Probabilistic Analysis of Liquefaction Potential: the First Eyewitness Case in Thailand

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Abstract

On the 24th March 2011, the 6.8 magnitude earthquake called Tarlay Earthquake strikes Myanmar. the 0.2 g acceleration was measured at Maesai, Chiengrai station which located 30 km from the earthquake epicenter. Since Maesai's subsoil consists of shallow loose to medium dense layer of sand, therefore the liquefaction has been widely observed. The gradation of the liquefied soil is matched well within the gradation range of the liquefiable soil. Probabilistic assessment of liquefaction potential were done and found that Maesai sand has high susceptibility to liquefy with about 75% to 95% in term of liquefaction probability. Luckily, most of the liquefied sites were located outside Maesai city therefore the damage was then minimized. This liquefaction phenomenon is recorded to be the first liquefaction ever witness in the modern time of Thailand.

Keywords: Liquefaction, Maesai's subsoil, Probabililistic, cyclic stress ratio

1. Introduction

In the past, the Northern of Thailand had felt many earthquakes but those were not caused great damage since either those had low magnitudes or the epicenter distance is far and located mostly in neighbor countries. However, recently on the 24th March 2011, the 6.8 magnitude earthquake called Tarlay Earthquake strikes Myanmar.

The epicenter of the earthquake locates just 10 km away from the northern border of Thailand (Fig 1).

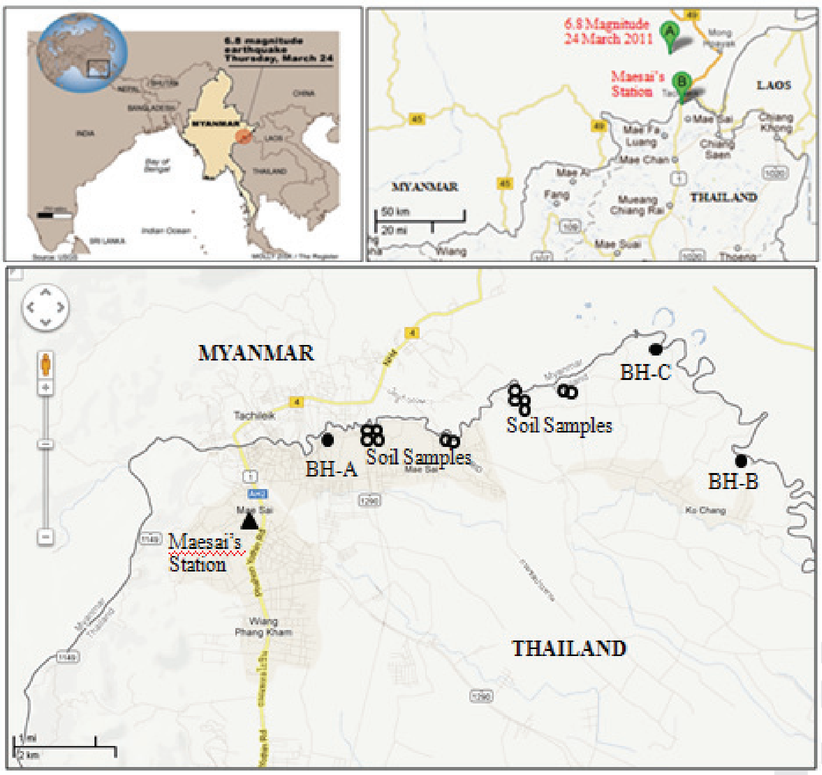


Figure 1 : Map location of Maesai area, soil borings, extruded sand sampling and earthquake epicenter

The 0.2g acceleration ([1]) was recorded at Maesai, Chiengrai. The accelerometer station is located 30 km from the earthquake epicenter. The measured acceleration fitted well with the selected attenuation relationship recommended by [2] (Fig 2). Since Maesai's subsoil consists of loose to medium dense layer of sand, therefore the liquefaction has been observed (Fig 3).

