Earthquake Related Geo-hazard Risks in Myanmar

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OUTLINES OF THE PRESENTATION

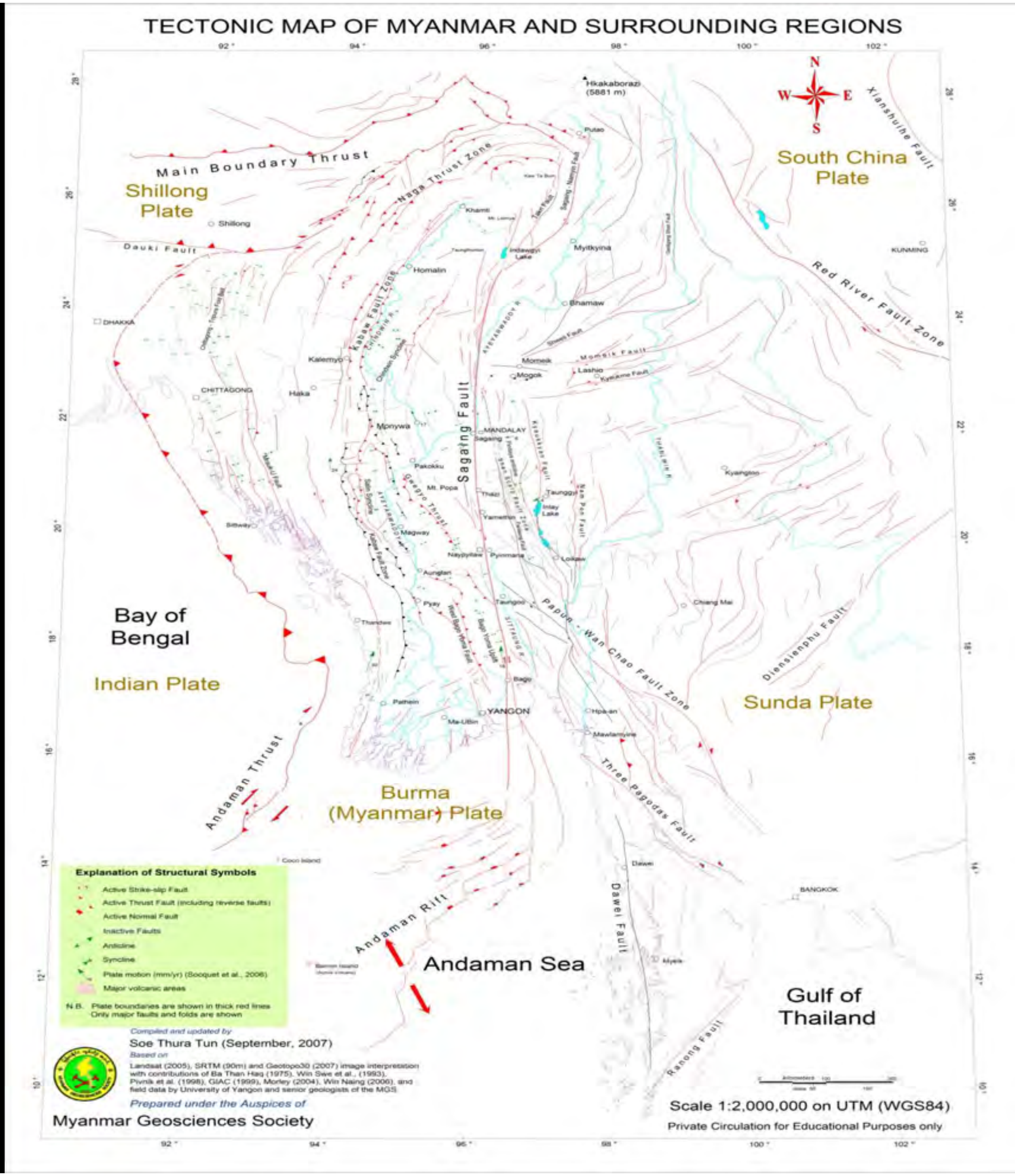
- Introduction
- Seismicity and Seismotectonics of Myanmar
- Earthquake related geo-hazards:
  - Landslide
  - Liquefaction
  - Tsunami
- Estimation of Liquefaction Induced Ground Settlement in Selected Areas
- Conclusion

INTRODUCTION

- The seismotectonics of the Myanmar region indicates that Myanmar indeed is situated in earthquake-prone area as it lies in one of the two principle earthquake belts of the world, the Alpide Belt.
- Earthquakes in Myanmar region have originated from two main causes:
  - *(1) the subduction (with collision only in the north) of northward moving Indian Plate underneath the Burma Plate at an average rate of 4 to 6 cm/yr along the Adman Megathrust Zone;*
  - *(2) the northward movement of the Burma Plate from a spreading centre in the Andaman Sea at an average rate of 2.5 to 3.0 cm/yr.*

EARTHQUAKE BELTS OF THE WORLD

Tectonic Map of Myanmar and Surrounding Region



Seismicity and Seismotectonics of Myanmar

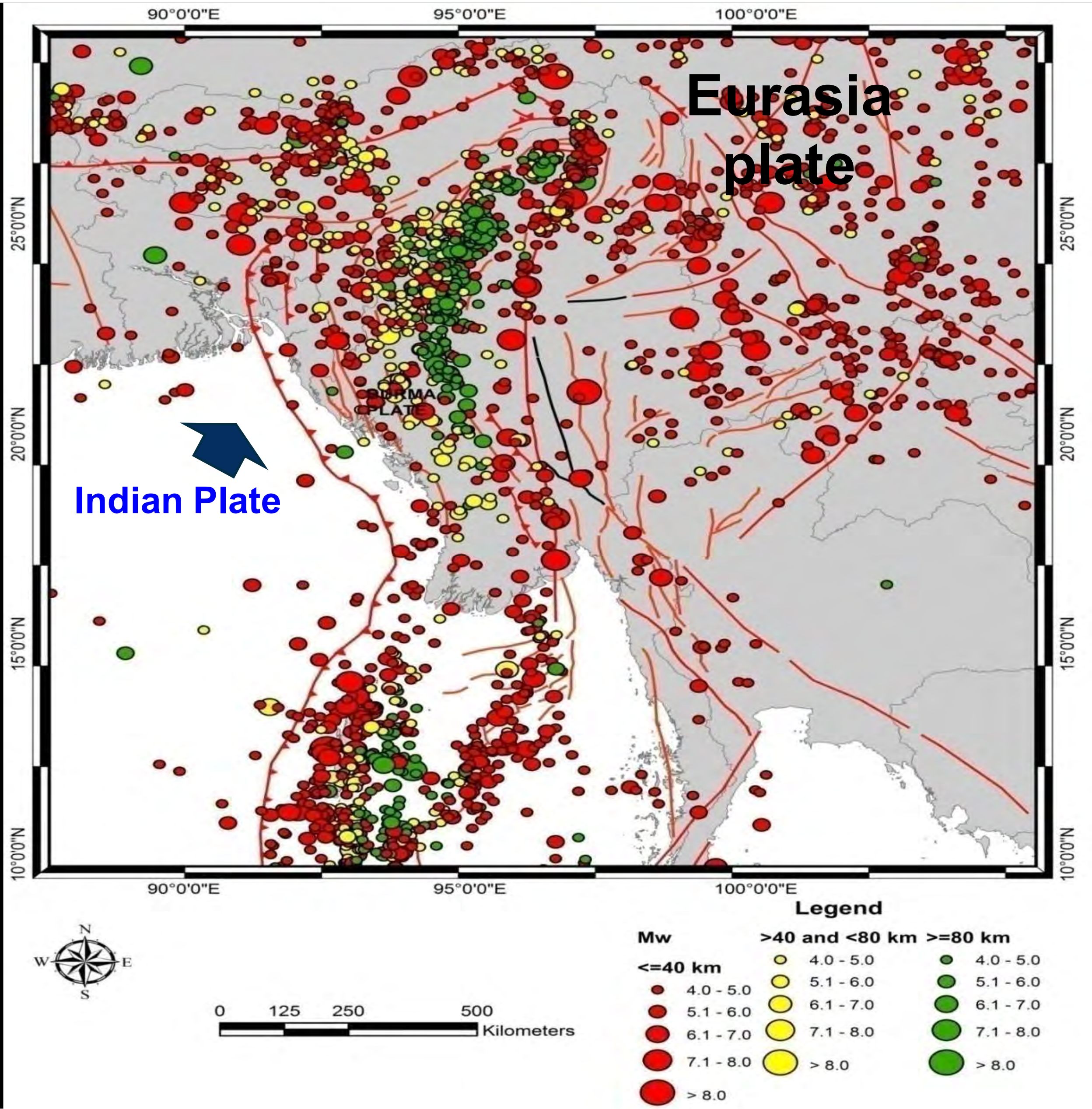
- Very large over-thrusts along the Western Fold Belt have resulted from the northward moving Indian Plate underneath the Burma Plate and the Sagaing and related faults from the northward movement of the Burma Plate from a spreading centre in the Andaman Sea

- Intermittent jerks along these major active faults have caused the majority of earthquakes in Myanmar. These seismotectonics processes are still going on.

- The earthquakes generated by sea-floor spreading in the Andaman Sea, however, are mostly small to moderate and shallow-focus.

