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ASSESSMENT OF SEISMIC SOIL LIQUEFACTION BASED ON SHEAR WAVE VELOCITY USING 2% AND 10% PROBABILITIES OF PGA VALUES WITH EARTHQUAKE MAGNITUDE-6.5 MW IN MANDALAY CITY

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Abstract

Mandalay city is located on the eastern bank of Irrawaddy River and about 8 km east of seismically active Sagaing fault. By this fault, Mandalay region has been experienced by many destructive earthquakes. All liquefaction events in Myanmar were observed nearly water body as rivers. Due to these conditions, the liquefaction susceptibility is threatening the Mandalay city. Liquefaction triggering of soils were mainly calculated based on 55 shear wave velocity tests by using 1998 NCEER recommended of Liq.IT v.4.7.7.5 software. The liquefaction potential (P_L) maps were developed by using overall liquefaction potential index (P_L). The liquefaction potential (P_L) maps by using PGA 2% probability should be considered for the construction of lifeline structures such as water pipe line, gas pipe line, transportation ways and telecommunication lines. The P_L maps using PGA 10% probability are appropriate for engineering construction of the various sorts of structures especially normal building. According to resulted data, the highly liquefied zones fall in the western parts of Aungmyaythazan and Chanayethazan townships. These P_L maps will help the structural designers or architects and city planners to check the vulnerability of the area against liquefaction. The present data will be very useful not only for seismic hazard mitigation programs but also for seismic safety plans.

Keywords: Mandalay city, shear wave velocity, peak ground acceleration (PGA), 1998 NCEER recommended method, liquefaction potential index (P_L)

Introduction

Today, liquefaction is one of the most important topics for geotechnical earthquake engineers. Ground failures are commonly caused by liquefaction events during numerous devastating earthquakes all over the world. Its effects are mostly observed in near water bodies such as river, lake, bays and oceans. The study area, Mandalay city lies on the eastern bank of Irrawaddy River and about 8 km east of seismically active Sagaing fault. By historical records, Mandalay region had been impacted several times by strong to major earthquakes in the past. Moreover, liquefaction effects as sand boils were caused nearly Irrawaddy and Myitnge river in this region during Innwa earthquake (23rdMarch, 1839) and Thabeikkyin earthquake (11 Nov, 2012) (Chibber, 1934, Win Swe, 2013 and Myo Thant, 2013). By above factors, Mandalay City suffers threatening the seismic related hazard especially, liquefaction near future. Thus, liquefaction risk assessment should be carried out for the study area.

Site Investigations

A total of 55 shallow boreholes and 197 microtremor points were commonly collected from various soil deposits at different locations in Mandalay city. Among them, only the best 55 shear wave velocity data nearly selected from 55 borehole points (Figure 1) were used for the evaluating soil liquefaction potential index of Mandalay city. The site investigations at 55 boreholes points of the Mandalay city were examined about ≤30 m depth of surface layer.

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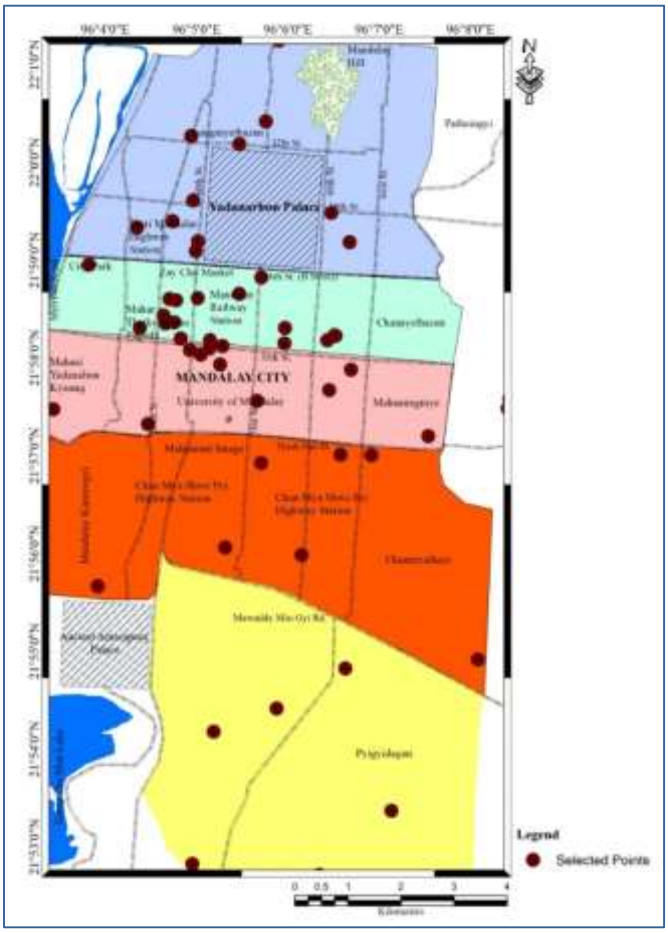