Luckily, most of the liquefied sites are located outside Maesai city therefore the damage was then minimized. This liquefaction phenomenon is recorded to be the first liquefaction ever witness in the modern time of Thailand.

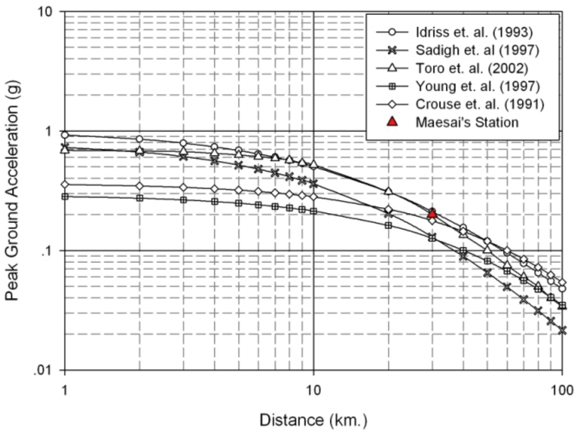


Figure 2 : Attenuation relationship comparing with recorded peak acceleration at Maesai's station

2. Objectives of the analysis

After the liquefaction occurred, concerns are addressed to the safety of the existing structures since the design standard and codes for the buildings and infrastructures in Maesai does not consider liquefaction. Therefore, the objective in this article is to confirm the liquefaction susceptibility of Maesai's sand layer by back analysis the probability of liquefaction from this event. Characteristics of Maesai's subsoil

3. Characteristics of Maesai's subsoil

Soil boring at Maesai, Chiengrai Province, investigated before the liquefaction shows that the subsoil mostly consists of sand layers with layers of thin medium stiff clay near the ground surface. The loose sand layers and the ground water are found in the shallow depth. This sand layers were liquefied and extruded out of the ground during the earthquake

Figure 3 : Liquefaction evidences in Maesai, Chiangrai, Thailand

The gradation data of sand layers before the earthquake were obtained at 13 different locations in Maesai.

After liquefaction occurred the authors collected 12 sand samples both extruded and below ground surface from where liquefaction has been found. Sieve analysis has been performed and found that all the sand samples have a uniform gradation. It is also founded that the gradation of the liquefied soil is matched well within the gradation range of the liquefiable soil reported by [3] (Fig 4). Based on the subsoil characteristics as discussed, it can be concluded that the sand layers in Maesai is susceptible for liquefaction.

4. Liquefaction analysis by cyclic stress approach

The cyclic stress approach, originally proposed by [4], is used to evaluate the factor of safety against liquefaction in Maesai. The average cyclic stress ratio (CSR) induced by earthquake is calculated by equation (2).

$$CSR = 0.65\frac{\sigma_v}{\sigma'_v}.\frac{a_{max}}{g}.\gamma_d \qquad (2)$$

Where; CSR = Cyclic shear ratio induced by earthquake

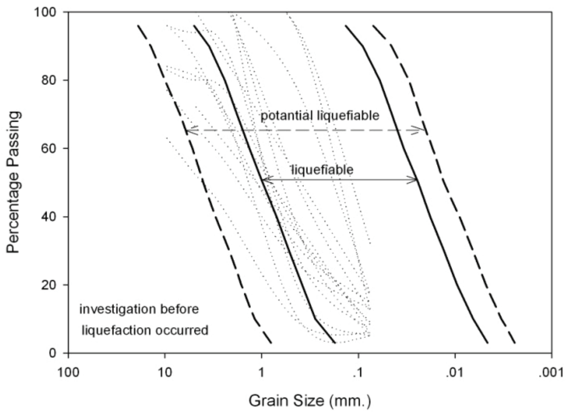
σ_v = Total overburden pressure in subsoil layers (t/m^2)

σ'_v = Effective overburden pressure in subsoil layers (t/m^2)

