Advances in Engineering Research, volume 198
International Seminar of Science and Applied Technology (ISSAT 2020)

The Foundations of Palangpang Bridge in the Area Potential to Liquefaction throughout the Cimandiri Fault

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ABSTRACT
Liquefaction is a phenomenon that occurred when soil loses its shear strength due to an earthquake. In general, liquefaction happens during a large magnitude earthquake on soil with loose to very loose sand consistency and high ground water level. Palangpang Bridge is in Ciwaru area, Sukabumi Regency, West Java Province, Indonesia and is located over the Cimandiri fault. Seismicity history showed that Palangpang Bridge have experienced up to 25 earthquakes in the last 50 years. In this paper, liquefaction potential analysis on the bridge foundation will be conducted with qualitative and quantitative methods. Based on the cone penetration test (CPT) results, in the area of Palangpang Bridge, the soil layers that supported the bridge is alluvium soil with beach sand sediments and the ground water level is 2.5-3.0 meter below ground surface. The results of liquefaction potential analysis showed that liquefaction occurred in the soil layers at the depth of 9 meter below surface, thus the foundation of Palangpang Bridge needs to be reinforced. The reinforcement design is to add 8 piles to the existing pile configuration for each footing so that the bridge can operate safely.
Keywords: *Liquefaction, Cimandiri fault, deep foundation, CPT, CSR, CRR*

1. INTRODUCTION

Indonesia, as a developing country, needs infrastructure development to achieve connectivity between regions that has an impact on the economic growth. Indonesia is prone to natural disasters such as earthquakes. This country is a meeting place for the world's major plates, namely the Eurasia Fault, Australian Fault, and the Pacific Fault, which means that that it has a large potential for earthquakes as shown in Figure 1 [1]. Soil liquefaction is one of the main causes of significant damage during an earthquake [2].

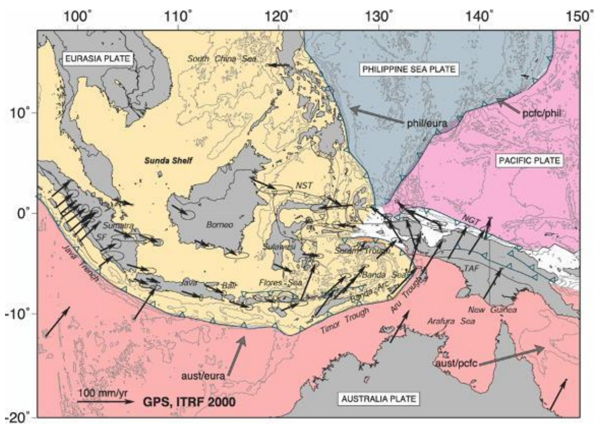

Figure 1 Indonesia tectonic plates [3]

Liquefaction is the process of change of soil condition from water-saturated sand to liquid due to the increase of pore water pressure, which value is equal to the total pressure due to dynamic loads, so that the effective stress of the soil becomes zero [4, 5]. Terzaghi and Peck (1967) referred to spontaneous liquefaction to describe the sudden loss of strength from very loose saturated sand due to increased stress, such as from earthquake vibrations or other sudden changes in stress for a short time [5]. Soil liquefaction has attracted attention because of its effect of causing significant infrastructure damage in residential areas since the earthquakes in Niigata and Alaska in 1964 [6, 7].

Nonetheless, liquefaction has caused damages, deaths, and huge economic losses. The phenomenon of liquefaction has an adverse impact on construction, one of which is what happened during the earthquake and tsunami disaster in Palu City, Indonesia in 2018, known as the Palu Earthquake. The earthquake with a magnitude of M7.8 caused a strong shaking and resulted in a tsunami that hit Palu City and massive liquefaction [8]. When an earthquake occurs, the soil is liquefied which makes the ground move. This caused buildings above to move and caused damage to them. These problems have been reported as the result of the liquefaction phenomenon.

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Figure 2 and Figure 3 show the earthquake following liquefaction in Palu, Indonesia.

