Assessment of Liquefaction Potential of Barhadashi Municipality, Jhapa District, Nepal

[1]Biswas Uprety

[1]Master's Scholar,
[1]Department of Civil Engineering,
[1] Lovely Professional University, Phagwara, Punjab, India.

Abstract : This paper evaluates the liquefaction potential of Barhadashi which is a small rural municipality of Jhapa district, Nepal. Mogami and Kubo (1953) first coined the term liquefaction. This paper follows R.W. Boulanger & I.M. Idriss (2014) which is SPT and CPT based procedures. Liquefaction occurs in saturated soils or partially saturated soils during earthquake or when it is subjected to stresses such as ground motion like underground mining, transportation, nuclear detonation, heavy machine vibration and so on. Major factors that affect the liquefaction are unit weight of soil, penetration test values, depth of water table, percentage of fines content and peak ground acceleration. Some of these factors have influence on each other and change in one factor brings the change in other factors too. Considering the sparsely populated and small area of Barhadashi three boreholes were drilled to obtain the SPT-N value and soil sample for laboratory testing. This paper analyses liquefaction for earthquake of magnitude 8.0 and compares CRR8.0 with CRR6.0. Liquefaction susceptibility and potential were determined at all three sites and it was found all three sites were susceptible to liquefaction up to depth 6.0m for earthquake of magnitude of 8.0.

***IndexTerms* - Liquefaction, Standard Penetration Test, Cyclic Stress Ratio, Cyclic Resistance Ratio, Peak ground acceleration.**

I. INTRODUCTION

Nepal lies in one of the most seismically active regions in the world. Nepal has witnessed many major earthquakes in its history and the most recent in 2015 with its epicenter being in Gorkha. Nepal has since then brought various practices to prevent and mitigate in the occurrence of such disaster. One such practice is liquefaction analysis and though it was in practice earlier, it has become mandatory in Nepal for small to large civil engineering projects since 2015 earthquake.

When the stress such as earthquake or any ground motion is applied to the saturated or partially saturated soil, it loses its strength and stiffness and behave as a liquid. This phenomenon is called liquefaction. Two types of liquefaction exist (Kramer, 1996) which are flow liquefaction and cyclic mobility cited from "Generation of a Geological database for the Liquefaction hazard assessment in Kathmandu Valley" by B. K. Piya, 2004. When the shear strength of the soil in its liquified state is less than the shear stress required for maintaining static equilibrium, flow liquefaction occurs. This type of liquefaction originates in a short time and covers a massive distance and the often move over which the materials are liquefied. When the shear strength of the liquified soil is greater than the shear stress required for maintaining static equilibrium cyclic mobility type of liquefaction occurs. This type of liquefaction causes permanent deformation during the time of earthquake shaking and mostly occurs in slightly sloping grounds or on grounds which are virtually flat and near the water bodies. Among the two types, cyclic mobility occurs more frequently but the effects of flow liquefaction are more severe. There are many methods available for liquefaction analysis and the most widely used approach consists of comparing the cyclic resistance ratio and cyclic stress ratio of the soil (CRR and CSR). Ground water table, pore pressure, soil deposits, fine contents, depth of soil layer, magnitude of the earthquake, duration and intensity of the ground motion and many other factors affect the soil liquefaction. Seed et al. (1984), Japanese Bridge Code (1990), NCEER (1997), Liao et al. (1998) probabilistic approach, Youd and Noble (2001) probabilistic approach, Boulanger and Idriss (2004), Cetin et al. (2004) deterministic approach are used for liquefaction analysis. These methods are used to determine whether the layer of the soil is liquefiable or not. After we know that layer is liquefiable, we need to know its severity and for that have Liquefaction Potential Index (LPI). LPI uses depth of the layer, thickness of the layer, factor of safety of the soil layers against liquefaction (FS) and it gives the prediction of severity at the earth level due to liquefaction. Iwasaki et al. (1982), Luna et al. (1998) and MERM (2003) are used for predicting liquefaction potential.

This paper performs liquefaction analysis on Barhadhasi, Jhapa district which lies in the Eastern terai region of Indo-Gagnetic plain zone of Nepal. Various investigations and research in Jhapa district have shown that the area is distributed from low to high earthquake prone area. The purpose of this paper is to add more insight about the liquefaction and create more awareness in that area. This paper primarily follows the work of Boulanger and Idriss (2014), "CPT AND SPT BASED LIQUEFACTION TRIGGERING PROCEDURES" and Iwasaki et.al (1982).

II. STUDY AREA AND GEOLOGY

Three boreholes were drilled at Barhadashi area of Jhapa district for soil investigation. Barhadashi is one of the 15 administrative divisions of Jhapa district which is further divided into seven wards. The major soil deposit at all the three borehole sites was Sandy SILT. The percentage of clay and gravels were very low to even zero at all three sites. Nepal can be divided into the following five major tectonic zones from south to north, each zone characterized by their own tectonics, structures, lithology and history.

