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SPT Based Liquefaction Potentiality Index, Susceptibility & Risk Assessment in the Rohingya Refugee Camp Hills of Ukhiya, Cox's Bazar, Bangladesh

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ABSTRACT

More than one million Rohingya refugees who fled from Myanmar, had constructed temporary shelters on the loose unconsolidated sandy hills (SC-SM, SP & ML) of Ukhiya-Teknaf region, Cox's Bazar area, Bangladesh. After entering Bangladesh, the green eco forests of Ukhiya Hills had to be destroyed by cutting trees and hill slopes as they built their shelters which eventually had destructive effects on the ecosystem of Ukhiya Teknaf region. Sands (SP-SM) are mainly uniformly graded and composed of more than 72% to 98 % sand. This research has been carried out to assess the liquefaction potentiality index values, susceptibility using SPT and risks associated with the Ukhiya hills at different earthquake magnitudes. During earthquake at Magnitudes 5 or greater, Ukhiya hill soils are susceptible to liquefy up to a depth of 12 m. From the Liquefaction Potentiality Index (LPI) values, risk and sensitivity analysis, it is established that the Ukhiya hills are medium to highly susceptible to liquefy at higher magnitudes (M= 5 or greater). It is also established that north western part of the camp hills are high to very high risk prone areas. Based on Liquefaction Potentiality Index (LPI) values, four seismic risk zones are identified in and around the Rohingya camp area. Some geo-engineering recommendations are also made to reduce this seismic hazard for sustainable community living in the camp area.

INTRODUCTION

Liquefaction can occur in moderate to major earthquakes resulting in severe damage to engineering structures. Structural damage due to liquefaction can be reduced by taking proper geo-engineering measures during any construction including shelters. Rohingyas constructed temporary shelters in the loose unconsolidated granular sandy soils of Ukhiya hills. This research has been carried out to see the risk associated with the Rohingya shelters at Ukhiya hills based on LPI values. Hazard zones in the camp area have also been identified based on liquefaction potentiality index & susceptibility analyses. Some structural damage mainly building collapse (Figure 1). Due to differential settlement near to Rohingya camp area clearly justify the importance of carrying out this research.

Variours researchers including Seed and Idriss,1971; Seed, 1979; Ishihara ,1985; Seed and Idriss, 1967, 1982;Seed et al.; 1985; Youd and Idriss, 1997; Youd et al., 2001;



Figure 1: Building damage near to Himchari

Youd; 2003; Cetin et al., 2000 and Idriss and Boulanger, 2006; Iwashaki, 1986, Ishihara, 1985 & Mahabub, et al.; 2020 have been carried out research on the liquefaction potentiality assessment of soils based on empirical methods in different parts of the world.

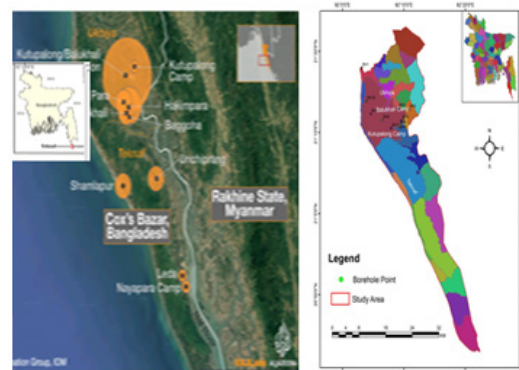


Figure 2: Location Map of the investigated area.

Bangladesh is a south Asian country. The investigated Ukhiya Rohingya camp area (Figure 2) is located in the south eastern folded part of Bangladesh. Bangladesh is seismically active and has experienced number of great earthquake events of magnitude exceeding 8 (eight) during 1897, 1905, 1934, 1950 and another 10 earthquakes exceeding magnitude 7.5 have occurred in the Himalayan belt during the last 100 years. The earthquake history of Bangladesh and surrounding region including Rohingya camp area of Ukhiya indicates that the country is seismically active. Based on more than one hundred years earthquake data of USGS (from 1900 to 2015), a seismic activity map of Bangladesh (Banglapedia, 2021) and surrounding area is shown in Figure 3.

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Earthquake induced soil liquefaction is a serious geotechnical problem and seismic hazard for sustainable infrastructure & community development in any area. Liquefaction mainly occurs in saturated granular soils with shallow ground water table condition and in recent years, liquefaction is considered as an important parameter for sustainable urban land use planning & development. Liquefaction of loose, saturated, cohesion less soils can produce several different types of ground failure depending on site conditions. These failure mechanisms include lateral spreading, loss of bearing capacity and

settlement, ground oscillations, and flow failure (Youd, 2003). Any of these mechanisms can potentially cause damage to engineering structures due to the ground and foundation movements that occur.