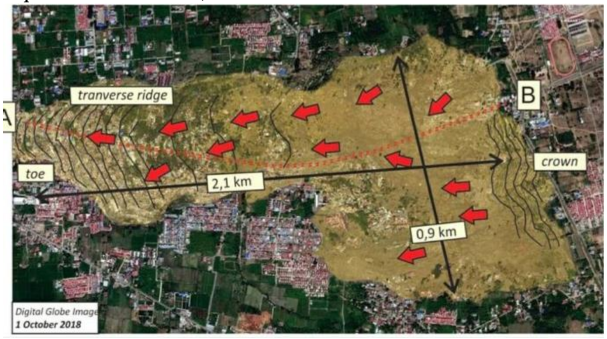

Figure 2 Liquefaction in Palu, Indonesia [8]

Figure 3 Offset observation map Palu earthquakes [8]

Considering that some parts of Indonesia are active faults, liquefaction is likely to happen. Sukabumi, West Java is an earthquake-prone area because there is an active fault, namely the Cimandiri fault. The Cimandiri Fault was formed from an active fault line extending from Pelabuhan Ratu bay to the south of Sukabumi City [9]. Figure 4 shows the Cimandiri fault over Sukabumi Regency through the Pelabuhan Ratu. Earthquake history is needed as data for qualitative analysis. The data is needed to estimate the magnitude of an earthquake that can cause liquefaction.

Figure 4 Cimandiri fault [9]

The Palangpang Bridge, which is classified as a class 1 bridge, is located on the West Java Provincial Road, Jalan Walura-Ciwaru-Palangpang km 221+600 with a length of 15 meters and a total width of 9 meters as shown in Figure 5. The geological condition of the Palangpang Bridge is in the area of Sukabumi Regency which is identified as an earthquake zone area 4. The soil structure of the Palangpang Bridge is alluvium type. The bridge is located close to the active Cimandiri-Lembang fault. The earthquake history used in this research is of the Sukabumi area. Table 1 shows the earthquakes that have occurred in Sukabumi during the last 50 years according to the *Badan Meteorologi Klimatologi dan Geofisika* (BMKG/Meteorology, Climatology, and Geophysical Agency) and the United States Geological Survey.

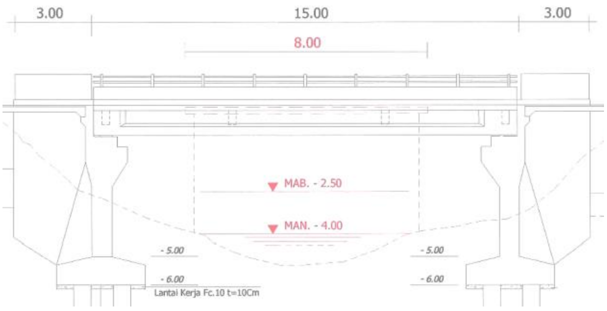

Figure 5 Palangpang Bridge

Table 1 Earthquakes historical record at Sukabumi

No	Date	Depth (km)	Magnitude
1	August 3, 2019	27	4.4
2	August 2, 2019	48	6.9
3	January 8, 2019	10	5.4
4	July 7, 2018	6	4.6
5	July 7, 2018	5	4.4
6	February 16, 2018	10	5.1
7	December 16, 2017	10	5.7
8	June 12, 2017	10	6.3
9	February 8, 2017	25	5.2
10	December 13, 2016	95	4.8
11	April 6. 2016	10	6.1
12	December 19, 2015	20	5.6
13	December 8, 2015	10	5.1
14	September 5, 2015	10	5.6
15	October 17, 2014	146	5.5
16	May 15, 2014	31	4.5
17	January 15, 2014	111	5.1
18	December 18, 2014	5	4.5
19	September 18, 2013	5	4.5
20	June 4, 2012	24	6.1
21	May 18, 2010	13	6.0
22	September 2, 2009	30	7.3
23	July, 12 2000	33	5.1
24	February 10, 1982	25	5.3
25	November 26, 1973	62	4.9

This paper investigates the soil in the area around the Palangpang Bridge and the Cimandiri Fault analyzes the potential for liquefaction using the Cone Penetration Test

(CPT) data, and determines the method of foundation reinforcement.