Figure 1 Location map of the sites where liquefaction potential index assessment is carried out.

Methodology

The main evaluation procedure in this research will be given to liquefaction potential analysis based on shear wave velocity to a depth of 30m (V_s^{30}) value obtained from *HVSR* data. For the present research, the Vs values have been obtained from SMAR 6A3P microtremor test using inversion process. In this study, the calculation procedures for liquefaction potential analysis of soils have been used Liq.IT v. 4.7.7.5 software. For present research, the calculation procedure of Liq.IT v.4.7.7.5 software is commonly considered based on National Center for Earthquake Engineering Research (NCEER-1998). The depth to water table, shear wave velocity, earthquake magnitude and peak ground acceleration are essential for determining liquefaction potential index of the study area by using this software (Figure 2). The simplified procedure has to needs for calculating the cyclic stress ratio (CSR) and the cyclic resistance ratio (CRR) based on shear wave velocity. With the simplified methods, the liquefaction potential of soil is expressed as a factor of safety Fs, which is defined as the ratio of cyclic resistance ratio (CRR) over the cyclic stress ratio (CSR). The soil is said to be liquefied if Fs $\leq$ 1 and be non-liquefied if Fs>1. It requires the calculation of three parameters; (i) the seismic demand on a soil layer, expressed as a cyclic stress ratio (CSR); (ii) stiffness of the soil, expressed as an overburden stress-corrected shear-wave velocity(V_{s1}); and (iii) the resistance of the soil to liquefaction, expressed as a cyclic resistance ratio (CRR) at depth, z (Seed and Idriss, 1971). To be accurate data, all result data obtained from Liq.IT software were manually adjusted based on SPT and microtremor data. The summarized calculation methods are shown in Figure 3.