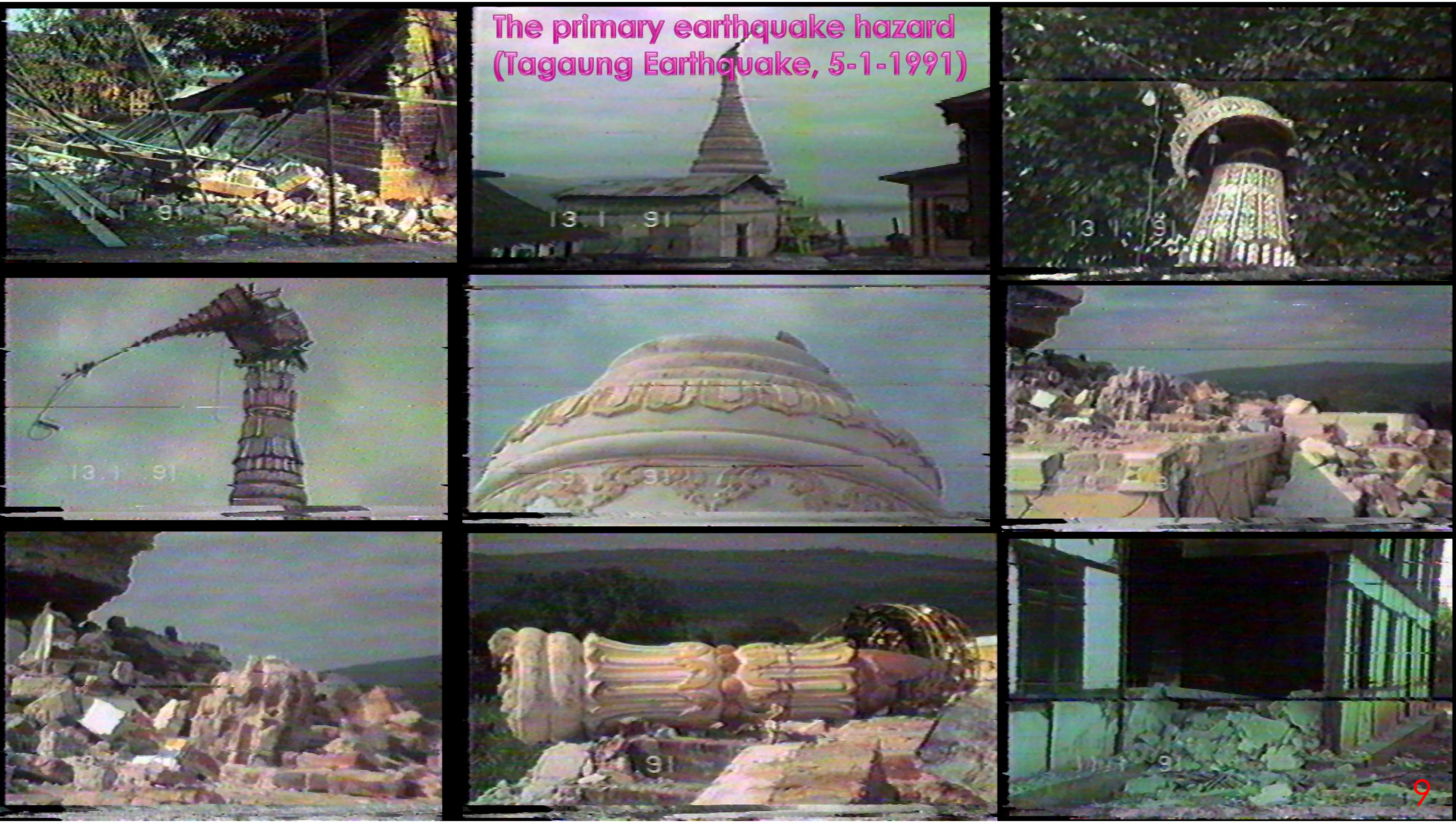
- Therefore, Myanmar is vulnerable to hazards from moderate and large magnitude earthquakes, including tsunami hazards along its long coastal areas.

Seismicity map of Myanmar
(ISC - 1906 - 2022)



Earthquake Related Geo-hazards

- Earthquakes are not great killers, but the buildings people constructed.
- They are the most unexpected of natural calamities because they do not negotiate.
- The primary earthquake hazard is the collapsing of buildings and
- The secondary earthquake related geological hazards are tsunami, landslide including subsidence and liquefaction as well as liquefaction induced ground settlement and lateral spreading.


The primary earthquake hazard
(Tagaung Earthquake, 5-1-1991)
13 1 91

Taungdwingyi Earthquake, 22-9-2003

Tarlay Earthquake (24-3-2011)

Thabeikkyin Earthquake (11-11-2012)

Bagan Earthquake (24-8-2016)









Kengtung (Minephyut) Earthquake (21-7-2022)






Earthquake Related Geohazards: **Landslide**

Causes of landslides

- (i) **Presence of Steep Slope**
- (ii) **Increasing of Pore-water Pressure in the Slope**
- (iii) **Erosion Processes**
- (iv) **Geological Structures**
- (v) **Presence of Troublesome Earth Materials**
- (vi) **Triggering Event [Earthquake and Torrential Rain (beyond the threshold value)]**

Landslide due to Earthquake in Myanmar

- Earthquake induced landslide events are observed during the previous earthquakes such as
  - Sittway (Chittagaung),
  - Maymyo (Pyin-Oo-Lwin),
  - Tagaung
  - Taungdwingyi,
  - Tarlay,
  - Thabeikkyin, and
  - Kengtung (Minephyat), etc.
- However, the intensity is **not so high** compare to the other countries.
- Although Landslide events for **Sittway and Maymyo** Earthquake are described in Literature, photographs are not available at present.

Landslide due to Tagaung Earthquake

Landslide due to Taungdwinggyi Earthquake


Landslide due to Tarlay Earthquake

Landslide due to Thabeikkyin Earthquake

Landslide due to Thabeikkyin Earthquake






Landslide (Debris Fall) due to Kengtung Earthquake (Minephyat)

Earthquake Related Geohazards: Liquefaction

FACTORS OF LIQUEFACTION

- According to past earthquake, liquefaction usually happen within 20 m from ground level
- In loose saturated **Sandy Soil**
- Fine content <35%
- Clay content ≤ 20%
- Clay or Silt Size materials with Low PI resemble as Cohessionless Soil (with high degree of Liquefaction (Ishihara-1985)
- Lower value of SPT blow count
- High Magnitude Earthquake


Liquefaction due to Tagaung Earthquake
12.1.91


Liquefaction due to Taungdwinggyi Earthquake
2003 10 1
2003 10 2


Liquefaction due to Tarlay Earthquake

Liquefaction due to Thabeikkyin Earthquake


The Liquefaction
Web Site

NIGITA EARTHQUAKE, 1964 (JAPAN)

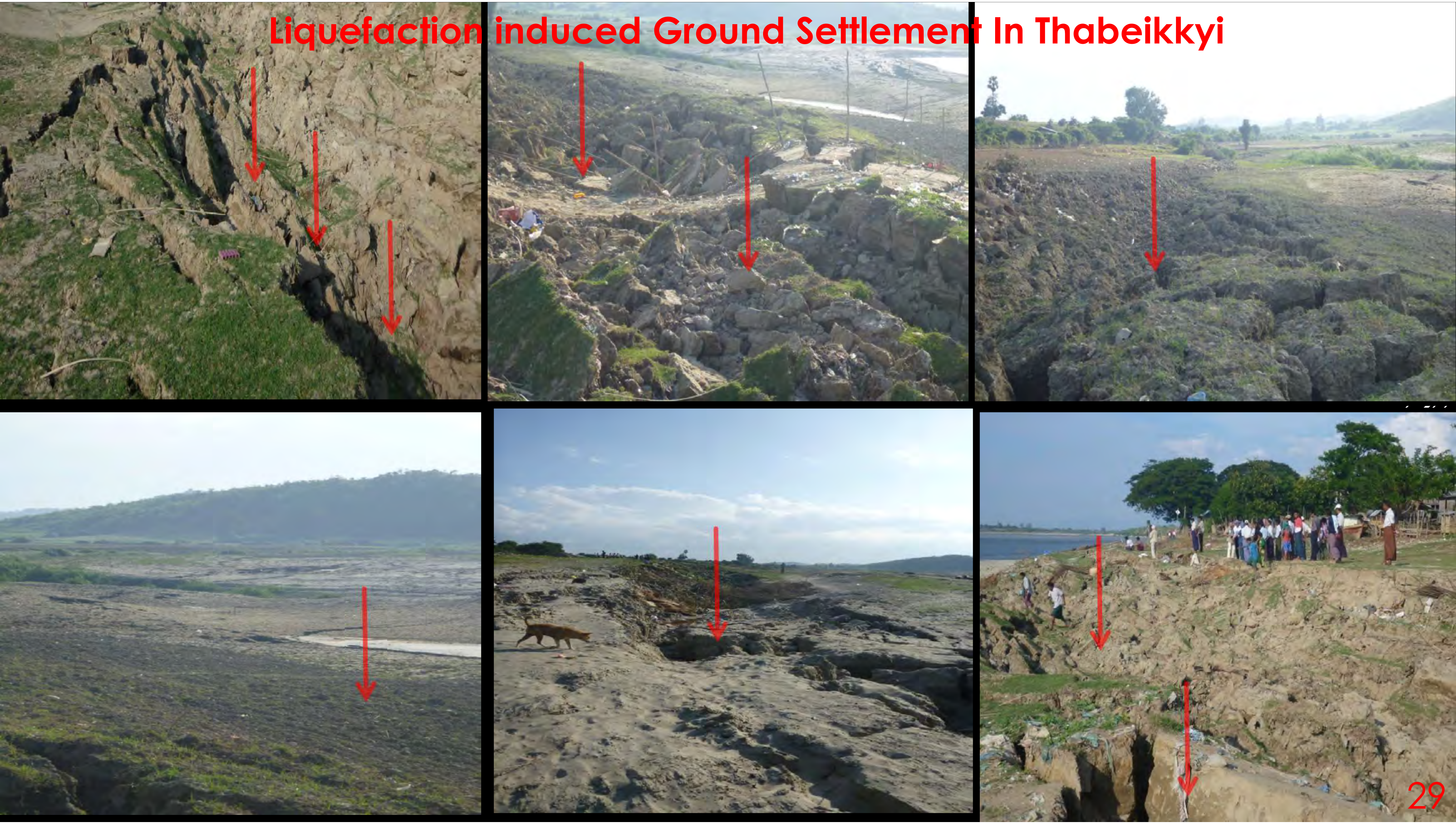
Liquefaction Induced Ground Settlement

- Liquefaction of **loose, saturated granular soils** during earthquakes is a major hazard for construction of facilities in many regions.
- Clay or Silt Size materials with Low PI resemble as Cohesionless Soil (with high degree of Liquefaction (Ishihara-1985)
- Liquefaction-induced ground deformations have caused significant damage to engineered structures and lifelines.
- Both ground settlements and lateral spreads are the pervasive types of liquefaction-induced ground deformations for level to gently sloping sites.
- Liquefaction-induced ground settlements are essentially vertical deformations of surficial soil layers caused by the densification and compaction of loose granular soils following earthquake loading.

Liquefaction Induced Ground Settlement in Taungdwingyi

Liquefaction Induced Ground Settlement in Tagaung

Liquefaction induced Ground Settlement In Thabeikkyi



Earthquake Related Geo-hazards: Tsunami

- Myanmar has experienced tsunami hazard along the coastal areas namely, the Rakhine Coastal Region in the west, the Ayeyawady Delta in the middle, and the Tanintháyi Coastal Region in the south in 2004 due to the hit of, the Indian Ocean tsunami.
- However, the intensity of the tsunami in terms of run-up and the extent of the inundation was comparatively lower than the other countries around the Indian Ocean and the causality and damage was also lesser.
- For distance tsunami (source like Sumatra), Myanmar coastal areas has some time (duration) for preparation to escape from the killer waves.
- But for the near source tsunami (for instance a large earthquake happened in the Andaman Island region and if it generates the tsunami), the delta region of Myanmar has only short duration for preparation.

