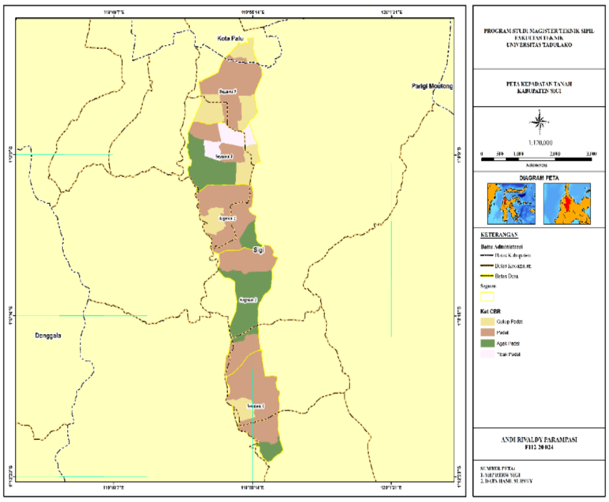

Figure 6. Soil Density Map

Dynamic Cone Penetrometer (DCP) field tests were conducted to evaluate near-surface soil density within a depth range of 0–1 m. The results show that Petobo and Jono-Oge Villages exhibit relatively high post-earthquake soil density, while Pandere and Maranata Villages are characterized by low soil density. Low-density soils are generally associated with loose soil conditions, which may increase susceptibility to liquefaction under future seismic loading. To further assess liquefaction potential, soil density data obtained from DCP testing were correlated with equivalent Standard Penetration Test (SPT) N-values.

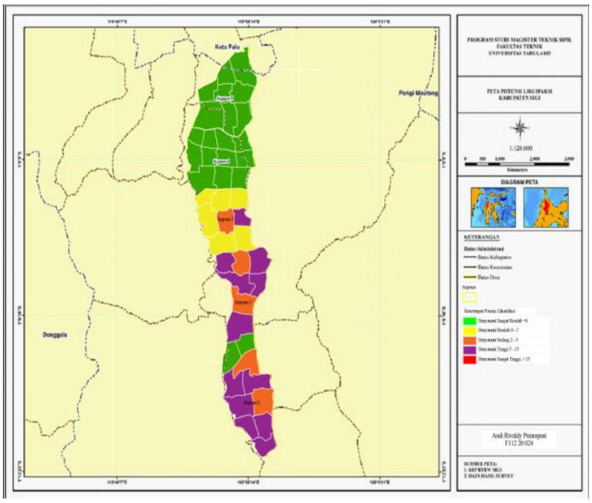

Figure 7. Liquefaction Potential Delineation Map

The processed liquefaction potential data indicate that, at observation point 1 within a depth of 0–1 m, the Liquefaction Potential Index (LPI) falls within the moderate to high category, suggesting potential liquefaction. In Sibowi and Sidondo Villages, two observation points show no liquefaction potential, while other points exhibit moderate to high LPI values. Maranata Village generally demonstrates low liquefaction potential, although one observation point is classified as having high liquefaction potential. In contrast, Sidera and Jono-Oge–Petobo Villages show no liquefaction potential based on LPI criteria. These results were spatially mapped, indicating that Pandere–Sibalaya Barat and Sibowi–Sidondo Villages exhibit high liquefaction potential, Maranata Village shows low potential, and Sidera as well as Jono-Oge–Petobo Villages are classified as non-liquefiable.

Infiltration rate, which represents soil permeability, plays a significant role in influencing liquefaction potential. The analyzed samples exhibit infiltration rates ranging from 2.6 to 10.6 cm/h, with the highest values observed in samples P5 and P6, which are classified as moderately rapid. These high infiltration rates correspond to elevated Liquefaction Potential Index (LPI) values (3.72 and 5.53), indicating increased liquefaction susceptibility. Although the soils are predominantly classified as well-graded sand (SW) with one silty sand (SM) according to the USCS, grain-size distribution analysis using the Tsuchida criteria places most samples within the liquefaction-prone zone. The dominance of non-plastic behavior and low fines content (2.23–10.1%) further enhances liquefaction susceptibility, particularly in samples P5 and P6, which show the most pronounced liquefaction potential. In contrast, sample P2, characterized by higher fines content (10.1%), measurable plasticity (PI = 3.98), and a lower infiltration rate (2.6 cm/h), exhibits reduced liquefaction potential, as reflected by its low LPI value (0.54). These findings highlight that liquefaction potential is governed by the combined interaction of infiltration rate, grain-size distribution, plasticity, fines content, and Tsuchida-based criteria, rather than a single controlling parameter.

