Study of Liquefaction Potential at Sabo dam Construction on Poi and Bangga River, Sigi Regency, Central Sulawesi

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Abstract. The Palukoro fault, an active sinistral fault that cuts through Sulawesi Island, was the cause of the earthquake and liquefaction disaster in Palu and Sigi Regency in 2018. A series of studies related to liquefaction have been carried out since then but more focused on the west side of the Palu River. This research will raise the potential for liquefaction on the eastern side of the Palu river, precisely in the sabo dam area at Poi and Bangga River. These rivers are located on the opposite side of the Sibalaya liquefaction area. Liquefaction potential was calculated using the Simplified Procedure Method based on NSPT values. Fifteen and twelve boreholes are located at Bangga and Poi rivers, respectively. The qualitative analysis assessed the criteria of vulnerability based on geological factors, groundwater levels, and seismicity. The Liquefaction Potential Index method was used and calculated using several earthquake scenarios based on historical data and potential earthquakes of The Palu-Koro fault. Based on LPI analysis, the Poi River has meager potential at the middle stream area and moderate level potential at the downstream. Bangga River has moderate to high liquefaction potential downstream and low to very low potential at the middle stream.

Keywords: Bangga river, potential liquefaction index, Palukoro fault, poi river, simplified procedure, sabo dam.

1. Introduction

Sulawesi Island is one of the regions in Indonesia with the highest earthquake hazard [1] [2]. Due to its location within the convergence zone between the Indo-Australian, Eurasian, and Philippine tectonic plates that have interacted since the Mesozoic era, a complex tectonic setting emerged on the island of Sulawesi [3] [4]. The primary tectonic structure in the Central Sulawesi region is the Palu-Koro fault system, which cuts Sulawesi from northwest to southeast for more than 300 km [5]. As an active fault located in the mainland, the activity of the Palu-koro fault has the potential to cause severe damage [1]. On September 28, 2018, tectonic activity occurred at the Palu-Koro fault, specifically located about 72 km to the north of Palu city [3]. This tectonic activity led to an earthquake with 7.5 Mw in a north-south direction, which extended through Palu City and other areas in Central Sulawesi, Indonesia [3]. The earthquake also led to aftershocks, including coastal landslides and tsunami in the coastal area of Palu bay and landslide-liquefaction on a reasonably large scale in Palu (Balaroa) and Sigi Regencies (Petobo, Jono Oge and Sibalaya) [6].

Liquefaction is defined as transforming the soil grains from solid to liquefied state due to increased pore-water pressure and reduced effective stress due to cyclic loading [7]. The entire area of landslide-liquefaction in Palu is located along the edge of the Palu valley. In that location, alluvial fan deposits
meet the alluvial valley of the Palu River, which cuts through the Palu and Sigi Regency areas from the south (upstream) to the north (downstream) [3]. Various studies related to the risk and potential for liquefaction have been carried out since 2018. However, these studies focused on areas where liquefaction has occurred, specifically on the east side of the Palu River. In contrast, the potential for liquefaction on the west side of the Palu River has not been widely studied until now.

This study was intended to analyze the vulnerability and potential risk of liquefaction in the area of the Sabo Dam building, particularly in the Poi and Bangga Rivers (Figure 1) located on the west side of the Palu River. The Poi River and the Bangga River are tributaries of the Palu River. The lower reaches of the Poi and Bangga Rivers form an alluvial fan area around the Palu River which is used as residential areas and rice fields. This location is interesting to be appointed because it crosses the liquefaction area in Sibalaya and the Palu River as a barrier between the two areas (Figure 2).

![Figure 1. Research Sites.](image1)

![Figure 2. Liquefaction Zones around Poi and Bangga Rivers.](image2)
The liquefaction analysis was carried out by referring to NSPT data obtained at both locations. The level of vulnerability was determined using the LPI equation from Sonmez based on the level of safety for each layer against liquefaction using the Idriss & Boulanger equation. The NSPT points are spread over the Sabo Dam locations, starting from the middle to the lower reaches of the Poi and Bangga Rivers. In the Poi River, there are 12 (twelve) NSPT points (as shown in Figure 2.a and Table 3), while in the Bangga River, there are 15 (fifteen) NSPT points (as shown as Figure 2.b and Table 4). This research was conducted to compare the level of liquefaction vulnerability on the west side of the Palu River and improve the liquefaction vulnerability map for the Sigi Regency area, especially in the area on the west side of the Palu River.

