Study on Liquefaction Potential of Mandalay

Zin Zin Nwe[1], and Kay Thwe Tun[2]

***Abstract*—Soil liquefaction and related ground failures are commonly associated with large earthquakes. In the historical records, several earthquakes happened in and around Mandalay-Amarapura-Innwa-Sagaing region of the Union of Republic of Myanmar. Liquefaction occurred and wells were choked up and dry in Mandalay city. This paper examines the liquefaction potential in terms of factor of safety against liquefaction for Mandalay city. The regional liquefaction potential is evaluated by summarizing the factor of safety (FS) and the contour map for liquefaction potential index (LPI) is developed by interpolation in ArcGIS. We found that the central three townships felt the major level of liquefaction severity. The worst liquefiable area was near the Ayeyarwaddy bank. The second potential places were the upper portion of Chan Aye Thar Zan and Maha Aung Myay townships. The liquefaction potential index (LPI) contour map will be very useful to make decision or plans in seismic hazard mitigation for regional level. This contour map will help for urban planners and structural design consideration by knowing the major area of liquefaction severity.**

***Keywords*—liquefaction, Mandalay city, factor of safety, potential index, ArcGIS.**

I. Introduction

Liquefaction is one of the most important and most commonly encountered problems in civil engineering. Liquefaction effect should be considered as a main part of engineering effect in all constructions. To mitigate the damages caused by liquefaction require accurate evaluation of liquefaction potential of soils. Soil liquefaction and related ground failures are commonly associated with large earthquakes. Therefore, the liquefaction potential assessment is very important for developed city located near the earthquake prone region. This paper examines the liquefaction potential for Mandalay which is very urbanized and densely populated city and locates near the Sagaing fault.

A simplified procedure proposed by Seed and Idriss (1971) can evaluate the liquefaction resistance of soils in terms of factors of safety (FS) by taking the ratio of capacity of a soil element to resist liquefaction (computed as the cyclic resistance ratio, CRR) to the seismic demand imposed on it (computed as the cyclic stress ratio, CSR). The most widely used are cyclic stress approach and cyclic strain approach to characterize the liquefaction resistance of soils both the laboratory and field tests. Some other approaches are probabilistic approaches, energy dissipation and effective stress based response analysis, etc. During the past two decades, several procedures have been proposed to estimate liquefaction resistance based on shear wave velocity, V_s. The cyclic stress due to earthquake is based on the peak ground surface acceleration that depends upon site specific ground motions.

If a soil layer with factors of safety (FS) is less than or equal to 1, it is generally classified as liquefiable and with factors of safety (FS) is greater than 1, it is classified as non-liquefiable (Seed and Idriss, 1971). Iwasaki et al. (1978) proposed liquefaction potential index (LPI) to show the degree of liquefaction severity at a liquefaction-prone site. Liquefaction potential index (LPI) provides an integration of liquefaction potential over the depth of a soil profile and predicts the performance of the whole soil column as opposed to a single soil layer at particular depth and depends on the magnitude of the peak horizontal ground acceleration (Luna and Frost, 1998).

II. Description on Study Area

Mandalay is the second-largest city and the last royal capital of the Union of Republic of Myanmar. Located 716 km (445 mi) north of Yangon on the east bank of the Ayeyarwaddy River, the city has a population of 1,225,553 (2014 census). Mandalay is located in the central dry zone of Myanmar by the Ayeyarwaddy River at 21.98° North, 96.08° East, 80 meters (260 feet) above sea level. Mandalay features noticeably warmer and cooler periods of the year. The highest reliably recorded temperature in Mandalay is 45.6 °C (114.1 °F) and the lowest is 5.6 °C (42.1 °F). Although there are seven townships in Mandalay city as of 2012, five townships are included in this paper. Fig. 1 shows the downtown area of Mandalay city.

The most distinct historical earthquake near Mandalay area was Innwa earthquake occurred in March 23, 1839. Due to Innwa earthquake (maximum intensity of MMI IX), about three to four hundred casualties were resulted in Mandalay area and many buildings including pagodas were severely damaged. The biggest earthquake in its history, with a magnitude of 7, occurred in July 16, 1956. The devastation was greatest in nearby Sagaing, and it came to be known as the Great Sagaing Quake. The Sagaing earthquake with (M_w=7.0) magnitude also caused some considerable damage and casualties. Liquefaction occurred and wells were choked up and dried.

Zin Zin Nwe, Mandalay Technological University, The Union of the Republic of Myanmar.

Kay Thwe Tun, Mandalay Technological University, The Union of the Republic of Myanmar.