PROBABLE EARTHQUAKE AND TSUNAMI HAZARDS ALONG THE MYANMAR COASTAL AREAS

- Rakhine Coast
  - Strong Zone with MMI- VIII
  - Moderate tsunami hazard
- Ayeyawady Delta
  - Moderate Zone with MMI- VII
  - Moderate tsunami hazard
- Tanintharyi Coast
  - Moderate Zone with MMI -VII
  - Light tsunami hazard

TSUNAMI CAUSES AND CHARACTERISTICS IN MYANMAR

- There were also records of moderate tsunami generated by two large magnitude earthquakes which originated in the Andaman-Nicobar Islands. These are the M 7.9 Car Nicobar Earthquake (31 December 1881) and the M 7.7 Andaman Island Earthquake (26 June 1941).
- The tsunami generated by the giant 2004 Sumatra Earthquake also caused moderate damage (Figures) in the delta region and the southern Myanmar Coast.
- The causality is also comparatively lower than the other countries around the Indian Ocean (Table)

TSUNAMI CAUSES AND CHARACTERISTICS IN MYANMAR

- Recent paleoseismlogical studies by the joint Myanmar-Japanese teams in the northern Rakhine Coast (Than Tin Aung et al., 2008) reveal that the presence of **at least three raised marine terraces** with radio carbon dates ranging from 1400 BC to 1860 AD.
- These studies indicate that there were **at least three great earthquakes** (including 1762 earth-quake) in that region in the past 3400 years.

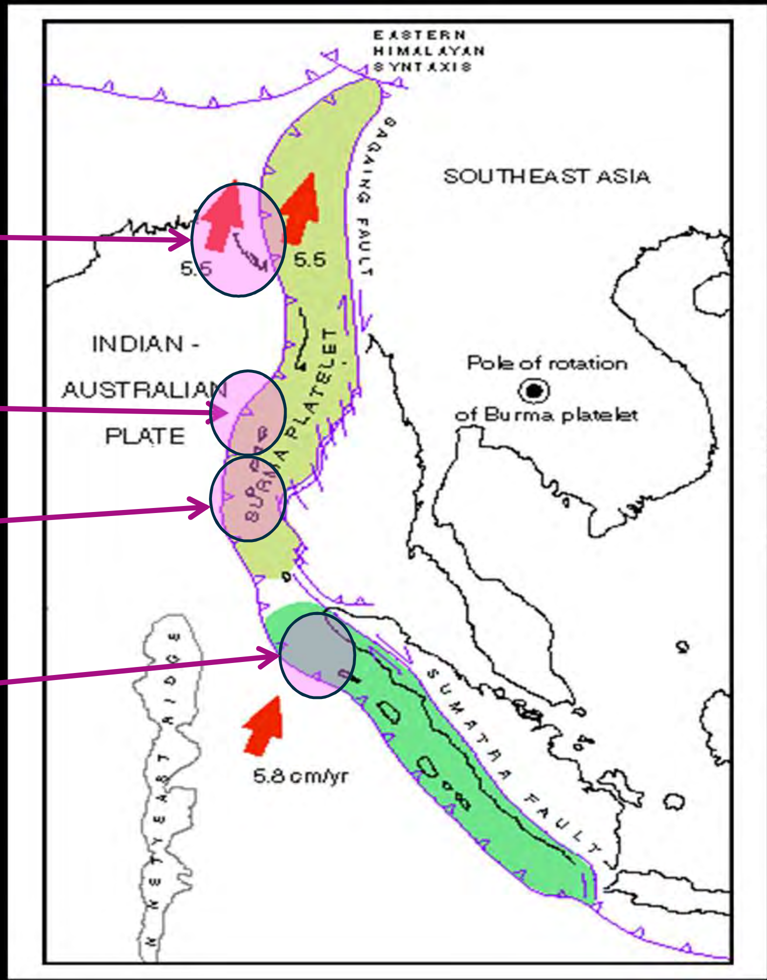
EARTHQUAKES AND TSUNAMIS IN THE ANDAMAN SEA AND BAY OF BENGAL

Possible location of 1762 Rakhine Earthquake

Andaman Island Earthquake 1941 June 26

Car Nicober Earthquake, Dec 1881

2004 December 26 Sumatra Earthquake and Indian Ocean Tsunami



Official damage and deaths for Myanmar in 2004

Location	Village	House -holds	Affected population	Injured	Missing	Death	Properties damage
Labutta	7	337	1,138	41	3	25	99 boats, 8 schools, 4 rice mills
Ngaputaw	9	108	1.007			5	19 boats, 1 bridge, 2 pagodas
Bogalae						1	wall collapsed
Rakhine State						22	
Tanin-thayi division	7	92	447			8	44 boats,3 warehouse 1 bridge
Total	23	537	2,592	41	3	61	162 boats,8 schools, 4 rice mills, 3 pagodas, 2 bridges, one wall

Record of damage and casualties in 2004 Tsunami at the Ayeyarwady delta region

EARTHQUAKE RELATED HAZARDS TSUNAMI

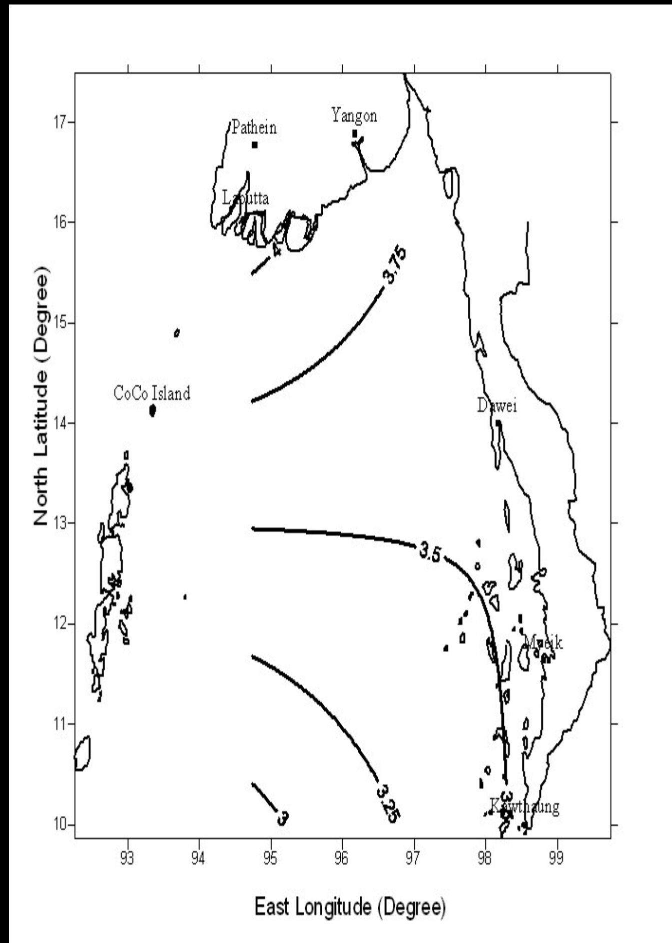
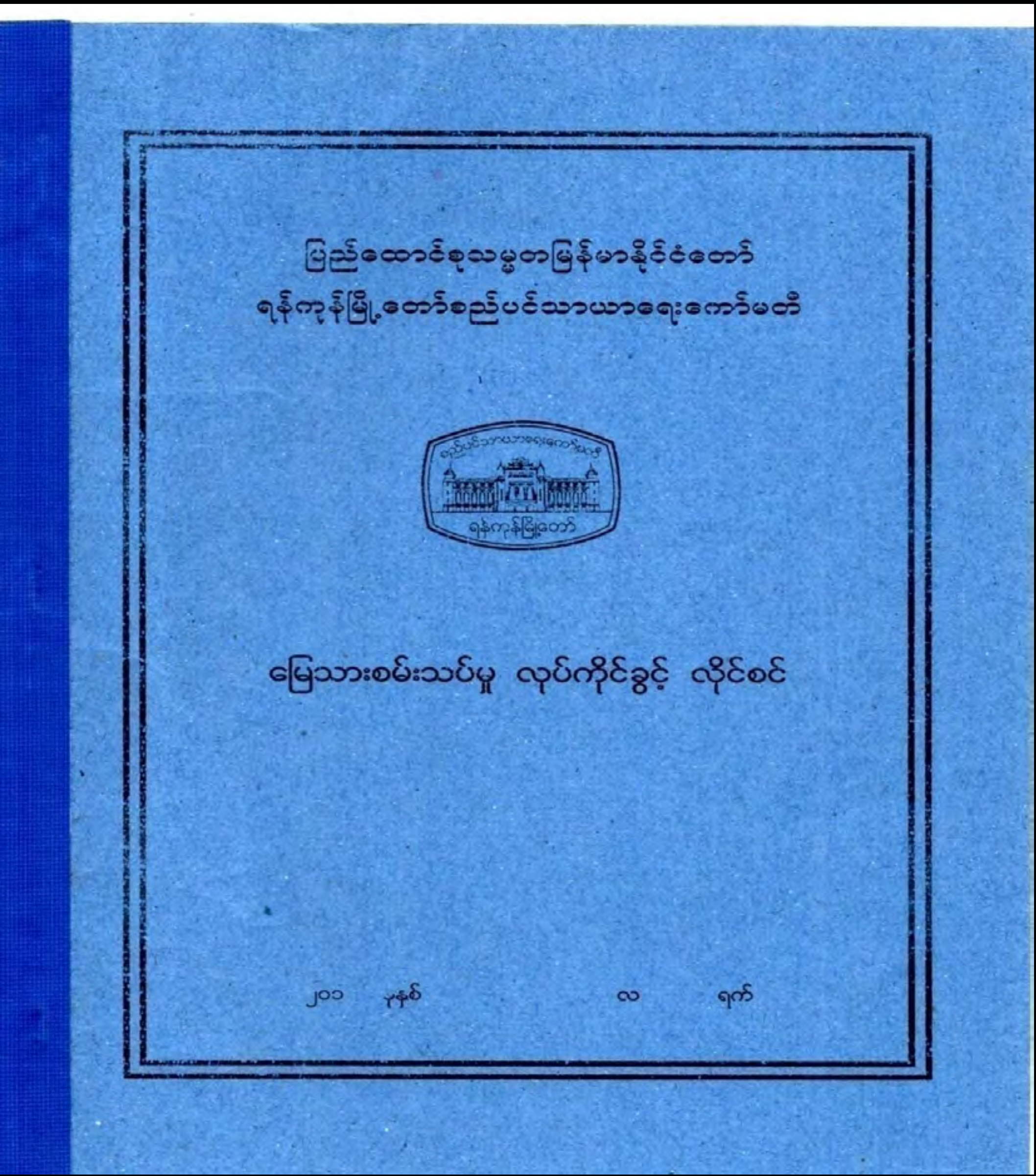