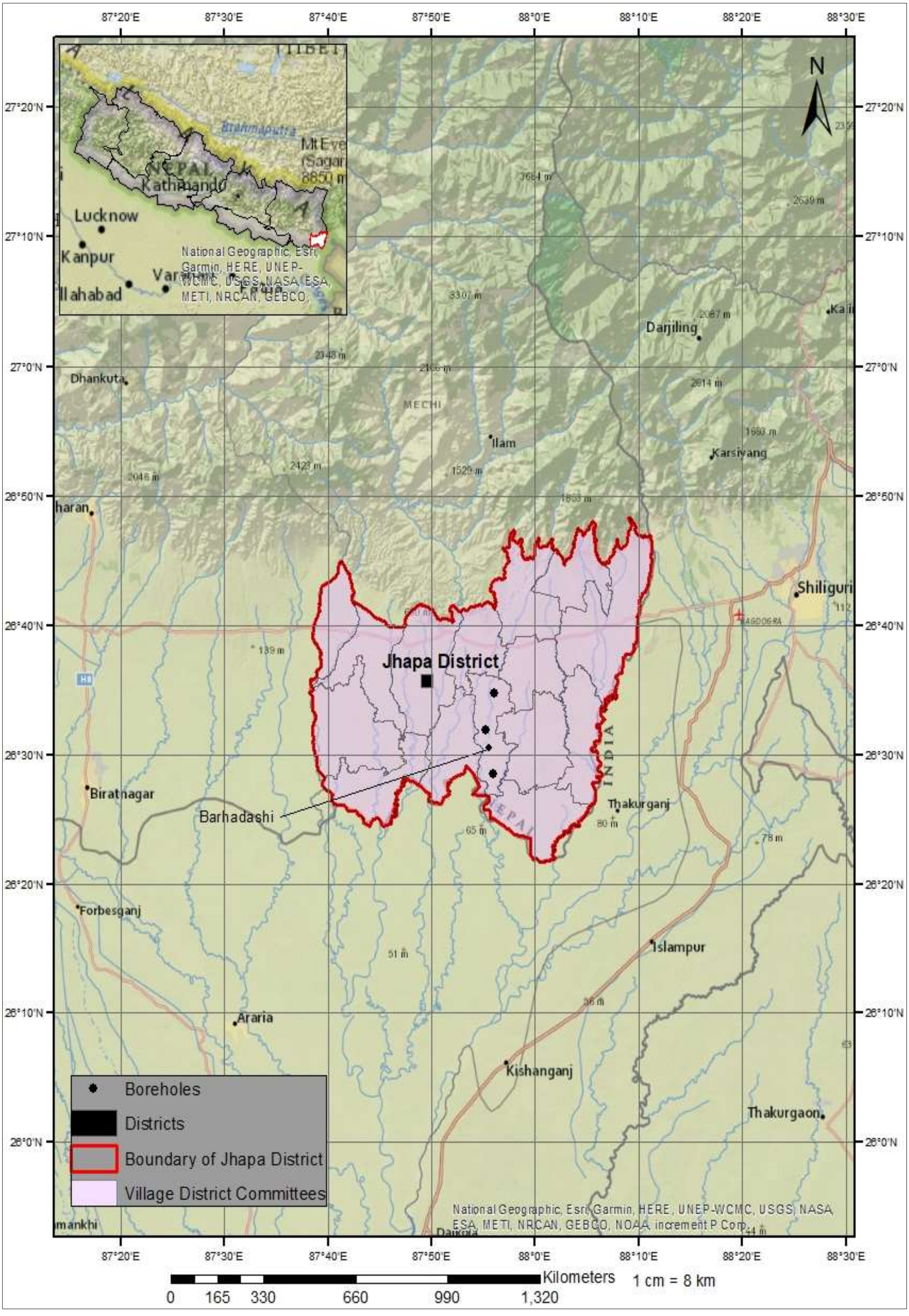

Fig. 1: Map of the site

The five zones can be seen in the geological map of Nepal (Figure 2).

1. Terai zone
2. Churia zone/Siwaliks (Sub Himalaya)
3. Midland and Mahabharat zone (Lesser Himalaya)
4. Higher Himalayan zone
5. Tethys zone

