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A STUDY ON THE LIQUEFACTION POTENTIAL IN BANDA ACEH CITY AFTER THE 2004 SUMATERA EARTHQUAKE

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ABSTRACT: Liquefaction is caused by an earthquake in which the energy propagates into soil layers to trigger the excess pore water pressure escalation so that the soil mass liquefies. This condition causes a decrease in effective stress, ground settlement, and lateral spreading. This study aims to determine the liquefaction potential in Banda Aceh City, Indonesia, due to the M_w 9.2 great earthquake that occurred in 2004. The analysis was conducted on 16 boreholes incorporating Standard Penetration Test (SPT) that investigated the soil engineering properties and geological conditions of the study area. The peak ground acceleration (PGA) for each borehole location was obtained from the value determined by the Ministry of Public Works and Public Settlement of Indonesia. The analysis of liquefaction potential in Banda Aceh City adopted the semi-empirical of the Idriss Method with an input moment magnitude of 7, 8, and 9.2 M_w, respectively. The liquefaction potential was evaluated at 5 m, 10 m, and 15 m depths below the ground surface. The analysis resulted in 4 zones of liquefaction potential levels, i.e., very high, high, low, and very low. High liquefaction potential zones occur in the Sub-districts of Baiturrahman, Kuta Alam, and Syiah Kuala. Meanwhile, low and very low liquefaction potential spread over the northeast, western, and southern parts of Banda Aceh.

Keywords: Liquefaction, Lateral spreading, Standard penetration test, Peak ground acceleration, Geological condition

1. INTRODUCTION

The liquefaction phenomenon is the secondary disaster likely to occur following an earthquake. It is caused by a sudden loose of the soil shear strength triggered by the increase of pore pressure excess due to the dynamic loads. Such conditions will lead to the ground being unable to support the load from the upper structures. The soil deposit liquefies after an earthquake and produces a large cyclic deformation. Softening is a change in the state of solid granular material to become liquid caused by the increasing water pressure and effective stress reduction [1]. The reduced effective stress on the soil deposit is influenced by the ratio of excess pore water pressure (*ru*). Experimental studies of *ru* parameters have been used by researchers who have researched liquefaction, such as [2]. In addition to experimental liquefaction, there are also many researchers conducting empirical analyzes such as [3-4]. Another parameter that can affect liquefaction is the condition of the soil to the seismic response [5]. Liquefaction is strongly influenced by soil engineering properties, geological conditions, and seismicity [6].

A major earthquake of M_w 9.2 that occurred on December 26, 2004, in Banda Aceh City [7,8] had caused liquefaction and lateral spreading. By using Seed and Idriss method (1971), it was found that the liquefaction potential at Krueng Raya coastal area in Banda Aceh occurs in the sand layer within 3 - 5 m depth when an earthquake magnitude that ranged between M_w 5 and 9 strikes [9]. The evaluation of liquefaction potential in Banda Aceh City was also carried out by using a simplified empirical method modified by NCEER (1997) in addition to the adoption of the Iwasaki et al. method [10]. The results showed that several coastal areas in Banda Aceh City contained high liquefaction potential.

A Japanese team has also studied the liquefaction potential at the coast of Banda Aceh and Aceh Besar District. They found that the land alongside the west coast mostly contained sand layers, and was prone to liquefaction. The influence of liquefaction that caused land settlement, lateral spread, and soil surface erosion due to the tsunami waves was investigated by [11]. Fig. 1 shows the liquefaction with the emergence of the foundation settlement of building and tilt in the Banda Aceh area after the 2004 earthquake. The site of liquefaction evidence is also shown in Fig 5.

The liquefaction phenomenon can be investigated by evaluating the correlation between soil depth and effective stress. When the effective stress turns to zero, the occurrence of liquefaction can be clarified. Such a decrease of effective stress to zero illustrates the soils inability to support the external load [12].

Ref [13] has reported that the loss of coastal land was caused by erosion resulting from the hydrodynamic forces of the tsunami waves so that the land along the coastline sank into the sea; however, liquefaction was likely to occur before the tsunami struck the Banda Aceh City [13]. The epicenter of the M_w 9.2 earthquake in 2004 was at 30 km depth and located approximately 250 km of the west part of Banda Aceh City.