The Bangladesh National Building Code 2015 (BNBC) identifies 4 zones having different intensities of earthquakes (Figure 4). The investigated area belong completely to zone 3. According to BNBC (2015), the map shows the horizontal ground surface acceleration $a_{max} = 0.28g$. The seismic zoning map of Bangladesh (BNBC, 2015) is shown in Figure 4.

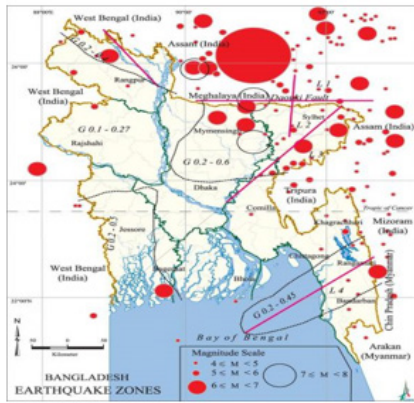


Figure 3: Seismic activity in Bangladesh
Source: BNBC (2015)



Figure 4: Seismic Zoning Map of Bangladesh
Source: Banglapedia (2021)

Geology & Seismo-Tectonics

Hossain et al. 2023 discussed the geology of the investigated area. The Rohingya refugee camps are located in the south eastern folded part of Bangladesh. These hills are mainly composed of loose to very loose yellowish brown sand, medium to coarse grained soils. Some subordinate clay soils are also associated with sands (SP, SM, SC & ML). Some parts of the camp hills are composed of loose ferruginous sands, greenish and brownish grey in color.

Some pebbles, cobbles, conglomeratic and shale parting are also present with sandy soils. Sandstone & siltstone with alteration of sands, silts and shales are also present. They are of Mio-Pliocene age. Twelve (12) boreholes (Figure 1) were drilled in the investigated area to evaluate the liquefaction potentiality and risk assessment. A generalized stratigraphic succession of the hills of Chittagong & Chittagong Hill Tracts is shown in Table 1.

Table 1: Geology of the investigated area

Group	Formation	Lithology	Age
	Alluvium	Clay, silt and dark colored sand.	Holocene
	Dupi Tills	Sandstone, yellowish brown, medium grained and massive with subordinate clay.	Mio-Pliocene
Tipam	Girujan Clay	Unconsolidated sandstone with molted clay, clay stone, siltstone.	Miocene
	Tipam	Thick coarse grain, ferruginous sandstone, greenish and brownish gray in color. Some conglomeratic and shale parting occur fossil wood and lignite.	Miocene
Surma	Boka Bil	Sandstone and siltstone with alternation of sand, silt and shale	Miocene
	Bhuban	shale, sandy shale, hard shaly sandstone, hard sandstone lenticular sandstone, conglomerate. (After, Evans, 1932)	Miocene

Concerning tectonics and seismicity, Bangladesh is located in one of the most active tectonic region of the world where three plates - The Indian plate, the Tibet and the Burmese Sub plates are colliding and thrusting against each other. Consequently, tremendous seismic activities have been resulted in the north and east of Bangladesh

and caused some major earthquakes within and outside the country (Hossain et al., 2022). The investigated area has already experienced many severe earthquakes. The epicentres of the most severe earthquakes are situated in the area of the Himalayan Mountains & Arkan Yoma folded hilly regions (near to the investigated area).

Earthquakes with epicentres within Bangladesh may also occur, but with lesser intensity. Hossain et al. (2022) also noted that earthquake epicenter in Assam in India is not far from Bangladesh, it is suggested to provide sufficient margin of safety, in designing the infrastructure in and around Ukhiya Hills.

METHODOLOGY

Both the field and laboratory geotechnical investigations were carried out to evaluate the liquefaction potentiality index, susceptibility and risk assessment in the Rohingya refugee camp area. At first a detailed site investigation was carried out in accordance with B .S.5930 (19990). and drilled twelve (12) boreholes in the camp area. During drilling each borehole, lithology was recorded with increasing depth up to a depth of 30 m. The SPT (Standard Penetration Test) tests with split spoon sampler were carried out in each borehole with a depth interval of 1.5 m. and the “N” value for each soil layer was recorded. The corrected SPT values were then used to calculate the Liquefaction Potentiality Index & factor of safety values. Based on Seed & Idriss (1971) , MIL-HDBK-1007/3, (1997), NCEER (1997) & Seed and Idriss (1982), liquefaction potentiality of soils were evaluated using Liquify Pro, version 5 (2011) software. The CSR (Cyclic Resistance Ratio), CRR (Cyclic Resistance Ratio) & Factor of safety values of each lithological unit at different depths and at different earthquake magnitudes (M = 4,5 , 6, & 7) were analyzed. The Rohingya refugee camps and the surrounding area of the project belong completely to zone 3.. According to BNBC (2015), the investigated area shows the horizontal ground surface acceleration $a_{max} = 0.28g$. This peak acceleration at ground surface (a_{max} .) value 0.28 at different earthquake magnitudes of the investigated area was considered

