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ESTIMATION OF GROUND SETTLEMENT BY EARTHQUAKE INDUCED LIQUEFACTION IN DOWNTOWN AREA, YANGON

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Abstract

As Yangon has undergone rapid development and expansion, it is needed to construct various new structures. Most of new constructions are on the alluvial deposit. Alluvial deposits are saturated loose sediments and thus, liquefaction is very liable to occur in Yangon area. For that reason, the estimation of ground settlement by earthquake induced liquefaction is needed to carry out. Liquefaction induced ground settlement is estimated at 120 representative sites in downtown based on the Standard Penetration Test and the laboratory results by semi-empirical method. The aim of this research is to provide potential ground settlement information at different locations of site at various depths for earthquakes magnitudes M_w 7.0 with peak ground acceleration of 0.2 g. It also helps in urban planning, prevention of earthquake hazard and determining the suitable foundation types and designs. The study area includes Latha, Pebedan, Kyauktada, and Botahtaung Townships. According to this research, the liquefaction induced ground settlement in the study area is ranging from 6 cm to 56 cm. The estimated ground settlement reveals that light damage may occur in the Ward (2) of Botahtaung Township, General Administrative Department in Kyauktada Township and Ward No. (8) of Botahtaung Township since they have settlement of 6 cm to 10 cm. So, minor cracks may occur when an earthquake of M_w 7.0 strikes. Most of the downtown area can occur medium settlement of 10 cm to 30 cm. Extensive damage may be along the Strand Road, lower part of Thein Phyu Road and Bo Aung Kyaw Roads where it may be the settlement of 30 cm to 56 cm. Therefore, adequate geotechnical site investigation should be done before construction and suitable earthquake resistant design and ground improvements should be applied for all constructions in the areas with high damage potential.

Keywords: alluvial deposits; liquefaction, settlement, Standard Penetration Test, saturated loose sediment

Introduction

Soil liquefaction describes a phenomenon whereby a saturated or partially saturated soil substantially loses strength and stiffness in response to an applied stress, usually earthquake shaking or other sudden change in stress condition, causing it to behave like a liquid. Typical effects of liquefaction are loss of bearing strength, lateral spreading, sand boil, flow failure, ground oscillation, flotation and settlement. Ground settlements due to soil liquefaction have been one of the major causes for infrastructure damages during an earthquake. It is challenging to predict liquefaction because natural variability of the ground is usually not well understood and the soil behavior is complex and difficult to access.

Yangon is located at the confluence of the Yangon and Bago rivers about 30 km away from the Gulf of Martaban. It is located between Latitude 16.8661° N and Longitude 96.1951° E, which refers to the map index 94 D/1. Research area includes Latha Township, Pebedan Township, Kyauktada Township, and Botahtaung Township and location map of research area is shown in Fig (1).

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Figure 1 Location map of research area

Method of study

Based on the methodologies for analysis of liquefaction-induced ground deformations, semi-empirical approach is used. Semi-empirical approaches follow a 3-phase methodology, as shown in Fig (2). The first step is typically a liquefaction triggering analysis in which the subsurface layers that are expected to liquefy as a result of scenario ground shaking are identified. The following step is to estimate the shear strain and reconsolidation volumetric strain in these liquefied sub-layers. Finally the ground lateral displacement and settlement are calculated on the basis of the estimated strain components. Representative semi-empirical approaches include the Tokimatsu and Seed (1984), Ishihara and Yoshimine (1992), and Shamoto et al.(1998).

