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A POST-LIQUEFACTION STUDY AFTER THE 2014 CHIANG RAI EARTHQUAKE IN THAILAND

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ABSTRACT: A post-liquefaction study at a remote village was conducted after the event of the6.3 M_L2014 Chiang Rai Earthquake in order to investigate the liquefaction condition and to compare liquefaction potential assessment methods for future use. Site surveying, aerial map study, standard penetration test were conducted and found that the subsoil at this site was easily liquefied because the village was lying within abandon river channels with very loose sand layer from the depth of approximately 1 to 6 meters underneath the cohesive soil layer of 1 - 1.5 meter thick at the surface. Four liquefaction potential assessment methods commonly used in the United States and in Japan: 1) modified Seed and Idriss' 1971 method; 2) Idriss and Boulanger (2014); 3) Iwasaki's 1990 method; and 4) Iwasaki's 1996 method were examined. The comparison demonstrates that Iwasaki' 1990 method yielded quite a different result from other three methods with the lowest values of a factor of safety. From this study, other three methods may be considered more favorable.

Keywords: Earthquake, Soil Liquefaction, Post-Liquefaction Evaluation, Liquefaction Potential, Liquefaction Susceptibility

1. INTRODUCTION

The 6.3 M_L earthquake [1] which struck Chiang Rai Province (the northern-most province of Thailand - Fig. 1) in the evening of May 5, 2014, was the first one that caused soil liquefaction in the recent history of earthquakes in Thailand. Induced by that earthquake, soil Liquefaction occurred widely over the radius of 25 kilometers around the epicenter. This phenomenon had never been a significant issue in the country's earthquake concern because most earthquakes in this country were relatively small. Since that day, it is believed that stronger earthquakes are possible in the future because there are four groups of active faults laying almost all over the area of Chiang Rai Province as shown in Fig. 2. Mae Chan - Chiang Saen Fault is the one that most people are concerned about because there was a tale that very strong earthquakes occurred at night causing an ancient city of Yonokto submerge underwater (possibly by liquefaction phenomena). There is an evidence of a large lake in Chiang Saen District supporting that this tale was possibly true.

Therefore, earthquake preparation activities are necessary including prevention or reducing the effect of liquefaction. To do so, assessing of liquefaction potential or liquefaction resistance of subsoil at certain sites is very important. It is widely accepted that in-situ testing of subsoil layers is more accurate than laboratory testing since obtaining undisturbed sand is not easy. Famous in-situ testing for liquefaction potential assessment includes Standard Penetration Test (SPT), Cone Penetration Test (CPT), Becker Penetration Test (BPT) and Shear Wave Velocity Test.

Among those in-situ tests, SPT is more common in Thailand. There are various liquefaction potential assessment methods based on the result of SPT available. However, it becomes very interesting to investigate which method is more suitable for Thailand. Therefore a post-liquefaction study was conducted in order to find the most appropriate method to assess liquefaction potential in Thailand for the future. This study will confirm the reliability of liquefaction potential assessment method.

Fig. 1 the location of Chiang Rai Province. (https://th.wikipedia.org)

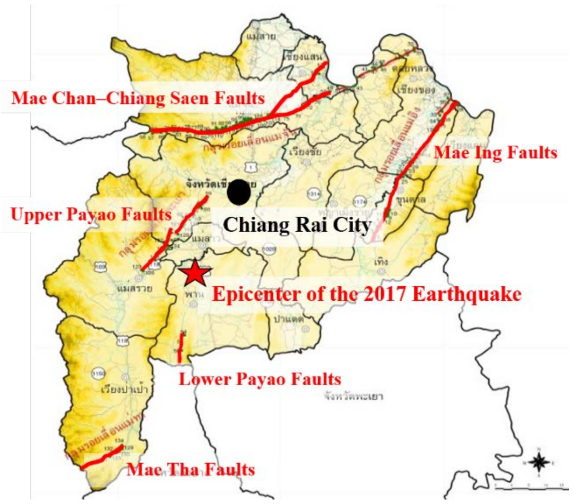

Fig. 2 ChiangRai Province and active faults. (Modified from www.dmr.go.th)

2. THE STUDY PROGRAM

This study was conducted in order to achieve two main objectives:

1) Understanding the conditions of factors affecting soil liquefaction at a selected site which liquefaction occurred during the Chiang Rai Earthquake in 2014.

