Liquefaction Potential Analysis of Reusep Prestress Bridge in Pidie Jaya due to 6.4 Mw Earthquake

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Abstract. Pidie Jaya is one of the districts in Aceh Province – Indonesia. On December 7, 2016, Pidie Jaya experienced a shallow 6.4 Mw earthquake which destroyed some vital buildings and also human loss. Based on preliminary field investigation, some geological damages like soil movement, soil cracks, and liquefactions occur because of the earthquake. Some liquefaction phenomena scattered in the area of Ulim, Panteraja, Meunasah Balek, Manohara Beach and Sagoe Trienggadeng. An evidence of liquefaction in Pidie Jaya area was displayed in this research based on several literature review. Furthermore, these paper aims to identify liquefaction possibilities in Trienggadeng Reusep Prestress Bridge based on a geotechnical investigation of N-SPT and some seismic data by using Kishida method. The surrounded area of the bridge was first evaluated in terms of geological setting, tectonics and seismic activity related to 6.4Mw of the previous earthquake. Furthermore, it was found from the soil profile that the studied area has a potency of liquefaction because of several saturated sand layers and high groundwater level. Effective overburden pressure of sand layers was calculated and plotted with N-SPT value to determine the possibility of liquefaction. The result shows that liquefaction potential shows high possibility for sand dominant layers both from bor-log 1 in 17.5 m and 25 m depths, and bor-log 2 in the depth of 17 m and 26.5 m.

1. Introduction

The liquefaction analysis potential was already studied in detail particularly since Niigata 1964 [1]. Research in liquefaction-related has been introduced in many ways for liquefaction potency estimation such as liquefaction histories and soil grain size conditions. Alluvial soil deposits liquefaction analysis by using an empirical method from the Nation Center for Earthquake Engineering Research was conducted by [2]. The research was conducted along the Nile river which already experienced liquefaction during October 1992 earthquake. There is also some previous liquefaction analysis in Indonesia which were conducted by [1], [3], and [4]. Assessment of liquefaction potency based on laboratory test was conducted by [1] while [3] try to predict the liquefaction probability by using shear wave velocity parameters. Moreover, [4] conducted another laboratory-based test to predict liquefaction according to the value of soil grain size and relative density. Specifically, liquefaction in Aceh was also analyzed by [5] and [6] by using Standard Penetration Test data. Aceh Province, where soil profile which has sand dominant layer shows the high possibility of liquefaction due to earthquake load as the Aceh location which closes to earthquake sources. Moreover, the shrink-swell behavior of soil also became a problem in Pidie Jaya soil as studied by [7].

Liquefaction damage to the structures due to earthquake disaster in Adapazari, Turkey was identified by [8]. The collapse of the building and construction during an earthquake to the effect of liquefaction potential are caused by structural defects poor quality of construction material. Research related to Pidie Jaya earthquake and the number of live and material loss was also conducted by [9] and [10]. The Pidie Jaya earthquake affected the geotechnical damage for up to 35 km radius mostly parallel to the seashore with approximately 101 people killed, more than 800 people wounded and economic loss around $139 million US [9]. As shown in figure 1, Aceh province surrounded by several faults which can be identified as an earthquake source. The main inland fault is known as Great Sumatran Fault. Moreover, according to [10], Samalanga-Sipopok fault (also known as Pidie Fault), was the source of the December 7th, 2016 of 6.4 Mw earthquakes.