Figure : The effect of 2004 Indian Ocean Tsunami at Kawthong (upper), Chaungwa (lower left) and Ayeyawady (middle). The arrival time of tsunami to Myanmar coast (right)



Action on Liquefaction Potential In Myanmar

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(စ) Soil Investigation Report တွင် ပါရှိရမည့်အချက်များ

1. Cover Page
2. Certification of Soil Investigation Report (Licensed by Y.C.D.C)
3. Personal In-charge of Soil Investigation
4. Introduction - General
5. Scope of Work
6. Field Testing
7. Laboratory
8. Description of Soil Strata
9. Liquefaction Analysis and Result (According to CQHP Guide Line)
10. Soil Settlement Result (According to CQHP Guide Line)
11. Soil Bearing Capacity (According to CQHP Guide Line)
12. Conclusion, Discussion and Recommendations

Appendix A - Site Location Plan
Appendix B - Bore Hole Location Plan
Appendix C - Bore Hole Logs
Appendix D - Probable Soil Profile
Appendix E - Summary of Field Test Results
Appendix F - Summary of Laboratory Test Results
Appendix G - Detailed of Laboractory Test Results
Appendix H - Site Photos and Soil Sample Photos
Appendix I - Detailed of Laboractory Test Results

(ဆ) မြေတူးစမ်းသပ်မှုဆိုင်ရာ သတ်မှတ်ချက်များ

(၁) မြေတူးစမ်းသပ်ရမည့် Bore Hole အရေအတွက် သတ်မှတ်ချက်

(a) Up to 10,000ft², minimum no. of bore holes shall be one bore hole / 2500 ft² of projected building area but not less than 2 holes.

(b) If the projected area is more than 10,000 ft²,
1. for the first 10,000ft², follow Rule 1.
2. for additional area no. of additional bore holes shall be one bore hole/ 5,000 ft² of projected building area.

(c) Additional Boring for angular Soil Conditions

Estimation of Liquefaction Potential

After being corrected the field SPT blow counts, the following procedures are conducted to estimate liquefaction potential in the research area

(1) Finding the Cyclic Stress Ratio (CSR)

The cyclic stress ratio, CSR, as proposed by Seed and Idriss (1971),

$$\boldsymbol{CSR} = \frac{\tau_{av}}{\sigma_{v''}} = 0.65\left(\frac{\alpha x_{ma}}{g}\right)\left(\frac{\sigma_v}{\sigma_{v'}}\right)rd$$

where

αx_{ma} = *maximum horizontal ground surface acceralation* (g)

g = *gravitational acceleration*

σ_v = *total overburden pressure at depth* z

$\sigma_{v'}$ = *effective overburden pressure at depth* z

rd = *stress reduction factor*

[Myanmar Earthquake Committee published Earthquake Hazard Map of Yangon Area in 2012. In their map, they proposed possible range of peak ground acceleration between 0.15 g and 0.2 g. For the research areas, the maximum ground acceleration is regarded as 0.2g.]

(2) Estimation of Stress Reduction Factor

The stress reduction factor, *rd*, is used to determine the maximum shear stress at different depths in the soil. Values generally range from 1 at the ground surface to lower values at larger depths.

The following formulations are provided by NCEER (1997)

$rd = 1.0 - 0.00765z \quad \text{for } z \leq 9.15\ m$

$rd = 1.174 - 0.0267z \quad \text{for } 9.15\ m < z < 23\ m$

$rd = 0.744 - 0.008z \quad \text{for } 23\ m < z \leq 30\ m$

$rd = 0.5 \quad \text{for } z > 30\ m$

3. Overburden Correction Factor (C_N)

The overburden correction factor adjusts N values to the $(N_1)_{60}$ value that would be measured at the same depth if the effective overburden stress was 1 atm. The following formulation is applied (Liao and Whiteman (1986):

$$C_N = \left(\frac{P_a}{\sigma'_v}\right)^{0.5}$$

4. Estimation of Cyclic Resistance Ratio

❖The most common used method for determining the liquefaction resistance is proposed by Papathanassious et al. (2006)

$$CRR_{7.5} = \frac{1}{34 - (N_1)_{60}} + \frac{(N_1)_{60}}{135} + \left(\frac{50}{10 \times (N_1)_{60} + 4.5}\right)^2 - \frac{1}{200}$$

$$N_{1\,60} = C_N N_{60}$$

$$N_{60} = C_E C_B C_S C_R$$

. Estimation of Cyclic Resistance Ratio (CRR) [Continued]

The cyclic resistance ratio is the other term required to calculate the factor of safety against liquefaction. The cyclic resistance ratio represents the maximum CSR at which a given soil can resist liquefaction. It can be calculated by using the following equation (Idriss and Boulanger, 2004):

$$(N_1)_{60cs} = (N_1)_{60} + \Delta (N_1)_{60}$$

$$\Delta(N_1)_{60} = \exp\left(1.63 + \frac{9.7}{FC+0.01} - \left(\frac{15.7}{FC+0.01}\right)^2\right)$$

$$CRR_{M=7.5} = exp\left(\frac{(N_1)_{60cs}}{14.1}) + \left(\frac{(N_1)_{60cs}}{126}\right)^2 - \left(\frac{(N_1)_{60cs}}{23.6}\right)^3 + \left(\frac{(N_1)_{60cs}}{25.4}\right)^4 - 2.8\right)$$

The equation for CRR, corrected for overburden pressure and magnitude, is

$$CRR = CRR_{M7.5} MSF$$

Where

For $M_w < 7.0$; → $MSF = 10^{3.00} \times M_w^{-3.46}$

For $M_w \geq 7.0$; → $MSF = 10^{2.24} \times M_w^{-2.56}$

5. Factor of Safety against Liquefaction

- The potential for liquefaction can be evaluated by comparing the earthquake loading (CSR) with the liquefaction resistance (CRR) – this is usually expressed as a factor of safety against Liquefaction:

$$FS = \frac{CRR}{CSR}$$

- Where *FS < 1.0* ; the soil is expressed to liquefy during the design earthquake

  FS > 1.0: the soil is not expected to liquefy during the earthquake

Evaluation of Liquefaction Induced Ground Settlement

- Vertical displacements from liquefaction occur due to settlement from reconsolidation as well as shear deformation from lateral spreading.
- Liquefaction settlement calculated in this project is based on the liquefied soil which is interpreted using SPT blow count and potential earthquake magnitude.
- Reconsolidation strains are calculated based on the maximum shear strains that developed during the cyclic loading.

$$S_v \int_0^{z_{max}} \varepsilon_v \, dz$$

where

S_v = settlement of the soil
ε_v=volumetric strain in percent
dz = the thickness of the soil layer

- According to Tokimatsu and Seed (1987) reviewed an empirical calculation of earthquake-induced volumetric strains in situated sands based on cyclic stress ratio and normalized SPT values.
- Based on their findings, the volumetric strains due to soil liquefaction during an earthquake magnitude of 7.5 may be approximated by the equation:

$$\varepsilon_v = 10(N_1)_{60cs}^{-0.6}$$

$(N_1)_{60cs}$ = corrected for fines and adjusted to an equivalent clean sand (for $\frac{CSR}{(N_1)_{60cs}} > 0.01$)

Estimation of Liquefaction Induced Ground Settlement in the Selected Areas

- ❖ Firstly, liquefaction potentials are estimated from the available data.
- ❖ Then ground settlement are evaluated for all selected areas.
- ❖ In this presentation, only some locations are selected as complete calculation (Both no potential areas and potential areas)
- ❖ Mandalay and Yangon (Bahan Township; Taung Nyunt Township (Set San))

Estimation of Liquefaction Analysis Based on SPT Mandalay

AMARAPURA

URBAN DEVELOPMENT PROJECT

(MANDALAY GREEN CITY PROJECT)

Results for Liquefaction Induced Ground **Settlement** Based on SPT Data & **0.4 g** Value

Depth (m)	N Value	CSR	CRR				CRR/CSR (SF)				Settlement (cm)			
			7.5	7.0	6.5	6.0	7.5	7.0	6.5	6.0	7.5	7.0	6.5	6.0
1	6	0.258	0.152	0.181	0.234	0.303	0.588	0.700	0.905	1.176	2.57	2.57	2.57	0.00
2	2	0.256	0.105	0.125	0.161	0.210	0.409	0.487	0.631	0.819	5.28	5.28	5.28	5.28
3	4	0.254	0.117	0.140	0.181	0.234	0.461	0.549	0.711	0.923	3.93	3.93	3.93	3.93
4	13	0.252	0.192	0.229	0.296	0.384	0.763	0.907	1.174	1.525	2.13	2.13	0.00	0.00
5	12	0.267	0.178	0.212	0.275	0.357	0.668	0.795	1.029	1.336	2.27	2.27	0.00	0.00
6	12	0.293	0.161	0.192	0.248	0.323	0.550	0.655	0.847	1.101	2.33	2.33	2.33	0.00
7	7	0.314	0.128	0.152	0.196	0.255	0.406	0.483	0.625	0.812	3.10	3.10	3.10	3.10
8	9	0.331	0.141	0.168	0.218	0.283	0.427	0.508	0.657	0.854	2.73	2.73	2.73	2.73
9	10	0.345	0.146	0.174	0.225	0.292	0.423	0.504	0.652	0.847	2.62	2.62	2.62	2.62
10	16	0.35	0.193	0.229	0.297	0.386	0.551	0.655	0.848	1.101	2.02	2.02	0.00	0.00
11	15	0.352	0.186	0.221	0.287	0.372	0.529	0.629	0.814	1.057	2.07	2.07	0.00	0.00
12	20	0.352	0.237	0.283	0.366	0.475	0.674	0.803	1.039	1.349	1.78	1.78	0.00	0.00
13	23	0.349	0.274	0.327	0.423	0.549	0.786	0.935	1.211	1.572	1.66	1.66	0.00	0.00
14	47	0.344	19.06	22.68	29.36	38.13	55.42	65.95	85.35	110.8	0.00	0.00	0.00	0.00
15	44	0.336	4.325	5.147	6.661	8.650	12.87	15.31	19.82	25.74	0.00	0.00	0.00	0.00
16	40	0.328	1.610	1.916	2.480	3.221	4.910	5.843	7.561	9.820	0.00	0.00	0.00	0.00
17	40	0.319	1.286	1.530	1.981	2.572	4.031	4.797	6.208	8.063	0.00	0.00	0.00	0.00
18	44	0.309	2.120	2.523	3.265	4.240	6.861	8.165	10.56	13.72	0.00	0.00	0.00	0.00
19	44	0.299	1.687	2.008	2.598	3.374	5.642	6.714	8.689	11.28	0.00	0.00	0.00	0.00
20	44	0.289	1.388	1.652	2.138	2.777	4.804	5.717	7.398	9.608	0.00	0.00	0.00	0.00
	WT = 3.0 m		BH-11-23					Total Settlement			34.5	34.5	22.6	17.7