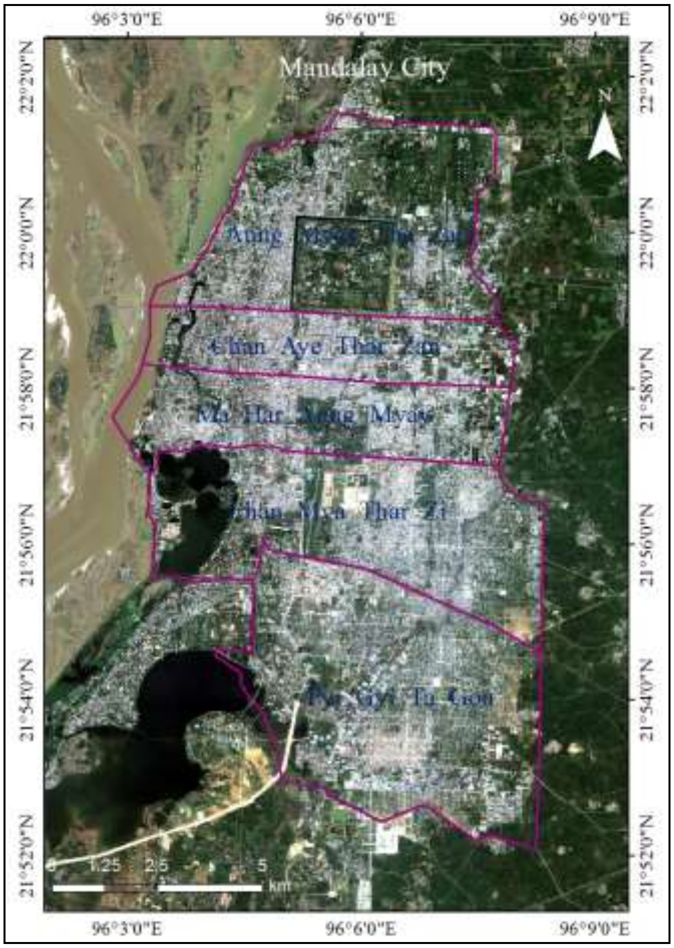

Fig. 1 Map of study area

III. Methodology

In this paper, the simplified procedure is used to calculate the factor of safety against liquefaction. The liquefaction potential index (LPI) is evaluated by summarizing the factor of safety (FS) proposed by Luna and Frost (1998) and the contour map for liquefaction potential index (LPI) is developed by interpolation in ArcGIS.

A. Potential for Liquefaction

A common way to quantify the potential for liquefaction is in term of Factor of Safety (FS). The suitable value of FS will depend on many factors, including the potential for ground deformation, extent and accuracy of seismic measurements, availability of other site information, and in determination of the design earthquake magnitude and expected value of PGA or a_{max}. The FS against liquefaction can be defined by;

$$FS = \frac{CRR\ 7.5}{CSR} \tag{1}$$

where,

$CRR_{7.5}$ = cyclic resistance ratio for 7.5 of earthquake magnitude

CSR = estimated cyclic stress ratio generated by possible earthquake

Liquefaction is predicted to happen when FS $\leq$ 1, and liquefaction is predicted not to occur when FS > 1.

(1) Cyclic Stress Ratio (CSR): The cyclic stress ratio, CSR, as proposed by Seed and Idriss (1971), is defined as the average cyclic shear stress, τ_{av}, developed on a horizontal surface of soil layers due to vertically propagating shear waves normalized by the initial vertical effective stress, σ'_v, to incorporate the increase in shear strength due to an increase in effective stress. A magnitude scaling factor (MSF) was added to incorporate the effects of magnitude of the earthquake shaking.

$$CSR = \frac{\tau_{av}}{\sigma'_v} = 0.65 \times r_d \times (\frac{a_{max}}{g})(\frac{\sigma_v}{\sigma'_v}) \times \frac{1}{MSF} \tag{2}$$

where,

r_d = stress reduction factor = 1–0.12z

a_{max} = peak ground acceleration generated by earthquake source

g = gravitational acceleration

MSF = magnitude scaling factor

(2) Cyclic Resistance Ratio (CRR): The cyclic resistance ratio value can be evaluated according to a recent update of these simplified methods developed by Youd et al (2001).

$$CRR_{7.5} = \frac{1}{34 - N_{1,60}} + \frac{N_{1,60}}{135} + \frac{50}{[10 \times N_{1,60} + 45]^2} - \frac{1}{200} \tag{3}$$

where,

$CRR_{7.5}$ = cyclic resistance ratio for 7.5 of earthquake magnitude

$N_{1,60}$ = the corrected SPT value for equipment and effective overburden stress