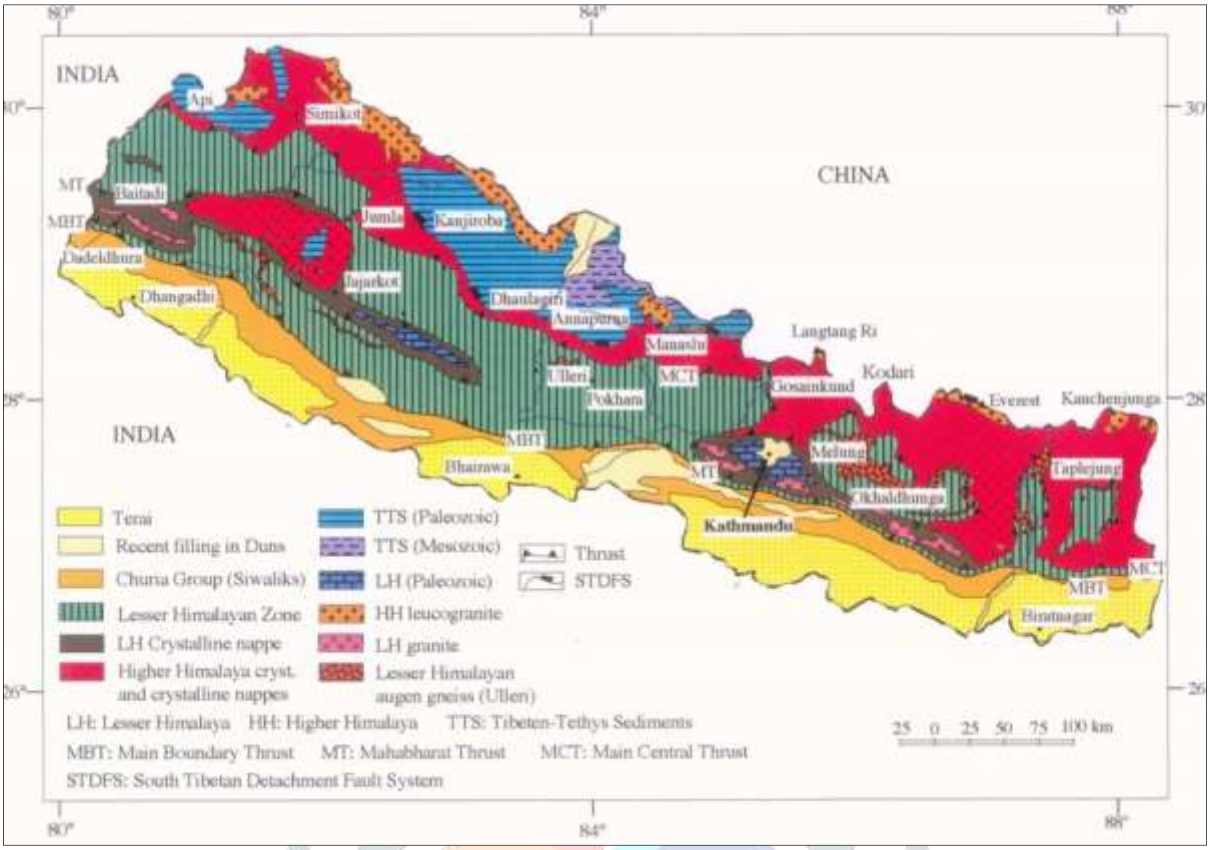

Fig. 2: Geological Map of Nepal

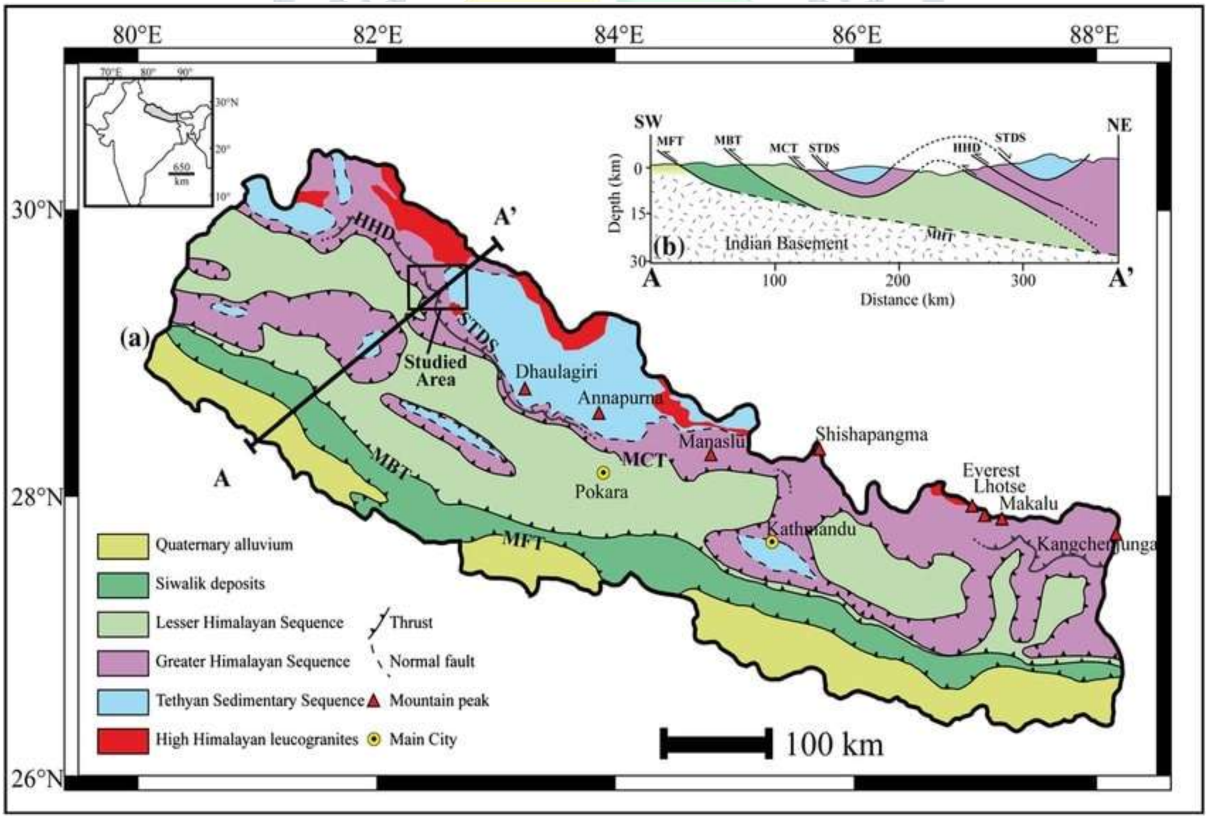

Fig. 3: Schematic Geological Map of Nepal

According to the Engineering and Environmental Geological Map of Nepal, the site lies in Indo-Gangnetic plain zone which consist of quaternary alluvium from Pleistocene age. Quaternary alluvium consists of silt, sand and gravels and on drilling the main deposit was found to be Sandy SILT.

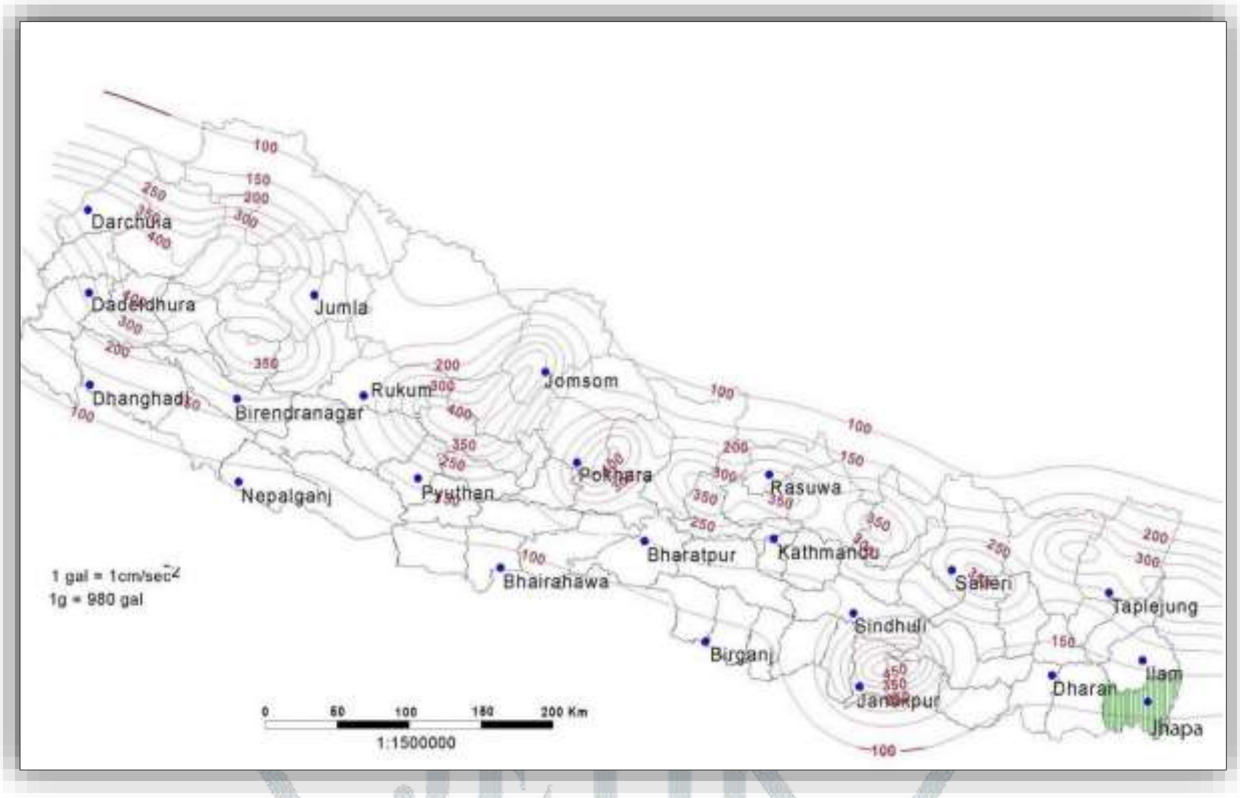

Fig. 4: Seismic Hazard Map of Nepal (Collected from website of National Seismological Centre, Nepal)

PGA (Peak Ground Acceleration) is the maximum acceleration or amplitude recorded during an earthquake on an accelerogram. More the obstacles on the ground, lower will be the PGA and less obstacles on the ground might result in higher value of PGA. Obstacles can be snow, trees, vegetation, rock formations, etc. PGA can be measured in g which is acceleration due to Earth's gravity in cm/s2 or in gal where 1gal is equal to 1 cm/s2. The PGA at the site was determined from the Seismic hazard map of Nepal which is given in Figure 2. As specific amount value of PGA is not indicated on the map, for safety purpose the value of PGA at the site is taken as 150gal which is 150cm/s2.

III. METHODOLOGY

Site investigation was performed following IS 1982-1979 "Code of Practice for Subsurface Investigation for foundation". Rotary drilling was used for drilling the boreholes. The depth of two boreholes was 16.5m and the third borehole was drilled up to the depth of 13.5m. Standard Penetration Test (SPT) was performed at every interval of 1.5m at all three sites to determine the SPT-N value and to collect the information on subsurface soil layer. The test was conducted according to IS 2131-1981 "Method for standard penetration test for soils" where a hammer of 63.5kg is dropped from a height of 760mm. 11 SPTs were conducted at two boreholes and 9 SPTs at last borehole. Water table was not encountered at any borehole sites even after observing the ground water for 72 hours after drilling. But for the safety purpose, liquefaction analysis is performed considering the water table at 0 meter. This is because of the low elevation of the site.