2. Material and Method

2.1 Qualitative Analysis of Liquefaction Potential

The qualitative approach used for potential liquefaction analysis aims to describe the liquefaction potential trend briefly. Liquefaction Threshold Method analysis introduced by Keith et al. in 1999 [8] was used in this study as a qualitative analysis method. This method considers the availability of data in the form of geological data and the groundwater table position. This method categorizes the potential for liquefaction from the lowest level (very low) to very high by looking at the geological characteristics, the dominant groundwater level, and the potential for acceleration of bedrock (PGA) triggered by seismic factors at the site [8] (Figure 3).

![Liquefaction Threshold Method by Keith et al. (1999) [8]](image-url)
2.2 Quantitative Analysis of Liquefaction Potential

2.2.1 Analysis of Soil Vulnerability to Liquefaction based on NSPT Data (Idriss & Boulanger Method, 2008)

Idriss and Boulanger Method [9] is developing the liquefaction vulnerability simplification method proposed by Seed & Idriss in 1971 [10] by referring to NSPT data. Seed and Idriss explained that the shear stress in the sand with a sufficiently large amount when receiving dynamic loads could be assumed as a rigid body [10] [11]. The maximum stress generated by the earthquake \(\tau_{\text{max}}\) was calculated based on the shear stress of the time history, which was converted into cyclic stress by determining the maximum ground acceleration and correction of the stress factor due to the earthquake (equation 1).

\[
\tau_{\text{max}} = rd \left( \frac{\gamma.z}{g} \right) a_{\text{max}} \tag{1}
\]

where \(a_{\text{max}}\) is the peak horizontal ground acceleration, and \(r_d\) is the value of the stress reduction function which is affected by the magnitude of the earthquake load.

In 2004, Idriss and Boulanger developed the CSR (Cyclic Stress Ratio) equation by adding a correction factor for the static shear load (K\(\alpha\)) (equation 3).

\[
CSR = 0.65 \frac{\tau_{\text{max}}}{\sigma'_{vc}} \frac{1}{K_{\alpha}} \tag{2}
\]

Seed and Idriss and Boulanger had succeeded in modeling the soil resistance function against liquefaction in the form of equation 4 by referring to the value of the NSPT on the soil [15] [10]. In their equation, Seed, Idriss, and Boulanger used N60 data corrected for various factors \(N_{60} \) (equation 5).

\[
CRR = \exp \left( \frac{(N_1)_{60cs}}{14,1} + \left( \frac{(N_1)_{60cs}}{126} - \left( \frac{(N_1)_{60cs}}{23.6} \right)^2 + \left( \frac{(N_1)_{60cs}}{25.4} \right)^3 - 2.8 \right) \right) \tag{4}
\]

\[
N_{1(60)} = N_m \cdot C_N \cdot C_E \cdot C_B \cdot C_R \cdot C_S \tag{5}
\]

While \(N_m\) stand for the NSPT value, \(C_N\) is overburden correction factor, \(C_E\) is factor for energy ratio, \(C_B\) is correction factor for borehole diameter, \(C_R\) is correction factor for rod length and \(C_S\) is correction factor for omitting sampler liners.

By comparing the Cyclic Resistance Ratio (CRR) and Cyclic Stress Ratio (CSR) values, the soil safety factor value against the liquefaction potential (FS) was successfully obtained (equation 6) where the soil layer with an FS value less than 1 (one) was considered to have a vulnerability to liquefaction.

\[
FS = \frac{CRR}{CSR} \tag{6}
\]