2) Finding the most appropriate method to assess liquefaction potential in Thailand for the future.

To obtain the answer and conclusion for the objectives indicated above, a program of study was designed that a study should be conducted at a liquefaction site. The study should include three main activities.

1) Site visit for investigating evidence of liquefaction and the environment suitable for liquefaction to occur,

2) Subsoil investigation by standard penetration test (SPT) to obtain the soil type and density.

3) Verifyingliquefaction potential assessment methods.

3. THE SITE: TUNG-FAH-PAH VILLAGE

Tung-Fah-Pah Village is located approximately 25 km southwest of the epicenter of the 2014 Chiang Rai Earthquake as shown in Fig. 3. Most liquefaction sites caused by this earthquake were within 15 km around the epicenter.The reason for selecting this village as the case study site was that this is the farthest site of liquefaction caused by this earthquake. Most liquefaction sites were within 15 km from the epicenter. Liquefaction and damages occurred here were very significant.

4. EVIDENCE OF SOIL LIQUEFACTION

People in the village told that during the earthquake, the ground was rocking strongly. A number of houses were shaken and damaged. Columns of a factory building near the village underwent differential settlement and heavily damaged. Cracks were seen on the ground. Liquefied sand was ejected from the ground through those cracks. Liquefied sand was also seen ejected into the wells replacing groundwater that people use in their everyday life. Liquefied sand was even seen rising into the air from the bottom of a pond. These were evidence indicating that liquefaction occurred here in the village as shown in Fig. 4 to Fig. 8.

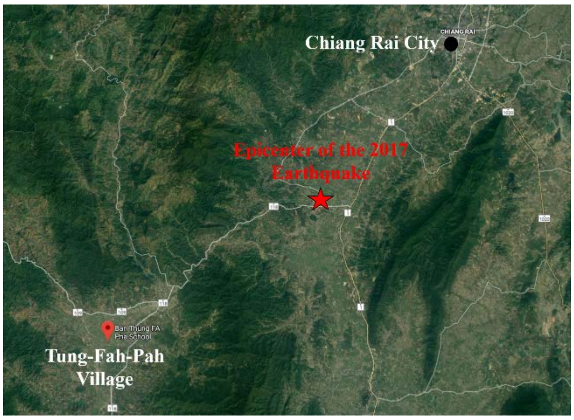

Fig. 3 Location of Tung-Fah-Pah Village and the epicenter of the 2014 Chiang Rai Earthquake. (Modified from www.google.com)

Fig. 4 Fine sand ejected through ground cracks.

(a) (b)

Fig. 5(a) Ground cracking (b) Pure sand appeared at the bottom of the cracks.

(a) (b)

Fig. 6 (a) Sand ejected through the joints of concrete pavement, (b) Separation of a wall made from interlocking bricks due to ground settlement.

Fig. 7 Liquefies sand was ejected from the bed of this pond like a fountain of about 3-meter high (from interviewing an eye-witness.)

Fig. 8 Sand injected into wells of several houses replacing the groundwater.

5. STANDARD PENETRATION TEST

After the first site visit, standard penetration test (SPT) was conducted at four locations in the village. Boreholes marked as BH-2, BH-3, and BH-5located within 3 meters from the wells filled with the injected sand. Borehole BH-4 was at the primary school front yard (see Fig. 12 for their locations).Fig. 9 demonstrates SPT *N*-values, and Fig. 10 shows the grain size distributions of the soil sample taken from the boreholes.