The corrected SPT values are calculated as;

$$N_{1,60} = N_m C_N C_E C_B C_R C_S \tag{4}$$

For clean sand,

$$N_{1,60cs} = K_s N_{1,60} \tag{5}$$

$$K_s = 1 + [(0.75/30)(FC-5)] \tag{6}$$

where,

K_s = Plastic soil correction factor

FC = Fineness content

C_N = Overburden pressure

C_E = Energy ratio

C_B = Borehole diameter

C_R = Rod length

C_S = Sampling method

B. Liquefaction Potential Index (LPI)

Liquefaction potential index (LPI) is a single-valued parameter to evaluate regional liquefaction potential. LPI at a site is computed by summarizing the factor of safety for the soil profiles with the depth less than 20 m. Liquefaction potential index (LPI) proposed by Luna and Frost (1998) is expressed as follows:

$$LPI = \sum_{i=1}^{n} \omega_i F_i H_i \tag{7}$$

with

$$F_i = 1 - FS_i \text{ for } FS_i < 1.0 \tag{8}$$

$$F_i = 0 \text{ for } FS_i \geq 1.0 \tag{9}$$

where,

ω_i = the weighting factor = $10-0.5z_i$
z_i = the depth of i-th layer
F_i = liquefaction severity for i-th layer
H_i = thickness of the discretized soil layers
FS_i = factor of safety for i-th layer

Table 1 shows the level of liquefaction severity.

TABLE 1: THE LEVEL OF LIQUEFACTION SEVERITY

LPI	Iwasaki et al. (1982)	Luna and Frost (1998)	MERM (2003)
LPI = 0	Very low	Little to none	None
0 < LPI < 5	Low	Minor	Low
5 < LPI < 15	High	Moderate	Medium
15 < LPI	Very high	Major	High

IV. COMPUTATION OF LIQUEFACTION POTENTIAL

The required soil information is collected from Myanmar Earthquake Committee (MEC), Mandalay City Development Committee (MCDC) and Civil Engineering Service (CES) Group. There are 52 bore holes that cover the study area. The soil deposits in Mandalay area consist of clayey silt, clayey sand, soft clay.

The maximum peak ground acceleration in calculation of CSR for the study area is assumed as 0.2 g. The depth of water table is not considered in this study. Myo Thant et al. (2012) identified the seismic sources and estimated the seismic source parameters for the development of the seismic maps of Myanmar by incorporating the fault source parameters of Soe Thura Tun et al. (2011). Regarding to these seismic source parameters, Myo Thant et. al. describes that the magnitude (M_w = 7.9) earthquake potential can happen from the middle segment of the Sagaing fault as the maximum. [5] Therefore, the maximum earthquake magnitude (M_w = 7.9) is considered for this study.

The factor of safety against liquefaction is calculated by using Eqs. (1) through (6). Liquefaction potential index (LPI) at particular site is calculated from the values of factor of safety against liquefaction based on the expressions proposed by Luna and Frost (1998). The contour map of liquefaction potential index (LPI) for Mandalay city is developed by interpolating in ArcGIS. Fig. 2 shows the contour map of liquefaction potential index (LPI) for study area.

In this paper, the peak ground acceleration (PGA) and the maximum earthquake potential due to the middle segment of Sagaing fault was assumed to estimate LPI. The cyclic stress due to earthquake is based on the peak ground surface acceleration that depends upon site specific ground motions. Therefore, the detail site investigation should be done for a specific site in checking the liquefaction effect in this area.