2.2.2 Liquefaction Potential Index (Sonmez 2003)

Iwasaki, Tokida, and Tatsuoka first introduced the Liquefaction Potential Index (LPI) in 1981 by assessing earthquake events in Japan from 1975 to 1981 [12]. In 2003, Sonmez modified the Iwasaki equation by considering the uncertainties parameters in the Liquefaction Potential Index (LPI) equation and carried out tests with liquefaction cases in Inegol City, Turkey [13]. The Sonmez equation (equation 7-13) sets the factor of safety of the soil that has the potential to liquefy to 1.2 (\(F_L\)) and divides the liquefaction probability category into 5 (five) categories (Table 1).
\[
LPI = \int_{0}^{20} F(z) \cdot w(z) dz
\]

\[
F(z) = 1 - F_L \quad \text{for} \quad F_L < 0.95
\]
\[
F(z) = 2 \times 10^6 e^{-18.427 F_L} \quad \text{for} \quad 1.2 > F_L < 0.95
\]
\[
F(z) = 0 \quad \text{for} \quad F_L \geq 1.2
\]
\[
w(z) = 10 - 0.5z \quad \text{for} \quad z < 20 \text{ m}
\]
\[
w(z) = 0 \quad \text{for} \quad z \geq 20 \text{ m}
\]

While \( F_L \) is safety factor value of soil’s liquefiable layer and \( z \) is the dept from ground surface in meters.

### Table 1. Liquefaction Potential Category Based on Sonmez Equation [13].

| Liquefaction Index (\( Li \)) | Liquefaction Potential |
|-------------------------------|------------------------|
| 0                             | Non-Liquefiable        |
| 0 < \( Li \) ≤ 2             | Low                    |
| 2 < \( Li \) ≤ 5             | Moderate               |
| 5 < \( Li \) ≤ 15            | High                   |
| 15 > \( Li \)                | Very High              |

3. Results and Discussion

#### 3.1 Qualitative Analysis

3.1.1 Geological Review of Poi and Bangga Rivers

Based on the geological map of the Pasangkayu (Figure 4) by Sukido, D. Sukarna, and K. Sutisna in 1993 [14], Poi and Bangga Rivers consist of 3 (three) rock formations, namely alluvium (Qa), pakuli formations (Qp) and intrusive rock formations including granite and diorite (Tmpi\(_{d,g}\)). The Alluvium (Qa) Formation consists of silt, sand, clay and gravel, formed in the river and deltaic environments. This formation is classified as the youngest sediment in the previously mentioned area and belongs to the Holocene Quaternary layer. This rock formation is located at the downstream end of the Poi and Bangga Rivers [14]. The soil conditions in this formation are generally in the form of material that has not been adequately compacted [15]. The Pakuli Formation (Qp) consists of conglomerate rock, sandstone formations and carbonaceous claystone. This rock formation belongs to the Quaternary layer with the category of Holocene to Pleistocene [14].

![Figure 4. Geological Map of Poi and Bangga River and NSPT Drilling Points ([14] with modified).](image-url)
The Pakuli Formation tends to be found in the river's lower reaches, which is an area of alluvium fan deposits and river terraces. Intrusive rocks (Tmpi) are in the form of diorite, andesite, granite, and granodiorite and are classified in the Tertiary layer category with an estimated middle-late Miocene age. Intrusive rock formations are relatively found in the middle to the upper reaches of the river. Based on the field survey, a significant number of hard granite rocks tend to be found in this area.

Liquefaction occurs in saturated cohesionless loose sandy soils, which cannot maintain their stiffness and strength due to dynamic load [16]. Furthermore, Tsuchida explained that liquefaction vulnerability is influenced by the diversity and grain size of the sedimentary soil. Fine-grained soil (0.1-1.0 mm) and uniformly graded soil are generally more susceptible to liquefaction [17]. According to Tsuchida, this soil grain distribution can be used as a preliminary analysis of liquefaction potential. The proposed analysis guideline is presented in the form of a soil grain distribution graph that provides an overview of the criteria for soil vulnerability to liquefaction (Figure 5).