This paper follows Boulanger & Idriss (2014) for liquefaction analysis and the different factors affecting this analysis are ground water table, pore pressure, soil deposits, fine contents, depth of soil layer, SPT-N value, magnitude of the earthquake, PGA of the area. SPT-N value, ground water table, general description of the soil deposit, depth of the soil layer was recorded in borehole log at the site. After soil testing and further investigation, the borehole log was modified with some few updates like more classified soil descriptions, soil layer's depth and so on. The soil classification was done following IS 1498-1970 "Classification and Identification of Soil for General Purposes". With the help of this code the soil was classified as silt, sand, gravel and clay because fines content and sand content are important parameters while determining liquefaction susceptibility.

3.1.1 SPT-N value correction

Idriss and Boulanger (2014) method of liquefaction analysis is based on the penetration value (CPT or SPT). But SPT-N value is influenced by various factors and using this field N value directly in analysis might give false results. To avoid this, field N value is corrected for various factors as:

$$(N)_{60} = N * C_B * C_R * C_S * \frac{E}{60}$$

N = Field SPT-N value
CB = Borehole diameter correction
CR = Rod length correction
CS = Sampler correction
E = Energy correction factor

Table 3.1: SPT corrections from Modified from Skempton (1986): Robertson and Wride (1998)

Factors	**Variable**	**Correction**
Energy Ratio	Automatic or Trip Hammer	0.8 to 1.5
	Pulley and Rope Safety Hammer	0.7 to 1.2
	Donut Hammer	0.5 to 1.0
Rod Length	>30 m	<1
	10 to 30 m	1.00
	6 to 10 m	0.95
	4 to 6 m	0.85
	3 to 4 m	0.75
Sampler	Without liner	1.1 to 1.3
	With liner (for dense sand, clay)	1.00
	With liner (for loose sand)	1.00
Borehole Diameter	6 to 12 cm	1.00
	15 cm	1.05
	200 cm	1.15

3.1.2 Overburden Correction Factor (C_N)

The corrected N-value, (N)60 is then corrected for overburden. Idriss and Boulanger recommended the correction for SPT N value as:

$$C_N = \left(\frac{P_a}{\sigma_v'}\right)^m \leq 1.7$$

$$m = 0.784 - 0.0768\sqrt{(N)_{60}}$$

where σ_v' is the overburden pressure at a particular depth.

The determined C_N is then multiplied with $(N)_{60}$ to calculate $(N_1)_{60}$.

$$(N_1)_{60} = (N)_{60} * C_N$$

3.2 Liquefaction Susceptibility analysis

Liquefaction susceptibility analysis according to Boulanger and Idriss (2014) consist of calculating cyclic stress ratio (CSR) and cyclic resistance ratio (CRR) for earthquake of particular magnitude. The ratio of CRR and CSR is factor of safety of soil layer against liquefaction (FS). If the CSR (Cyclic Stress Ratio) induced by the earthquake of particular magnitude is larger than the CRR (Cyclic Resistance Ratio) of the soil at the site, liquefaction at the site is likely to occur.

3.2.1 Determination of Cyclic Stress Ratio (CSR)

Cyclic Stress Ratio are the stresses in the soil induced during the earthquake and it is calculated using the maximum horizontal acceleration which is a direct function of the magnitude of the earthquake. CSR is calculated as:

$$CSR = 0.65 * \left(\frac{a_{max}}{g}\right) * \left(\frac{\sigma_0}{\sigma_0{}'}\right) * r_d \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (i)$$

a max = maximum horizontal ground acceleration (cm/s2)
g = acceleration due to gravity (cm/s2)
σ0 = Total soil stress depth ‘z’ from the ground surface
σ0’= Overburden pressure at depth ‘z’ from the ground surface level and
rd = Factor for Stress reduction

To calculate the equivalent uniform stress cycles which is required to generate same amount of water pressure during earthquake, a weighing factor of 0.65 is used.

3.2.2 Calculation of Stress reduction factor (r_d)

Idriss (1999) after performing several hundreds of parametric sites analysis came up with the expression for the stress reduction factor:

$$rd = \exp[(\alpha)z + (\beta)z * M] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (ii) \text{ where}$$

$$(\alpha)z = -1.012 - 1.126\sin\left(\frac{z}{11.73}\right) + 5.133$$

$$(\beta)z = 0.106 + 0.118\sin\left(\frac{z}{11.28}\right) + 5.142$$

M is the magnitude of the earthquake. In this paper, three values of magnitude of earthquake are taken: 6.0, 7.5 and 8.0.

3.2.3 Calculation of Cyclic Resistance Ratio (CRR)

Cyclic Resistance Ratio is the resistance offered by the in-situ soil during the earthquake of particular magnitude. CRR is calculated as:

$$CRR = \exp\left(\frac{(N_1)_{60cs}}{14.1} + \left(\frac{(N_1)_{60cs}}{126}\right)^2 - \left(\frac{(N_1)_{60cs}}{23.6}\right)^3 + \left(\frac{(N_1)_{60cs}}{25.4}\right)^4 - 2.8\right) \dots\dots\dots\dots\dots.(iii)$$

The cyclic resistance ratio of the soil is dependent on overburden pressure and duration of the shaking. For this reason, the CRR is correlated by adjusting the CSR values to an earthquake of magnitude, M = 7.5 and overburden pressure equal to 1atm as:

$$CSR_{M=7.5,\sigma'_v=1atm} = \frac{CSR_{M,\sigma'_v}}{MSF*K_\sigma}.$$

This value of CSR was then adjusted to the value of CRR determined from eq.(iii). The adjusted value of CRR becomes:

$$CRR_{M,\sigma'_v} = CRR_{M=7.5,\sigma'_v=1atm} * MSF * K_\sigma$$

MSF is the Magnitude Scaling Factor which account for the effects of the duration of the earthquake on the triggering of liquefaction. The MSF relationship by Idriss and Boulanger for sand and clays is written as:

$$MSF = 1 + (MSF_{max} - 1)(8.64\exp\left(-\frac{M}{4}\right) - 1.325) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (iv)$$

Idriss and Boulanger developed an MSF curve (M vs MSF) for a range of soil conditions where MSF_{max} was related to $(N_1)_{60cs}$ as:

$$MSF_{max} = 1.09 + \left(\frac{(N_1)_{60cs}}{31.5}\right)^2 \leq 2.2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.(v)$$

3.2.4 Overburden Correction Factor, K_σ

Idriss and Boulanger (2008) proposed the expression in terms of (N1)60cs for the relationship of K_σ as:

$$K_\sigma = 1 - C_\sigma \ln\left(\frac{\sigma'_v}{P_a}\right) \leq 1.1 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (vi)$$

$$C_\sigma = \frac{1}{18.9 - 2.55\sqrt{(N_1)_{60cs}}} \leq 0.3 \dots\dots\dots\dots\dots\dots\dots\dots (vii)$$

The value of Cs is limited up to 0.3 to restrict the value of $(N_1)_{60cs} > 37$.