during liquefaction potentiality analysis. Finally, based on obtained results, Liquefaction Potentiality Index (LPI) values at different locations and depths were calculated (Table 3) in accordance with Iwasaki et al. (1982). The results were then compared and analyzed to identify risks.

RESULTS

Basic Geotechnical Properties

Hossain et al. (2022) discussed the grain size results as shown in Figure 5. From the grain size analysis results it is established that these soils are sand dominated soils (more than 82% to 98% sand), uniformly graded and fall within range of 0.01 to 1 mm. The cohesion of these soils is almost zero with an angle of internal friction (ϕ°) value range from 23 to 27 degrees.SPT versus Depth curves Based on SPT values three (3) zones are identified viz. Very low, Medium and High as shown in Figures 6. Low SPT zones might be more susceptible to liquefaction in comparison to high SPT zones. That’s why an attempt has been taken to evaluate the risk zones using Liquefy Pro software (2011) to see the impacts of liquefaction potentiality at different earthquake magnitudes.

All the boreholes data were used to investigate the liquefaction potentiality at different earthquake magnitudes (M = 4, 5, 6, & 7). Highest amount of ground response due to liquefaction was observed at M =7. Liquefaction potentiality analyses results of some boreholes at magnitude (M = 7) with the calculated shear stress ratio curves, settlement amount and corresponding factor of safety (Fs) values at different depths are shown in Figures 7.A maximum settlement amount of 11.89 cm, was observed for Borehole 7 at earthquake magnitude (M) 7 during analysis. At lower magnitudes, settlement amounts were low for all-other boreholes. It is established that settlement amount for other boreholes are lower in

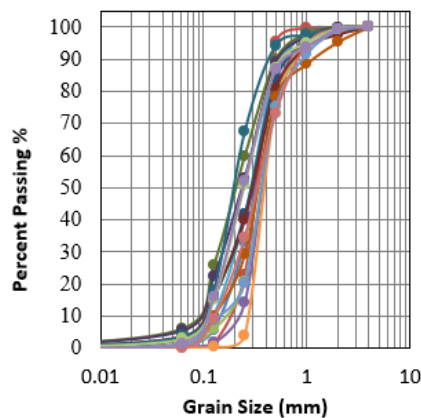


Figure 5: Grain size results

comparison with borehole 7 for the same magnitude (M = 7).The obtained liquefaction potentiality analyses results for borehole 7 at earthquake magnitude (M) 7 are listed in Table 2. The obtained CSR values for Borehole 7 range from 0.18 to 0,28, CRR values range from 0.17 to 2.00. Lower CSR values for all other boreholes at shallow depths (up to 4 m.) also indicate that these soils are susceptible

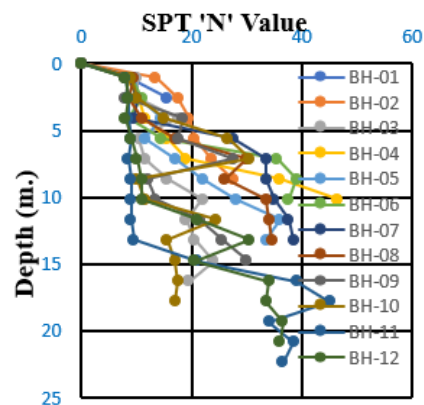


Figure 6: SPT versus depth curves

to liquefy. A significant drop of factor of safety value less than one ($F_s < 1$) was observed up to a depth of 4.5 m. for Borehole 7 (North west of Balukhali camp) at magnitude (M) 7 and at greater depths higher factor of safety values were observed. .It is also established that liquefaction occurred with lower CSR values at shallow depths. The variation of factor of safety (Fs) with depths