All 4 SPT boreholes discovered very identical soil layers. The top layer was cohesive soil from the ground surface down to the depth of approximately 1.0 to 1.2 meter, the layer of gravel and stones was found from approximately 6 to 7 meters down from the ground surface. Between the top cohesive soil layer and the gravel layer was a layer of loose to medium sand which was expected to undergo liquefaction due to its relatively low SPT-N values. (The liquefaction analysis will be shown later.)

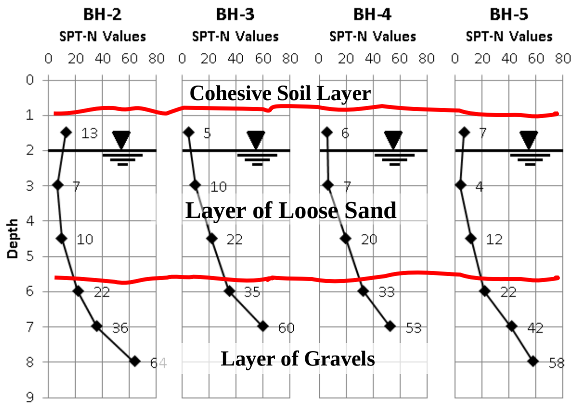

Fig. 9 SPT *N*-values from all 4 boreholes.

An interesting finding from the SPT investigation was that the sand taken from the liquefied layer has “gap-graded” distribution as shown in Fig. 10. However, when looking at Fig. 11, which shows the grain size distribution of the fine sand found on the ground (Fig. 4) and in those wells (Fig. 8), it can be seen that these injected sand particles may be those missing from the curves shown in Fig. 10.

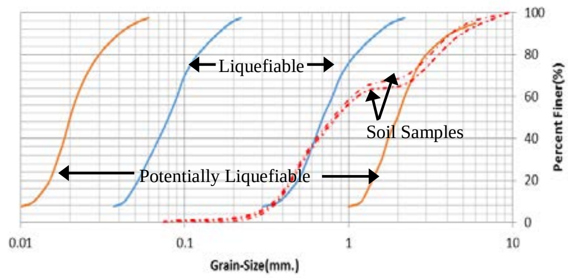

Fig. 10 Grain size distribution of the sand samples taken from boreholes by SPT sampler.

This means sand particles of a certain range of size were ejected from the liquefied loose sand layer sneaking through the voids between larger sand particles.

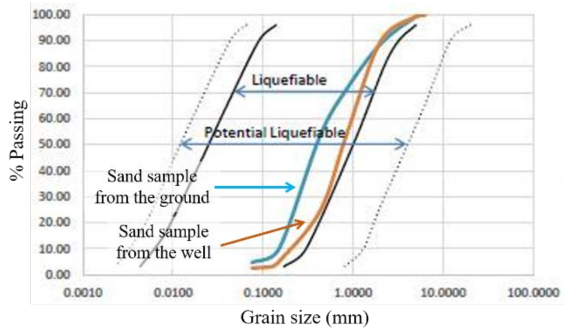

Fig. 11 Grain size distribution of the sand found on the ground in Fig. 4 and found in the well in Fig. 8.

6. SITE ANALYSIS

There is another issue that should be addressed in this study. It was very interesting to find out why this site liquefied easily while other villages nearby and within closer distances did not have any significant sign of liquefaction. This issue can be easily explained by 1) an aerial photo of the village's landscape as shown in Fig. 12. The village was situated in the area with traces of abandoned rivers which can be liquefied easily [2], especially a group of houses was in the area of a so called "the island" which indicates that it was surrounded by water, 2) the sand layer should be saturated when earthquake struck because the groundwater at the time of the earthquake was at only 1.0-1.2 m below the ground surface and the area around the village wall filled with water as the farmer grew their off-season rice farm, 3) the distance of approximately 25 km from the epicenter was not surprise because this conforms to Fig. 13 showing the earthquake of 6.3 Richter's magnitude can cause liquefaction at sites farther than 25 km, and 4) at this distance the peak ground acceleration was still high enough assuming this earthquake conformed to the relationship shown in Fig. 14.