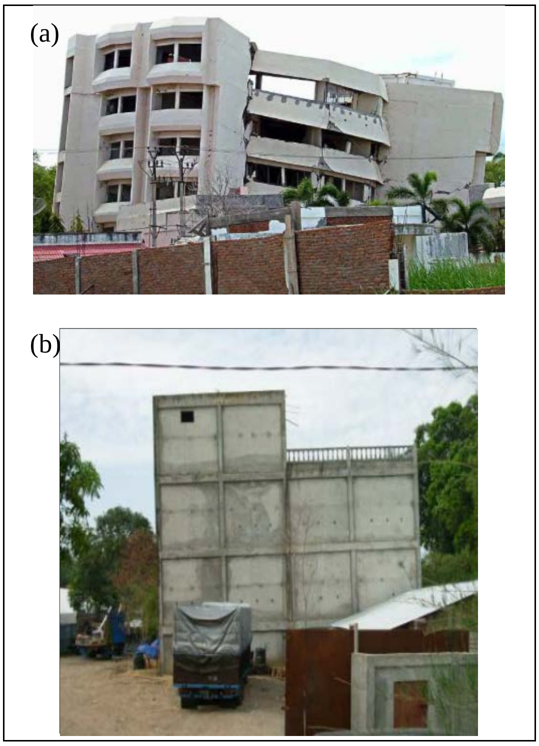

Fig. 1 Liquefaction occurrence after the December 26, 2004 earthquake: (a) Foundation settlement of a hotel building (5°32'57.03"N, 95°18'58.44"E) [14]; and (b) Phenomenon of the foundation settlement of a multi-storey building due to liquefaction (5°33'13.93"N, 95°19'11.08"E) [15].

Previous studies on the liquefaction potential in Banda Aceh have been carried out by using the site investigation, which was obtained from field investigations, i.e., core drilling and downhole seismic tests. Site-specific response analysis was performed by using the one-dimensional shear wave propagation approach as well as the evaluation of liquefaction potential by using a simplified empirical procedure [10]. Studies of liquefaction potential of Banda Aceh were conducted by applying the Cone Penetration Test (CPT) data under the Seed and Idriss (1971) method [7]. The empirical analysis of liquefaction using the combination of seismic ground response analysis and empirical analysis is adopted in several studies [16-17].

The earthquake source that was compatible with the maximum estimated peak seismic acceleration (MCE_G) was used to evaluate the liquefaction potential and the loss of soil strength [18]. Peak ground acceleration was determined by using the site-specific studies that considered the effect of specific amplification or peak soil acceleration (PGA_M) [19].

By recognizing the active fault line, PGA analysis can be performed with various attenuation equations; hence, the deterministic approach yields different results on each site [20]. In the Indonesian national standard for designing earthquake resistance buildings, SNI 03-1726-2012, the site factor is expressed by F_{PGA}, which is the site amplification factor coefficient from the PGA on the bedrock to the ground level as represented by (PGA_M). In this study, we also need to consider the reliability of SNI seismic design, because amplification is also a significant problem in this study. The reliability of the seismic design of SNI 03-1726-2012 has been discussed [21].

To analyze the liquefaction potential in Banda Aceh, this research referred to a semi-empirical procedure by Idriss and Boulanger (2008). It used the equations developed by [22,23]. This empirical approach is the best one for the empirical analysis method [24]. The results of this study are expected to make a valuable contribution to infrastructure development and spatial planning through potential liquefaction maps.

2. GEOLOGICAL CONDITION OF THE STUDY AREA

Banda Aceh City is located on the northern tip of Sumatera Island and in the Quaternary terrestrial sediments of sandstone, shale, and volcanoes, and surrounded by the Quaternary volcanic rock and lower Cretaceous-upper Jurassic sediments [25]. The city is located on a lowland area underlined by alluvium, gravels, sands, and muds (Qh) as shown in Fig. 2 [26]. The surface and subsurface geology in the area is classified mainly as clay, silt, mud, and sand deposits. The deposits were found in the Banda Aceh City area and along the coastline.

The location of 16 boreholes (BH) used for the analysis is shown in Fig. 2. Fig. 3 shows the cross-section of the soil profile and Standard Penetration Test (SPT) from Northwest to Southeast direction. The loose sand layer was found between 5 to 10 meters depth below the ground surface on the Northwest, whereas a relatively hard layer was found in the Southeast. In 25-27 meters depth below the ground surface, the average N-SPT value was higher than 50 that indicated the existence of a stiff clay layer.