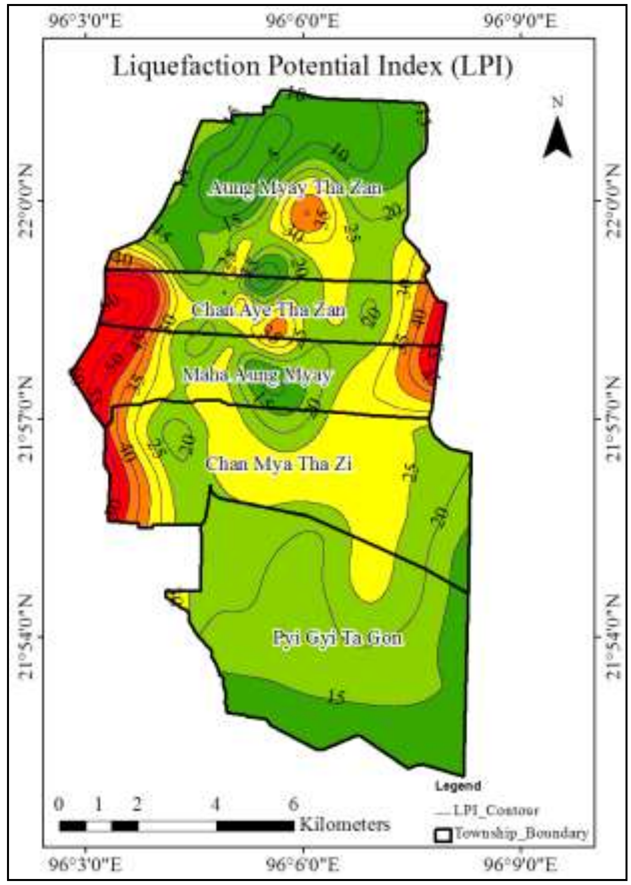

Fig. 2 Liquefaction potential index (LPI) map

V. DISCUSSION AND CONCLUSIONS

Mandalay lies near the Ayeyarwaddy River and it is very close to the active segment called the Sagaing fault. Liquefaction occurred and wells were choked up and dried from the records of the historical strong earthquakes. Therefore, this study attempts to evaluate the liquefaction potential assessment for Mandalay city. The liquefaction potential in terms of factor of safety against liquefaction was firstly calculated based on the SPT-N values. The maximum ground acceleration in calculating cyclic stress ratio (CSR) was assumed as 0.2g and the earthquake magnitude was used as (M_w = 7.9). Secondly, regional liquefaction potential was evaluated by summarizing the factor of safety (FS) values based on the expressions proposed by Luna and Frost (1998). Finally, the contour map of liquefaction potential index (LPI) was developed by using ArcGIS.

While the levels of liquefaction severity were classified based on the liquefaction potential index (LPI), we found that nearly the whole city felt the major level in liquefaction severity. The worst liquefiable area was near the Ayeyarwaddy bank. The second potential places were the upper portion of Chan Aye Thar Zan and Maha Aung Myay townships. The liquefaction potential index (LPI) contour map will be very useful to make decision or plans in seismic hazard mitigation for regional level. This contour map will help for urban planners and structural design consideration by knowing the major area of liquefaction severity.

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REFERENCES

[1] Arango, I.: Magnitude "Scaling Factors for Soil Liquefaction Evaluations" J. Geotech. Engg. 122(11),929--936 (1996). https://doi.org/10.1061/(ASCE)0733-9410(1996)122:11(929)

[2] J. Dixit, D. M. Dewaikar, and R. S. Jangid, "Assessment of liquefaction potential index for Mumbai city," *Natural Hazards and Earth System Science*, vol. 12, no. 9, pp. 2759–2768, 2012. https://doi.org/10.5194/nhess-12-2759-2012

[3] Kramer, S. L.: "Geotechnical Earthquake Engineering", Prentice Hall, New Jersey, 1996.

[4] Manish H. Sharma and Dr. C.H. Solanki, "LIQUEFACTION HAZARD MAPPING", *International Journal of Civil Engineering and Technology*, Volume 4, Issue 1, January- February (2013), pp. 52-70.

[5] Myo Thant, Geology Department, University of Yangon, "Development of Seismic Microzonation Maps of Mandalay City, Mandalay Region, Myanmar", 2014.

[6] R. D. Andrus and K. H. Stokoe II, "Liquefaction resistance of soils from shear-wave velocity," *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 126, no. 11, pp. 1015–1025, 2000. https://doi.org/10.1061/(ASCE)1090-0241(2000)126:11(1015)

[7] R. Luna and J. D. Frost, "Spatial liquefaction analysis system," *Journal of Computing in Civil Engineering*, vol. 12, no. 1, pp. 48–56, 1998. https://doi.org/10.1061/(ASCE)0887-3801(1998)12:1(48)

[8] Seed, H. B. and Idriss, I. M.: "Simplified procedure for evaluating soil liquefaction potential", J. Soil Mech. Foundation Division, 97, 1249–1273, 1971.

[9] Vijay Kumar, Kumar Venkatesh, and Yeetendra Kumar, "Approaches for Estimating Liquefaction Potential of Soils", *International Journal of Structural and Civil Engineering,* ISSN: 2277-7032 Volume 1 Issue 2 (February 2012).

About Author (s):

Ms. Zin Zin Nwe
Ph.D. Student
Department of Civil Engineering
Mandalay Technological University
The Union of Republic of Myanmar

Dr. Kay Thwe Tun
Associate Professor
Department of Civil Engineering
Mandalay Technological University
The Union of Republic of Myanmar