3.2.5 Correction for fines content

Various researches and case histories have shown that the fines content in the in-situ soil have influence in the liquefaction triggering potential. Therefore, an empirical expression is used to determine the equivalent clean sand adjustments and this expression accounts for both the effects that the fines content have on penetration resistance and CRR values. Idriss and Boulanger (2008) used the following expression for clean sand adjustments

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

where FC is fines content in percentage present in the in-situ soil.

For this paper, the amount of fines content in the soil was determined by grading/sieving of soil following IS 1498-1970 “Classification and identification of soils for general engineering purposes”. Particles passing through 75 microns IS sieve were considered as fines.

This above expression of clean sand adjustment is for SPT and not for CPT. For CPT different expression is used.

The $\Delta(N_1)_{60}$ is added with $(N_1)_{60}$ to determine $(N_1)_{60cs}$:

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

3.3 Liquefaction Potential Index

The value of the factor of safety determined for liquefaction indicates whether the in-situ soil is prone to liquefaction or not but enough to determine its severity. Liquefaction potential index helps to quantify the severity of liquefaction or the potential of failure in liquefaction prone area. Iwasaki et al. (1982), Luna et al. (1998) and MERM (2003) gave various range of liquefaction potential which is shown in Table II.

Table3.3: Range of severity due to liquefaction: J. Dixit et al. (2012)

LPI	**Iwasaki et al. (1982)**	**Luna et al. (1998)**	**MERM (2003)**
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

This paper follows Iwasaki et al. (1982) to determine the severity of the liquefaction. Liquefaction potential as proposed by Iwasaki et al. (1982) is given below:

$$LPI = \int_0^{20} F\,(z)\,.\,w(z)dz \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(ix)$$

where z is the midpoint of the particular soil layer, F(z) is the severity factor, w(z) is the weighing factor at every depth and d(z) is the differential increment of depth up to 20 m.

$F(z) = 1 - FS\ for\ FS < 1.0$

$F(z) = 0\ for\ FS \geq 1.0$

$w\ (z) = 10 - 0.5z\ for\ z < 20\ m$

$w\ (z) = 0\ for\ z > 20\ m$

Since the maximum depth of the borehole drilled was 16.5m, the above expression works for all three boreholes.

IV. Results and Discussion

The calculation of FS for liquefaction susceptibility are shown in the Table III, Table IV and Table V. It is seen that in BH-1, there no liquefaction is likely to occur up to depth 6.0m and from 7.5m to 10.0m there is no liquefaction susceptibility. This is due to high N-value at these depths which consist of sand and silt as the main deposition with few percentages of gravels between soil layers. Then again after 12.0m up to 15.0m liquefaction is likely to occur and we can see in Table III that value of FS increases with depth which is the reason why there is no liquefaction susceptibility at depth 16.5m.

In both BH-2 and BH-3 shown in Table IV and V, liquefaction is likely to occur up to depth 6.0m which also had sand and silt as the main deposition in the soil. There is no liquefaction susceptibility after 6.0m up to 16.5m though these depths also had the same deposition as soil layer from ground to 6.0m. This change in liquefaction susceptibility is due to the depth factor which also the case in BH-1 for depth 16.5m.

Several researches and papers have been published showing the influence of overburden pressure on penetration resistance values. As the overburden pressure increases with depth, penetration resistance values also increase accordingly. Also, CSR being a function of depth, its value decreases with the increase in depth. As the liquefaction analysis in this paper is done on the basis of SPT-N value, with increase in the N-value, the likelihood of occurrence of liquefaction decreases because CRR7.5 is a direct function of (N1)60cs. This is the reason why the overburden correction factor (Kσ) is considered while determining factor of safety.

The liquefaction potential index shown in Table VI, VII and VIII are calculated following Iwasaki et.al (1982). In all three boreholes the severity factor (Fz) is zero from 7.50m onwards as the factor of safety (FS) is greater than 1 from 7.50m onwards. However, at BH-1, values of FS from depth 12.0m to 15.0m are less than 1.0 so severity factor is calculated for these depths. It can be seen from the calculation table that the value of weighing factor (wz) decreases with depth, the overall liquefaction potential also decreases with depth. The reason behind considering wz in calculating liquefaction potential index is that the overburden pressure increases with the increase in depth. Liquefaction severity of all three boreholes lie in very high range as mentioned in the Iwasaki et. al (1982). Of the three boreholes, BH-3 has less severity index with value of 17.035 compared to BH-1 and BH-2 with severity index values of 22.588 and 22.631 respectively.

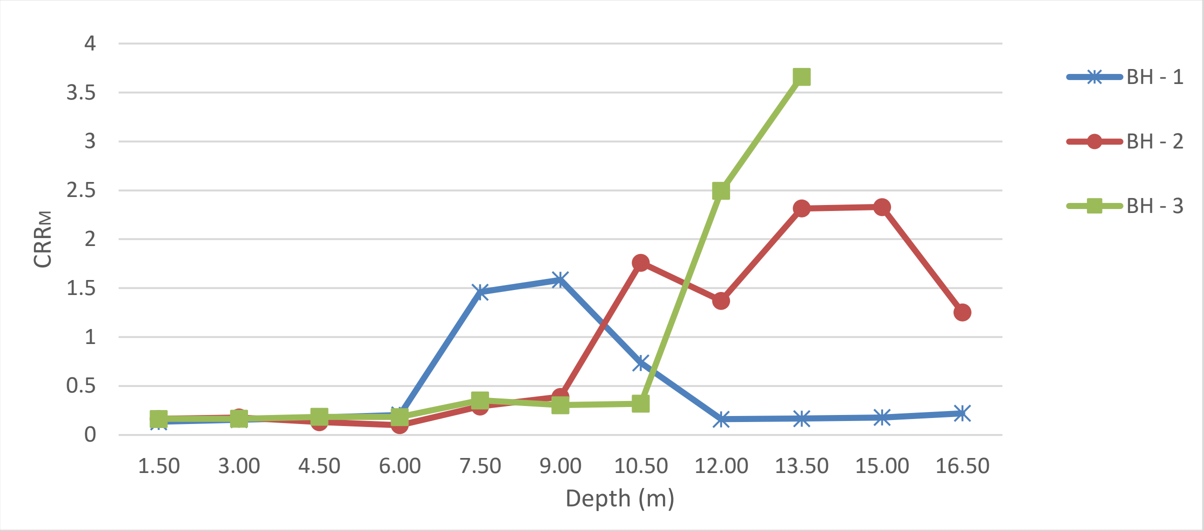

Fig. 5: Comparison of CRR of three boreholes at various depths

The value of CRRM at all three boreholes compared at various depths are shown in Figure 5. The values of CRRM is higher at BH-1 up to depth of 9.0m as compared to other two boreholes and decreases after 9.0m. The values of CRRM decreases so much that liquefaction is likely to occur from depth 13.5m to 15.0m at BH-1. This decrease in CRRM at BH-1 with depth is due to low SPT-N values at those depths. At BH-2 and BH-3, it can be seen that CRRM increases with depth as it usually does.