Results for Liquefaction Induced Ground **Settlement** Based on SPT Data & **0.4 g** Value

Depth (m)	N Value	CSR	CRR				CRR/CSR (SF)				Settlement (cm)			
			7.5	7.0	6.5	6.0	7.5	7.0	6.5	6.0	7.5	7.0	6.5	6.0
1	2	0.258	0.132	0.157	0.204	0.265	0.513	0.61	0.79	1.03	3.28	3.28	3.28	0
2	4	0.256	0.124	0.148	0.191	0.248	0.485	0.58	0.75	0.97	3.68	3.68	3.68	3.68
3	4	0.254	0.117	0.14	0.181	0.235	0.462	0.55	0.71	0.92	4.16	4.16	4.16	4.16
4	7	0.252	0.133	0.159	0.205	0.267	0.529	0.63	0.82	1.06	3.24	3.24	3.24	0
5	7	0.25	0.131	0.156	0.202	0.262	0.524	0.62	0.81	1.05	3.34	3.34	3.34	0
6	6	0.272	0.123	0.146	0.189	0.246	0.452	0.54	0.7	0.9	3.76	3.76	3.76	3.76
7	13	0.291	0.178	0.212	0.275	0.357	0.613	0.73	0.94	1.23	2.27	2.27	2.27	0
8	8	0.305	0.137	0.163	0.211	0.274	0.449	0.53	0.69	0.9	3.11	3.11	3.11	3.11
9	13	0.317	0.17	0.202	0.262	0.34	0.536	0.64	0.83	1.07	2.37	2.37	2.37	0
10	20	0.321	0.231	0.275	0.356	0.463	0.721	0.86	1.11	1.44	1.87	1.87	0	0
11	19	0.322	0.224	0.266	0.345	0.448	0.695	0.83	1.07	1.39	1.91	1.91	0	0
12	41	0.321	2.725	3.242	4.196	5.449	8.488	10.1	13.07	16.98	0	0	0	0
13	39	0.32	1.482	1.764	2.282	2.964	4.631	5.51	7.13	9.26	0	0	0	0
14	35	0.317	0.618	0.735	0.951	1.235	1.948	2.32	3	3.9	0	0	0	0
15	31	0.314	0.39	0.464	0.600	0.779	1.241	1.48	1.91	2.48	0	0	0	0
16	31	0.309	0.371	0.441	0.571	0.742	1.200	1.43	1.85	2.4	0	0	0	0
17	31	0.303	0.355	0.422	0.546	0.709	1.170	1.39	1.8	2.34	0	0	0	0
18	36	0.296	0.495	0.589	0.762	0.99	1.672	1.99	2.58	3.34	0	0	0	0
19	36	0.288	0.463	0.551	0.713	0.925	1.607	1.91	2.47	3.21	0	0	0	0
20	50	0.28	3.051	3.63	4.698	6.101	10.90	12.96	16.78	21.79	0	0	0	0
	WT = 3.0 m		BH-16-145					Total Settlement			32.97	32.97	29.19	14.7

Results for Liquefaction Induced Ground **Settlement** Based on SPT Data & **0.4 g** Value

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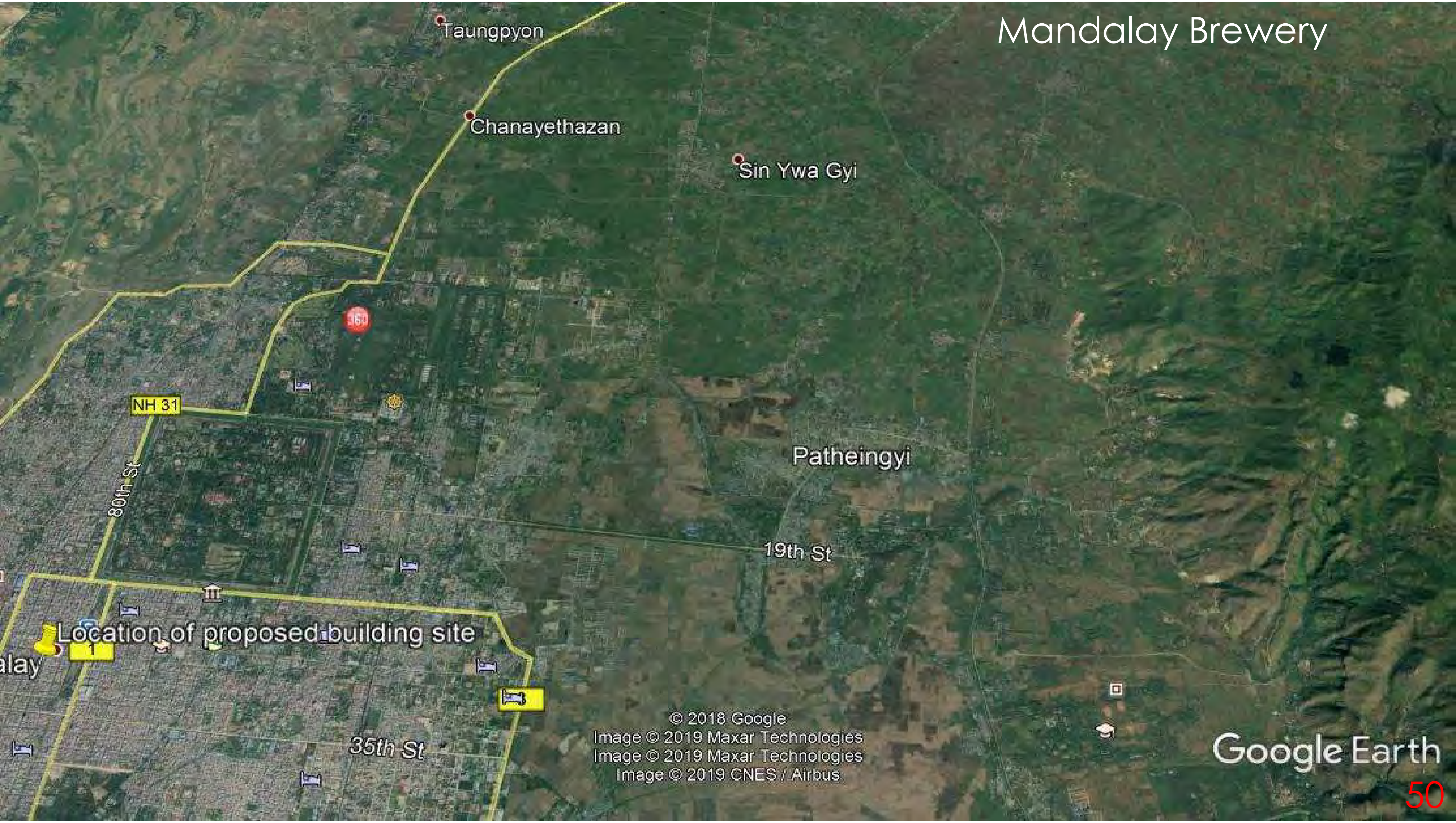
1	2	0.258	0.109	0.13	0.168	0.218	0.423	0.503	0.651	0.846	4.98	4.98	4.98	4.98
2	2	0.256	0.105	0.125	0.162	0.21	0.411	0.489	0.632	0.821	5.65	5.65	5.65	5.65
3	3	0.254	0.109	0.13	0.168	0.218	0.429	0.51	0.66	0.858	5.00	5.00	5.00	5.00
4	9	0.252	0.146	0.173	0.224	0.291	0.578	0.688	0.89	1.156	2.82	2.82	2.82	0.00
5	9	0.264	0.144	0.171	0.222	0.288	0.546	0.649	0.84	1.091	2.87	2.87	2.87	0.00
6	4	0.285	0.11	0.131	0.17	0.221	0.388	0.461	0.597	0.775	4.80	4.80	4.80	4.80
7	7	0.301	0.131	0.156	0.202	0.263	0.436	0.519	0.672	0.873	3.30	3.30	3.30	3.30
8	5	0.315	0.117	0.139	0.18	0.234	0.371	0.442	0.572	0.743	4.13	4.13	4.13	4.13
9	10	0.326	0.147	0.175	0.226	0.294	0.451	0.537	0.694	0.902	2.79	2.79	2.79	2.79
10	18	0.329	0.207	0.246	0.319	0.414	0.629	0.748	0.969	1.258	2.00	2.00	2.00	0.00
11	17	0.328	0.2	0.238	0.308	0.401	0.611	0.727	0.940	1.221	2.05	2.05	2.05	0.00
12	33	0.327	0.636	0.757	0.98	1.272	1.945	2.315	2.996	3.891	0.00	0.00	0.00	0.00
13	33	0.324	0.569	0.677	0.876	1.137	1.755	2.089	2.703	3.510	0.00	0.00	0.00	0.00
14	26	0.319	0.278	0.33	0.428	0.555	0.870	1.036	1.341	1.741	1.67	0.00	0.00	0.00
15	26	0.314	0.267	0.318	0.412	0.535	0.852	1.014	1.312	1.704	1.70	0.00	0.00	0.00
16	31	0.308	0.351	0.417	0.54	0.702	1.139	1.355	1.754	2.278	0.00	0.00	0.00	0.00
17	33	0.302	0.385	0.458	0.592	0.769	1.274	1.516	1.961	2.547	0.00	0.00	0.00	0.00
18	33	0.294	0.365	0.434	0.562	0.73	1.242	1.478	1.912	2.484	0.00	0.00	0.00	0.00
19	23	0.286	0.21	0.249	0.323	0.419	0.733	0.872	1.128	1.465	1.93	1.93	0.00	0.00
20	22	0.278	0.198	0.236	0.305	0.396	0.712	0.848	1.097	1.425	2.00	2.00	0.00	0.00
	WT = 3.0 m		BH-16-145					Total Settlement			47.69	44.32	40.39	30.65


