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ASSESSMENT OF LIQUEFACTION POTENTIAL FOR SEISMIC RISK REDUCTION IN NORTH-EAST INDIA

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Abstract **—The study of liquefaction potential of a region is of utmost importance regarding the safety of both life and property. Soil Liquefaction occurs when is there is loss of strength and stiffness in saturated and cohesion less soil due to increase in pore water pressure. The strength of the soil is sometimes reduced by earthquake shaking or rapid loading. Liquefaction causes soil failures which leads to severe damages to structures supported on such grounds leading to significant economic losses. The main purpose of the present study is to analyse liquefaction of some selected sites of Northeast India which falls in the zone of highest seismic risk zone level(Zone V in India)using bore log data of 95boreholes upto a depth of 15m. The liquefaction analysis is carried out with the help of 2 different methods and results are compared. Factor of safety versus depth curves plotted for showing the change in soil liquefaction with increasing depth. The methods used for analysis are simplified approach by Seed and Idriss (1971) and IS code procedure for evaluation of liquefaction potential (2016). More detailed study can be done in future and also various mitigation strategies can be put forward to reduce the impact of hazard.**

Keywords– **Borehole data, Cyclic resistance ratio, Cyclic stress ratio, Factor of safety, Liquefaction.**

I. INTRODUCTION

Liquefaction is typically associated with earthquake-induced shaking that causes the ground to lose its bearing strength and act like a fluid. This can cause entire buildings to topple and cars to get sucked in. It can cause surface layers to slide downhill, damaging roads and rupturing distributed infrastructure systems like water and gas lines Earthquakes seismic event caused number of disturbances in the ground which could harm or damage structural stability leading to liquefaction. The construction of building near water bodies use retaining walls which are heavily dependent on the strength and stiffness of the soil. Once the soil gets liquefied, the retaining wall collapse which could cause landslide. The best known cases of foundation failures due to liquefaction are those that occurred during the 1964 earthquake in Niigata, Japan (Kishida, 1966).

Liquefaction is typically characterized by generation of excess pore pressure under undrained loading. The tendency of loose sands to densify under drained loading is well known. When loose sands are saturated and loaded under undrained conditions, the tendency to densify causes an increase in pore pressure, leading to a decrease in effective confining pressure. This lowers the shear strength of the soil, causing it to liquefy.

Guwahati city lies on a very high seismic zone (zone V) as per IS: 1893 along with the entire North Eastern region vulnerable to major earthquakes. The drifting of the Indian subcontinent also plate towards the Eurasian plate with the passage of time has been one of the sole reasons of earthquake occurrence in this part of the world. The northward moving Indian plate at the rate of 20mm/year can provide earthquakes of magnitudes 8 and above every few hundred years. Most part of the city is built on soft sediments it can reasonably amplify the earthquake ground motion in case of a seismic event. Such areas have high risk of liquefaction occurrence of a strong intensity earthquake.

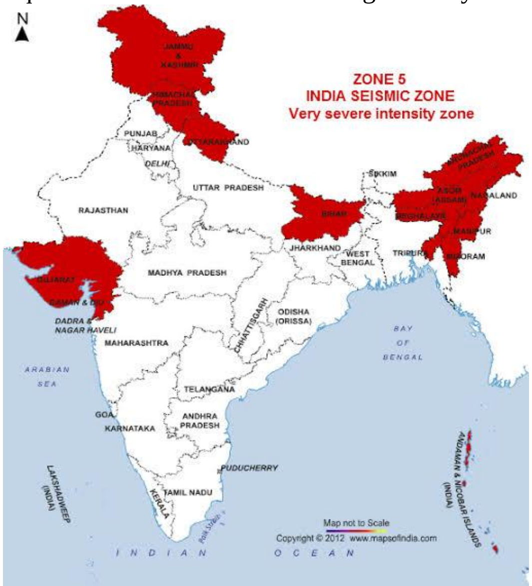

Fig1:- INDIA Seismic Zone

II. BACKGROUND INFORMATION

The devastating effect of liquefaction was first observed during various worldwide earthquakes including the 1987 great Assam Earthquake and the 1950 Assam earthquake both of magnitude 8.7 approximately. These instances of liquefaction necessitate the need to evaluate liquefaction susceptibility of an area. Evaluations of soil liquefaction potential using laboratory as well as several field techniques like standard penetration test (SPT), cone penetration test(CPT), shear wave velocity(Vs) etc. have become popular among the practising engineers.