Table 4.1: PROBABLE LIQUEFACTION ANALYSIS OF BH-1 USING R.W. BOULANGER & I.M. IDRISS (2014)

Depth (d)	**Bulk Density (gm/cm^3)**	**Field SPT-N Value**	**Fines Content (%)**	**N_{60}**	**σ (kN/m²)**	**σ' (kN/m²)**	**(C_N)**	**$(N_1)_{60}$**	**$\Delta(N_1)_{60}$**	**$(N_1)_{60CS}$**	**K_σ**	**r_d**	**MSF**	**CSR**	**$CRR_{7.5}$**	**CRR_M**	**FS**	**Liquefaction (Yes/No)**
1.50	1.63	4	30.90	3	23.99	9.27	1.70	6	5.397	11	1.100	0.998	0.967	0.257	0.126	0.134	0.521	Yes
3.00	1.67	6	22.22	5	49.15	19.72	1.70	9	4.795	14	1.100	0.989	0.956	0.245	0.147	0.155	0.631	Yes
4.50	1.77	7	28.98	7	78.14	33.99	1.70	11	5.319	17	1.100	0.979	0.943	0.224	0.170	0.177	0.789	Yes
6.00	1.72	9	18.94	10	101.24	42.38	1.60	15	4.286	20	1.100	0.968	0.926	0.230	0.201	0.204	0.889	Yes
7.50	1.74	23	91.15	24	128.02	54.45	1.28	31	5.511	37	1.100	0.955	0.813	0.223	1.631	1.459	6.539	No
9.00	1.80	28	15.19	30	158.92	70.63	1.14	34	3.324	37	1.100	0.941	0.813	0.210	1.773	1.586	7.536	No
10.50	1.70	22	85.08	25	175.11	72.10	1.14	28	5.529	34	1.079	0.926	0.813	0.223	0.838	0.735	3.290	No
12.00	1.76	9	86.95	10	207.19	89.47	1.06	11	5.523	16	1.013	0.910	0.945	0.209	0.167	0.159	0.761	Yes
13.50	1.69	10	92.45	11	223.82	91.38	1.05	12	5.507	17	1.011	0.894	0.939	0.218	0.176	0.167	0.768	Yes
15.00	1.70	12	90.00	13	250.16	103.01	0.99	13	5.514	19	0.996	0.877	0.931	0.212	0.191	0.177	0.838	Yes
16.50	1.73	17	93.26	19	280.03	118.16	0.93	18	5.505	23	0.975	0.860	0.902	0.202	0.251	0.221	1.092	No

Table 4.2: *PROBABLE LIQUEFACTION ANALYSIS OF BH-2 USING R.W. BOULANGER & I.M. IDRISS (2014)*

Depth (d)	**Bulk Density (gm/cm^3)**	**Field SPT-N Value**	**Fines Content (%)**	**N_{60}**	**σ (kN/m²)**	**σ' (kN/m²)**	**(C_N)**	**$(N_1)_{60}$**	**$\Delta(N_1)_{60}$**	**$(N_1)_{60CS}$**	**K_σ**	**r_d**	**MSF**	**CSR**	**$CRR_{7.5}$**	**CRR_M**	**FS**	**Liquefaction (Yes/No)**
1.50	1.66	5	28.92	4	24.43	9.71	1.70	7	5.316	15	1.100	1.001	0.916	0.250	0.156	0.157	0.627	Yes
3.00	1.68	7	90.66	7	49.44	20.01	1.70	11	5.512	17	1.100	0.996	0.901	0.244	0.171	0.169	0.693	Yes
4.50	1.79	3	87.08	3	79.02	34.87	1.70	5	5.523	11	1.099	0.990	0.946	0.223	0.122	0.127	0.571	Yes
6.00	1.76	3	10.50	3	103.59	44.73	1.69	5	1.379	6	1.065	0.983	0.965	0.226	0.095	0.097	0.430	Yes
7.50	1.72	13	84.48	14	126.55	52.97	1.37	20	5.530	25	1.100	0.975	0.803	0.231	0.298	0.263	1.137	No
9.00	1.71	17	31.14	19	150.98	62.69	1.23	23	5.405	29	1.089	0.966	0.753	0.231	0.418	0.343	1.482	No
10.50	1.73	27	18.32	30	178.20	75.19	1.11	33	4.160	38	1.086	0.957	0.680	0.225	1.995	1.472	6.532	No
12.00	1.77	28	13.66	33	208.36	90.64	1.03	34	2.775	37	1.029	0.946	0.680	0.216	1.638	1.145	5.297	No
13.50	1.70	28	24.41	33	225.14	92.70	1.03	34	5.022	39	1.023	0.935	0.680	0.226	2.784	1.935	8.576	No
15.00	1.72	29	85.47	34	253.10	105.95	0.98	33	5.528	39	0.983	0.923	0.680	0.219	2.916	1.947	8.885	No
16.50	1.72	28	87.37	33	278.41	116.54	0.95	31	5.522	37	0.956	0.910	0.680	0.216	1.612	1.047	4.845	No

Table 4.3: *PROBABLE LIQUEFACTION ANALYSIS OF BH-3 USING R.W. BOULANGER & I.M. IDRISS (2014)*

Depth (d)	Bulk Density (gm/cm^3)	Field SPT-N Value	Fines Content (%)	N_{60}	σ (kN/m^2)	σ' (kN/m^2)	(C_N)	$(N_1)_{60}$	$\Delta(N_1)_{60}$	$(N_1)_{60CS}$	K_σ	r_d	MSF	CSR	$CRR_{7.5}$	CRR_M	FS	Liquefaction (Yes/No)
1.50	1.64	4	86.22	4	24.13	9.42	1.70	6	5.525	15	1.100	1.001	0.916	0.255	0.156	0.157	0.615	Yes
3.00	1.65	6	79.95	6	48.56	19.13	1.70	10	5.544	15	1.100	0.996	0.915	0.251	0.157	0.158	0.629	Yes
4.50	1.67	7	79.78	7	73.72	29.58	1.70	12	5.545	17	1.100	0.990	0.894	0.245	0.178	0.175	0.714	Yes
6.00	1.68	7	90.25	7	98.88	40.02	1.70	12	5.514	17	1.100	0.983	0.895	0.241	0.177	0.175	0.724	Yes
7.50	1.66	14	63.74	16	122.13	48.56	1.42	22	5.593	28	1.100	0.975	0.770	0.244	0.370	0.314	1.287	No
9.00	1.72	15	93.26	17	151.86	63.57	1.24	21	5.505	26	1.077	0.966	0.792	0.229	0.321	0.274	1.193	No
10.50	1.73	17	90.02	19	178.20	75.19	1.14	22	5.514	27	1.051	0.957	0.779	0.225	0.348	0.285	1.264	No
12.00	1.67	26	55.84	30	196.59	78.87	1.09	33	5.611	39	1.071	0.946	0.680	0.234	2.863	2.084	8.894	No
13.50	1.65	28	38.46	33	218.52	86.08	1.05	35	5.560	40	1.045	0.935	0.680	0.236	4.308	3.060	12.971	No