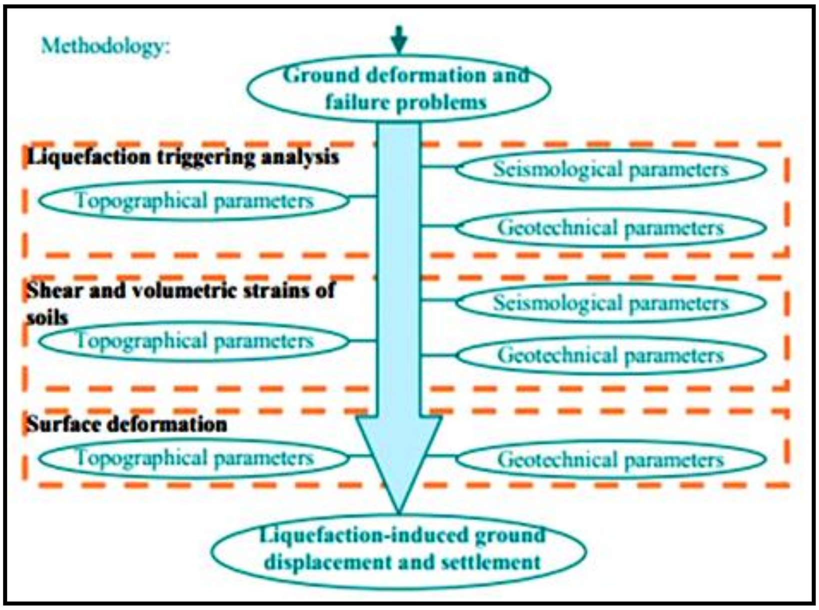

Figure 2 Components of semi-empirical based method

For this research, ground settlement by earthquake induced liquefaction is estimated at (120) representative sites in downtown area by using the borehole records and their standard penetration test results. Based on the SPT value and the laboratory results, estimation of liquefaction induced settlements are carried out by semi-empirical method. Groundwater level is noted on each bore holes. Liquefaction induced ground settlement at different soil profiles are estimated by using earthquakes moment magnitudes M_w 7.0 with peak ground acceleration 0.2 g. The suitable foundation type and ground improvement method can be chosen by estimating the liquefaction induced ground deformation. The locations of analysed sites in downtown area are shown in Fig (3).The number of projects for analysis of liquefaction induced ground settlement is shown in Table (1).

Table 1 Number of projects for liquefaction induced settlement analysis

No	Township	Number of Projects
1	Latha	13
2	Pebedan	33
3	Kyauktada	31
4	Botahtaung	43
Total		**120**

Figure 3 Location of project in research area

Topography and regional geology

The topography of the Yangon area can be divided into hilly area, ridge areas, terraces, low lying flat plain, and tidal flat and channel. The research area is situated on the low lying flat plain. In Yangon, three geological rock units such as alluvial deposits, Irrawaddy Formation and Pegu Group can be found. The alluvial deposit is divided into recent alluvium and valley filled deposit. Irrawaddy Formation consists of Danyingon Clay and Arzarnigon Sandrocks. Pegu Group includes Bewsapet Alternations, Thadugan Sandstone and Hlawga Shale. Recent alluvium consists essentially of yellowish grey, bluish grey, brownish grey silt, sand and clays. Most of downtown areas are located on the recent alluvium. Most of the alluvial deposits are saturated loose sediments. Geological map of the Greater Yangon area is shown in Fig (4).

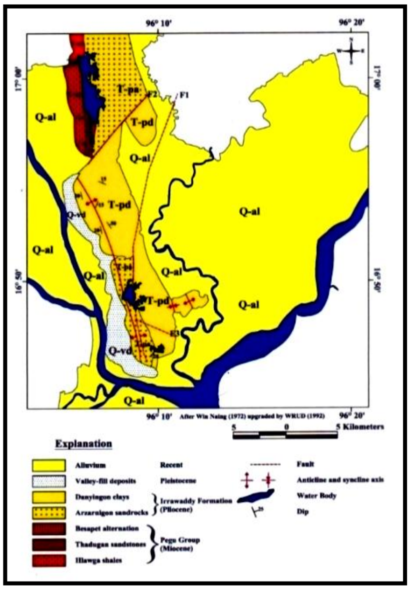

Figure 4 Geological map of the greater Yangon area

Theoretical background

Liquefaction-induced ground settlement is of great engineering significance. There are many mechanisms that can vertical result in liquefaction-induced ground settlements, as shown in Fig (5). Most of these involve settlements as a result of deviatoric ground deformation, but Fig (5) illustrates purely volumetric reconsolidation settlement in level or near level ground. This mechanism of liquefaction-induced settlement is mainly attributed to the densification of sandy and/or silty deposits resulting from the dissipation of excess pore water pressures.