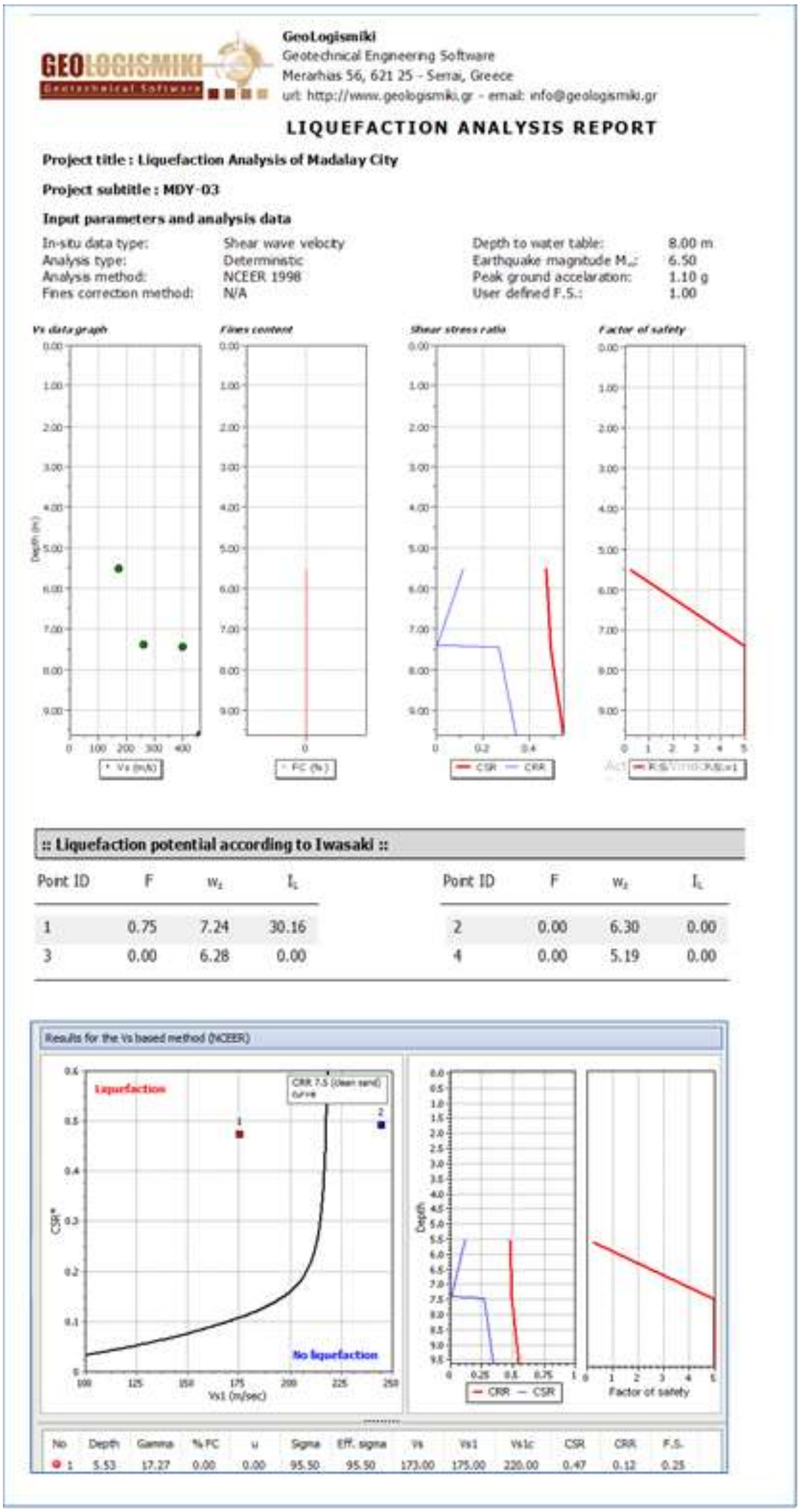

Figure 2 Example of Liq.IT v.4.7.7.5 soil liquefaction assessment software data at MD