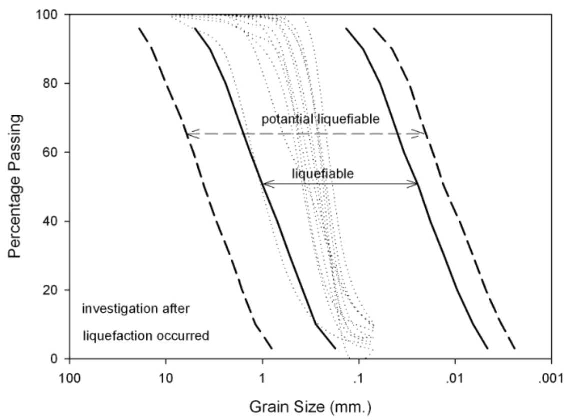
g = gravity's acceleration (m/s^2)

a_{max} = peak horizontal ground acceleration (m/s^2)

γ_d = stress reduction factor



(a) Gradation curve of soil in sand layers collected before earthquake



(b) Gradation curve of extruded liquefied sands collected on the ground surface after liquefaction occurred

Figure 4 : Gradation curve of sands are collected from Maesai sites comparing with the gradation range of liquefiable soil suggested by Iwasaki (1986), [3]

In order to calculate the factor of safety against liquefaction of each soil layers, cyclic resistance ratio (CRR) of each soil layer will need to be calculated as shown in equation (3).

$$CRR_{M_W} = CRR_{7.5} MSF \qquad (3)$$

Cyclic Resistance Ratio (CRR) is empirically related with corrected SPT-N value ($(N_1)_{60}$). The correlation has been proposed by [5] only for the earthquake 7.5 M_w ($CRR_{7.5}$). The magnitude Scaling Factor (MSF) is required to be applied in the equation for the earthquake that has magnitude other than 7.5 M_w by [6]

Finally, the factor of safety against liquefaction (F.S.) can be calculated as shown in equation (4) in which the liquefaction is considered to be occurred if F.S. is lower than unity.

$$F.S. = \frac{CRR}{CSR} \qquad (4)$$

The above approach is used to evaluate the liquefaction potential of Maesai's subsoil and to back analysis for the subsoil layer that is likely to be liquefied. This information is rather important for the future of the design building codes of Maesai. The safety factors against liquefaction of each soil layer were calculated using the soil data from the boreholes in Maesai. The peak horizontal ground acceleration (PGA) is considered to be equal to 0.2g as recorded by accelerometer station of TMD at maesai (Fig5). However, since the analysis will be done in various locations depths, the average actual acceleration for each considered locations and depth is none to be known. Therefore, considering the amplification effect, the 0.2g PGA values were used. The MSF is equal to 1.33 for earthquake magnitude of 6.8. The ground water table obtained from the boreholes is reported in shallow depth. The boreholes were drilled before liquefaction occurred. The first SPT-N value data starts below the top crust layer, therefore the evaluation was done below this level and also below the present of ground water table. The clay layer was not evaluated since it's considered to be non-liquefiable material

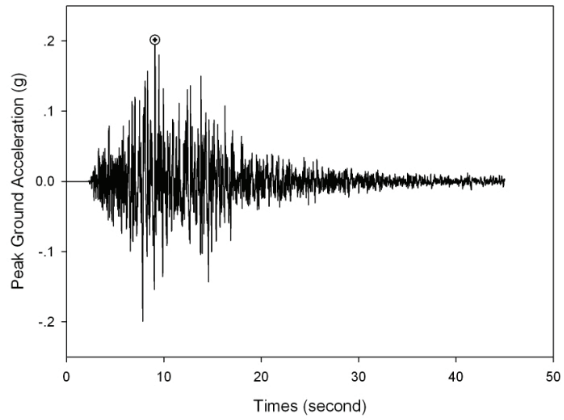


Figure5 : acceleration records at Maesai 24 March 2011, [Thai Meteorological Department]