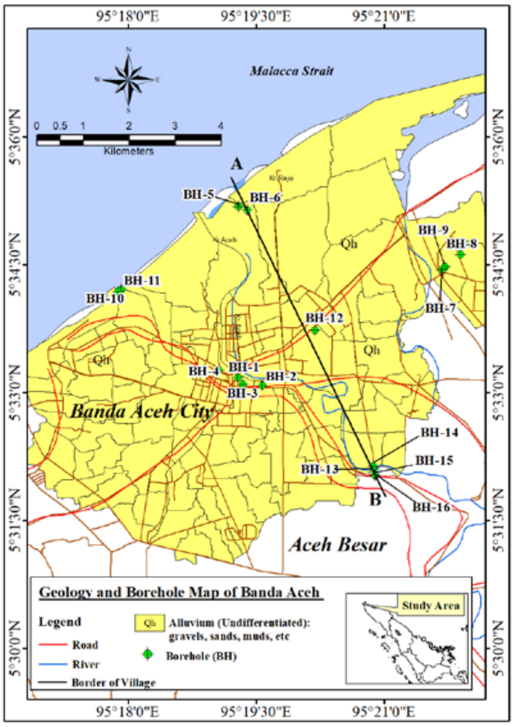

Fig. 2 The Geological map of Banda Aceh City (modified [26]).

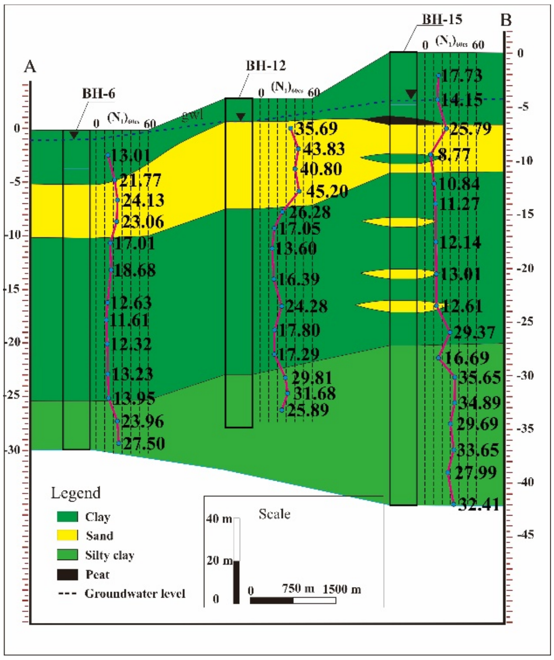

Fig. 3 The cross-section of the soil layer from the northwest to the southeast direction of Banda Aceh City.

In the middle area of Banda Aceh City (BH-12), the $(N_1)_{60cs}$ value was 40.80 in 5 to the 10-meter depth, which indicated the existence of medium to dense sand layer. The medium to low-level soil density was found in 10 to 20 meters, depth below the ground surface. The clay soil was found in 0 to 5 meters and 10 to 25 meters, depth below the ground surface. Sand and silty clay were found in 5 to 10 and 26 to the 30-meter depth below the ground surface, respectively. Such soil profile also consisted of peat soil lenses and Mollusca mixed with fine sand lenses, which was part of the Banda Aceh soil sediment.

3. DETERMINATION OF LIQUEFACTION POTENTIAL

In the preliminary study, Peak Ground Acceleration (PGA) of Banda Aceh City was determined according to the Ministry of Public Works and Public Settlement, the Republic of Indonesia by inputting the geographic coordinates. The method used to generate PGA is to fill the geographical coordinates on the spectrum design website of Indonesia. Peak soil acceleration was determined by using the site-specific studies and considering the effect of specific amplification, PGA_M.

$$PGA_M = F_{PGA} \times PGA \tag{1}$$

where PGA_M is the maximum peak ground acceleration adapted to the site classification effect, PGA is a value taken from the Indonesian seismic hazard map, which was determined by the Ministry of Public Works and Public Settlement. Also, F_{PGA} is the site coefficient. The soil site of the Banda Aceh City area was classified by using the Standard Penetration Test (SPT) based on SNI 03-1726-2012 [19]. SPT value measures the condition of local soil at the surface; local soil conditions influence the peak acceleration value of the earthquake from the bedrock to the ground surface. Local soil conditions will affect the value of the amplification factor. Therefore, some researchers conducted a study of parametric seismic site responses to determine the soil amplification factor, as examined by [5, 17].