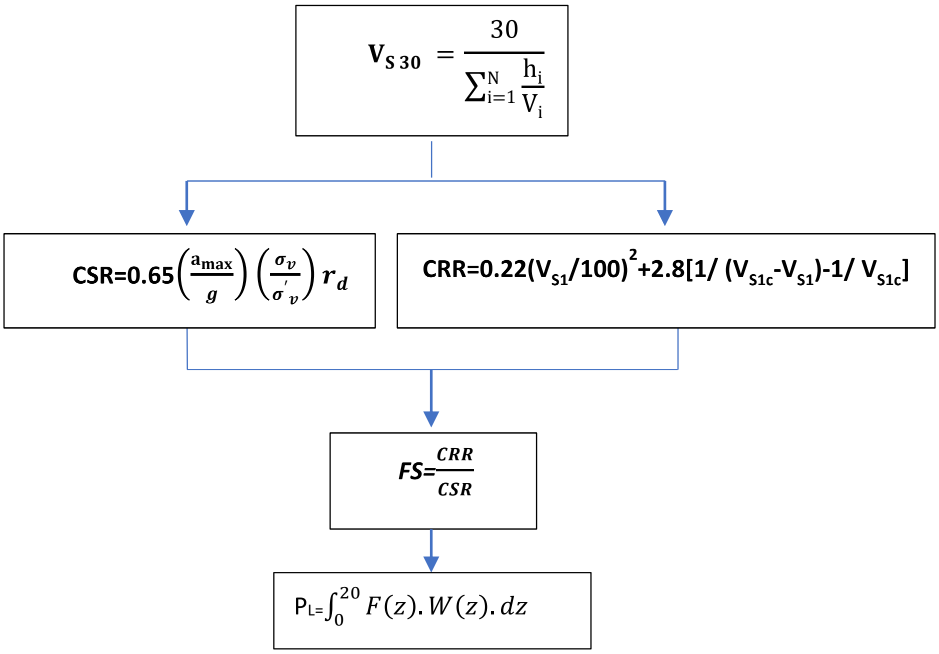

Figure 3 Flow chart of calculation procedure of P_L index

Results and Discussion

Liquefaction assessment was performed by using 197 microtremor points compare with 55 boreholes but liquefaction susceptibility maps were established by using 55 shear wave velocity tests. Each point is subdivided into four layers for estimating P_L index. The variations of underground water depth in Mandalay city were defined by using ground water level in well log borehole data. Ground water levels were mostly found to vary from 0 to 20 m in the study area as shown in table (1). According to probabilistic seismic hazard map (Myo Thant 2013), various peak ground acceleration values as 0.7 – 1.4 g for 2% and 0.5 – 0.9 g for 10% with an scenario earthquake magnitude; Mw- 6.5 have already used for predicting liquefaction susceptibility of soils.

According to present resulted data, low velocities, shallow depth to water table (z), high peak ground acceleration (a_{max}) and earthquake magnitude (Mw) in soils lead to a higher liquefaction potential. The resulted data of liquefied layers in each site of the study area are shown in Table 1 for 2% and Table 2 for 10% PGA value.Liquefaction potential zones of the study area were designated based on Iwasaki (1984) namely as very low or not probable for P_L=0, low for 0< P_L < 5, moderate for 5< P_L <15 and high for 15< P_L <25 and very high P_L >25. By these P_L value, it is occurred at very low or not probable liquefied area represent 45% of the whole area: low liquefied zone is < 23% of the study area; moderate liquefied zone is < 10%; high liquefied sites are < 12% of the area and very high liquefied points are < 10% of the study area. According to P_L resulted values, we should need to obey the following recommendations of Iwasaki (1984);

- For very low liquefaction susceptibility (P_L=0), detail investigations on soil liquefaction aren't needed in general
- For low liquefaction susceptibility (0<P_L<5), detail investigations on soil liquefaction are needed only for especially important structures.

- For moderate liquefaction susceptibility ($5<P_L<15$), detail investigations for soil liquefaction are needed for important structures and countermeasures of soil liquefaction are needed in general.
- For high liquefaction susceptibility ($15<P_L<25$), detail soil investigations are mandatory
- For very high liquefaction susceptibility ($P_L>25$), area should be avoided for developing structures

Table 1 Detail resulted data of liquefied layers in each site of Mandalay City by using Mw 6.5 & PGA 2% probability.