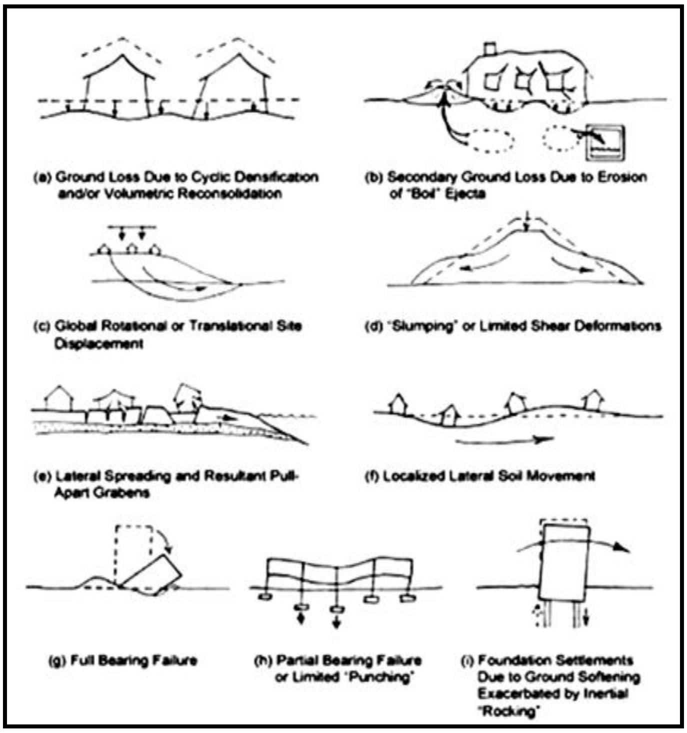

Figure 5 Illustration of liquefaction induced ground settlement mechanisms

Procedure for estimating liquefaction induced ground settlement

Required parameters

The required parameters for the estimating liquefaction induced ground settlement are shown in Table (2).

Table 2 Required parameters

Factor	**Parameter**
Seismic excitation	M_w, PGA
Topography	Level of gentle sloping ground ($\propto$~0)
Subsurface condition	SPT N values, Fines content (FC), groundwater level, soil densities, thickness of layer

Determination of corrected SPT N value

Based on SPT Blow count, N_{60} is first normalized for overburden stress at the depth of the test and corrected to a standardized value of $(N_1)_{60.}$ To calculate $(N_1)_{60}$, the following equations are used.

$$(N_{60}) = C_E.C_B.C_S.C_R.N \qquad (1)$$

$$(N_1)_{60} = C_N.\ (N_{60}) \qquad (2)$$

Where, $(N_1)_{60}$ = Corrected SPT Values

C_E = Hammer Efficiency

C_B = Borehole Diameter Correction

C_R = Rod Length Correction

C_S = Sample Correction

N = Measured SPT N value

C_N = Corrected Factor for Overburden Pressure = $(100/\ \sigma'_v)^{0.5}$

Correction for the fine content and soil plasticity is done from $(N_1)_{60}$ value by using Seed and Idriss, (1982) equation.

$$(N_1)_{60,cs} = \alpha + \beta\ (N_1)_{60} \qquad (3)$$

Where, $\alpha = 0; \beta = 1$ for FC $\leq$ 5

$\alpha = \exp[1.76\ (190/FC^2)]$ for 5% < FC < 35%

$\beta = [0.99+ (FC^{1.5}/100)]$

$\alpha = 5; \quad \beta = 1.2$ for FC $\geq$ 35%

Determination of cyclic stress ratio (CSR)

According to the Seed and Idriss (1972), the cyclic stress ratio for magnitude M_w =7.0 earthquake is calculated by using the following equation.

$$CSR = 0.65 r_d\ (\sigma_{vo}/\ \sigma'_{vo})\ (\alpha_{max}/\ g) \qquad (4)$$

where, CSR = Cyclic Stress Ratio

α_{max} = Peak horizontal ground acceleration (ft/s^2 or m/s^2)

g = Acceleration due to gravity

σ_{vo} = Total vertical Stress (lb/ft^2 or kPa)

σ'_{vo} = Vertical Effective Stress (lb/ft^2 or kPa)

r_d = Stress Reduction with Depth = 1- (0.012 z)

z = Depth from Ground Surface

Determination of reconsolidation volumetric strain (ε_v%)

Reconsolidation volumetric strain (ε_v) is determined by the following chart.