Mandalay Brewery
Taungpyon
Chanayethazan
Sin Ywa Gyi
NH 31
80th St
Patheingyi
19th St
Location of proposed building site
1
alay
35th St
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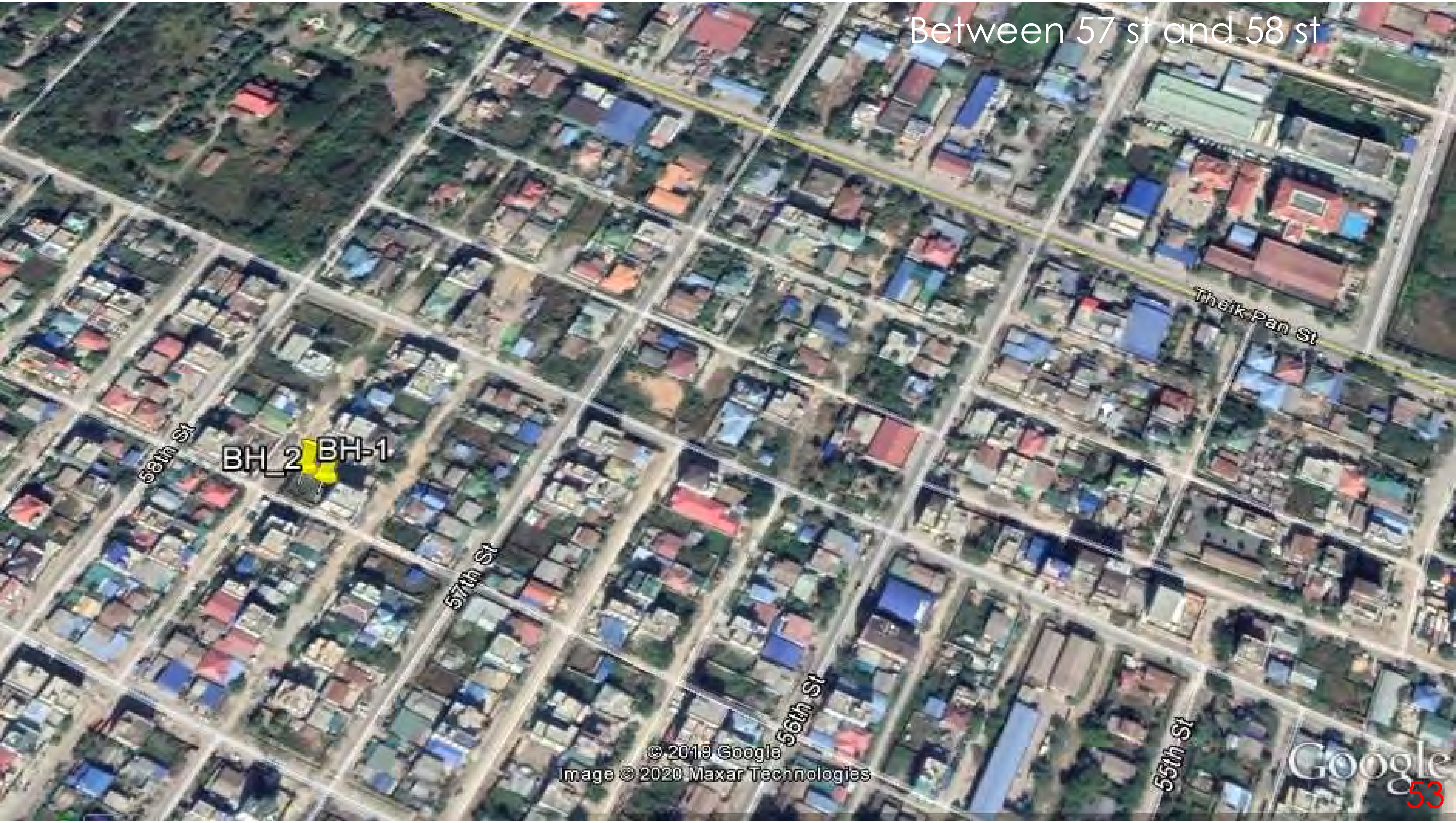
Google Earth

Results for Liquefaction Induced Ground **Settlement** Based on SPT Data & **0.4 g** Value

Depth (m)	N Value	CSR	CRR				CRR/CSR (SF)				Settlement (cm)			
			7.5	7.0	6.5	6.0	7.5	7.0	6.5	6.0	7.5	7.0	6.5	6.0
1	10	0.194	0.23	0.27	0.35	0.45	1.17	1.39	1.8	2.32	0.00	0.00	0.00	0.00
2	20	0.192	0.81	0.97	1.25	1.62	4.23	5.03	6.5	8.44	0.00	0.00	0.00	0.00
3	25	0.191	0.9	1.07	1.39	1.8	4.72	5.62	7.3	9.42	0.00	0.00	0.00	0.00
4	34	0.189	6.05	7.20	9.32	12.1	32.02	38.1	49.3	64.02	0.00	0.00	0.00	0.00
5	46	0.188	232.3	276.4	357.7	464.5	1235.6	>1470	>1902	2470	0.00	0.00	0.00	0.00
6	50	0.186	176.0	209.5	271.1	352.1	946.63	>1126	1457	1893	0.00	0.00	0.00	0.00
7	45	0.185	33.43	39.78	51.48	66.86	180.69	215	278	361.41	0.00	0.00	0.00	0.00
8	25	0.183	0.32	0.38	0.49	0.64	1.74	2.07	2.70	3.50	0.00	0.00	0.00	0.00
9	18	0.182	0.20	0.24	0.31	0.40	1.1	1.31	1.70	2.20	0.00	0.00	0.00	0.00
10	22	0.188	0.25	0.30	0.39	0.50	1.34	1.59	2.10	2.66	0.00	0.00	0.00	0.00
11	48	0.192	13.14	15.64	20.24	26.28	68.45	81.45	105	136.88	0.00	0.00	0.00	0.00
12	22	0.195	0.24	0.29	0.37	0.48	1.23	1.46	1.90	2.46	0.00	0.00	0.00	0.00
13	25	0.197	0.28	0.33	0.43	0.55	1.4	1.67	2.20	2.79	0.00	0.00	0.00	0.00
14	58	0.198	215.4	256.3	331.7	430.8	1087.9	>1294	1675	2175	0.00	0.00	0.00	0.00
15	60	0.198	323.6	385.1	498.4	647.3	1634.7	>1945	>2517	3269	0.00	0.00	0.00	0.00
16	33	0.196	0.43	0.51	0.66	0.86	2.2	2.62	3.40	4.39	0.00	0.00	0.00	0.00
17	35	0.194	0.49	0.58	0.75	0.98	2.52	3.00	3.90	5.05	0.00	0.00	0.00	0.00
18	24	0.192	0.23	0.28	0.36	0.47	1.22	1.45	1.90	2.45	0.00	0.00	0.00	0.00
19	32	0.188	0.35	0.42	0.55	0.71	1.88	2.24	2.90	3.78	0.00	0.00	0.00	0.00
20	40	0.185	0.67	0.79	1.03	1.33	3.61	4.29	5.60	7.19	0.00	0.00	0.00	0.00
	WT = 9.0 m		BH-01					Total Settlement			0.00	0.00	0.00	0.00

Results for Liquefaction Induced Ground **Settlement** Based on SPT Data & **0.4 g** Value

Depth (m)	N Value	CSR	CRR				CRR/CSR (SF)				Settlement (cm)			
			7.5	7.0	6.5	6.0	7.5	7.0	6.5	6.0	7.5	7.0	6.5	6.0
1	14	0.194	0.381	0.454	0.587	0.762	1.97	2.34	3.03	3.93	0.00	0.00	0.00	0.00
2	22	0.192	1.309	1.558	2.016	2.618	6.82	8.11	10.5	13.64	0.00	0.00	0.00	0.00
3	23	0.191	0.591	0.703	0.91	1.182	3.09	3.68	4.76	6.19	0.00	0.00	0.00	0.00
4	27	0.189	0.832	0.99	1.281	1.664	4.4	5.24	6.78	8.80	0.00	0.00	0.00	0.00
5	20	0.188	0.27	0.322	0.416	0.54	1.44	1.71	2.21	2.87	0.00	0.00	0.00	0.00
6	25	0.186	0.337	0.402	0.52	0.674	1.81	2.16	2.79	3.62	0.00	0.00	0.00	0.00
7	22	0.201	0.307	0.366	0.473	0.614	1.53	1.82	2.36	3.05	0.00	0.00	0.00	0.00
8	24	0.214	0.342	0.407	0.526	0.684	1.6	1.9	2.46	3.20	0.00	0.00	0.00	0.00
9	27	0.226	0.422	0.502	0.65	0.844	1.87	2.22	2.88	3.73	0.00	0.00	0.00	0.00
10	29	0.231	0.57	0.679	0.878	1.14	2.47	2.94	3.8	4.94	0.00	0.00	0.00	0.00
11	31	0.234	0.672	0.8	1.035	1.344	2.87	3.42	4.42	5.74	0.00	0.00	0.00	0.00
12	33	0.236	0.799	0.951	1.231	1.598	3.39	4.03	5.22	6.77	0.00	0.00	0.00	0.00
13	32	0.236	0.628	0.747	0.967	1.256	2.66	3.16	4.1	5.32	0.00	0.00	0.00	0.00
14	28	0.235	0.386	0.459	0.594	0.772	1.64	1.95	2.53	3.29	0.00	0.00	0.00	0.00
15	36	0.233	0.888	1.057	1.368	1.776	3.81	4.54	5.87	7.62	0.00	0.00	0.00	0.00
16	37	0.231	0.924	1.099	1.422	1.848	4	4.76	6.16	8.00	0.00	0.00	0.00	0.00
17	37	0.227	0.834	0.993	1.285	1.668	3.68	4.37	5.66	7.35	0.00	0.00	0.00	0.00
18	29	0.223	0.35	0.416	0.538	0.7	1.57	1.87	2.41	3.14	0.00	0.00	0.00	0.00
19	34	0.218	0.507	0.604	0.781	1.014	2.33	2.77	3.58	4.65	0.00	0.00	0.00	0.00
20	39	0.213	0.828	0.985	1.275	1.656	3.89	4.63	5.99	7.77	0.00	0.00	0.00	0.00
	WT = 9.0 m		BH-15					Total Settlement			0.00	0.00	0.00	0.00