The liquefaction analysis adopted the semi-empirical procedure developed by Idriss and Boulanger (2008). This approach is a reliable method because the method closest to the occurrence of liquefaction in the field was found after the 2007 earthquake [24]. It considered the moment magnitude, the unit weight of wet and dry soil condition, the groundwater level, and the SPT data. The data used in this research were obtained from several sites underlined by the soils investigation. Core drillings were conducted on sites and shaken by three different earthquake magnitudes ranging from M_w 7 to 9.2. The M_w 9.2 earthquake was the one that struck Banda Aceh on December 26, 2004 [27]. The Cyclic Stress Ratio (CSR) was determined using Eq. (2), which developed by [28].

$$CSR = 0.65 \times \left(PGA_M \frac{\sigma_{vc}}{\sigma'_{vc}} \right) \times r_d \quad (2)$$

where, PGA_M is the maximum peak ground acceleration on the surface; σ'_{vc} and σ_{vc} are the effective and total vertical stress at the depth z. Earthquake-induced by cyclic stress is represented by an equivalent uniform values of 65% of the cyclic stress peak. The r_d parameter is the shear stress reduction coefficient, which shows the depth function and the moment magnitude. In situ Cyclic Resistant Ratio (CRR) when M_w = 7.5 and on effective vertical stress σ'_{v0}=1 atm can be calculated under the following equation.

$$CRR_{M=7.5,\sigma'_{vc}=1} = exp\left(\frac{(N_1)_{60cs}}{14.1} + \left(\frac{(N_1)_{60cs}}{126}\right)^2 - \left(\frac{(N_1)_{60cs}}{23.6}\right)^3 + \left(\frac{(N_1)_{60cs}}{25.4}\right)^4 - 28 \right) \quad (3)$$

In the term, the subscript M=7.5 and σ'_{vc}=1 of CRR are apply to M=7.5 and an effective overburden pressure of σ'_{vc} = 1 atm.

By using the same correction factor, the correlation for CRR can be extended to other earthquake magnitude values and effective overburden pressure, namely.

$$CRR_{M,\sigma'_{vc}} = CRR_{M=7.5,\sigma'_{vc}=1} \times MSF \times K_\sigma \quad (4)$$

where, MSF is the magnitude scaling factor, and K_σ is the overburden correction factor described by Idriss and Boulanger (2008). Safety factor against liquefaction is calculated by dividing the value of the Cyclic Resistant Ratio (CRR), which is calculated from MSF, and Cyclic Stress Ratio (CSR), which is induced by the earthquake. Different earthquake magnitudes were accommodated in this investigation by using the Magnitude Scaling Factors (MSF) developed by [29].

$$MSF = 6.9\ \exp\left(\frac{-M_w}{4}\right) - 0.058 \quad \leq 1.8 \quad (5)$$

The safety factor (FS_{Liq}) against liquefaction is given as:

$$FS_{liq} = \frac{CRR_{M_w,\sigma'_{vc}}}{CSR} \quad (6)$$

where FS_{liq} is the safety factor against liquefaction. The formula is used to predict whether a certain layer is undergoing liquefaction.

The FS_{Liq} from the semi-empirical procedure is not an adequate instrument to evaluate liquefaction potential and its damage at any foundation settlement [30,31]. The FS_{liq} cannot specifically measure the extent of foundation damage caused by soil liquefaction, and this depends in turn on the severity of the liquefaction. Instead, it is determined by using the Liquefaction Potential Index (LPI) method to express the severity of liquefaction. The Liquefaction Potential Index (LPI) was proposed by Iwasaki [32,33] and defined as:

$$LPI = \int_0^{20} FW(z)\, dz \quad (7)$$

where, F =1- FS_{Liq} for $FS_{Liq} \leq 1.0$ and $F = 0$ for $FS_{Liq} > 1.0$; z is the depth below the ground surface (in meter) and $W(z)$ = a depth weighting factor equal to 10-0.5z, and dz is the differential increment of depth.

Ref. [32] proposed a Liquefaction Potential Index (LPI) and a potential classification based on LPI (Table 1) to measure the severity of liquefaction. The LPI is evaluated from z = 0 to z = 20 m depth below the ground surface, given with Eq. (7).