7. LIQUEFACTION POTENTIAL EVALUATION

Due to the availability of SPT test, the following methods of liquefaction potential evaluation were studied.

1. Modified Seed and Idriss' 1971 method proposed by Youd et al. in NCEER workshop in 1996 [4]. This method went through a lot of modifications from the original in 1971 such as the modification of stress reduction coefficient by Liao and Whitman [5], and later by Idriss [6].
2. Method proposed by Boulanger and Idriss in 2014 [7]. This method has been modified from the prior with some correcting factors.
3. Method proposed by Iwasaki in 1990 [8]. This one was the most commonly used in Japan in the past as it appears in the Japanese Highway Bridge Code. The method relies heavily on D_{50} of the subsoil particles which can be obtained from grain size distribution curves

Fig. 12 Aerial view of Tung-Fah-Pah Village (modified from www.google.com).

4. The method proposed by Iwasaki in 1996 which has been revised from the 1990 version by adding the effect of SPT *N*-value, adding more consideration on fine content and plastic index of the soil in the considered layers and earthquake motion factor was included in this version [9].

Those four methods are similar in the stress-based approach but the major differences between them are criteria, equations, correcting factors and some input data. Details of those four methods can be found in the indicated references.

Another important factor was the ground acceleration at the site. For this study, there was no ground acceleration record available. Therefore, the relationship between peak acceleration versus epicenter distance as shown in Fig.14 should be helpful. From the distance of about 25 km, ground acceleration of 0.15g, 0.20g, and 0.25g was used in the calculation when g is gravity acceleration (9.8 m/s^2)

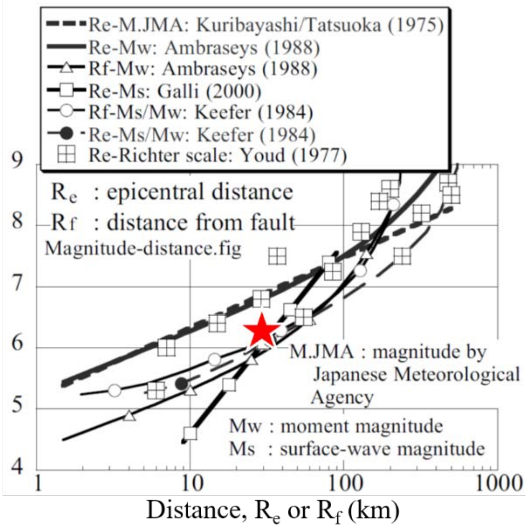

Fig. 13 A plot of approximated distance from the epicenter to Tung-Fah-Pah Village on the original graph of maximum distance from epicenters to liquefaction sites [3].

8. RESULTS AND DISCUSSION

Figure 15, 16, 17 and 18 show values of the factor of safety against liquefaction of soil layers at BH-2, BH-3, BH-4, and BH-5, respectively. Following are the analysis of the results.

1) Those four methods are reasonably reliable since all of them indicated liquefaction should have occurred considering that the sandy soil layer should be looser than in this study. In these Figures, some factor of safety numbers shown here is slightly more than 1.0 because they were calculated by using post-liquefaction SPT surveying.
2) Those three methods other than Iwasaki version 1990 yielded very close factor of safety values except when the SPT *N*-values reached 20 (see Fig. 16 and 17 at the elevation below -3.5 m along with SPT *N*-values in Fig. 9).