Analysis of Guwahati city was performed by Nath et al. (2008) and PGA falls in the range 0.22g-1.27g with amplification factor 2-10. Different research developments in determination of liquefaction potential using the deterministic as well as the probabilistic approach have evolved due to the continued effort of many research workers. The developments started with the pioneering work of Seed and Idriss in 1971, and gradually by Seed and Idriss (1982) and Seed et al. (1985), by Liao and Whitman (1986), by Idriss (1999), NCEER Workshops- (1996 and 1997), by Toprak et al. (1999), by Juang et al. (2002), by Cetin et al. (2004), by Idriss and Boulanger (2004, 2006) etc.

A detailed study on the status of liquefaction potential of Guwahati city was first attempted by Raghukanth and Dash (2010) based on the scenario earthquakes of this region. Accordingto their research findings, the central part of the city near Dispur, Chandmari and along the Guwahati-Shillong (GS) road is highly vulnerable to liquefaction. The FOS was found to be less than 1 in almost all the places under study which means almost entire Guwahati city is susceptible to liquefaction.

III. STUDY AREA

Guwahati city which lies in the North Eastern region of India, falls in the highest seismic risk zonal level i.e. zone V in India. Liquefaction of soil and its associated damages have been widely observed in many previous earthquakes in North Eastern region of Assam. The entire North Eastern region has witnessed many high magnitude earthquakes in the past decades.
Guwahati, is India`s biggest city that falls in zone V. Guwahati is also amongst the list of cities, Government of India has shortlisted to be developed as “smart city”. For this reason, the city attracts a lot of infrastructural growth in the times to come. Also recent developments have led to more construction of oil refineries, industries, hospitals, flyovers, multiplex halls etc. These heavy buildings require pile foundations which are embedded deep into the ground because of soil support. But if the soil is not strong enough to support then the foundation buckle which leads to collapsing of the structure. A major earthquake in this region shalllead to extensive damages to life and property.

Fig 2:- Map of Guwahati

The evaluation was done by using 95bore log datas, which were collected from the different infrastructural, commercial and educational centres of Guwahati where the development is thick and fast with every passing year along with a rise in population. Hence it is important to check liquefaction so that adequate precaution can be taken before construction. The obtained values and results will provide very useful information to field engineers regarding where and who much ground improvement is required for avoiding future liquefaction. In addition, the present study will be helpful for planning and microzonation of the city.

IV. METHODOLOGY

In order to analyse liquefaction of Guwahati city 95 boreholes of 15m depth was taken The analysis for liquefaction was done for each depth of the bore hole using Simplified Approach Method by Seed and Idriss(1971) and IS Code Procedure for Evaluation of Liquefaction Potential (2016). Assumption of few data was taken accordingly.