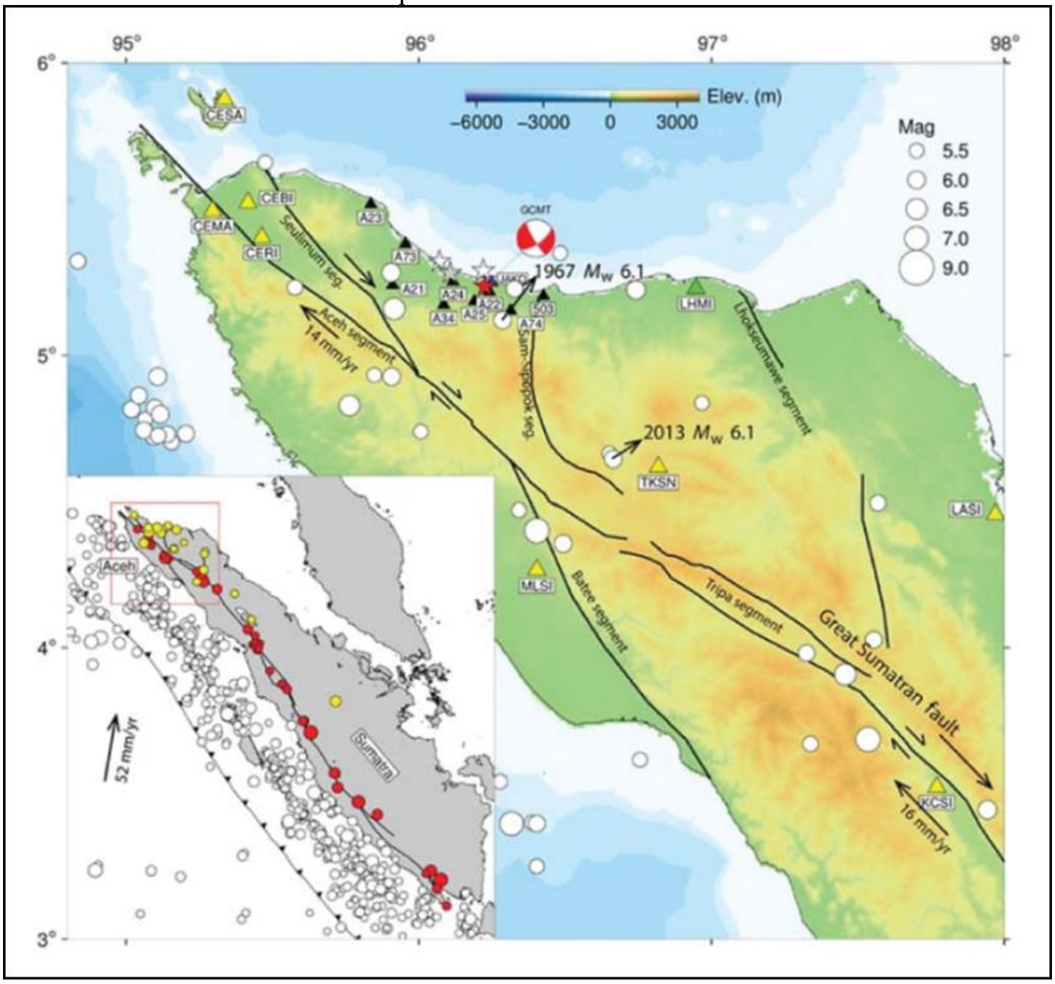


Figure 1. Aceh Faults along Sumatera [10]

Earthquake disasters often cause damage to buildings located far from the source of the earthquake. Previous study by [11] and [12] considering the earthquake load effect to civil engineering construction for design purposes. The difference in the level of damage to buildings indicates that the condition of the soil layer has a significant influence on the characteristics of seismic waves. Soft soil layers may amplify certain frequencies of earthquake vibrations. This condition may become extreme in areas that are based on thick soft soils [1], as a result, there is a change in material stiffness at the boundary between bedrock and soft soil that can cause amplification.

(a) (b)

(c) (d)

Figure 2. Liquefaction evidence in Pidie Jaya and the surrounding area, (a) boiling sand in local resident, (b) sand boil appears after the earthquake (c) sand boil shown up between tile crack (d) another sand boil evidence in resident area [14]

Some liquefaction phenomenal happened with the evidence of sandy like soil boiled in the west coast of Pidie Jaya along the shorelines such as in Manohara Beach [9]. The identified liquefaction zone spread along Ulim, Panteraja, West Panteraja, Meunasah Balek, Manohara Beach, and Sagoe Trienggadeng. Figure 2 explained some liquefaction evidence in Pidie Jaya and the surrounding area after the earthquake disaster from direct photograph in several resident areas surrounding Pidie Jaya after the earthquake disaster [13]. Reusep prestresses bridge, as a research location, was built in 2017 and located around Sagoe Trienggadeng at 5^{o}14’21” N and 96^{o}9’44” E. This bridge is 20 m long and 7 m wide. The soil profile below the bridge can be seen in figure 2. From the earthquake data in Table 1, it can be explained that Aceh Province lies in an active earthquake area, especially Banda Aceh which is an area that often experiences earthquakes. These earthquakes spread earthquake waves to the surface of the earth resulting in dynamic cyclic forces or regular alternating shear forces. Therefore, a study was conducted to find out the potential liquefaction. Only earthquake above Mw 5.0 was presented in Table 1. The raw data were obtained from Indonesia Agency of Meteorology, Climatology, and Geophysics in 2018 and had been sorted and presented as in Table 1.