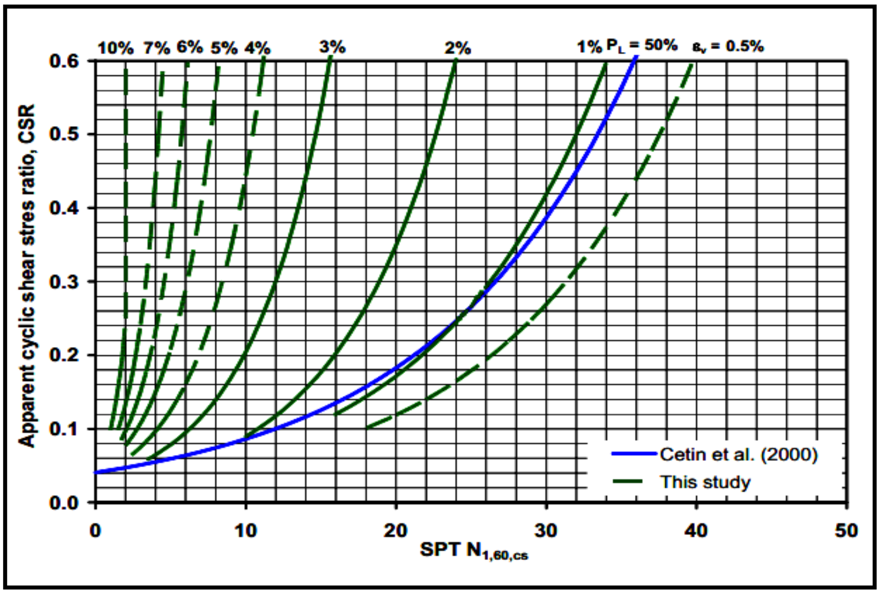

Figure 6 Correlations between CSR, $(N_1)_{60,cs}$ and reconsolidation volumetric strain

Determination of liquefaction induced ground settlement

By using the value of reconsolidation volumetric strain, liquefaction induced ground settlement can be determined. In the evaluation of settlement, computation of field observation is made by Ohsaki (1970) method. In this method, the highest volumetric strain is 10% and it will cause the settlement of 4 in (10.16cm). Depending on this standard, the settlement of individual soil layer can be calculated. The total estimated ground settlement for individual borehole is estimated by adding the settlement of individual soil layers. According to the ground settlement, there is no destruction area where the settlement is 10 cm or less and medium damage area where the settlement are roughly between 10 cm to 20 cm. If the settlement becomes greater than 30 cm, there always occurs considerable destruction on ground surface such as sand spurting, causing fissures and large offsets. The qualitative correspondence between the damage extent and settlements is summarized as shown in Table(3).

Table 3 Relation between damage extent and approximate settlements

Extent of damage	Settlement (cm)	Phenomenon on the ground surface
Light to no damage	0 ~ 10	Minor cracks
Medium damage	10 ~ 30	Small cracks, oozing of sand
Extensive damage	30 ~ 70	Large cracks, spouting of sands, large offsets, lateral movement

Result and Discussion

According to the above procedures (120) representative borehole sites have been performed for ground settlement by earthquake induced liquefaction analysis. The study area is totally covered by alluvial deposits of loosely cemented soil. The most common soil types in these areas are SW, SM, and SC soil types according to the Unified Soil Classification System. The blow count of Standard Penetration Test varies from 2 to 49 within 20 m depth. CL and ML soil type occasionally occurs in some part of downtown area. Groundwater level is high and the soils in these areas are saturated. Moreover, very loose and fine to coarse sand occurs in some part of the downtown area. The extensive damage can occur in these areas. The features of settlement depend on the soil profile and nature of soils composing the deposits. Fig (7) shows the geotechnical properties of borehole at 21st Street, Latha Township. Fig (8) shows subsurface condition of soil at Trader Square, Pebedan Township. Fig (9) shows the geotechnical properties of borehole at proposed Fly Over Project, Kyauktada Township. Fig (10) shows subsurface condition of soil at 48th Street, (10) Ward, Botahtaung Township.