Table 4.4: *LIQUEFACTION POTENTIAL INDEX OF BH-1 USING IWASAKI et.al (1982)*

Depth (d)	Bulk Density	Field SPT-N Value	Fines Content (%)	(N1)60	Δ(N1)60	(N1)60CS	F.O.S.	z	H	wz	Fz	LPI
1.50	1.63	4	30.90	6	5.397	11	0.521	0.75	1.50	9.63	0.479	6.914
3.00	1.67	6	22.22	9	4.795	14	0.631	1.50	1.50	9.25	0.369	5.119
4.50	1.77	7	28.98	11	5.319	17	0.789	2.25	1.50	8.88	0.211	2.803
6.00	1.72	9	18.94	15	4.286	20	0.889	3.00	1.50	8.50	0.111	1.413
7.50	1.74	23	91.15	31	5.511	37	6.539	3.75	1.50	8.13	0.000	0.000
9.00	1.80	28	15.19	34	3.324	37	7.536	4.50	1.50	7.75	0.000	0.000
10.50	1.70	22	2.62	28	0.000	28	1.576	5.25	1.50	7.38	0.000	0.000
12.00	1.76	9	86.95	11	5.523	16	0.761	6.00	1.50	7.00	0.239	2.513
13.50	1.69	10	92.45	12	5.507	17	0.768	6.75	1.50	6.63	0.232	2.304
15.00	1.70	12	90.00	13	5.5143	19	0.838	7.50	1.50	6.25	0.162	1.520
16.50	1.73	17	93.26	18	5.5050	23	1.092	8.25	1.50	5.88	0.000	0.000
											∑LPI =	**22.588**

Table 4.5: *LIQUEFACTION POTENTIAL INDEX OF BH-2 USING IWASAKI et.al (1982)*

Depth (d)	Bulk Density	Field SPT-N Value	Fines Content (%)	(N1)60	Δ(N1)60	(N1)60CS	F.O.S.	z	H	wz	Fz	LPI
1.50	1.66	5	28.92	7	5.316	15	0.627	0.75	1.50	9.63	0.373	5.386
3.00	1.68	7	90.66	11	5.512	17	0.693	1.50	1.50	9.25	0.307	4.262
4.50	1.79	3	87.08	5	5.523	11	0.571	2.25	1.50	8.88	0.429	5.715
6.00	1.76	3	10.50	5	1.379	6	0.430	3.00	1.50	8.50	0.570	7.269
7.50	1.72	13	84.48	20	5.530	25	1.137	3.75	1.50	8.13	0.000	0.000
9.00	1.71	17	31.14	23	5.405	29	1.482	4.50	1.50	7.75	0.000	0.000
10.50	1.73	27	18.32	33	4.160	38	6.532	5.25	1.50	7.38	0.000	0.000
12.00	1.77	28	13.66	34	2.775	37	5.297	6.00	1.50	7.00	0.000	0.000
13.50	1.70	28	24.41	34	5.022	39	8.576	6.75	1.50	6.63	0.000	0.000
15.00	1.72	29	85.47	33	5.5275	39	8.885	7.50	1.50	6.25	0.000	0.000
16.50	1.72	28	87.37	31	5.5219	37	4.845	8.25	1.50	5.88	0.000	0.000
											∑LPI =	**22.631**

Table 4.6: LIQUEFACTION POTENTIAL INDEX OF BH-3 USING IWASAKI et.al (1982)

Depth (d)	Bulk Density	Field SPT-N Value	Fines Content (%)	(N1)60	Δ(N1)60	(N1)60CS	F.O.S.	z	H	wz	Fz	LPI
1.50	1.64	4	86.22	6	5.525	15	0.615	0.75	1.50	9.63	0.385	5.553
3.00	1.65	6	79.95	10	5.544	15	0.629	2.25	1.50	8.88	0.371	4.938
4.50	1.67	7	79.78	12	5.545	17	0.714	3.75	1.50	8.13	0.286	3.491
6.00	1.68	7	90.25	12	5.514	17	0.724	5.25	1.50	7.38	0.276	3.053
7.50	1.66	14	63.74	22	5.593	28	1.287	6.75	1.50	6.63	0.000	0.000
9.00	1.72	15	93.26	21	5.505	26	1.193	8.25	1.50	5.88	0.000	0.000
10.50	1.73	17	90.02	22	5.514	27	1.264	9.75	1.50	5.13	0.000	0.000
12.00	1.67	26	55.84	33	5.611	39	8.894	11.25	1.50	4.38	0.000	0.000
13.50	1.65	28	38.46	35	5.560	40	12.971	12.75	1.50	3.63	0.000	0.000
											∑LPI =	**17.035**