Table 1. Recapitulation of recorded earthquake events in Aceh, from Indonesian Agency for Meteorological, Climatological, and Geophysics, Aceh 2018

No	Date			Latitude (N)	Longitude (E)	Depth (m)	Magnitude
	Year	Month	Day				
1	2004	December	28	5.11	96.162	30	5.2
2	2019	April	01	7.61	94.58	10	5.3
3	2017	February	15	5.19	96.16	27	5.4
4	2004	December	26	4.47	96.34	30	5.5
5	2016	December	07	5.25	96.24	15	6.5
6	2010	May	09	3.61	95.84	30	7.2
7	2008	February	20	2.77	94.31	16	7.5
8	2016	March	02	4.91	94.31	16	7.8
9	2005	March	28	2.09	95.50	30	8.6
10	2004	December	26	3.30	95.98	30	9.0

2. Analysis of Liquefaction

Kishida (1969) methods of liquefaction analysis were based on earthquake histories around the world for saturated sand [11]. This method was already used for predicting preliminary result of liquefaction potential. Furthermore, the method explained the relationship between N-SPT values and effective vertical stress (σ’) with three types of liquefaction possibilities. The liquefaction potential can be classified as a high possibility, medium possibility and low possibility of liquefaction.

Table 2. Soil Parameters based on SPT (Cohesionless Soil: Fairly Reliable) [15]

SPT N-Value		**0 to 4**	**4 to 10**	**10 to 30**	**30 to 50**	**>50**
Compactness		very loose	loose	Medium	dense	very dense
Relative Density, Dr (%)		0 to 15	15 to 35	35 to 65	65 to 85	85 to 100
Angle of Internal Friction, ϕ (^{o})		<28	28 to 30	30 to 36	36 to 41	>41
Unit Weight (moist)	pcf	<100	95 to 125	110 to 130	110 to 140	>130
	kN/m^3	<15.7	14.9 to 19.6	17.3 to 20.4	17.3 to 22.0	>20.4
Submerged unit weight	pcf	<60	55 to 65	60 to 70	65 to 85	>75
	kN/m^3	<9.4	8.6-10.2	9.4 to 11.0	10.5 to 13.4	>11.8

The liquefaction analysis in this study is the liquefaction that occurs due to cyclic loading, the liquefaction that usually occurs in water-saturated sand soils that experience earthquake loads. The vibration may result the saturated sand loses it carrying capacity. This means that only soil layers with water-saturated sand were observed. Moreover, the sand layer must be below the groundwater level. Due to the limitation of soil parameter data for liquefaction analysis, engineering estimation based on N-SPT was used. Previous research in the correlation between N-SPT result with soil properties was showed by [15] and [16] as shown in Table 2. The N-SPT values were obtained from soil profile in figure 3 and the effective vertical stress was calculated and depend on soil type. Additionally, the unit weight and submerged unit weight of soil was needed to obtain soil vertical stress. The soil parameters used in the calculation were based on estimation by using table 2.