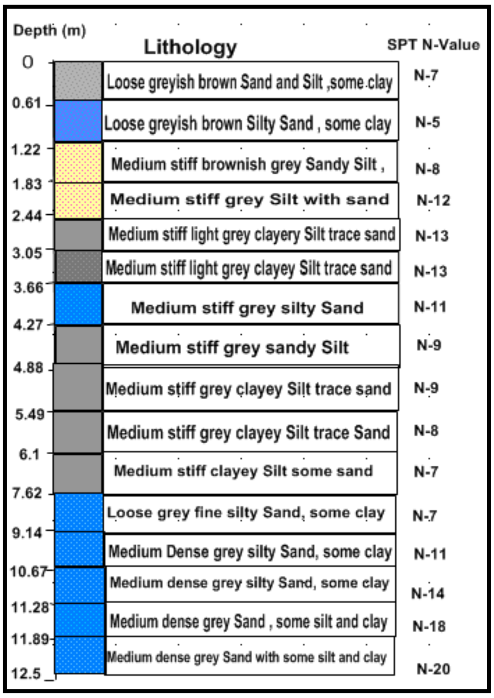

Figure 7 Subsurface soil profile of a site at 21st Street, Latha Township

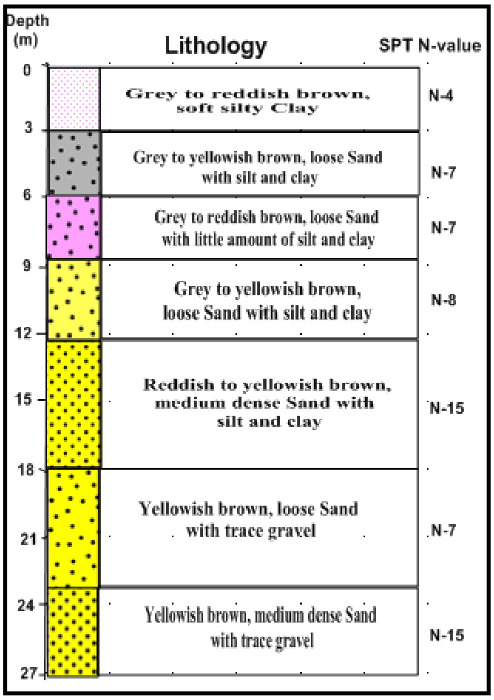

Figure 8 Subsurface soil profile of a site at Trader Square, Pebedan Township

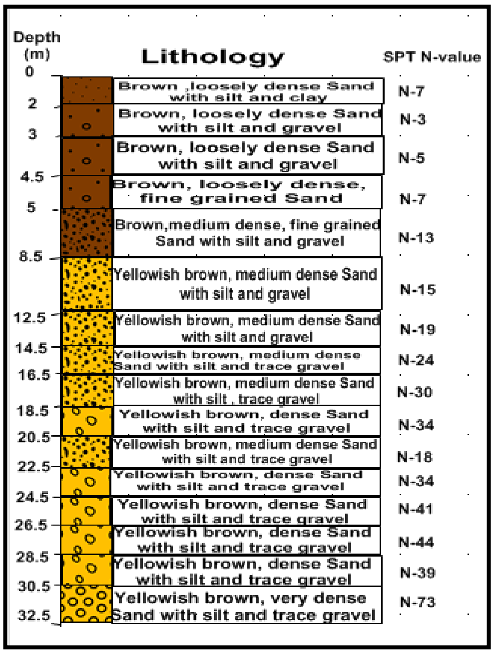

Figure 9 Subsurface soil profile of proposed Fly Over Project, Kyauktada Township