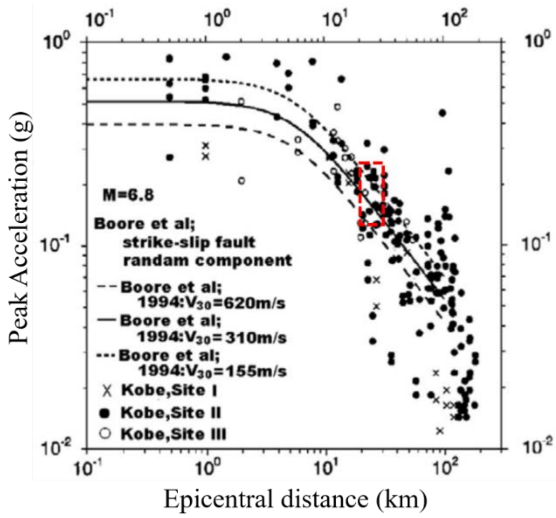

Fig. 14 Relationship between peak ground acceleration versus distance from the earthquake epicenter. [10]

9. CONCLUSION

The site of Tung-Fah-Pah Village of this project was perfect for liquefaction. The village was situated on the area between abandoned river channel and the current river channel, which was exactly indicated by Wakamatsu [2]. The loose sand layer was found at a shallow depth of 1.2 m. At the time of earthquake occurrence, the soil was expected to be saturated because the rice field was filled with water and it had been rained nearly every day for a month in the area before the earthquake.

Among those four methods, Iwasaki's method version 1990 was the most conservative because it gave the lowest values of a factor of safety against liquefaction. While his revised version in 1996, resulted in the factors of safety closer to the modified Seed and Idriss' 1971 method and the 2014 Boulanger and Idriss' method. This is possibly caused by the 1996 version was adjusted to a higher standard horizontal seismic coefficient.

Therefore, according to this study, it is reasonable to rely on any of these three methods for liquefaction potential assessment in the future: 1) modified Seed and Idriss' 1971 method; 2) Idriss and Boulanger's 2014 method, and 3) Iwasaki' 1996 method.