The LPI method only defines the effect of safety factors on the potential for linear liquefaction from zero to one. So that if the smallest safety factor can cause more damage to the surface. However, several studies have developed a probabilistic approach to overcome the weaknesses of the LPI method [30,34].

Table 1 The classification of Liquefaction Potential Index [32]

Liquefaction Potential Index (LPI)	Liquefaction potential classification
0	Very Low
0<LPI≤5	Low
5<LPI≤15	High
LPI>15	Very high

The LPI values obtained at each borehole profile would be mapped in the study area based on the potential classification (Table 1). The liquefaction depth severity was reviewed at depth intervals of 5 meters, 10 meters, and 15 meters below the ground surface.

4. RESULTS AND DISCUSSION

4.1 Determination of Peak Ground Acceleration

The average N-SPT of the top 30 m of the soil profile was observed to determine the site class classification.

The procedure referred to Indonesian Standard SNI 03-1726-2012, in which the average N-SPT values between 15 to 50 and <15 are classified as medium (SD) and soft soil (SE), respectively. The observation result indicated average N-SPT values of the 16 boreholes were ranged from 5 to 29. Thus, according to SNI 03-1726-2012, the soil site classifications in Banda Aceh consisted of both medium (SD) and soft (SE). Characteristics of medium soil site class (SD) with N-SPT value of 15 to 50 were found in BH-5, BH-6, BH-7, and BH-10 to BH-14 locations. Meanwhile, characteristics of soft soil site class (SE) with N-SPT value ≤ 15 were found in BH-1, BH-2, BH-3, BH-4, BH-8, BH-9, BH-15, and BH-16 locations.

The depth of the groundwater level was between 0.5 and 4.2 meters below the ground surface in the research area. In the southwest part, the groundwater was close to the surface; however, it became more in-depth in the southeast part (Fig. 3). Measurement of the groundwater level (GWL) was essential to analyze the Cyclic Stress Ratio (CSR) since it would affect the excess pore water pressure while experiencing earthquake shocks.

The PGA value used for each borehole locations was determined according to the Ministry of Public Works and Public Settlement. Furthermore, the seismic ground motion map was obtained by accessing the spectra design provided on the website, which matched to the geographical coordinates of the boreholes in Banda Aceh City. Peak ground acceleration must be determined by studying the specific site and considering the amplification factor, which includes the site coefficient value (F_{PGA}). Peak ground acceleration value adjusted with the effect of site classification (PGA_M) by Eq. (1) is presented in Table 2. The PGA_M value in Table 2 ranges from 0.484 to 0.610g.

Consequently, these results were in correspondence with [10], which concluded that the wave propagation analysis in Banda Aceh area from bedrock to ground surface determined the peak acceleration values on the ground surface which were 0.5 to 0.58g and from 0.42 to 0.68g for soft soil (SE) and medium soil (SD) [5], respectively.

The soil density parameters of BH-7 were dry and wet soil unit weight of 14.11 kN/m^3 and 17.55 kN/m^3, respectively. The calculation of total stress was affected by the groundwater level but not the effective vertical stress. The depth of the groundwater level in BH-7 was 0.5 meters. The calculation of liquefaction potential is shown in Table 3, and the parameters used for the calculation are listed in Table 2.

Table 2 PGA_M values on each borehole

Borehole	GWL (m)	PGA (g)	F_{PGA}	PGA_M (g)
BH-1	1.0	0.611	0.9	0.550
BH-2	2.0	0.609	0.9	0.548
BH-3	2.8	0.607	0.9	0.546
BH-4	3.5	0.604	0.9	0.544
BH-5	1.0	0.531	1.0	0.531
BH-6	1.0	0.533	1.0	0.533
BH-7	0.5	0.543	1.0	0.543
BH-8	1.5	0.538	0.9	0.484
BH-9	0.5	0.544	0.9	0.490
BH-10	0.5	0.557	1.0	0.557
BH-11	0.5	0.559	1.0	0.559
BH-12	2.0	0.575	1.0	0.575
BH-13	2.5	0.610	1.0	0.610
BH-14	3.2	0.610	1.0	0.610
BH-15	4.2	0.612	0.9	0.551
BH-16	4.1	0.611	0.9	0.550

Some correction factor values were applied in the analysis, as shown in Table 3; i.e., C_E is the energy ratio correction factor, C_B is the correction factor for borehole diameter, C_R is the short rod correction factor, and C_S is the correction factor for a sampler. The analysis results of the liquefaction potential are plotted in Fig. 4. The soil profile of BH-7 plotted in Fig. 4 shows that the topsoil layer is classified as clayey sand with gravel (SC) which has ≥ 15% fine content, and the bottom layer is classified as poorly graded sand (SP), which has <15% fine content.