Site No	Depth(m) /Layer	Gamma	u	Sigma	Eff. sigma	Vs	Vs1	Vs1c	CSR	CRR	FS
MDY-3	5.53/1	17.27	0.00	95.50	95.50	173	175	220	0.47	0.12	**0.25**
MDY-4	5.19 / 1	17.68	0.00	91.76	91.76	200	204.35	220	0.45	0.26	**0.57**
MDY-08	5.58 /1	17.68	0.00	98.65	98.65	200	200.68	220	0.43	0.22	**0.51**
MDY-10	5.19 /1	17.68	0.00	91.76	91.76	200	204	220	0.45	0.26	**0.57**
MDY-11	3.19 /1	16.87	0.00	53.82	53.82	150	175.13	220	0.48	0.12	**0.24**
MDY-19	5.53 /1	17.27	0.00	95.50	95.50	173	175	220	0.48	0.12	**0.25**
MDY-20	2.24/ 1	15.73	0.00	35.24	35.24	100	129.79	220	0.49	0.06	**0.11**
MDY-21	2.00 /1	16.24	0.00	32.48	32.48	120	158.96	220	0.47	0.09	**0.19**
	6.00 /2	17.68	0.00	103.20	103.20	200	198	220	0.45	0.20	**0.44**
MDY-24	3,05 /1	13.78	0.00	42.03	42.03	50	62.10	220	0.48	0.01	**0.03**
	7.62 /2	15.73	0.00	113.92	113.92	100	96.80	220	0.48	0.03	**0.06**
	14.33 /3	16.87	22.86	227.11	204.26	150	125.47	220	0.50	0.05	**0.10**
MDY-25	5.24 /1	15.73	0.00	82.43	82.43	100	104.95	220	0.56	0.04	**0.07**
	8.05 /2	16.87	0.49	129.83	129.34	150	140.66	220	0.58	0.07	**0.12**
MDY-28	4.67 /1	17.68	0.00	82.57	82.57	200	209.81	220	0.48	0.36	**0.75**
MDY-29	6.10 /1	16.24	0.00	99.06	99.06	120	120.28	220	0.47	0.05	**0.10**
MDY-34	2.74 /1	17.05	0.00	46.72	46.72	160	193.53	220	0.46	0.18	**0.38**
MDY-36	6.10	17.61	0.00	107.42	107.42	195	191.54	220	0.48	0.17	**0.35**
MDY-37	5.53/1	17.27	0.00	95.50	95.50	173	175	220	0.50	0.12	**0.24**
MDY-40	5.19/1	16.87	0.00	87.56	87.56	150	155.07	220	0.56	0.08	**0.14**
	9.05 /2	17.68	0.00	10.30	155.80	145.50	200	220	0.63	0.13	**0.21**
MDY-42	9.14 /1	17.75	0.00	162.24	162.24	205	181.64	220	0.51	0.13	**0.26**
MDY-44	3.96 /1	16.87	0.00	66.81	66.81	150	165.92	220	0.48	0.10	**0.21**
MDY-47	8.44 /1	17.86	0.00	150.74	150.74	213.00	192.23	220	0.48	0.17	**0.35**
MDY-48	2.19 /1	16.87	0.00	36.95	36.95	150	192.40	220	0.53	0.17	**0.32**
MDY-55	4.67 /1	16.87	0.00	78.78	78.78	150	159.21	220	0.48	0.09	**0.19**

Table 2 Detail resulted data of liquefied layers in each site of Mandalay City by using Mw 6.5 & PGA 10% probability