![Figure 5. Boundaries of grain size distribution on liquefiable soil from Tsuchida [13].](image)

### 3.1.2 Seismicity Aspect

The active geological structures that pass through Palu City and Sigi Regency are the Palu Koro Fault and the Matano Fault [18]. The Palu Koro Fault has a north-south direction and partly a southwest-northeast direction. The physiology of the city of Palu and Sigi Regency is related to the occurrence of structural processes and the types of constituent rocks, where the left and right sides consist of a major fault line, namely the Palu Koro fault [15]. The Palu-koro Fault is classified as an active sinistral fault with displacement speed of about 25-30 mm/year [1].

The earthquake that occurred in the Palu area and its surroundings is classified as a transform zone type, caused by two tectonic plates sliding against each other. The earthquake that occurred is generally considered an earthquake in the shallow crust caused by the Palu-Koro and Matano faults [19]. Firmansyah and Irsyam in their study on the classification of earthquake zones in Indonesia, stated that the maximum earthquake potential from the Palu-Koro fault has amounted to 7.6 Mw [19]. Meanwhile, based on the Source Map and Indonesia Earthquake Hazard Books, the earthquake potential for the Palu-koro fault reaches 7.9 Mw [18].

### 3.1.3 Threshold Method Analysis

The qualitative analysis was successfully conducted using threshold method analysis based on geological data, lithography, and water table level. Lithographic data on the cross-section of the soil and the water table level were obtained through Bor Log data at the location. Based on Bor Log data, the water table in the Poi River tended to be at moderate to shallow depths with an average water table level of fewer than 10 meters. In the Bangga River, relatively drastic fluctuations in the water table level were found. Bor Log data in September 2019 indicated a very shallow water table level (less than 5 meters). However, Bor Log data in January 2021 showed a relatively significant change, where the depth of the water table in the lower reaches of the river was not found until the depth of 8 meters.

This was considered as an influence contributed by climate change and the work of the Sabo dam construction process, which needs to form a dam and change the flow of the Bangga River. Consequently, it affected the quantity of water infiltration into the soil. Based on lithographic data, most
of the deposited materials in the Bangga and Poi Rivers area were classified as sandy soils. In regards to these data, qualitative analysis of liquefaction potential in the Bangga and Poi Rivers showed that the downstream to the end of the river contributed a moderate to the high level of liquefaction potential, while the middle to the upstream part of the stream did not provide any liquefaction potential (very low) (Table 2).

Table 2. Results of qualitative analysis for the Poi and Bangga Rivers.

| Section Area     | Geological Condition | Average Ground Water Level | Liquefaction Potential |
|------------------|----------------------|---------------------------|------------------------|
| Poi and Bangga River |                      |                           |                        |
| Downstream       | Early Holosen-Pleistosen | < 10 m              | Moderate               |
| Middle-Up Stream | Miosen               | < 10 m                   | Very Low               |

Referring to the sieve test results, most of the soil material was classified as sandy soil with Fines Content value above 90%. The test samples were gathered at points with relatively low NSPT values and points considered the dominant soil group based on the Bor Log data. In the Poi River, 3 (three) point samples were obtained, namely at the consolidation dams 3 and 6 (CDB 3 and CDB 6) located in the middle stream of the river and at the bridge (SDB BG) which located at the downstream end of the river. In the Bangga River, five soil samples were selected, namely at the location of Sabo dam 3 (BH 8 and BH 9), located at the middle stream of the river and at the location of Consolidation dam 1 (BH 16), Consolidation dam 2 (BH17) and Consolidation dam 3 (BH 18) which were located in the lower reaches of the river close to residential areas.

The plotting of the results from the sieve test to the graph of soil gradation with potential liquefaction from Tsuchida showed that the area of the Poi River and the Bangga River was included in the zone of potentially liquefied soil. Soil samples in the middle stream in the Poi River showed results with relatively uniform grain distribution and were in the "most liquefiable soils" zone for the point of CDB 3 and the "Potentially liquefiable soils" zone at the drill point of CDB6 (Figure 6). The grain size distribution was in the "most liquefiable soils" zone with a uniform grain size tendency (Figure 7).

The analysis of the size gradation of soil material in the Bangga River showed slightly different results. The grain gradation in the Bangga River area was slightly better than the Poi River because it had grain size distribution that tended to be non-uniform. In the middle stream, it was classified into the "potentially liquefiable soils" zone (Figure 9), while in the downstream area, some of the test samples were classified in the "most liquefiable soils" zone (BH 17 and 18) and the rest were classified at the zone of "potentially liquefiable soils" (BH 16) (Figure 8).