2. LITERATURE STUDY

2.1. Previous Research

Lonteng, Balamba, Monintja and Sarajar [4] conducted a research on liquefaction analysis using the Cyclic Stress Ratio (CSR) and Cyclic Resistance Ratio (CRR) calculation methods using Standard Penetration Test (SPT) and Core Penetration Test (CPT) data, and then compared the results of the potential for liquefaction. The research results revealed that the safety factor obtained did not have the potential for liquefaction [4]. Soebowo, Tohari, and Sarah [10] investigated the potential for liquefaction in the Opak Patalan Fault Zone, Bantul, Yogyakarta, and found that the area is prone to liquefaction after an analysis using the "simplified procedure" calculation [10]. Tini, Tohari and Iryanti [11] presented research on the Analysis of Potential Liquefaction Due to Earthquakes Using the Standard Penetration Test and Cone Penetration Test Methods in Bantul Regency, Yogyakarta. The study used the CSR and CRR calculation methods. The result was that the area has the potential for liquefaction [11]. Mase and Somantri [12] stated that liquefaction has the potential to occur in the Lempuing Village area. This research used the critical maximum acceleration as the method of analysis [12]. Analysis of the potential for liquefaction in the construction of the Sei Batang Serangan-Langkat Bridge was the title of research by Situmorang and Iskandar and [13]. This research used the CSR and CRR calculation methods. The results showed that the area has the potential for liquefaction as deep as 11.5 meters of sand layer [13].

2.2. Liquefaction

Liquefaction is a symptom of soil structural collapse due to receiving cyclic (repeated) loads. The loads cause changes in the sand soil deposit in the form of an increase in pore water pressure. As a result, the shear strength of the soil is reduced or even completely lost (loose of strength) so that the soil is sandy, melts and behaves like fluid [4, 5].

In general, liquefaction can occur to grained soil, which is usually found in sand and silty sand that is low in clay. Uniform sand is more likely liquefied than well-graded sand and saturated sand with shallow groundwater levels and short dynamic loads (large earthquake>M5).

Before an earthquake occurs, the soil is solid which can withstand loads. Due to the propagation of strong earthquake waves that cause the pore water pressure to increase, the soil becomes liquid. When the pore water pressure increases and the effective stress decreases, the shear strength also decreases.

The liquefaction potential is generally evaluated by measuring the earthquake load and liquefaction resistance. It is common to base comparisons on the amplitude of cyclic shear stress, usually normalized by the initial effective stress and expressed in CSR for loading and CRR for resistance. The potential for liquefaction is then expressed in the safety factor against liquefaction, FS=CRR/CSR [7].

2.3. Cimandiri Fault

According to the National Center for Earthquake Studies [9], the Cimandiri Fault forms a 100 km line running northeast to southwest from Padalarang to Pelabuhan Ratu in West Java. Many large earthquakes occurred in this fault zone, including M5.5 in 1982, M5.4, and M5.1 in 2000, as well as M.7 that occurred in 1900. The geodetic slip rate of the fault is estimated to be quite small in the range 0.4-1 mm/year. The Cimandiri fault zone consists of many vertical and horizontal faults with an orientation to the east-west and northeast-southwest; however, more detailed information about the fault is not widely known [8].

Marliyani, Arrowsmith, and Whipple [14] identified part of the active Cimandiri fault zone based on quantitative analysis of bedrock channel geomorphology using two main proxies of normalized channel steepness index and knickpoints, and combined with geomorphological and quaternary geology tectonic mapping. According to Marliyani et al. [14] the active Cimandiri fault zone consists of 6 segments (Loji, Cidadap, Nyalindung, Cibeber, Saguling, and Padalarang segments illustrated in Figure 6) whose dominant mechanism is upward faults with a sledding component. Using the hypsometric curve morphometric meters, asymmetrical basins, river length index gradient, mountain face and width comparisons, and valley heights, the active parts of the Cimandiri fault was mapped [14].