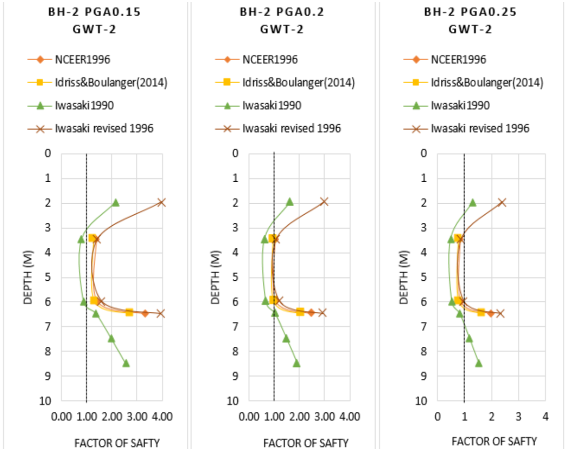

Fig.15 Factor of safety against liquefaction, BH-2

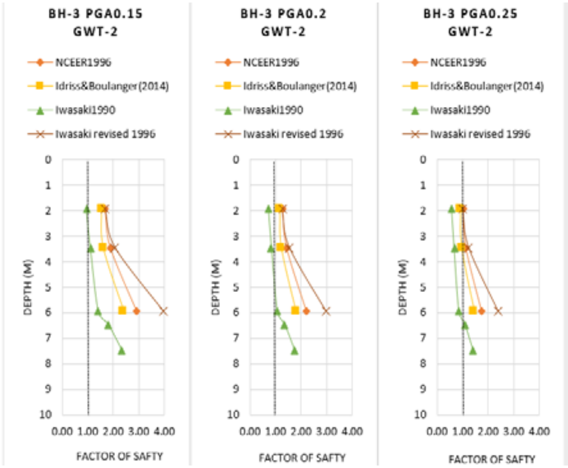

Fig.16 Factor of safety against liquefaction, BH-3

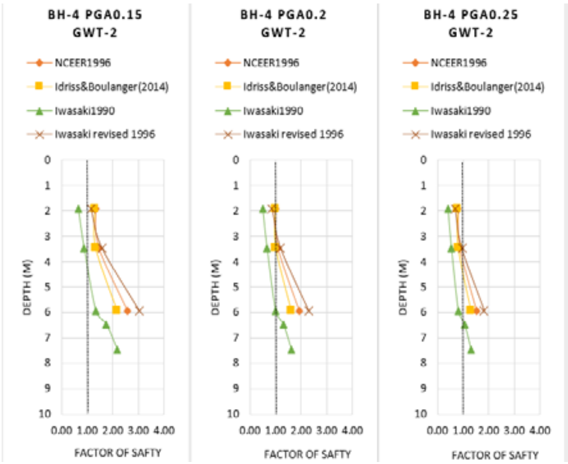

Fig. 17 Factor of safety against liquefaction, BH-4

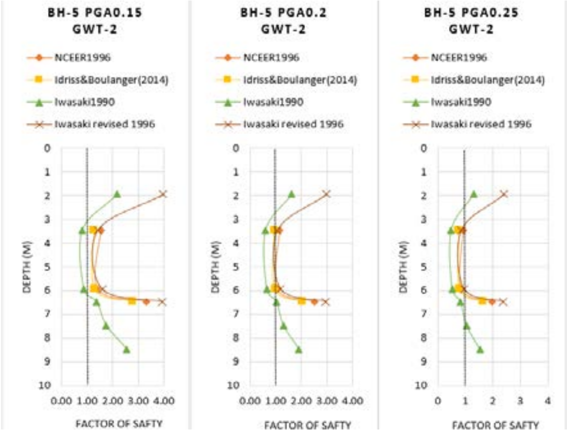

Fig. 18 Factor of safety against liquefaction, BH-5

9. ACKNOWLEDGEMENTS

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10. REFERENCES

[1] Thai Meteorological Department, Report on the 2014 Chiang Rai Earthquake (in Thai), available at http://www.earthquake.tmd.go.th.

[2] Wakamatsu, K., Evaluation of Liquefaction Susceptibility Based on Detailed Geomorphological Classification. Proc., Technical Papers of Annual Meeting Architectural Institute of Japan, pp. 1443-1444.

[3] Towhata, I., Geotechnical Earthquake Engineering, Verlag Berlin Heidelberg: Springer, 2008.

[4] Youd, T. L.,Idriss, I. M., Andrus, R.D., Arango, I., Castro, G., Christian, J.T., Dobry, R., Liam Finn, W.D., Harder Jr., L.F., Hynes, M.E., Ishihara, K., Koester, J.P., Liao, S., Marcuson III, W.F., Martin, G.R., Mitchell, J.K., Moriwaki, Y., Power, M.S., Robertson, P.K., Seed, R.B., and Stoke II, K.H., Liquefaction Resistance of Soils: summary report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of soils. Geotechnical and Geoenvironmental Engineering, 2001, 127(4), 297-313.

[5] Liao, S., and Whitman, R.V., Catalogue of Liquefaction and Non-Liquefaction Occurrences during Earthquakes, Research Report, Department of Civil Engineering,

Massachusetts Institute of Technology, Cambridge, Massachusetts, 1986.
[6] Transportation Research Board (TRB), TRB Workshop on New Approaches to Liquefaction Analysis, Publication No. FHWA-RD-99-165, Federal Highway Administration, Washington, D.C., 1999.
[7] Boulanger, R. W., and Idriss, I. M., CPT AND SPT Based Liquefaction Triggering Procedure, Report No.UCD/CGM-14/01, Center for Geotechnical Modeling, Department of Civil & Environmental Engineering, the University of California at Davis, 2014.
[8] Japan Road Association, Highway Bridge Design Code Part V: Seismic Design, 1990.
[9] Japan Road Association, Specifications for Highway Bridges, 1996.
[10] Joyner, W.B., and Boore, D.M., Recent “Developments in Strong-motion Attenuation Relationships”, UJNR 28th Joint Meeting of United States-Japan Panel on Wind and Seismic Effects, NIST SP904, Gaithersburg, 1996, pp.101-115.