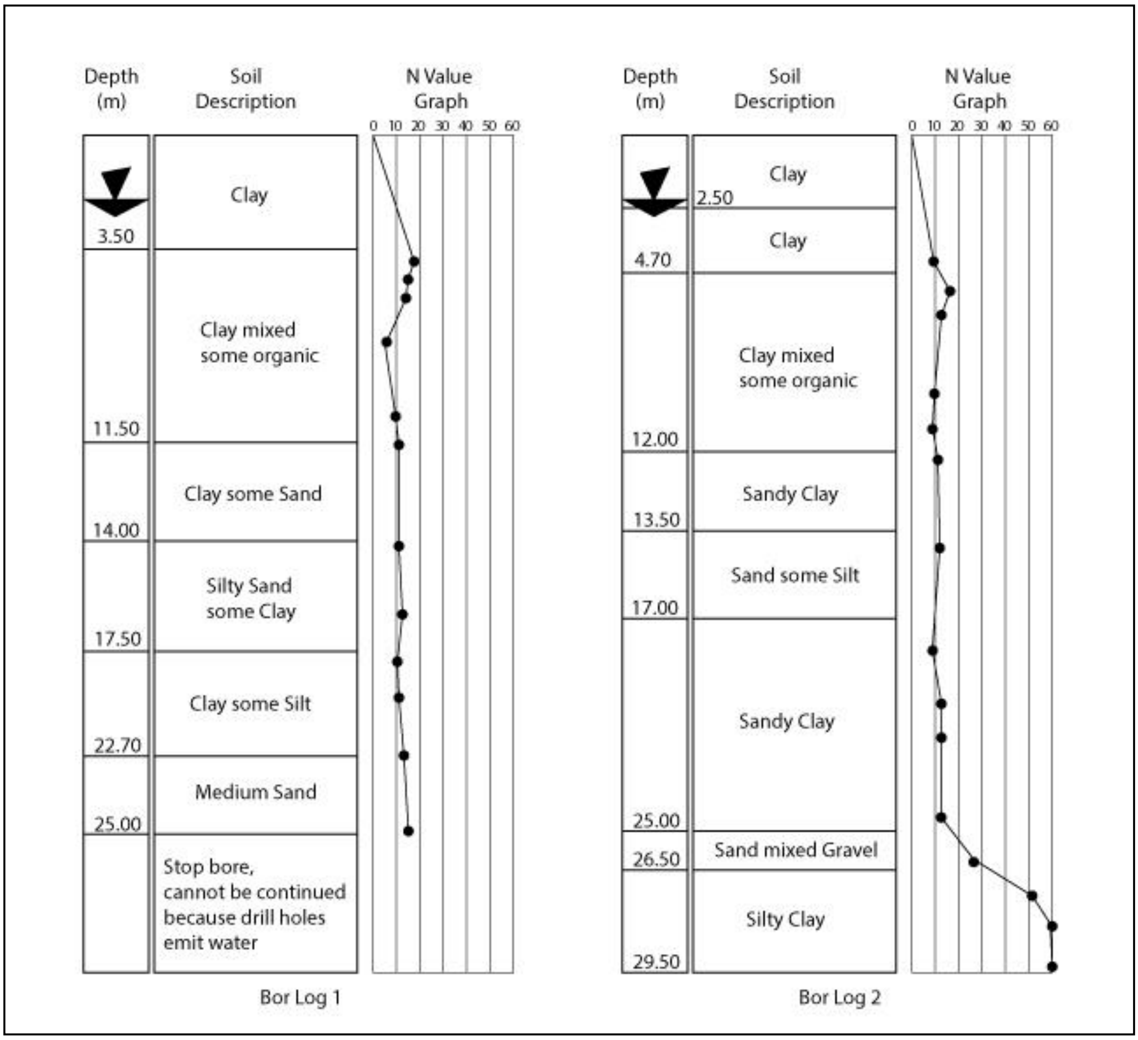
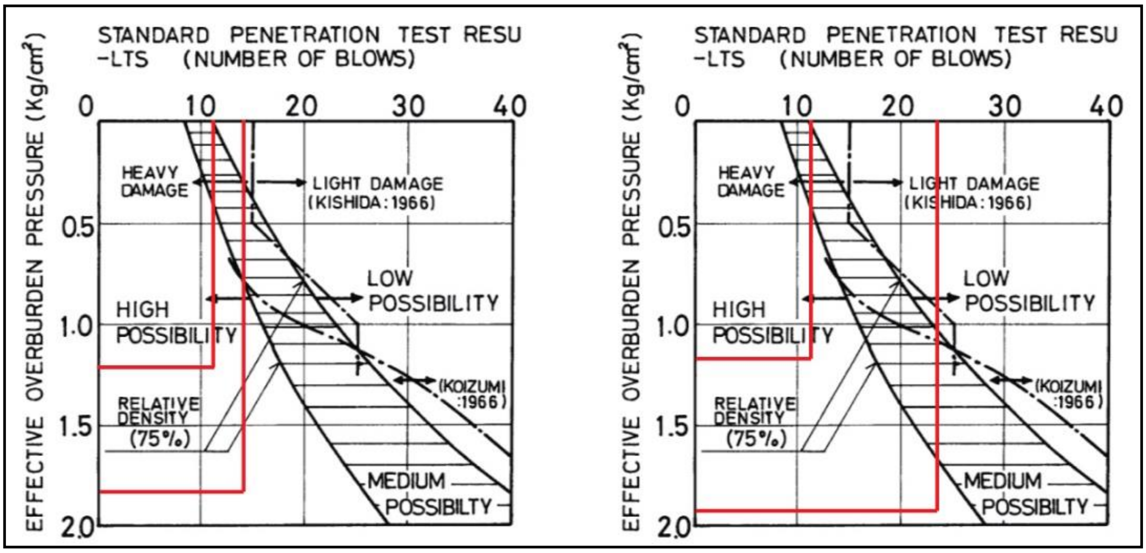