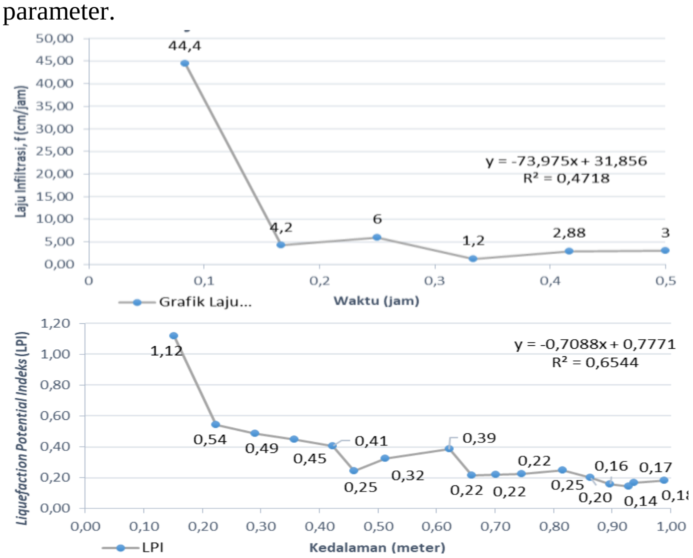

Figure 8. Relationship between LPI and Infiltration Rate for Sample P6 in Maranata Village

The relationship between the Liquefaction Potential Index (LPI) and infiltration rate was evaluated based on the results of each analysis. As shown in Figure 4.9, infiltration rates measured between 5 and 30 minutes indicate an average infiltration rate of 10.6 cm/h for sample P6, which corresponds to a high LPI value (5–15). The results of this study demonstrate that higher infiltration rates are associated with increased LPI values, indicating a greater potential for liquefaction in the affected areas.

III. CONCLUSIONS

Based on the results of field and laboratory tests conducted on several soil samples, the following conclusions can be drawn:

1. The hydraulic conductivity values obtained from infiltration tests conducted over a 20-minute period in paddy field areas indicate that Pandere–Sibalaya Barat Village has an infiltration rate of 4.5 cm/h (moderate), Sibowi and Sidondo Villages 1.1 cm/h (moderately slow), Maranata Village 3.0 cm/h (moderate), Sidera Village 8.6 cm/h (moderately rapid), and Jono-Oge and Petobo Villages 1.1 cm/h (moderately slow). Compared to pre-earthquake conditions in 2017, when the infiltration rate reached 9.9 cm/h, all villages experienced a decrease in infiltration capacity following the 2018 earthquake. The most significant reduction occurred in Pandere–Sibalaya Barat and Maranata Villages, while Sidera, Sibowi–Sidondo, and Jono-Oge–Petobo Villages showed relatively smaller decreases.
2. A reduction in groundwater level requirements in paddy field areas was observed across all villages due to earthquake and liquefaction effects. The average value decreased from 9.9 cm/h (20 minutes) to 4.4 cm/h in Pandere–Sibalaya Barat, 8.8 cm/h in Sibowi and Sidondo, 6.9 cm/h in Maranata, 6.4 cm/h in Sidera, and 8.8 cm/h in Jono-Oge and Petobo Villages.
3. Liquefaction potential assessment based on the Tsuchida (1970) grain-size distribution curve indicates that Pandere–Sibalaya Barat and Maranata Villages are susceptible to liquefaction, whereas Sidera, Sibowi–Sidondo, and Jono-Oge–Petobo Villages exhibit no significant liquefaction potential. Based on the Liquefaction Potential Index (LPI), areas with high liquefaction potential at a depth of 1 m are identified in Pandere–Sibalaya Barat and Sibowi–Sidondo Villages, while low liquefaction potential is observed in Petobo, Jono-Oge, and Sidera Villages.
4. Laboratory test results, including sieve and hydrometer analyses, Atterberg limits, and soil classification based on the Unified Soil Classification System (USCS), indicate that soils in Pandere–Sibalaya Barat are predominantly poorly graded sand, Sibowi and Sidondo Villages are dominated by organic silt with minor sand content, Maranata Village consists mainly of sandy soil, Sidera Village is dominated by clayey soil, and Jono-Oge and Petobo Villages are characterized by clayey sand. These variations reflect changes in soil properties caused by the earthquake event.
5. The average safety factor values indicate that Pandere–Sibalaya Barat Village has a high liquefaction potential

(6.02), Sibowi and Sidondo Villages have moderate potential (4.61), Maranata Village has low potential (1.95), while Sidera and Jono-Oge–Petobo Villages exhibit very low to negligible liquefaction potential (0). Accordingly, Pandere–Sibalaya Barat and Sibowi–Sidondo Villages are classified as having high liquefaction susceptibility, Maranata Village shows low susceptibility, and Sidera as well as Jono-Oge–Petobo Villages are considered to have very low or no liquefaction potential.

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