4.2 Analysis of Liquefaction Potential

The liquefaction potential analysis was performed for each borehole. Table 3 shows an example of the potential liquefaction calculation for borehole BH-7 with a moment magnitude of 9.2 M_w scenario. Table 4 shows the summaries analysis results of the selected borehole in different LPI values. The depth intervals reviewed were 5, 10, and 15 meters below the ground surface.

The BH-1, BH-3, and BH-8 boreholes showed the liquefiable layers with respective LPI values of 6.20, 6.57, and 5.83 at 5-meter depth. Based on the potential liquefaction calculation under the moment magnitude scenario, it was found that M_w 9.2 would generate high liquefaction potential in BH-1, BH-3, and BH-8. ArcGIS software was used to compile a map of liquefaction potential based on LPI calculations for various depths of 5, 10, and 15 meters, respectively.

Table 3 The Calculation example of liquefaction potential by using N-SPT data for borehole BH-7, M_w 9.2, and PGA_M 0.543g (according to Idriss I. M and Boulanger R.W, 2008).

Depth (m)	Measured N-SPT	Soil Type USCS	Fines Content (%)	Energy Ratio, ER (%)	C_E	C_B	C_R	C_S	N_{60}	σ_{vc} (kPa)	σ'_{vc} (kPa)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
3.0	14	SC	32.65	45	0.75	1	0.85	1.00	8.93	50.92	26.40
6.0	50	SC	32.65	45	0.75	1	0.95	1.00	35.63	103.56	49.61
9.5	12	SP	8.37	45	0.75	1	1.00	1.00	9.00	164.97	76.68
12.5	21	SP	8.37	45	0.75	1	1.00	1.00	15.75	217.61	99.89
15.0	7	SP	8.37	45	0.75	1	1.00	1.00	5.25	261.47	119.23
18.0	7	SP	8.69	45	0.75	1	1.00	1.00	5.25	314.11	142.44
21.0	13	SP	8.69	45	0.75	1	1.00	1.00	9.75	366.75	165.65
24.5	25	SP	6.37	45	0.75	1	1.00	1.00	18.75	428.16	192.72
27.0	50	SP	6.37	45	0.75	1	1.00	1.00	37.50	472.03	212.06
30.0	50	SP	6.90	45	0.75	1	1.00	1.00	37.50	524.66	235.27

Depth (m)	C_N	$(N_1)_{60}$	ΔN For Fines Content	$(N_1)_{60cs}$	Stress reduce coef, r_d	CSR	*MSF* For Sand	K_σ For Sand	CRR For M=7.5 & σ'_{vc}=1 atm	CRR	FS_{liq}
(1)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
3.0	1.70	15.17	5.45	20.62	1.01	0.69	0.65	1.10	0.21	0.15	0.22
6.0	1.21	42.95	5.45	48.41	1.01	0.75	0.65	1.10	2.00	1.44	1.92
9.5	1.16	10.42	0.49	10.90	1.02	0.77	0.65	1.03	0.12	0.08	0.11
12.5	1.01	15.83	0.49	16.32	1.02	0.79	0.65	1.00	017	0.11	0.14
15.0	0.90	4.75	0.49	5.23	1.02	0.79	0.65	0.99	0.09	0.06	0.07
18.0	0.81	4.25	0.60	4.85	1.02	0.79	0.65	0.97	0.09	0.05	0.07
21.0	0.76	7.36	0.60	7.96	1.01	0.79	0.65	0.96	0.10	0.07	0.08
24.5	0.72	13.57	0.05	13.62	0.99	0.77	0.65	0.93	0.14	0.09	0.11
27.0	0.76	28.41	0.05	28.46	0.97	0.76	0.65	0.86	0.40	0.23	0.30
30.0	0.72	27.12	0.12	27.24	0.94	0.74	0.65	0.85	0.35	0.20	0.27