Figure 3. Soil Profile of Reusep Prestress Bridge from N-SPT Test

As can be seen in figure 3, there is more than 25.00 m depth of soil profile according to bor log 1 and up to 29.50 m depth of soil profile for bor log 2 with dominant soils are clay and sand. The groundwater level of the site is approximately 2.50 m below ground level. Sand dominant layers from bor-log 1 are in the depth of 14.00 – 17.50 m for silty sand with some clay (N-SPT average, 11) and 22.70 – 25.00 m for medium sand with N-SPT average is 14. Moreover, sand with some silt in 13.50 – 17.00 m with N-SPT average is 11 and sand mixed gravel (Average N-SPT, 23) in 25.00 – 26.50 m presented in bor-log 2. The potency of liquefaction may occur in layer of silty sand with some clay and medium sand for bor log 1 and in layers sand with some silt and sand mixed gravel for bor log 2. All liquefaction prediction layers were saturated layers and domination with sand soil as mention by [13].

3. Result and Discussion

Calculation results and discussion about the potential of liquefaction occurring in water-saturated sand layer at Prestress Bridge in Reusep Pidie Jaya can be explained in term of possibility level. From soil unit weight and soil depth observed, vertical stresses can be determined, both total and effective stress which then used as parameter for obtaining liquefaction potency. This article result was also another extended research result of [17] of determining soil characteristic and behavior under earthquake load in Pidie Jaya area. Depth and thickness of the layer under analysis were identified from the soil layer profile (drill log) as Figure 3. Furthermore, there are four saturated sand layers were identified based on soil profile in figure 4. These sands dominated layers were then analyzed for liquefaction potential. From bor log 1 it can be seen that at the depth of 14.00 - 17.50 m the soil is silty sand with some clay and at the depth of 22.70 - 25.00 m the soil is medium sand. Furthermore, according to bor log 2, there is sand with some silt layer at 13.50 - 17.00 m depth and sand mixed with gravel at 25.00 - 26.50 m depth.



(a) (b)

Figure 4. Probability of Liquefaction for Saturated Sand, (a) Bor log 1, (b) Bor log 2

By using N SPT value and correlation with Table 2, the effective overburden pressure (σ'_{vo}) calculation from bor log 1 for the depth of 17.5 m and 25.0 m are 118.02 kN/m^3 (1.20 kg/cm^2) and 179.21 kN/m^3 (1.83 kg/cm^2) respectively. Moreover, from bor log 2, σ'_{vo} obtained at 17.0 m depth and 26.5 m depth are 109.6 kN/m^2 (1.12 kg/cm^2) and 188.9 kN/m^2 (1.92 kg/cm^2) respectively. Based on effective overburden pressure of sand layers and average N-SPT value, then plotted to figure 4 to determine the possibility of liquefaction. Figure 4 is the probability of liquefaction for the saturated sand method proposed by [11]. The result shows that all plotted data were on the left side of the figure which means that liquefaction potential shows were high possibility for sand dominant layers both from bor-log 1 in 17.5 m and 25 m depths, and bor-log 2 in the depth of 17 m and 26.5 m.

4. Conclusion

The result of liquefaction analysis from this article can be classified as a preliminary result. Further soil parameter analysis from the laboratory is necessary for more appropriate results. The potency of liquefaction result is related to site condition as already described by [9]. Due to earthquake history and liquefaction potency in Pidie Jaya, for future construction development, liquefaction analysis is highly recommended for detail engineering design. Furthermore, the limitation of this liquefaction analysis was based on several factors including few site soil parameters. As a result, comprehensive physical soil parameter analysis from laboratory tests was important for more detail result of liquefaction analysis. For a large construction in areas known to have high liquefaction potential, firstly, it is best to treat the soil with stone columns or other soil liquefaction treatment such as grouting and compaction to improve soil strength and reduce the risk of liquefaction.

5. References

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