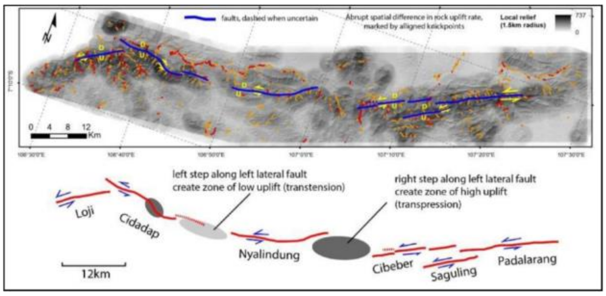

Figure 6 Cimandiri fault segments [14]

3. METHODOLOGY

The analysis of the liquefaction potential was carried out after obtaining the necessary data. There are two ways to determine the potential for liquefaction, namely qualitative analysis and quantitative analysis. The analysis used existing data as components to analyze potential liquefaction including geological criteria, historical seismic criteria, and bridge criteria.

To determine the bridge foundation capacity, it was necessary to calculate precisely according to the construction plan and soil characteristics so that the foundation can work efficiently and optimally. SNI 1725:2016 guidelines concerning “Load for Bridges” and SNI 2833:2016 concerning “Bridge Planning against Earthquake Loads” were needed to calculate the load of the bridge. The soil characteristics field testing was carried out using CPT adhering to the SNI 2827:2008 guidelines.

The method for evaluating the potential for liquefaction is to obtain the safety factor (FS) from CSR and CRR. After analyzing using both qualitative and quantitatively, the method that is suitable for soil improvement in areas prone to liquefaction potential was determined.

4. ANALYSIS AND DISCUSSION

4.1. Soil Investigation

In the field testing, it was necessary to plan the CPT point to be reviewed on the bridge to be made. On the Palangpang Bridge, there were 2 points namely S-1 (CPT-1) and S-2 (CPT-2). Figure 7 illustrates the Palangpang Bridge. The bridge has a length of 15 meters and a total road width of 9 meters. It uses 12 bore piles for each head as foundation, with diameters of 0.4 meters and depth of 6 meters as shown in Figure 8.

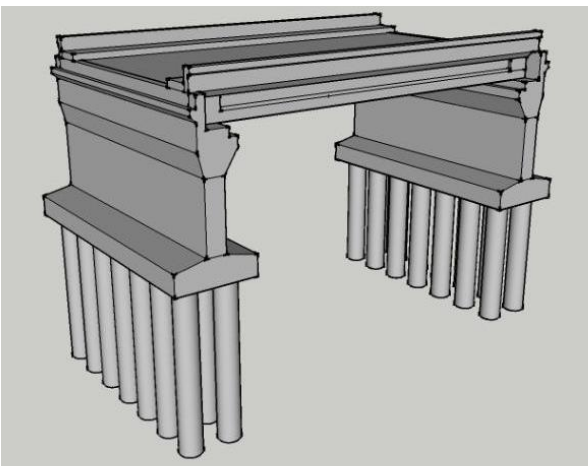

Figure 7 Illustration of Palangpang Bridge

The stratigraphy, which is the arrangement of soil layers on the bridge that is needed to analyze the bridge foundation, was obtained from soil investigation with CPT that is presented in Figure 9. CPT result shows that at the depth of 8.3-10.3 meters (S-1) and 1.40-3.40 meters (S-2) the soil layer was very loose sand, so it has the potential for liquefaction. Table 2 and Table 3 show the results of soil investigation.