5. Probabilistic liquefaction Potential of Maesai's soil

The approach of [7] to estimate the probabilistic of liquefaction in the sites. This method is related between cyclic stress ratio (CSR) and corrected SPT values that correlation can be expressed in (5). Moreover, the fine contents of 12% is used as the boundary between clean and silty sands. Where β_0, β_1 and β_2 are equal 16.447, 6.4603 and -0.3976 for clean sand cases, then equal to 6.4831, 2.6854 and -0.1819 for silty sand cases, respectively.

$$P_L = \frac{1}{1+\exp[-(\beta_0 + \beta_1 \ln(CSR) + \beta_2 (N_1)_{60})]} \quad (5)$$

Where P_L = Probability of liquefaction
CSR = Cyclic stress ratio values
$N_{1(60)}$ = corrected SPT values (blows/foot)
β_0, β_1 and β_2 = constant values

6. Back Analysis Results

The properties and liquefaction analysis results of all boreholes in Maesai area are expressed in Fig6. The results are shown in term of factor of safety and liquefaction probability of each liquefiable soil layers.

Moreover, The summary of the liquefied soil informations and the related calculations are presented in table 1. It is found that the liquefied soil may have been generated at 3.5 -11 m depth within the loose to medium dense sand layers where SPT-N values are lower than 17 blows/foot.

By plotting the analysis data into Seed's curves ([5]), it can also be seen that the liquefaction data in Measai located in the liquefied zone in which coincided with the actual condition (Fig 7).

The liquefaction probability of sand layer that has F.S. less than 1.0 are calculated to be about 75 to 95% which in range of very likely to liquefy-almost certain (class 4 to class 5) classified by [8] **(table 2.). Furthermore,** The relationship between probability of liquefaction and factor safety in Maesai region, Chiengrai province can be expressed in Fig.8 and can be expressed in equation(6).

$$P_L = \frac{1}{1+\left(\frac{F.S.}{1.25}\right)^{3.76}} \quad \textbf{(6)}$$

Where P_L = Probability of liquefaction
F.S.= Factor of safety

Table 1 Summary of the soil information and calculated results of liquefaction potential analysis in Maesai region

Case	Borehole	Depth (m.)	Soil classification	σ_v (T/m^2)	σ'_v (T/m^2)	FC%	$(N_1)_{60}$	a_{max}	M_W	CRR	CSR	FS	P_L%
1	BH-B1	3.5	SM-SP	6.58	5.68	9	3.0	0.2	6.8	0.09	0.15	0.64	95
2	BH-B1	5.0	SM-SP	9.18	6.78	5	3.6	0.2	6.8	0.05	0.17	0.31	97
3	BH-B1	6.5	SM-SP	11.98	8.08	6	9.1	0.2	6.8	0.13	0.18	0.73	87
4	BH-B1	9.5	SM	17.59	10.69	13	5.0	0.2	6.8	0.13	0.20	0.68	98
5	BH-B1	11.0	SM	20.34	11.94	-	9.5	0.2	6.8	0.19	0.20	0.96	59
6	BH-B3	5.0	SM-SP	8.82	6.62	7	6.4	0.2	6.8	0.11	0.17	0.64	91
7	BH-C1	5.0	SM-SP	9.07	8.07	-	4.1	0.2	6.8	0.08	0.14	0.57	89
8	BH-C1	6.5	SM-SP	11.67	9.17	5	4.7	0.2	6.8	0.07	0.16	0.42	93
9	BH-C1	11	SM-SP	19.78	12.78	-	7.2	0.2	6.8	0.17	0.18	0.98	76
10	BH-C2	5.0	SM-SP	8.97	8.47	5	8.1	0.2	6.8	0.12	0.13	0.90	55
11	BH-A1	3.5	SM	5.80	2.80	17	9.8	0.2	6.8	0.21	0.26	0.81	75
12	BH-A1	5.0	SM-SP	8.63	4.13	6	17.3	0.2	6.8	0.23	0.26	0.89	71
13	BH-A2	6.5	SM-SP	11.18	7.18	8	9.6	0.2	6.8	0.18	0.19	0.96	88