Site No	Depth(m)/ Layer	Gamma	u	Sigma	Eff. sigma	Vs	Vs1	Vs1c	CSR	CRR	FS
MDY-3	5.53/1	17.27	0.00	95.50	95.50	173	175	220	0.35	0.12	0.34
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MDY-08	5.58 /1	17.68	0.00	98.65	98.65	200	200.68	220	0.28	0.22	0.79
MDY-10	5.19 /1	17.68	0.00	91.76	91.76	200	204	220	0.30	0.26	0.85
MDY-11	3.19 /1	16.87	0.00	53.82	53.82	150	175.13	220	0.31	0.12	0.38
MDY-19	5.53 /1	17.27	0.00	95.50	95.50	173	175	220	0.35	0.12	0.34
MDY-20	2.24/ 1	15.73	0.00	35.24	35.24	100	129.79	220	0.33	0.06	0.17
MDY-21	2.00 /1	16.24	0.00	32.48	32.48	120	158.96	220	0.31	0.09	0.29
	6.00 /2	17.68	0.00	103.20	103.20	200	198	220	0.30	0.20	0.67
MDY-24	3,05 /1	13.78	0.00	42.03	42.03	50	62.10	220	0.35	0.01	0.04
	7.62 /2	15.73	0.00	113.92	113.92	100	96.80	220	0.35	0.03	0.09
	14.33 /3	16.87	22.86	227.11	204.26	150	125.47	220	0.37	0.05	0.14
MDY-25	5.24 /1	15.73	0.00	82.43	82.43	100	104.95	220	0.39	0.04	0.09
	8.05 /2	16.87	0.49	129.83	129.34	150	140.66	220	0.40	0.07	0.16
MDY-28	4.67 /1	17.68	0.00	82.57	82.57	200	209.81	220	0.33	0.36	1.10
MDY-29	6.10 /1	16.24	0.00	99.06	99.06	120	120.28	220	0.32	0.05	0.15
MDY-34	2.74 /1	17.05	0.00	46.72	46.72	160	193.53	220	0.31	0.18	0.57
MDY-36	6.10	17.61	0.00	107.42	107.42	195	191.54	220	0.33	0.17	0.51
MDY-37	5.53/1	17.27	0.00	95.50	95.50	173	175	220	0.35	0.12	0.34
MDY-40	5.19/1	16.87	0.00	87.56	87.56	150	155.07	220	0.39	0.08	0.21
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MDY-44	3.96 /1	16.87	0.00	66.81	66.81	150	165.92	220	0.33	0.10	0.30
MDY-47	8.44 /1	17.86	0.00	150.74	150.74	213.00	192.23	220	0.32	0.17	0.53
MDY-48	2.19 /1	16.87	0.00	36.95	36.95	150	192.40	220	0.38	0.17	0.45
MDY-55	4.67 /1	16.87	0.00	78.78	78.78	150	159.21	220	0.33	0.09	0.27

Development of Liquefaction Susceptibility Maps

For the study area, liquefaction susceptibility maps are created by means of GIS software using overall potential values (P_L) of each point. These maps are evaluated for liquefaction susceptibility zones. The potential liquefaction hazard zone representing to five levels of liquefaction susceptibility such as very low, low, moderate, high and very high are shown in Figures (4 and 5). Each map represents different intensity values because of using different PGA values as shown in Table (1 & 2). The liquefaction potential (P_L) maps by using PGA 2% probability should be considered for the construction of lifeline structures such as water pipe line, gas pipe line, transportation ways and telecommunication lines. The P_L maps using PGA 10% probability are appropriate for engineering construction of the various sorts of structures especially normal building. Most of the area falling P_L index > 25 are more suffered the liquefaction susceptibility than other one.

Figure 4 represent liquefaction potential map of Mandalay City for PGA value of 10% probability in Mw-6.5. The maximum P_L index value of P_L map using 10% PGA value is 49.19. Figure 5 shows liquefaction potential map of the study area for PGA 2% probability of Mw-6.5. The highest P_L index value of P_L map using 2% PGA value is 51.09. By these maps, the very high representing red color and high (orange color) liquefied susceptible zones occurred at the western portions of Aungmyaythazan and Chanayethazan townships, and north western part of Mahaaungmyay township. The very low or not probable potential liquefied area of Figure 4 is larger spaced than the area of Figure 5. Moderately liquefied zone represents yellow color.