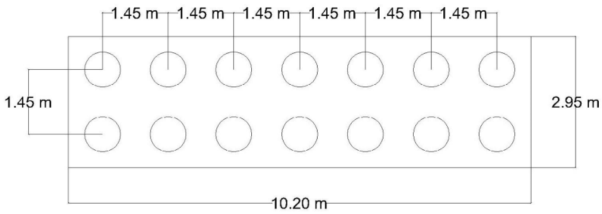

Figure 8 Existing foundation configuration

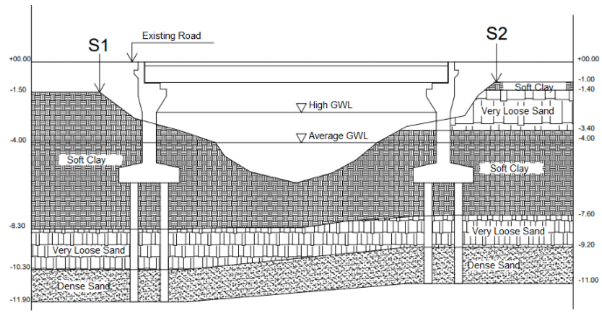

Figure 9 Palangpang bridge stratigraphy

Table 2 Soil investigation result of S-1

Layer	Depth (m)	Soil Type	Notes
H_1	1.00-8.30	Soft clay	No potential for liquefaction
H_2	8.30-10.30	Very loose sand	Potential for liquefaction
H_3	10.30-11.90	Dense sand	No potential for liquefaction

Table 3 Soil investigation result of S-2

Layer	Depth (m)	Soil Type	Notes
H_1	1.00-1.40	Soft clay	No potential for liquefaction
H_2	1.40-3.40	Very loose sand	Potential for liquefaction
H_3	3.40-7.60	Soft clay	No potential for liquefaction
H_4	7.60-9.20	Very loose sand	Potential of liquefaction
H_5	9.20-11.00	Dense sand	No potential for liquefaction

Palangpang Bridge is located on alluvium soil and coastal sediment. Moreover, the land surface is at a depth of 3 meters and 2.5 meters. The Palangpang Bridge is often hit by earthquakes with the highest scale being M7.3. The qualitative analysis showed that the Palangpang Bridge has the potential to experience liquefaction.

4.2. Analysis Results

Analysis of the liquefaction potential of the bridge must be considered because the bridge is located close to an active fault. Palangpang Bridge is in Sukabumi Regency which has the spectral value of the soil surface at 1.0 second (SD1)=0.64. According to SNI 2833:2016, if the SD1 value is >0.5, then the area is an earthquake zone 4.
The calculation of the potential for liquefaction used a method based on CPT data. The analysis was performed at each CPT point. The results of the analysis are the values of CSR and CRR. Comparison of CRR and CSR produced FS value. The value of FS≥1 means that the land has no potential for liquefaction and if FS <1 then the land has the potential for liquefaction.
Soil liquefaction may occur at point S-1 to a depth of 9.80 meters from a depth of 10.40 meters in the event of M6.5 earthquake. Whereas for M7.0 earthquake and M8.5 earthquake, liquefaction may occur to a depth of 10.00 meters from a depth of 10.40 meters as presented in Figure 10. For the M6.5 earthquake the q_c value was more than 140 kg/cm^2; for the M7.5 earthquake and the M8.5 earthquake, the q_c value was more than 160 kg/cm^2; thus the soil has no potential for liquefaction. Liquefaction occurs in sandy silt soils and sand obtained in H_2 (very loose sand) and H_3 (dense sand).