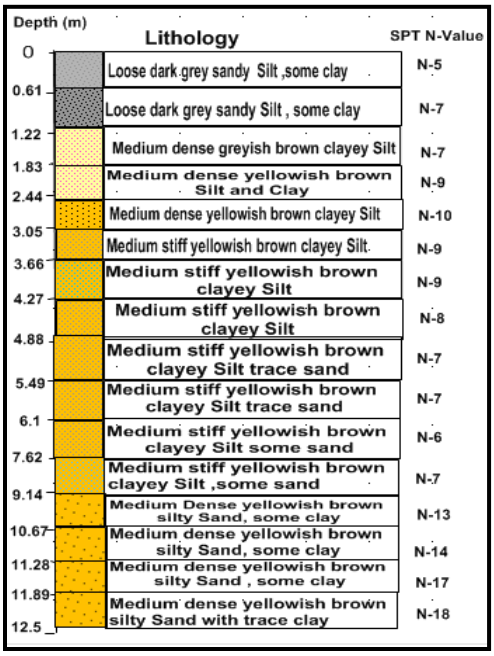

Figure 10 Subsurface soil profile of a site at 48th Street, Botahtaung Township

Some example calculations of liquefaction induced ground settlement are shown in Tables (4), (5), (6) and (7). According to the calculation, ground settlement by earthquake induced liquefaction in study area is between 6 cm and 56 cm.

Table 4 Example calculation of liquefaction induced ground settlement in 21st St. Latha Township

Depth m	ϒ sat kN/m³	Soil Type	σ´ kPa	r_d	CSR	N	$N_{1(60)}$	$N_1(60)_{cs}$	ε_v(%)	Settlement (in)	Settlement (cm)
0.61	17.19	SC	10.49	0.99	0.13	7	16.34	24.61	0	0.00	0.00
1.22	16.97	SM	17.66	0.99	0.15	5	8.99	15.79	1.6	0.64	1.63
1.83	17.38	ML	22.78	0.98	0.18	8	12.67	20.21	1	0.40	1.02
2.44	17.33	ML	27.28	0.97	0.20	12	17.37	25.84	0.5	0.20	0.51
3.05	17.65	SC	32.84	0.96	0.21	13	17.15	25.58	0.6	0.24	0.61
3.66	17.47	SC	36.96	0.96	0.22	13	16.17	24.40	0.8	0.32	0.81
4.27	17.35	SM	41.12	0.95	0.22	11	12.97	20.56	1.2	0.48	1.22
4.88	17.1	SC	44.50	0.94	0.23	9	10.20	17.24	2	0.80	2.03
5.49	16.91	SC	47.91	0.93	0.24	9	9.83	16.80	2	0.80	2.03
6.1	16.99	SC	52.73	0.93	0.24	8	8.33	15.00	2.4	0.96	2.44
7.62	17.1	SM	64.48	0.91	0.24	7	6.59	12.91	2.7	1.08	2.74
9.14	17	SM	74.64	0.89	0.24	7	6.13	12.35	2.8	1.12	2.84
10.67	17.3	SM	88.85	0.87	0.24	11	8.82	15.59	2.3	0.92	2.34
11.28	17.77	SM	98.72	0.86	0.23	14	10.65	17.78	1.8	0.72	1.83
11.89	18.09	SM	107.38	0.86	0.22	18	13.13	20.76	1.2	0.48	1.22
12.5	18.17	SM	113.43	0.85	0.22	20	14.20	22.04	1.1	0.44	1.12
13.11	18.59	SW	124.03	0.84	0.22	23	15.61	22.12	1.1	0.44	1.12
							Total Settlement			8.56	21.74

Table 5 Example calculation of liquefaction induced ground settlement in Upper 27th St in Pebedan Township