Between 57 st and 58 st
Theik Pan St
58th St
BH_2
BH-1
57th St
56th St
55th St
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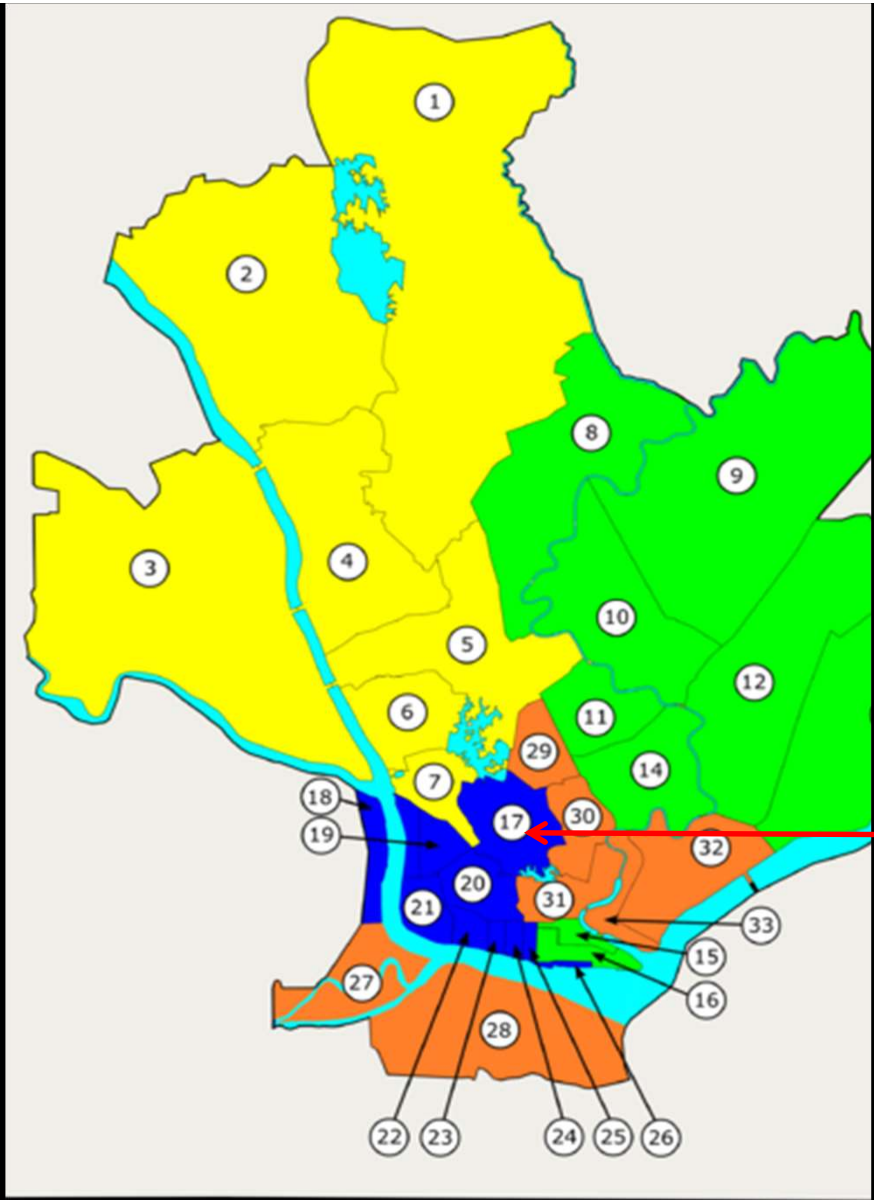
Results for Liquefaction Induced Ground **Settlement** Based on SPT Data & **0.4 g** Value

Depth (m)	N Value	CSR	CRR				CRR/CSR (SF)				Settlement (cm)			
			7.5	7.0	6.5	6.0	7.5	7.0	6.5	6.0	7.5	7.0	6.5	6.0
1	4	0.194	0.194	0.157	0.203	0.264	0.681	0.8099	1.0482	1.3613	3.28	3.28	0.00	0.00
2	4	0.192	0.192	0.147	0.190	0.247	0.643	0.7651	0.9902	1.2860	3.71	3.71	3.71	0.00
3	5	0.191	0.191	0.148	0.191	0.248	0.650	0.7735	1.0010	1.3000	3.67	3.67	0.00	0.00
4	5	0.189	0.189	0.142	0.183	0.238	0.630	0.7500	0.9706	1.2606	4.00	4.00	4.00	0.00
5	6	0.198	0.198	0.148	0.192	0.249	0.630	0.7495	0.9699	1.2596	3.64	3.64	3.64	0.00
6	9	0.214	0.214	0.169	0.219	0.284	0.664	0.7899	1.0222	1.3275	2.93	2.93	0.00	0.00
7	9	0.226	0.226	0.174	0.225	0.292	0.647	0.7699	0.9963	1.2939	2.83	2.83	2.83	0.00
8	13	0.236	0.236	0.206	0.267	0.346	0.734	0.8731	1.1298	1.4673	2.33	2.33	0.00	0.00
9	20	0.244	0.244	0.284	0.367	0.477	0.977	1.1632	1.5053	1.9549	1.84	0.00	0.00	0.00
10	28	0.246	0.246	0.466	0.603	0.784	1.593	1.8951	2.4525	3.1851	0.00	0.00	0.00	0.00
11	28	0.246	0.246	0.488	0.632	0.821	1.668	1.9853	2.5691	3.3366	0.00	0.00	0.00	0.00
12	29	0.245	0.245	0.495	0.641	0.832	1.698	2.0207	2.6150	3.3961	0.00	0.00	0.00	0.00
13	29	0.242	0.242	0.464	0.601	0.780	1.612	1.9182	2.4823	3.2238	0.00	0.00	0.00	0.00
14	17	0.239	0.239	0.224	0.290	0.377	0.789	0.9387	1.2147	1.5776	2.16	2.16	0.00	0.00
15	18	0.235	0.235	0.229	0.297	0.385	0.820	0.9758	1.2628	1.6400	2.12	2.12	0.00	0.00
16	18	0.230	0.23	0.224	0.290	0.377	0.819	0.9744	1.2610	1.6377	2.16	2.16	0.00	0.00
17	35	0.224	0.224	0.578	0.749	0.972	2.170	2.5825	3.3421	4.3403	0.00	0.00	0.00	0.00
18	35	0.218	0.218	0.536	0.693	0.900	2.065	2.4570	3.1797	4.1294	0.00	0.00	0.00	0.00
19	36	0.212	0.212	0.541	0.700	0.909	2.145	2.5522	3.3029	4.2894	0.00	0.00	0.00	0.00
20	50	0.205	0.205	2.731	3.535	4.591	11.196	13.323	17.242	22.392	0.00	0.00	0.00	0.00
	WT = 4.5 m		BH-01					Total Settlement			34.67	32.83	14.17	0.00

Estimation of Liquefaction Analysis Based on SPT

- According to the above formula and SPT blow counts, liquefaction potential is evaluated for all boreholes in selected Townships as shown in the following Tables.

Sr. No	Township	Numbers of Borehole	Estimation Depth (m)
1	Dagon	40	20
2	Bahan	40	20
3	Botahtaung	20	20
4	Pabedan	25	20
5	Kyauktada	20	20
6	Latha	10	20
7	Lammadaw	9	20
8	Minglar Taung Nyunt	10	20
9	Sanchaung	12	20
10	Alone	9	20
11	Yankin	12	20
12	Tarmwe	15	20
13	Pazun Taung	9	20
	Total	229	



Bahan Township

Most Areas are situated on Residual Soil

Results for Liquefaction Induced Ground **Settlement** Based on SPT Data & **0.2 g** Value

Depth (m)	N Value	CSR	CRR				CRR/CSR (SF)				Settlement (cm)			
			7.5	7.0	6.5	6.0	7.5	7.0	6.5	6.0	7.5	7.0	6.5	6.0
1	48	0.129	0.646	0.768	0.994	1.291	5.005	5.956	7.707	10.009	0	0	0	0
2	48	0.128	0.448	0.533	0.690	0.896	3.500	4.166	5.391	7.001	0	0	0	0
3	47	0.127	0.340	0.404	0.523	0.679	2.674	3.182	4.118	5.349	0	0	0	0
4	47	0.126	0.299	0.356	0.460	0.598	2.371	2.822	3.652	4.743	0	0	0	0
5	48	0.138	0.278	0.331	0.428	0.556	2.011	2.393	3.097	4.022	0	0	0	0
6	99	0.147	0.630	0.749	0.970	1.259	4.270	5.081	6.575	8.540	0	0	0	0
7	99	0.155	0.670	0.798	1.032	1.340	4.335	5.159	6.676	8.670	0	0	0	0
8	99	0.160	0.640	0.762	0.986	1.281	3.998	4.758	6.157	7.996	0	0	0	0
9	100	0.165	0.620	0.738	0.955	1.240	3.769	4.485	5.804	7.538	0	0	0	0
10	100	0.165	0.628	0.748	0.968	1.257	3.808	4.531	5.864	7.615	0	0	0	0
11	100	0.164	0.606	0.721	0.933	1.212	3.692	4.394	5.686	7.384	0	0	0	0
12	100	0.162	0.586	0.697	0.902	1.171	3.604	4.289	5.551	7.209	0	0	0	0
13	100	0.160	0.567	0.675	0.873	1.134	3.539	4.211	5.450	7.078	0	0	0	0
14	100	0.157	0.550	0.655	0.847	1.100	3.492	4.156	5.378	6.985	0	0	0	0
15	100	0.154	0.534	0.636	0.823	1.068	3.462	4.119	5.331	6.923	0	0	0	0
16	100	0.151	0.520	0.618	0.800	1.039	3.445	4.100	5.306	6.891	0	0	0	0
17	100	0.147	0.506	0.602	0.779	1.012	3.442	4.096	5.301	6.884	0	0	0	0
18	100	0.143	0.493	0.587	0.760	0.987	3.451	4.106	5.314	6.902	0	0	0	0
19	100	0.139	0.481	0.573	0.741	0.963	3.471	4.131	5.346	6.943	0	0	0	0
20	100	0.134	0.470	0.559	0.724	0.940	3.503	5.956	7.707	10.009	0	0	0	0
	WT = 4.0 m		BH-01					Total Settlement			0	0	0	0