Table 4. Summary of LPI on selected borehole

Borehole	M_w	Liquefaction Potential Index		
		5 m	10 m	15 m
BH-1	7	4.72	3.92	2.30
	8	5.50	4.15	2.44
	9.2	6.20	4.35	2.55
BH-2	7	0.00	3.81	2.15
	8	0.00	4.08	2.34
	9.2	0.00	4.30	2.49
BH-3	7	5.57	0.00	1.98
	8	6.10	0.00	2.22
	9.2	6.57	0.00	2.41
BH-4	7	0.00	3.76	0.00
	8	0.00	4.04	0.00
	9.2	1.61	4.27	0.00
BH-5	7	0.00	0.00	2.44
	8	0.00	0.00	2.69
	9.2	0.00	0.00	2.89
BH-6	7	4.07	2.98	0.00
	8	4.96	3.72	2.75
	9.2	5.75	4.35	0.00
BH-7	7	0.00	4.10	2.09
	8	0.00	4.42	2.22
	9.2	0.00	4.68	2.32
BH-8	7	5.00	3.95	1.86
	8	5.45	4.37	2.06
	9.2	5.83	4.73	2.22

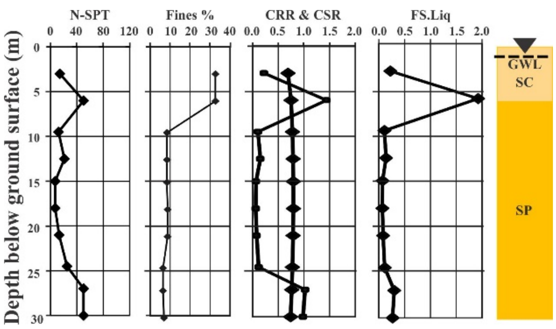

Fig. 4 The borehole data of BH-7, CRR & CSR, soil profile, and safety factor against liquefaction curve

Based on the LPI results, the liquefaction potential map is, as illustrated in Fig. 5. It is displayed on the map of the original administrative area of Banda Aceh City. The geological surface units of the Banda Aceh City have been divided into four categories of liquefaction potential, namely very high, high, low, and very low, which were determined based on the frequency distribution of LPI values.

The high liquefaction potential occurred 5 meters depth in BH-1, BH-3, and BH-8, with a moment magnitude scenario of M_w 9.2 and 8, as shown in Fig. 5(d) and Fig. 5(g). The low and very low liquefaction potential was distributed in all boreholes at 10 and 15-meter depth below the ground surface, while M_w 8 and 9.2-moment magnitude are as shown in Fig. 5(e,f) and Fig. 5(h,i), respectively.

Low and very low liquefaction potential was found in M_w 7 moment magnitude scenario (as shown in Fig. 5(b) and Fig. 5(c)), except in BH-3 where high liquefaction potential occurred at 5 meters depth (as shown in Fig. 5(a)).

Fig. 3 shows loose sand layer in the Northern coastline; and domination of a thick layer of dense clay in the Southern area. Hence, the Southern part of Banda Aceh City indicated very low liquefaction potential.