Figure 6. Grain size distribution analysis of Poi river at middle stream area.

Figure 7. Grain size distribution analysis of Poi river at downstream area.
3.2 Quantitative Analysis

Quantitative analysis of liquefaction potential was carried out based on NSPT data, water table level, seismicity, and maximum peak ground acceleration in bedrock (PGA). The Peak Ground Acceleration value was obtained from the spectrum response design issued by the Design Response Spectrum Application from the Ministry of Public Works, and Public Housing of Indonesia. The analysis was calculated using two seismicity scenarios. The first scenario was executed based on historical seismicity that has occurred in the Palu-koro fault, with the value of 7.5 Mw. The second scenario was executed based on the maximal potential of seismicity in the Palu-koro fault, which was amounted to 7.9 Mw.

The calculations by utilizing the Idriss and Boulanger equations [9] using NSPT data indicated the potential for liquefaction in certain soil layers in the Poi and Bangga Rivers. In the Poi River area, calculation simulations with seismicity of 7.5 Mw and 7.9 Mw showed results that were not significantly different. In the middle stream area, it was found that the soil was not susceptible to liquefaction, except at the point of CDB 6, which indicated the potential for liquefaction at a depth of 2 m (FS<1) (Table 3).

| No. | Drilling Point Number | Location                  | Liquefaction Potential (7.5 Mw earthquake) | Liquefaction Potential (7.9 Mw earthquake) |
|-----|-----------------------|---------------------------|--------------------------------------------|--------------------------------------------|
| 1   | SDB 1                 | Sabo Dam (Middle Stream)  | Not liquefied                              | Not liquefied                              |
| 2   | SDB 2                 |                           | Not liquefied                              | Not liquefied                              |
| 3   | SDB 3                 |                           | Not liquefied                              | Not liquefied                              |
| 4   | SDB 4                 |                           | Not liquefied                              | Not liquefied                              |
| 5   | SDB 5                 |                           | Not liquefied                              | Not liquefied                              |
| 6   | SDB 6                 |                           | Liquefaction potential at the depth of 2 meters | Liquefaction potential at the depth of 2 meters |
| 7   | CDB 1                 | Consolidation Dam 1 (middle stream) | Not liquefied                              | Not liquefied                              |
| 8   | CDB 2                 | Consolidation Dam 2 (middle stream) | Not liquefied                              | Not liquefied                              |
| 9   | CDB 3                 | Consolidation Dam 3 (middle stream) | Not liquefied                              | Not liquefied                              |
| 10  | CDB 4                 | Consolidation Dam 4 (middle stream) | Liquefaction potential at the depth of 2 meters | Liquefaction potential at the depth of 2 meters |
| 11  | CDB 5                 | Consolidation Dam 5 (down stream) | Not liquefied                              | Not liquefied                              |
| 12  | CDB BG                | Consolidation Dam 6-Bridge (downstream) | Liquefaction potential at the depth of 2 meters | Liquefaction potential at the depth of 2 meters |

Table 3. Soil vulnerability to liquefaction based on the Idriss & Boulanger method at the location of the Poi River.
Table 4. The level of soil vulnerability to liquefaction based on the Idriss & Boulanger method at the location of the Bangga River.