Depth m	ϒ sat kN/m^3	Soil Type (USCS)	σ′ kPa	rd	CSR	N	$N_{1(60)}$	$N_1(60)_{cs}$	$\varepsilon_{v(\%)}$	Settlement (in)	Settlement (cm)
0.61	17.6	SM	10.74	0.99	0.13	11	25.38	32.77	0	0.00	0.00
1.22	17.27	SM	15.09	0.99	0.18	8	15.57	21.78	0.7	0.28	0.71
1.83	17.08	SM	19.29	0.98	0.21	6	10.33	15.91	2	0.80	2.03
2.44	17.68	SM	25.19	0.97	0.22	14	21.09	27.96	0.4	0.16	0.41
3.05	18.01	SM	30.99	0.96	0.22	17	23.09	32.15	0	0.00	0.00
3.66	18.26	SM	36.91	0.96	0.23	18	22.40	31.88	0	0.00	0.00
4.27	18.28	SM	42.15	0.95	0.23	18	20.96	30.15	0	0.00	0.00
4.88	18.65	SM	49.12	0.94	0.23	19	20.49	29.59	0	0.00	0.00
5.49	18.65	SM	54.52	0.93	0.23	18	18.43	27.12	0.7	0.28	0.71
6.1	18.45	SM	58.69	0.93	0.23	18	17.76	26.32	0.7	0.28	0.71
7.62	18.18	SM	69.76	0.91	0.23	17	15.39	23.46	0.9	0.36	0.91
9.14	18.07	SM	81.48	0.89	0.23	17	14.24	22.09	1.2	0.48	1.22
							Total Settlement			2.64	6.71

Table 6 Example calculation of liquefaction induced ground settlement in Flyover Pass in Kyauktada Township

Depth m	$ϒ_{sat}$ kN/m^3	Soil Type (USCS)	σ′ kPa	r_d	CSR	N	$N_{1(60)}$	$N_1(60)_{cs}$	$\varepsilon_{v\%}$	Settlement (in)	Settlement (cm)
1	21	SM	21.00	0.99	0.13	7	10.58	17.18	1	0.40	1.02
2	17.7	SM	25.59	0.98	0.18	7	10.58	17.70	1.5	0.60	1.52
3	19.9	SM	40.08	0.96	0.19	3	3.58	9.30	3.3	1.32	3.35
4	19.9	SM	50.17	0.95	0.20	5	5.34	11.40	2.8	1.12	2.84
5	21.9	SM	70.26	0.94	0.19	7	6.31	9.40	3.2	1.28	3.25
6	17.9	SM	58.35	0.93	0.22	7	6.93	13.31	2.6	1.04	2.64
8	21.2	SM	100.93	0.90	0.20	13	9.78	11.63	2.7	1.08	2.74
10	30.8	SW	219.71	0.88	0.16	13	6.63	12.22	2.4	0.96	2.44
12	22.8	SW	165.69	0.86	0.18	15	8.81	12.65	2.3	0.92	2.34
14	22.1	SW	181.87	0.83	0.18	19	10.65	12.17	2.6	1.04	2.64
16	21	SW	188.85	0.81	0.19	24	13.20	13.20	2.4	0.96	2.44
18	20.9	SW	209.43	0.78	0.18	30	15.67	15.67	1.8	0.72	1.83
20	21.5	SW	243.61	0.76	0.17	34	16.47	16.47	1.6	0.64	1.63
							Total Settlement			12.08	30.68

Table 7 Example calculation of liquefaction induced ground settlement in Mya Nanda St. Botahtaung Township

Depth m	ϒ sat kN/m³	Soil Type (USCS)	σ′ kPa	r_d	CSR	N	$N_{1(60)}$	$N_{1(60)cs}$	$\varepsilon_{v(\%)}$	Settlement (in)	Settlement (cm)
1.5	17.5	SM	26.25	0.98	0.13	4	5.90	12.08	2.1	0.84	2.13
3	17.5	SM	52.50	0.96	0.13	3	3.13	8.76	2.8	1.12	2.84
4.5	18.34	SM	77.63	0.95	0.13	3	2.57	8.09	2.9	1.16	2.95
6	18.34	SM	90.42	0.93	0.15	4	3.18	8.82	2.8	1.12	2.84
7.5	20.37	SM	118.44	0.91	0.15	4	2.78	5.96	3.9	1.56	3.96
9	20.37	SM	134.28	0.89	0.16	17	11.09	14.77	1.8	0.72	1.83
10.5	20.37	SM	150.12	0.87	0.16	11	6.79	10.20	2.8	1.12	2.84
12	20.37	SW	165.96	0.86	0.16	27	15.84	19.81	0.8	0.32	0.81
13.5	20.37	SW	181.80	0.84	0.16	20	11.21	14.90	1.8	0.72	1.83
15	20.37	SM	197.64	0.82	0.16	13	6.99	10.42	2.8	1.12	2.84
16.5	20.37	SM	213.48	0.80	0.16	17	8.80	13.50	2	0.80	2.03
18	21.36	SW	247.14	0.78	0.16	25	12.02	17.52	1.8	0.72	1.83
19.5	21.36	SW	264.47	0.77	0.16	16	7.44	12.44	2.3	0.92	2.34
20	21.36	SW	270.24	0.76	0.16	18	8.28	14.19	2	0.80	2.03
							Total Settlement			13.04	33.12