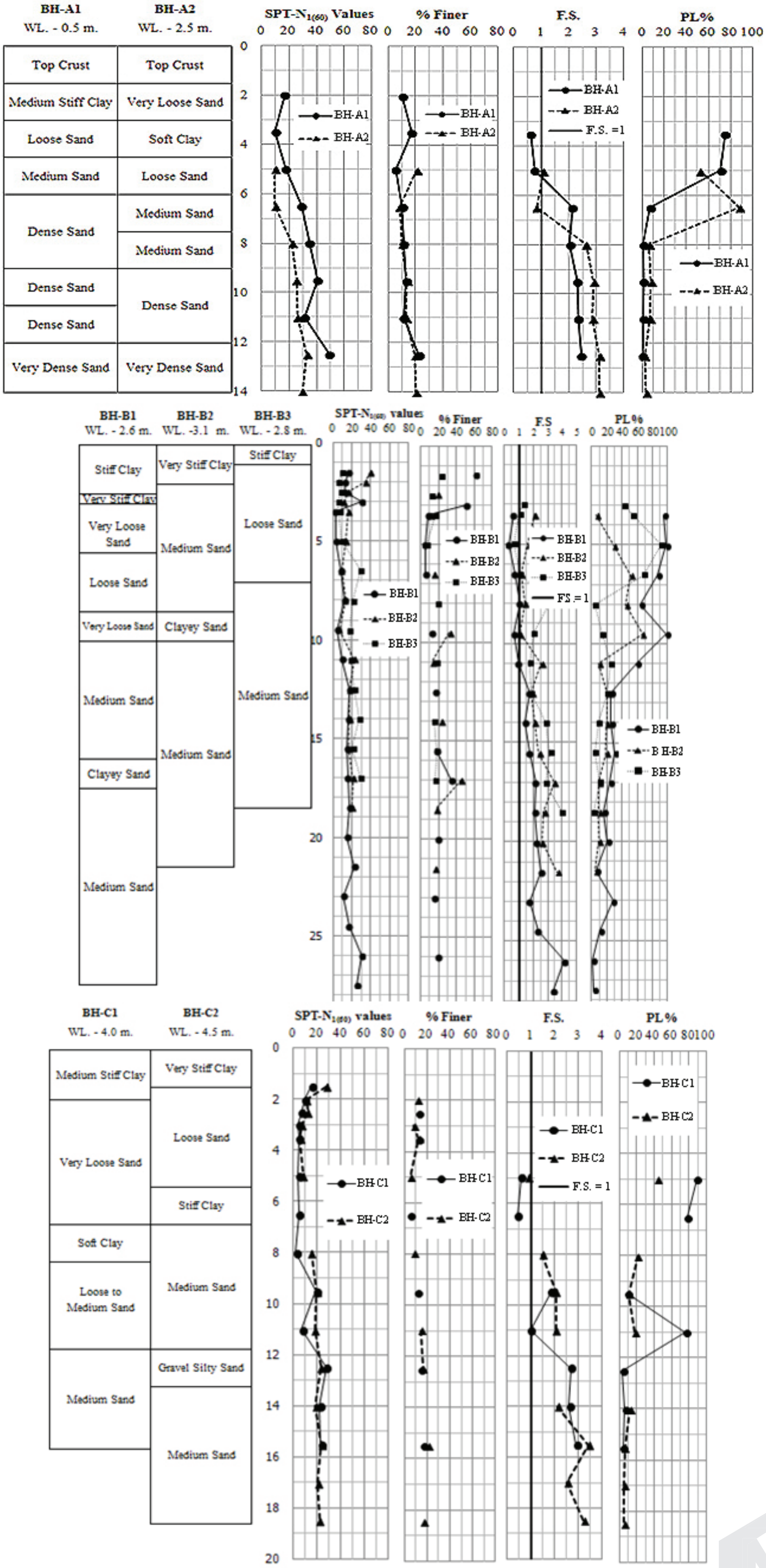


Figure 6 : Liquefaction evaluation of Maesai's subsoil

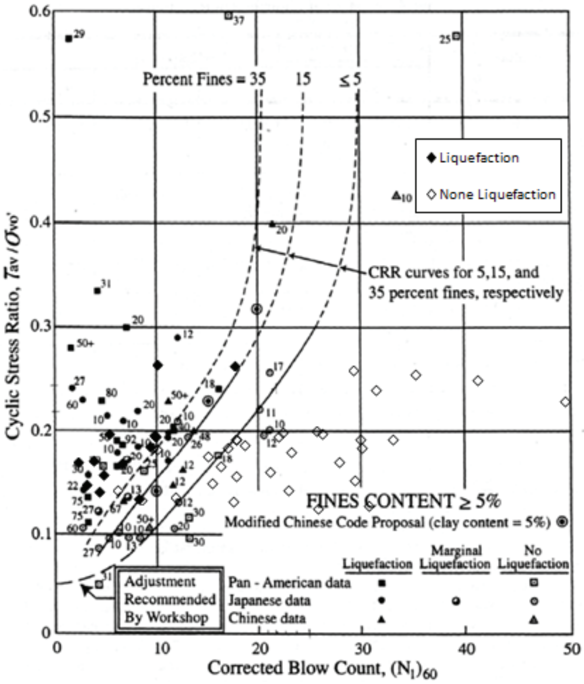


Figure 7 : Liquefaction potential of Maesai from Tarlay Earthquake 2011 plotted in Seed's curve

Table 2 liquefaction likelihood classification introduced by Chen and Juang(2000) [8]

Class	Probability of Liquefaction (P_L)	Description Of likelihood
1	$P_L < 15$	Almost certain that it will not liquefy
2	$15 \le P_L \le 35$	Unlikely to liquefy
3	$35 \le P_L \le 65$	Liquefaction and no liquefaction are equally likely
4	$65 \le P_L \le 85$	Very likely to liquefy
5	$P_L \ge 85$	Almost certain that it will liquefy

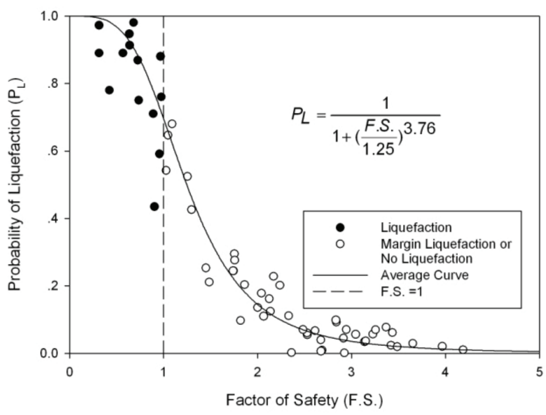


Figure 8 : Probability of liquefaction variation with liquefied FS for CSR approach in Maesai region

7. Conclusion

7.1 The liquefaction has been found in Maesai, Yhe analysis found that it might be liquefied from medium to loose sand layer at depth between 3.5-11.0 m.

7.2 The gradation of sand layers are found to be in the range of liquefiable material

7.3 The relationship between liquefaction probability and F.S. against liquefaction from cyclic stress approach is proposed in this paper

7.4 The probability of liquefaction of Maesai's liquefied subsoil from 6.8M Tarlay earthquake in 2011 is averaged to be 82.62%

7.5 Therefore, The development of foundation design code and remedial process for the buildings and on ground structures to withstand liquefaction of subsoil in Maesai need to be seriously conducted to prevent catastrophic loss in the next strong earthquake. The Maesai city is located between Mae Jun and Namma fault which they are considered to be active and have high potential if producting large earthquake.

8. Acknowledgements

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