| No. | Drilling Point Number | Location | Liquefaction Potential (7.5 Mw earthquake) | Liquefaction Potential (7.9 Mw earthquake) |
|-----|-----------------------|----------|-------------------------------------------|-------------------------------------------|
| 1   | SDB 1                 | Sabo Dam (Middle Stream) | Not liquefied | Not liquefied |
| 2   | SDB 2                 | Sabo Dam (Middle Stream) | Not liquefied | Not liquefied |
| 3   | SDB 3                 | Sabo Dam (Middle Stream) | Liquefaction potential at the depth of 3 meters | Liquefaction potential at the depth of 3 meters |
| 4   | BH 1                  | Not liquefied | Not liquefied |
| 5   | BH 2                  | Not liquefied | Not liquefied |
| 6   | BH 3                  | Not liquefied | Not liquefied |
| 7   | BH 4                  | Liquefaction potential at the depth of 9 and 11 meters | Liquefaction potential at the depth of 9 and 11 meters |
| 8   | BH 7                  | Not liquefied | Not liquefied |
| 9   | BH 8                  | Liquefaction potential at the depth of 10 meters | Liquefaction potential at the depth of 9-10 meters |
| 10  | BH 9                  | Liquefaction potential at the depth of 9-10 meters | Liquefaction potential at the depth of 9-10 meters and 13 meters |
| 11  | BH 10                 | Not liquefied | Not liquefied |
| 12  | SDB BG                | Consolidation Dam 2-Bridge (downstream) | Liquefaction potential at the depth of 3 meters | Liquefaction potential at the depth of 3 meters |
| 13  | BH 16                 | Consolidation Dam 1 (middle-stream) | Liquefaction potential at the depth of 16 meters | Liquefaction potential at the depth of 16 meters |
| 14  | BH 17                 | Consolidation Dam 2 (middle-stream) | Liquefaction potential at the depth of 12-13 meters | Liquefaction potential at the depth of 12-13 meters |
| 15  | BH 18                 | Consolidation Dam 3 (down stream) | Liquefaction potential at the depth of 12 meters | Liquefaction potential at the depth of 12 meters |

The results of the analysis on the Bangga River (Table 4) showed that from 15 drill points, there were 8 points with layers that were susceptible to liquefaction events (FS < 1). Analysis carried out by using earthquake magnitudes of 7.5 Mw, and 7.9 Mw showed that the most critical locations were found in the downstream area. The four drill points in the downstream area indicated a vulnerability to liquefaction in certain layers. This area was considered to be the area closest to the settlement location and was a sediment area of the Bangga River flow.

Table 5. LPI Analysis of Poi River.

| No. | Drilling Point Number | Location | Liquefaction Potential Index (7.5 Mw earthquake) | Liquefaction Potential Index (7.9 Mw earthquake) |
|-----|-----------------------|----------|-----------------------------------------------|-----------------------------------------------|
| 1   | SDB 1                 | Sabo Dam (Middle Stream) | Non-liquefied | Non-liquefied |
| 2   | SDB 2                 | Sabo Dam (Middle Stream) | Non-liquefied | Non-liquefied |
| 3   | SDB 3                 | Sabo Dam (Middle Stream) | Non-liquefied | Non-liquefied |
| 4   | SDB 4                 | Sabo Dam (Middle Stream) | Low | Non-liquefied |
| 5   | SDB 5                 | Sabo Dam (Middle Stream) | Non-liquefied | Non-liquefied |
| 6   | SDB 6                 | Sabo Dam (Middle Stream) | Low | Low |
| 7   | CDB 1                 | Consolidation Dam 1 (middle stream) | Non-liquefied | Low |
| 8   | CDB 2                 | Consolidation Dam 2 (middle stream) | Non-liquefied | Non-liquefied |
| 9   | CDB 3                 | Consolidation Dam 3 (middle stream) | Non-liquefied | Non-liquefied |
| 10  | CDB 4                 | Consolidation Dam 4 (middle stream) | Moderate | Moderate |
| 11  | CDB 5                 | Consolidation Dam 5 (down stream) | Non-liquefied | Non-liquefied |
| 12  | CDB BG                | Consolidation Dam 6-Bridge (down stream) | Low | Moderate |
Subsequent analysis was carried out using the Liquefaction Potential Index (LPI) method proposed by Sonmez. This method was intended to classify each high level of potential liquefaction, starting from the lowest to the highest. At the earthquake scale of 7.5 Mw, the Poi River area showed a relatively safe result against liquefaction. The middle stream area belongs to the “non-liquefiable” category. The potential for liquefaction in the “low” to “moderate” category began to be found in the downstream area to the end of the Poi River. Not significantly different results were obtained for loading with an earthquake scale of 7.9 Mw (Table 5).