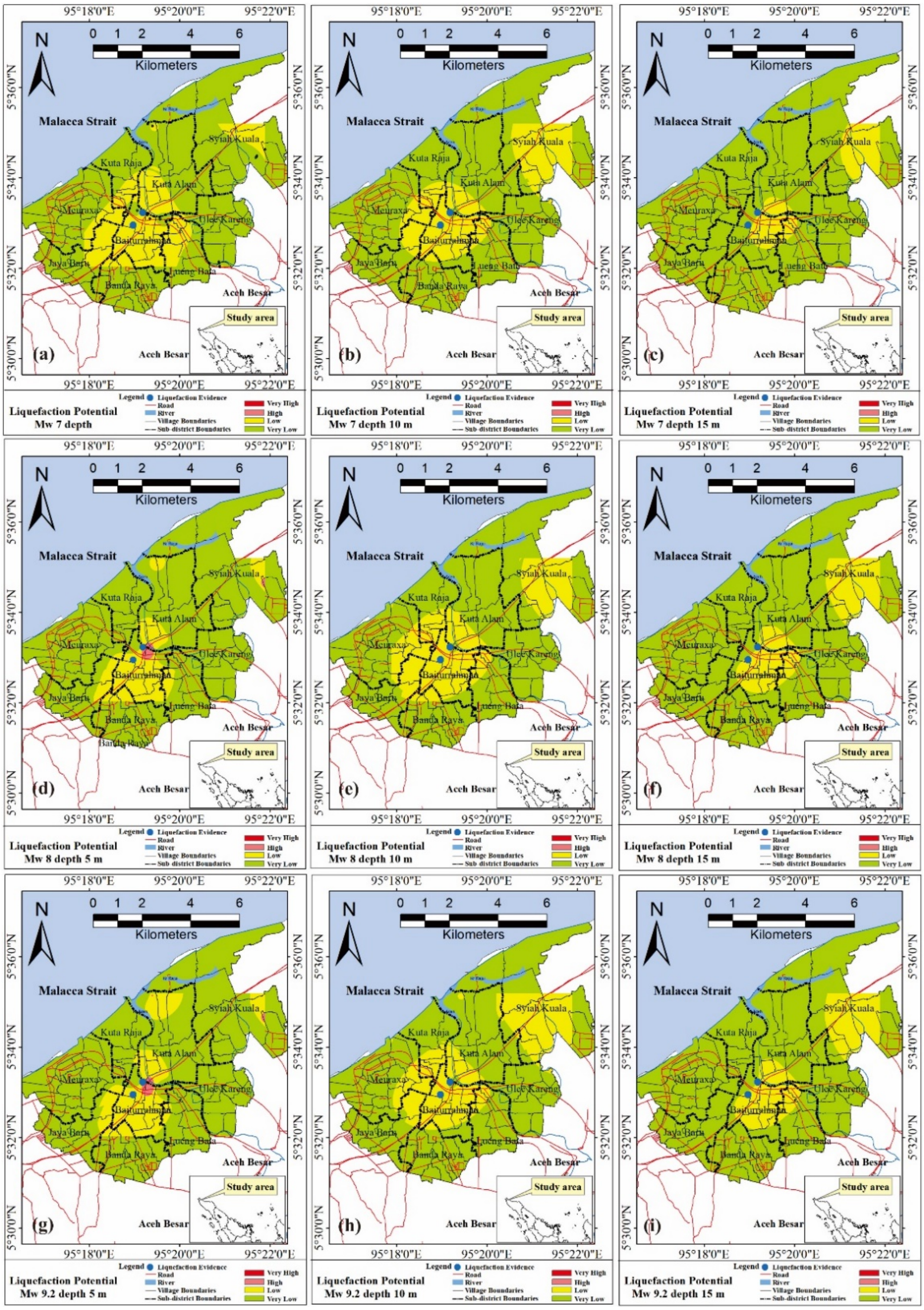

Fig. 5 The Map of liquefaction potential of Banda Aceh City in various moment magnitude and depth.

5. CONCLUSION

Determining the liquefaction potential by using the LPI method resulted in different liquefaction potential for various moment magnitude. The seismic parameters of M_w 9.2 (consistent with Aceh 2004 earthquake) was used in this study. The seismic parameters of M_w 7 and 8 were also used to measure the liquefaction potential.

Under the M_w 7 earthquake scenario, a high liquefaction potential was found in 5-meter depth below the ground surface at Baiturrahman Sub-district. The high liquefaction potential was also founded under Mw 8 and 9.2 scenarios in 5-meter depth in Baiturrahman, Kuta Alam, and Syiah Kuala Sub-districts. In this area, it is observed with LPI > 5 so that it is categorized as a region with high potential liquefaction. This result is consistent with the liquefaction event in the 2004 earthquake with M_w 9.2, as shown in Fig.5.

The geological characteristics of Baiturrahman and Syiah Kuala Sub-districts are areas with a thick sand deposits, Mollusca inserts, and a thin layer of clay that are vulnerable to liquefaction. The soil profile of the Southeastern part showed a stiff layer of clay and thin layers of sand, which tends to have very low liquefaction potential.

A map of liquefaction potential is required as a reference for infrastructure development and spatial planning. The 2004 major earthquake in Banda Aceh City induced infrastructure damages that showed liquefaction evidences. The soil site classification and liquefaction potential were investigated and identified with arranging the spatial planning policy.

Although this study used a common method in liquefaction potential analysis, various methods such as probabilistic and laboratory modeling may be considered in the further research in order to validate and enrich the results obtained in this study.

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