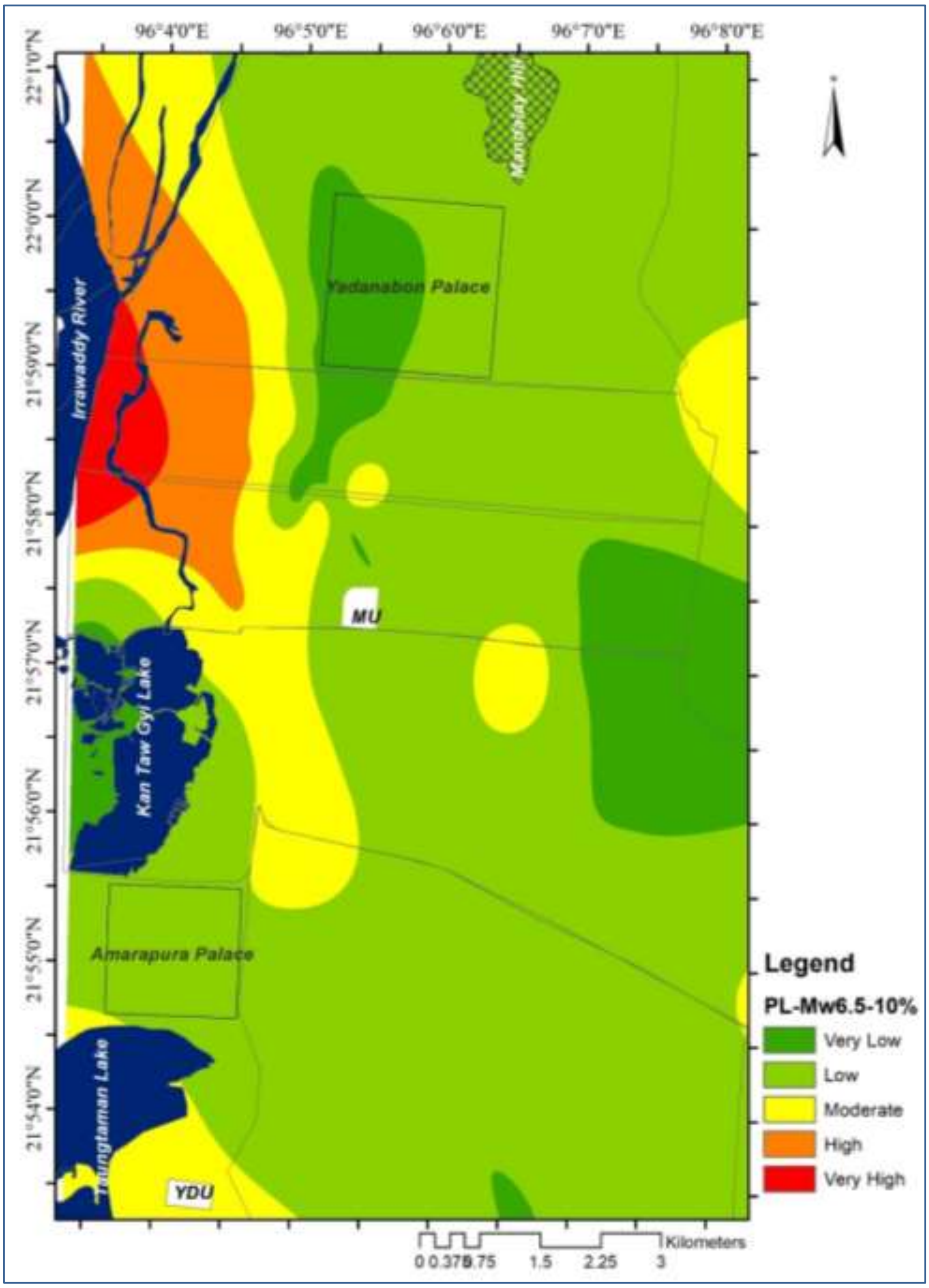

Figure 4 Liquefaction potential map of Mandalay City using PGA10% probability and Mw-6.5