Example Location of Estimating Potential and ground Settlement

Nga Moe Yeik Creek

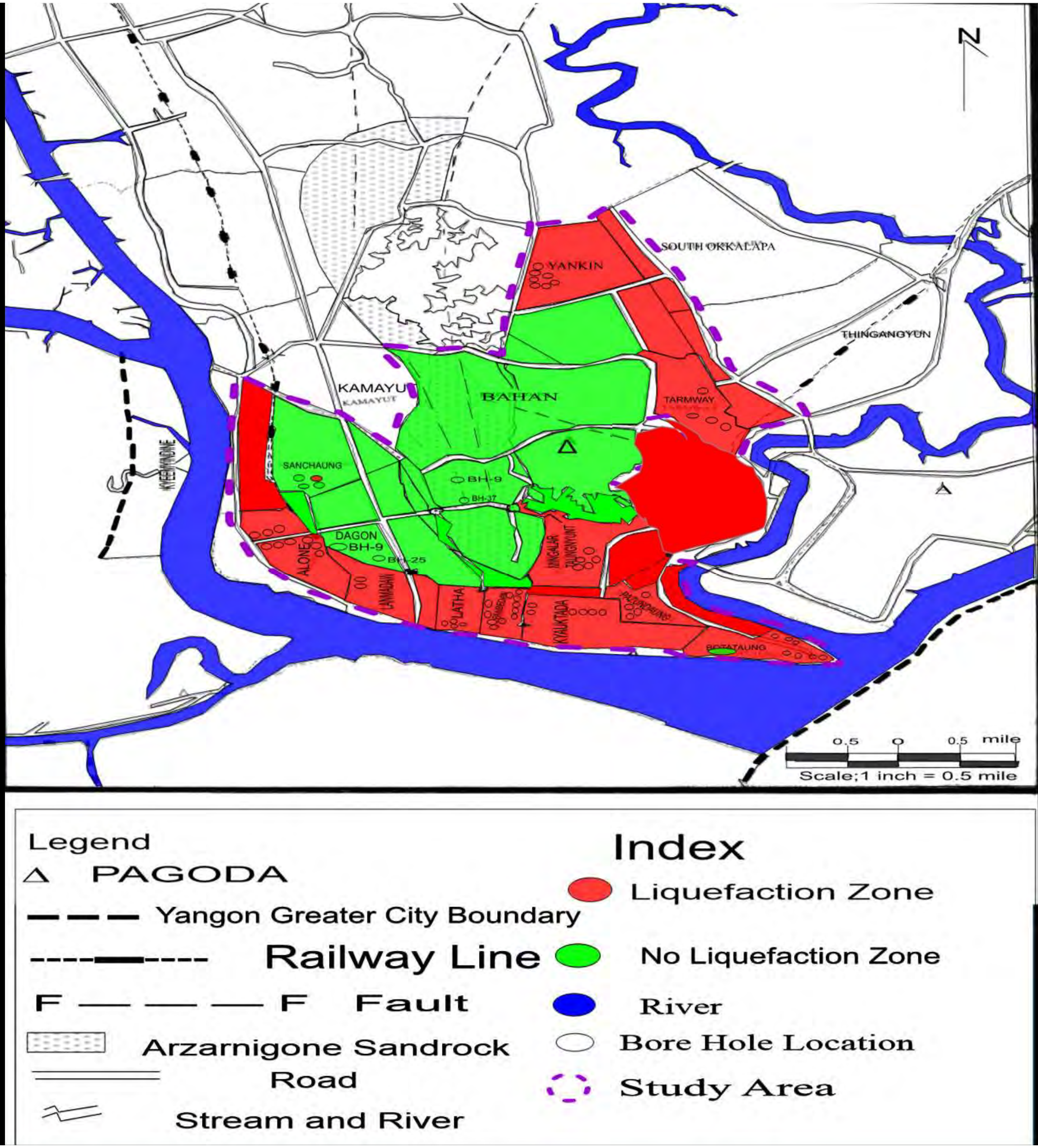
Results for Liquefaction Induced Ground **Settlement** Based on SPT Data & **0.2 g** Value

Depth (m)	N Value	CSR	CRR				CRR/CSR (SF)				Settlement (cm)			
			7.5	7.0	6.5	6.0	7.5	7.0	6.5	6.0	7.5	7.0	6.5	6.0
1	6	0.129	0.158	0.188	0.243	0.315	1.221	1.4531	1.8805	2.4422	0.00	0.00	0.00	0.00
2	2	0.184	0.111	0.132	0.171	0.222	0.603	0.7178	0.9289	1.2063	4.82	4.82	0.00	0.00
3	5	0.211	0.139	0.166	0.214	0.278	0.660	0.7859	1.0170	1.3208	3.03	3.03	0.00	0.00
4	5	0.226	0.137	0.162	0.210	0.273	0.604	0.7191	0.9306	1.2086	3.12	3.12	0.00	0.00
5	1	0.235	0.097	0.116	0.150	0.194	0.413	0.4914	0.6359	0.8259	8.65	8.65	8.65	8.65
6	1	0.242	0.097	0.115	0.149	0.193	0.399	0.4751	0.6148	0.7985	9.04	9.04	9.04	9.04
7	2	0.247	0.105	0.125	0.162	0.210	0.426	0.5064	0.6553	0.8511	5.79	5.79	5.79	5.79
8	2	0.250	0.104	0.124	0.160	0.208	0.417	0.4964	0.6424	0.8342	6.00	6.00	6.00	6.00
9	2	0.251	0.103	0.123	0.159	0.206	0.411	0.4887	0.6324	0.8213	6.19	6.19	6.19	6.19
10	5	0.248	0.126	0.150	0.194	0.252	0.509	0.6055	0.7836	1.0177	3.56	3.56	3.56	0.00
11	5	0.243	0.125	0.148	0.192	0.249	0.512	0.6090	0.7881	1.0235	3.65	3.65	3.65	0.00
12	2	0.239	0.102	0.122	0.157	0.204	0.428	0.5097	0.6596	0.8566	6.47	6.47	6.47	0.00
13	3	0.233	0.108	0.129	0.167	0.217	0.464	0.5522	0.7146	0.9281	5.18	5.18	5.18	0.00
14	4	0.227	0.114	0.136	0.176	0.228	0.502	0.5972	0.7729	1.0038	4.45	4.45	4.45	0.00
15	7	0.222	0.133	0.159	0.206	0.267	0.602	0.7165	0.9272	1.2041	3.24	3.24	3.24	0.00
16	7	0.216	0.132	0.157	0.203	0.264	0.613	0.7294	0.9439	1.2259	3.29	3.29	3.29	0.00
17	8	0.209	0.137	0.164	0.212	0.275	0.657	0.7814	1.0112	1.3133	3.09	3.09	0.00	0.00
18	8	0.203	0.136	0.162	0.210	0.272	0.671	0.7982	1.0329	1.3415	3.13	3.13	0.00	0.00
19	8	0.196	0.135	0.161	0.208	0.270	0.688	0.8182	1.0589	1.3752	3.18	3.18	0.00	0.00
20	9	0.189	0.140	0.167	0.216	0.280	0.740	0.8802	1.1391	1.4794	3.00	3.00	0.00	0.00
	WT = 1.0 m		BH-01					Total Settlement			**88.87**	**88.87**	**65.51**	**35.67**

Results for Liquefaction Induced Ground **Settlement** Based on SPT Data & **0.2 g** Value

Sr. No.	BH No.	Town-ship	Settlement (cm)			
			7.5	7.0	6.5	6.0
1	BH-01	Bahan	0	0	0	0
2	BH-03	Bahan	0	0	0	0
3	BH-24 to 30	Bahan	0	0	0	0
4		Bahan	0	0	0	0
5	BH-01	San-chaung	0	0	0	0
6	BH-02		0	0	0	0
7	BH-03		0	0	0	0
8	BH-04		0	0	0	0
9	BH-01	Bota-htaung	19.11	7.95	0	0
10	BH-02		21.75	14.85	0	0
11	BH-03		15.44	15.44	0	0
12	BH-04		26.69	11.43	0	0
13	BH-01	Pazun-taung	13.65	6.51	0	0
14	BH-02		26.69	11.43	0	0
15	BH-03		14.73	5.87	0	0
16	BH-01	Pabe-dan	37.52	23.55	8.17	0
17	BH-02		27.02	15.92	0	0
18	BH-03		34.93	23.83	4.65	0
19	BH-01	Latha	20.46	11.59	2.14	0
20	BH-02		6.35	2.43	0	0
21	BH-03		6.65	0	0	0

Sr. No.	BH No.	Town-ship	Settlement (cm)			
			7.5	7.0	6.5	6.0
22	BH-01	Lammadaw	3.61	2.0	0	0
23	BH-02		0	0	0	0
24	BH-01	Kyauk-tadar	20.06	2.94	0	0
25	BH-02		2.48	0	0	0
26	BH-03		4.48	4.48	0	0
27	BH-01	Mingalarta ungnyunt	2.03	0	0	0
28	BH-02		0	0	0	0
29	BH-03		9.57	0	0	0
30	BH-01	Ahlone	10.01	0	0	0
31	BH-02		12.4	5.4	0	0
32	BH-01	Tar-mway	3.4	0	0	0
33	BH-02		0	0	0	0
34	BH-01	East Dagon	98.42	89.87	73.51	45.86
35	BH-02		92.69	90.41	60.07	35.10
36	BH-03		97.61	97.61	66.41	27.87
37	BH-01	Dagon Seikkan	88.87	88.87	65.51	35.6
38	BH-02		80.83	75.86	55.67	34.2
39	BH-03		80.51	67.32	50.17	36.5
40	BH-04		91.53	62.91	45.66	0.00
41	BH-01	S-Dagon NMY-Br	30.55	19.04	11.41	0.00
42	BH-04		35.91	32.05	18.30	0.00



Liquefaction Potential Map of the Yangon Areas

CONCLUSION

- Earthquakes and their related hazards such as landslide in hilly terrain and along river bank, liquefaction in alluvial plain and tsunami along costal regions are observed, as Myanmar is vulnerable to hazards from moderate and large magnitude earthquakes.
- Earthquake related landslide hazards occur low potential in the previous quakes. Most events are observed near and along the river bank.
- Earthquake related liquefaction hazards happened with higher magnitude quake in saturated Sandy soil, Silty and Clayey soil with low PI.
- Many of cities in the central part of Myanmar are situated on the alluvial plain, which are highly venerable to liquefaction when large magnitude earthquake happens.
- Costal regions are vulnerable to tsunami hazards and have experienced in 2004 due to the hit of the Indian Ocean tsunami.
- However, the intensity of the tsunami in terms of run-up and the extent of the inundation was comparatively lower than the other countries around the Indian Ocean and the causality and damage was also lesser.

THANK YOU VERY MUCH FOR YOUR KIND ATTENTION

The cyclic resistance ratio is the other term required to calculate the factor of safety against liquefaction. The cyclic resistance ratio represents the maximum CSR at which a given soil can resist liquefaction. It can be calculated by using the following equation (Idriss and Boulanger, 2004):

$$(N_1)_{60cs} = (N_1)_{60} + \Delta (N_1)_{60}$$

$$\Delta(N_1)_{60} = \exp\left(1.63 + \frac{9.7}{FC + 0.01} - \left(\frac{15.7}{FC + 0.01}\right)^2\right)$$

$$CRR_{M=7.5} = exp\left(\frac{(N_1)_{60cs}}{14.1}) + \left(\frac{(N_1)_{60cs}}{126}\right)^2 - \left(\frac{(N_1)_{60cs}}{23.6}\right)^3 + \left(\frac{(N_1)_{60cs}}{25.4}\right)^4 - 2.8\right)$$

for $(N_1)_{60}$>37.5

The equation for CRR, corrected for overburden pressure and magnitude, is

$$CRR = CRR_{M7.5} MSF$$

Where

For M_w<7.0 ; $\rightarrow$ $\boxed{MSF = 10^{3.00} \times M_w^{-3.46}}$

For $M_w \geq 7.0$; $\rightarrow$ $\boxed{MSF = 10^{2.24} \times M_w^{-2.56}}$

Estimation of Cyclic Resistance Ratio (CRR)

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