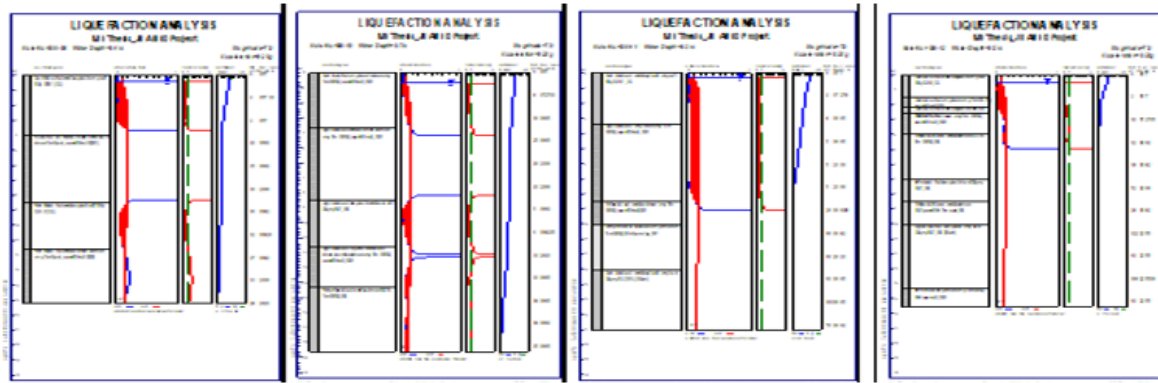


Figure 7: Liquefaction analyses results at magnitude (M) 7 for boreholes 9,10,11 & 12

Table 2: Summary of the liquefaction parameters for Borehole 7 at earthquake magnitude (M) 7

Depth(m.)	CSR	CRR	Fs	Settlement (cm.)
0.5	0.18	0.06	0.33	11.896
1.5	0.28	0.08	0.28	7.692
3.0	0.34	0.17	0.50	3.991
4.5	0.35	0.14	0.41	0.843
6.0	0.35	1.75	5.00	0.000
7.5	0.33	2.00	6.00	0.000
10	0.31	2.00	6.00	0.000
15	0.27	2.00	7.00	0.000
20	0.28	2.00	7.00	0.000

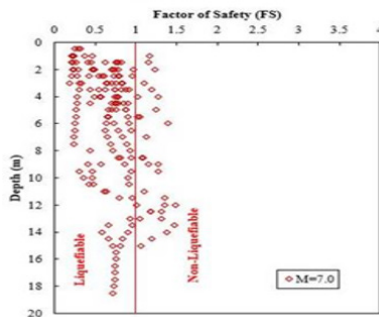


Figure 8: Variation of factor of safety with depths for all boreholes at M=7

for all other boreholes at magnitude (M) 7 is shown in Figure 8. It is clearly established that factor of safety (Fs) at earthquake magnitude (M) 7, most of the soils of the

camp area are liquefiable ($F_s < 1$) from near surface to up to a greater depths. Therefore, at higher earthquake magnitudes (>5) prominent potential zones can be identified up to 12 m. depth. A smaller number of soil samples at all depths even at lower magnitudes showed factor of safety value ($F_s > 1$). These are non-liquefiable soils. On the other hand, no potential liquefiable zones are identified at lower earthquake magnitudes (M) up to 4.

Liquefaction Potentiality Index (LPI)

In this research an attempt has also been taken to calculate the liquefy potentiality index (LPI) values at different earthquake magnitudes (M) 5 to 8, during wet season to identify degree of risk in the investigated area in accordance with Iwasaki (1982).The obtained LPI values of all borehole samples are listed in Table 3.

Table 3: Summary of determined LPI vales to identify risk

Boreholes Information		Ground Elevation (m)	Total Drilling Depth (m)	Wet Season G.W.L.(m.)	Earthquake Magnitudes (M) at $a_{max}=0.28$	Liquefaction Potential Index (LPI)	Severity and Potential Risk
Boreholes No	Coordinates Easting Northing						
BH-01	401693.03 2355583.88	14.02	10.67	1.00	5.00 6.00 7.00 8.00	0.00 0.00 5.75 11.02	Very Low or None Very Low or None Medium Medium