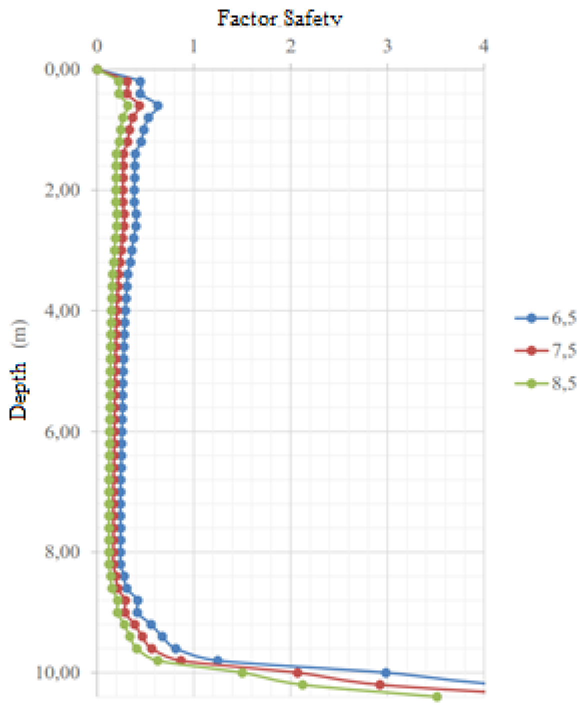

Figure 10 Graph of FS vs. depth at S-1

Soil liquefaction may occur at point S-2 to a depth of 9.40 meters from a depth of 10.00 in the event of a M6.5 earthquake, while for a M7.0 earthquake to a depth of 9.60 meters from a depth of 10.00 meters and a M8.5 earthquake the liquefaction may occur to a depth of 9.80 from a depth of 10.00 meters, which is presented in Figure 11. For the M6.5 earthquake, the q_c value was more than 155 kg/cm^2; for the M7.5 earthquake the qc value is more than 155 kg/cm^2; and for the M8.5, the q_c value is more than 200 kg/cm^2; so the land has no liquefaction potential. Liquefaction occurs in sandy silt soils and sand obtained in H_2 (very loose sand) and H_3 (dense sand).

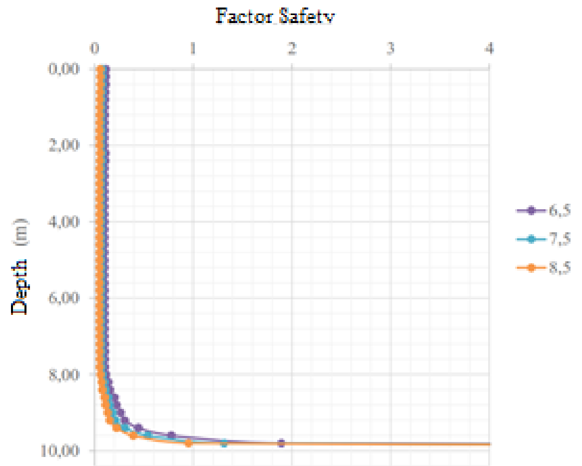

Figure 11 Graph of FS vs. depth graph at S-2

From the results of quantitative analysis of the foundations of the Palangpang Bridge, it was found that the foundations had the potential for liquefaction. The calculation results of the carrying capacity of the group after liquefaction showed that the carrying capacity of the group does not have the allowable carrying capacity. The foundation strengthening is needed to anticipate earthquakes larger than the megathrust by adding 8 bore piles to the foundations with 10 meters depth. The pile configuration after being reinforced is depicted in Figure 12.

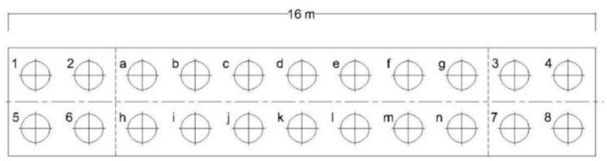

Figure 12 Pile foundation configurations after the reinforcement

4. CONCLUSIONS

Based on the analysis of the potential for liquefaction at the Palangpang Bridge, several conclusions of this research are as follows:

1. Palangpang Bridge is located on alluvium soil and coastal sediment, besides that the land surface is at a depth of 3 meters and 2.5 meters. The Palangpang Bridge is often hit by earthquakes with the highest scale being M7.3. The qualitative analysis showed that

the Palangpang Bridge has the potential for liquefaction.

2. In the quantitative analysis at point S1, liquefaction may occur to a depth of 9.80 meters from a depth of 10.40 in the M6.5 earthquake. Meanwhile, for the M7.0 earthquake and the M8.5 earthquake, liquefaction may occur to a depth of 10.00 meters from a depth of 10.40 meters. Whereas at point S2 liquefaction may occur to a depth of 9.40 meters from a depth of 10.00 meters in the M6.5 earthquake; while in the M7.0 earthquake liquefaction may occur to a depth of 9.60 meters from a depth of 10.00 meters; and the M8.5 earthquake liquefaction may occur to a depth 9.80 meters from a depth of 10.00 meters.
3. The foundation was strengthened to anticipate earthquakes larger than the megathrust by adding 8 bore pile foundations at the depth of 10 meters.

ACKNOWLEDGMENT

This work was supported by the Department of Civil Engineering, Politeknik Negeri Bandung; Geotechnical Area of Expertise Group, Politeknik Negeri Bandung; Research and Community Service Unit, Politeknik Negeri Bandung, which has fostered, facilitated and coordinated the research activities.

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