The Bangga River area indicated a higher soil susceptibility to liquefaction. Referring to the results of the Liquefaction Potential Index (LPI) analysis on an earthquake scale of 7.5 Mw, this area was dominantly located in a zone with “low” level of liquefaction vulnerability in the middle stream. In the downstream, the results of the LPI indicated a zone classified in the “moderate” category. More critical results were shown at the 7.9 Mw earthquake scale. The upper zone of the river middle stream still tended to be found in areas with “non-liquefiable” to “low” LPI levels. However, the area that was classified as “moderate” LPI category extended from the downstream part to the middle stream area of the river. The potential for liquefaction on a “high” level category was also found in the area around the bridge (SDB Bridge), located in the downstream area (Table 6).

The results of the LPI analysis for the Bangga River and the Poi River were presented in the form of a disaster risk map, as shown in Figure 6 and Figure 7.

Table 6. LPI Analysis of Bangga River.

| No. | Drilling Point Number | Location                          | Liquefaction Potential Index (7.5 Mw earthquake) | Liquefaction Potential Index (7.9 Mw earthquake) |
|-----|-----------------------|-----------------------------------|-------------------------------------------------|-------------------------------------------------|
| 1   | SDB 1                 | Sabo Dam (Middle Stream)          | Non-liquefied                                   | Non-liquefied                                   |
| 2   | SDB 2                 |                                   | Non-liquefied                                   | Non-liquefied                                   |
| 3   | SDB 3                 |                                   | Non-liquefied                                   | Low                                             |
| 4   | BH 1                  |                                   | Non-liquefied                                   | Non-liquefied                                   |
| 5   | BH 2                  |                                   | Non-liquefied                                   | Non-liquefied                                   |
| 6   | BH 3                  |                                   | Non-liquefied                                   | Non-liquefied                                   |
| 7   | BH 4                  |                                   | Non-liquefied                                   | Non-liquefied                                   |
| 8   | BH 7                  |                                   | Non-liquefied                                   | Non-liquefied                                   |
| 9   | BH 8                  |                                   | Low                                             | Moderate                                        |
| 10  | BH 9                  |                                   | Low                                             | Moderate                                        |
| 11  | BH 10                 |                                   | Non-liquefied                                   | Non-liquefied                                   |
| 12  | SDB BG                | Consolidation Dam 2-Brigde (down stream) | High                                            | High                                            |
| 13  | BH 16                 | Consolidation Dam 1 (middle-stream) | Low                                             | Low                                             |
| 14  | BH 17                 | Consolidation Dam 2 (middle-stream) | Moderate                                        | Moderate                                        |
| 15  | BH 18                 | Consolidation Dam 3 (down stream)  | Moderate                                        | Moderate                                        |
4. Conclusion
The qualitative analysis, which was carried out by utilizing the threshold Liquefaction Method proposed by Keith et al. (1999), showed that the lower reaches of the Poi and Bangga Rivers had a moderate susceptibility to liquefaction, while the middle part tended to be safe from liquefaction. The sieve tests carried out on several samples obtained at both locations showed that the grain gradation in the Poi and Bangga rivers was classified in the liquefaction potential zone.
Referring to the quantitative analysis that was carried out using the Idriss and Boulanger (2004) method based on NSPT data, it was found that several layers were vulnerable to liquefaction events. In the Poi watershed, the layer susceptible to liquefaction was found in the downstream area at a depth of 2 (two) meters. The analysis results on the Bangga River area showed that the soil layer that was susceptible to liquefaction was located in the downstream area close to the residential area at a depth of 3 to 11 meters.

The results of the LPI analysis for the Bangga River and the Poi River were presented in the form of a disaster risk map, as shown in Figure 6 and Figure 7. It can be seen that the Poi and Bangga River areas had a level of risk of potential liquefaction ranging from "moderate" to "Non-liquefied". The Bangga River area had a higher level of vulnerability than the Poi River. The results of the 7.5 Mw and 7.9 Mw earthquake scenarios did not show any significant changes. However, it can be seen that the 7.9 Mw seismicity level had a wider "moderate" potential level compared to the 7.5 Mw earthquake.

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