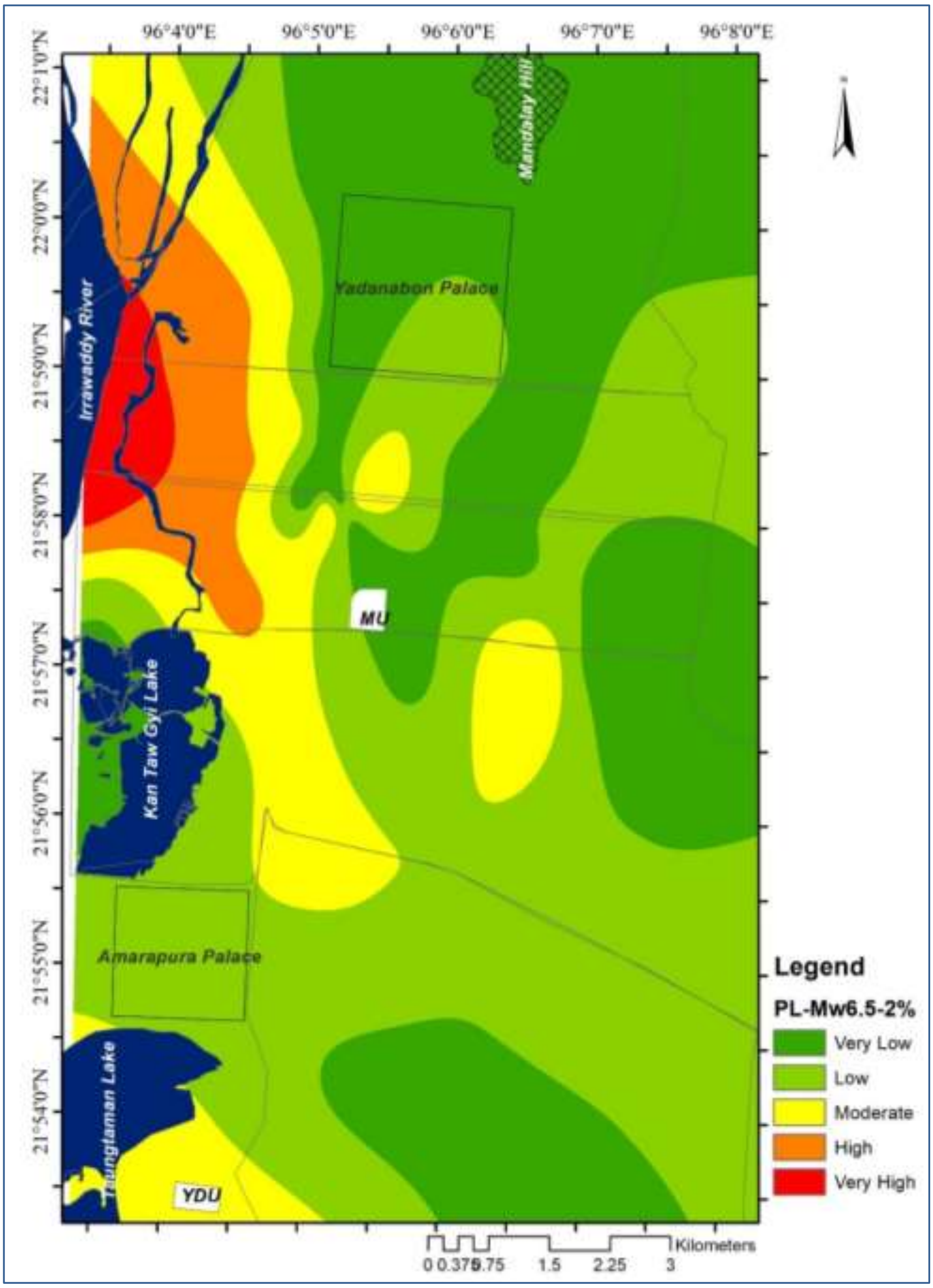

Figure 5 Liquefaction potential map of Mandalay City using PGA 2% probability and Mw-6.5

Conclusion

In this study, the liquefaction susceptibility of the study area had been calculated by using shear wave velocity, depth to water table and PGA value (2% & 10%) based on probabilistic seismic hazard assessment (PSHA). According to all resulted data, the high liquefaction susceptibility zone in the study area mainly lies under loose saturated soil, high thickness soil layer, low Vs value, shallow ground water depth and high PGA value. Exactly the northwestern portions of the study area fall under the very high liquefied zone due to representing maximum P_L index and low Vs30 value. Thus, liquefaction susceptibility analysis is urgently needed for the study area in order to provide an effective mitigation plan for coming future earthquakes related hazards. The produced P_L maps can be effectively used for development plans and risk management practices in the study area.

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