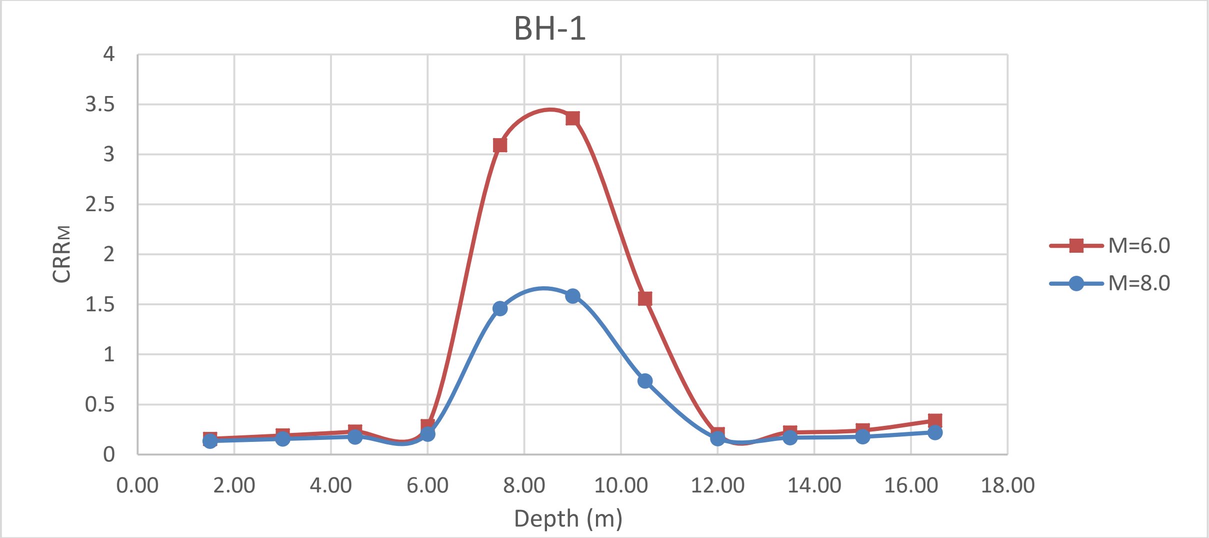

Fig. 6: CRR_M compared at M=6.0 & 8.0

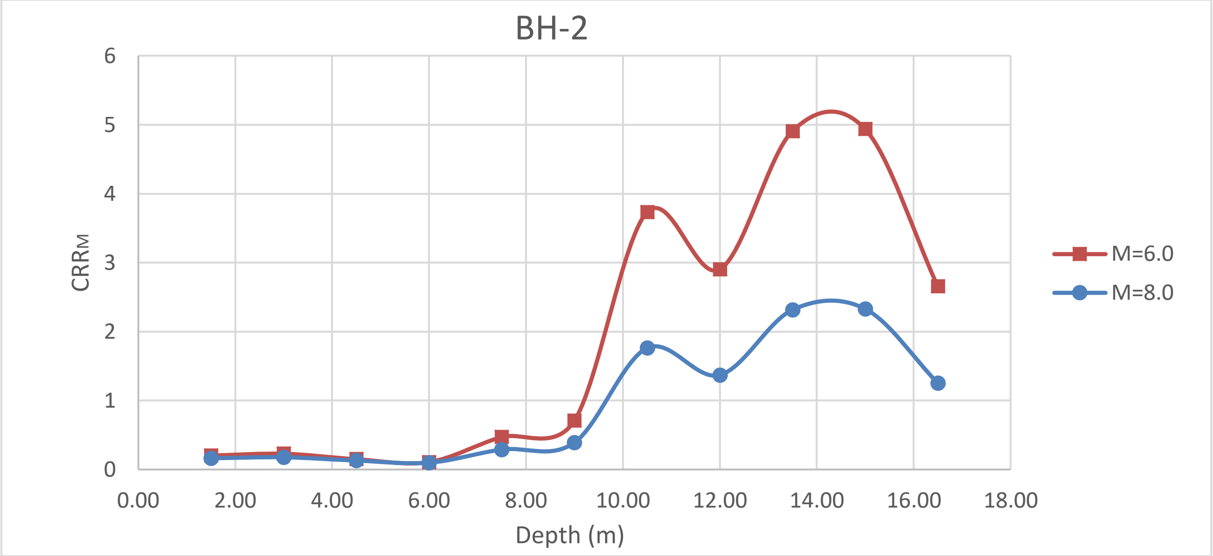

Fig. 7: CRR_M compared at M=6.0 & 8.0

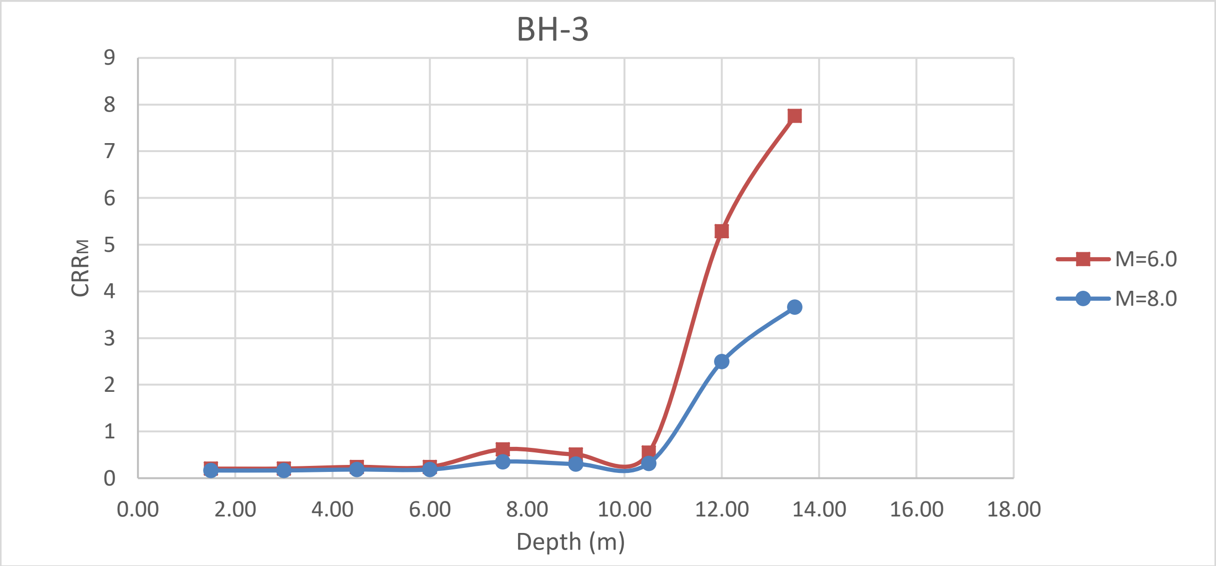

Fig. 8: CRR_M compared at M=6.0 & 8.0

The values of CRRM at M= 6.0 and M=8.0 are similar up to depth 6.0m at all three boreholes. After that it is seen that the CRRM increase with depth. The values of Magnitude Scaling Factor (MSF) were greater than 0.900 up to 6.0m and comes in the range of 0.800 after 6.0m. These values of MSF govern the increase and decrease of CRRM when the magnitude of the earthquake (M) change.

V. CONCLUSION

This paper attempts to evaluate the factor of safety (FS) against liquefaction based on the empirical relationship between Cyclic Stress Ratio and penetration values (SPT-N value in this paper). All the investigated locations were found to be liquefiable with very high severity as referenced with the range given by Iwasaki et. al (1982). The areas have Sandy SILT as the main deposits which is one of the factors for the area being liquefiable. Liquefaction analysis was done for 6.0 and 8.0 magnitude of earthquakes. It was found that the areas are safe from the earthquake of magnitude 6.0 from depth 4.5m even though the analysis was done considering the depth of water table as 0m. But the areas are at very high risk when the earthquake of magnitude 8.0 occurs. The minimum depth of 7.5m shall be taken for construction activities in these areas while earthquake of magnitude 8.0 is considered. Barhadashi is a rural municipality of Jhapa district with few low-rise buildings and residential houses are sparsely populated and are generally 1-2 storey. Therefore, the intensity of the earthquake might not be too high in the occurrence of moderate earthquakes. Since, the area lies in Terai region of Nepal, its water table is very high. So, water pumping before construction activities in these areas should be practiced to reduce the liquefaction potential. The areas consist of Sandy SILT as the main soil deposition so densifying the soil by replacing or mixing of appropriate sized gravels shall also help in reducing the liquefaction potential of those areas.

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