						5.00	0.00	Very Low or None
BH-02	412769.33	2346093.54	14.93	10.67	0.80	6.00	0.00	Very Low or None
						7.00	0.00	Very Low or None
						8.00	4.55	Low
						5.00	0.00	Very Low or None
BH-03	411930.21	2346332.35	22.55	15.24	1.21	6.00	0.00	Very Low or None
						7.00	15.26	Very High
						8.00	30.15	Very High
						5.00	0.00	Very Low or None
BH-04	412824.50	2343618.95	16.76	10.67	1.00	6.00	0.00	Very Low or None
						7.00	5.85	Medium
						8.00	15.59	Very High
						5.00	0.00	Very Low or None
BH-05	412247.42	2341979.42	14.63	15.24	1.00	6.00	0.11	Low
						7.00	12.27	Medium
						8.00	25.45	Very High
						5.00	0.00	Very Low or None
BH-06	412110.94	2342395.77	15.54	15.24	1.10	6.00	0.00	Very Low or None
						7.00	9.62	Medium
						8.00	21.87	Very High
						5.00	1.01	Low
BH-07	409881.82	2341785.87	24.38	14.02	1.00	6.00	18.16	Very High
						7.00	27.91	Very High
						8.00	33.81	Very High
						5.00	16.04	Very High
BH-09	404198.26	2345113.30	47.54	15.00	0.40	6.00	28.10	Very High
						7.00	35.53	Very High
						8.00	40.16	Very High
						5.00	2.14	Low
BH-10	402968.10	2348025.48	30.78	18.59	0.70	6.00	16.21	Very High
						7.00	29.56	Very High
						8.00	40.16	Very High
						5.00	29.12	Very High
BH-11	404265.88	2350603.47	24.68	17.06	0.30	6.00	43.30	Very High
						7.00	51.06	Very High
						8.00	55.76	Very High
						5.00	8.20	Medium
BH-12	402962.48	2353090.17	26.82	15.54	0.30	6.00	13.33	Medium
						7.00	18.86	Very High
						8.00	23.52	Very High

Based on overall estimation of LPI values, 5 (five) liquefaction potential risk zones are identified viz. Very low (LPI =0), Low (LPI = 0 to 5), Medium. (LPI = 5 to 14), High (LPI = 14 to 25), & Very High (LPI = 25 to 55). This will eventually help urban planners, engineers & policy makers to take geo-engineering measures for sustainable community living to reduce number of

casualties & damage and to attain sustainability in the camp area. From the obtained LPI values at higher earthquake magnitudes, it is established that the north western part of Balukhali & Kutubpalong Rohingya camp area is very highly potential to liquefy in comparison with other parts. On the other hand, Balukhali camp area is a medium risk prone area and Kutubpalong camp is a very low to low

risk prone area at higher earthquake magnitudes.

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CONCLUSION

It is established from the grain size analysis results these soils are mainly sand dominated (SC-SM, SP & ML (which contains more than 82% to 98% sand,, uniformly graded and fall within range of 0.01 to 1 mm., which clearly indicate that that these soils are highly potential to liquefy at higher earthquake magnitudes. The cohesion of these soils is almost zero with an angle of internal friction (φ°) value range from 23 to 27 degrees.

Based on SPT data, it is also established that SPT values are low to very low up to 4 m. at different locations and soils are very loose to loose in nature, The obtained SPT values from a depth of 4m. to 10 m. indicating medium dense soils and at higher depths SPT values are very high indicating dense soils. A wide variation of SPT values with respect to depth at different locations were also observed. Lower CSR values for all boreholes at shallow depths (up to 4 m.) indicates that these soils are susceptible to liquefy at higher earthquake magnitudes. At higher depths CSR values are high with a factor of safety value greater than 1. A significant drop of factor of safety value less than one ($F_s < 1$) was observed up to a depth of 4.5 m. for Borehole 7 at magnitude (M) 7 and at greater depths higher factor of safety values were observed. It is also established that liquefaction occurred at magnitude (M) 7 with lower CSR values. No potential liquefiable zones are identified at lower earthquake magnitudes (M) up to 4. At greater earthquake magnitudes (M) 7, soils are liquefiable even up to greater depths. At higher magnitudes, a smaller number of soil samples for all boreholes at all depths showed factor of safety value (F_s) > 1. These are non-liquefiable soils. From the overall Liquefaction Potentiality Index (LPI) results, 5 (five) potential liquefaction risk zones are identified viz. Very low (LPI =0), Low (LPI = 0 to 5), Medium. (LPI = 5 to 15), High (LPI = 15 to 25), & Very High (LPI = 26 to 55). It is established that the north western part of Balukhali & Kutubpalong Rohingya camp area is very highly potential to liquefy and high risk prone area in comparison with other parts. On the other hand, Balukhali camp area is a medium risk prone area and Kutubpalong camp area is

a very low to low risk prone area at higher earthquake magnitudes. This will help planners, engineers & policy makers to construct infrastructures safely for community living in the camp area, to reduce number of casualties & damage and to attain sustainability in the camp area.

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