Zonal distribution of liquefaction induced ground settlement

Zonal distribution of liquefaction induced ground settlement is presented in the form of contour, based on the ground settlement values by using Surfer software. It shows the level of severity of settlement when the earthquake with the magnitude of M_w= 7.0 occurs. Fig (11) shows zonal distribution of liquefaction induced ground settlement.

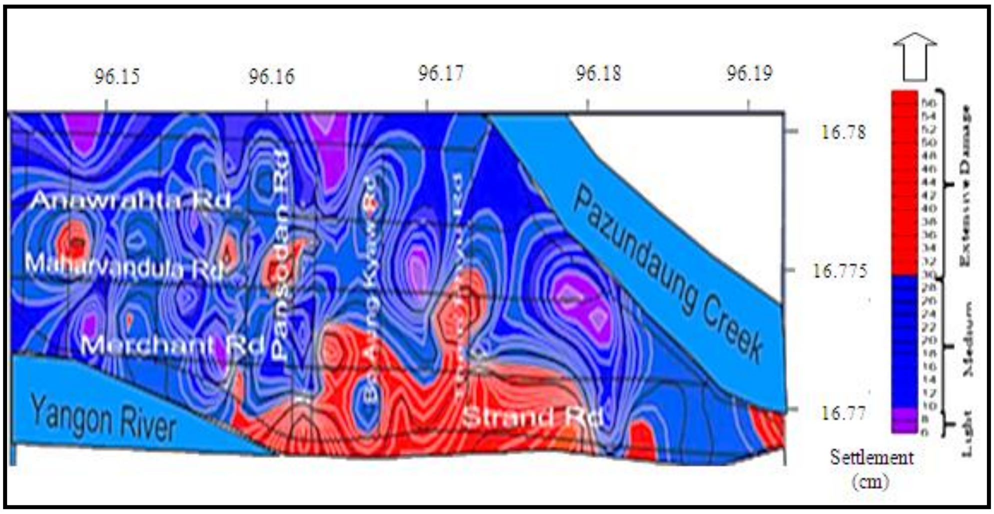

Figure 11 Zonal distribution of liquefaction induced ground settlement when M_w= 7.0 earthquake occur

The zonal distribution of estimated ground settlement reveals that light damage may occur in the Ward (2) of Botahtaung Township, General Administrative Department in Kyauktada Township and Ward No.(8) of Botahtaung Township since they have settlement of 6 cm to 10 cm. So, minor cracks may occur due to ground settlement in these areas when an earthquake of M_w 7.0 strikes. As shown in Fig (11), most of the downtown area can occur medium settlement since the ground settlement range from 10 cm to 30 cm. Small cracks, oozing of sand can occur in these area. Extensive damage may be along the Strand Road, lower part of Thein Phyu Road and Bo Aung Kyaw Roads where the ground settlement may be 30 cm to 56 cm. Moreover, some part of Latha, Pebedan and Kyauktada may occur extensive damage. Spouting of sand, large offset and lateral movement of ground will occur in these places when earthquake of M_w 7.0 occur. Therefore, adequate geotechnical investigation and elaborate tests should be carried out and suitable ground improvement methods should be done for multi-storied buildings. It is hoped that the data and results presented herein will contribute to the further development and calibration of increasingly accurate and reliable methods for assessing hazard due to triggering of liquefaction and consequent liquefaction induced ground deformations and displacements.

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