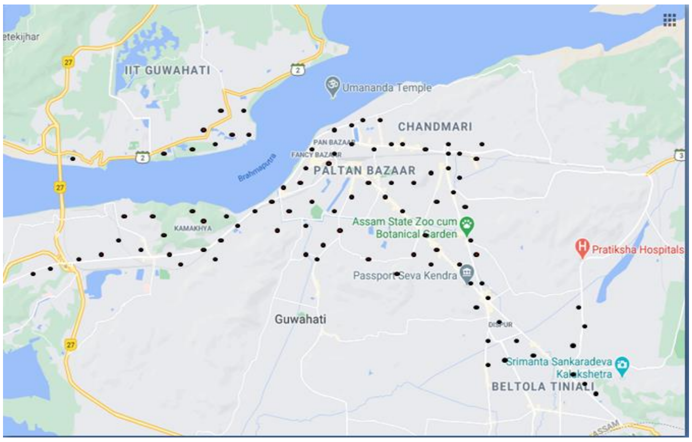

Fig3:- Location of the boreholes

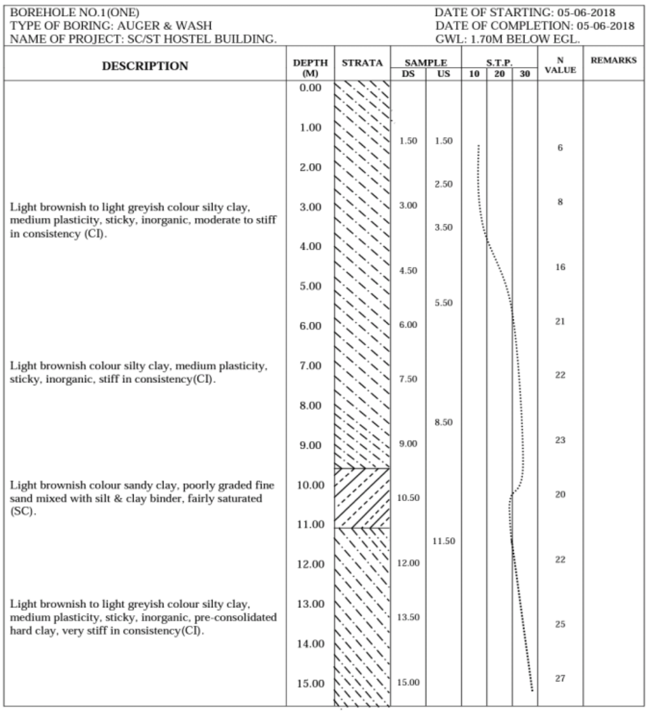

Fig4:-Collected borelog of one borehole.

A.**Procedure of Simplified Approach Method by Seed and Idriss (1971)**

The procedure allows the factor of safety (FOS) against liquefaction to be calculated for soil structure at a given depth.

With the help of specific gravity and void ratio, the saturated unit weight and submerged unit weight was found out by:-

$$\gamma_{sat} = \left(\frac{g+e}{1+e}\right)\gamma_w$$

$$\gamma_{sub} = \gamma_{sat} - \gamma_w$$

Then total vertical stress(σv) and effective overburden pressure($\sigma' v$) was found out by:

$$\sigma_{v1=\gamma_{sat\times}H_1}$$

$$\sigma'_{v1=\gamma_{sat\times}H_1}$$

Then, value of stress reduction factor(r_d) was calculated for depth H from Seed and Idriss curve(1971) shown in fig 3.

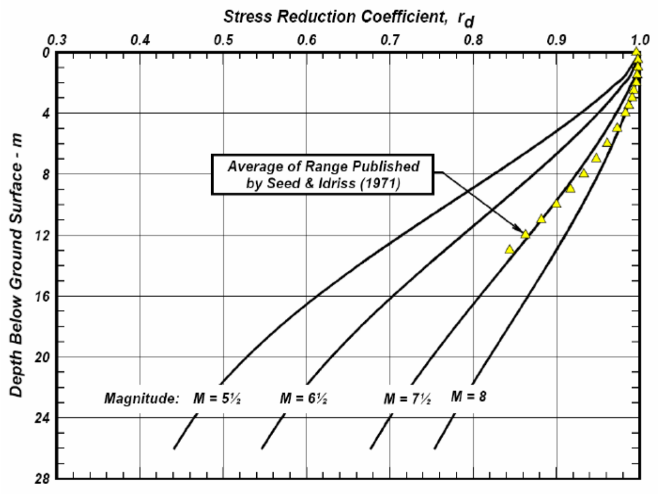

Fig5:- Seed and Idriss curve

Peak ground surface acceleration (a_{max}) is considered as 0.36g.

Now, cyclic stress ratio(CSR) is given by:

$$CSR = 0.65 \times \frac{a_{max}}{g} \times \frac{\sigma_v}{\sigma'_v} \times r_d$$

Observed value of no. of blows (N_m) is taken from bore log chart.

Now, overburden correction factor (C_N) was calculated using the formula:

$$C_N = 9.81 \times \sqrt{\frac{1}{\sigma'_V}}$$

Actual hammer energy (E_m) was considered to be 72% of theoretical free fall energy (E_{eff}).

Now, corrected value of no. of blows $(N_1)_{60}$ was found out and hammer efficiency of 60% was taken:-

$$(N_1)_{60} = N_m \times C_N \times \frac{E_m}{0.6E_{eff}}$$

Then, the value of CRR was taken from $(N_1)_{60}$ versus CRR curve shown in Fig 4.

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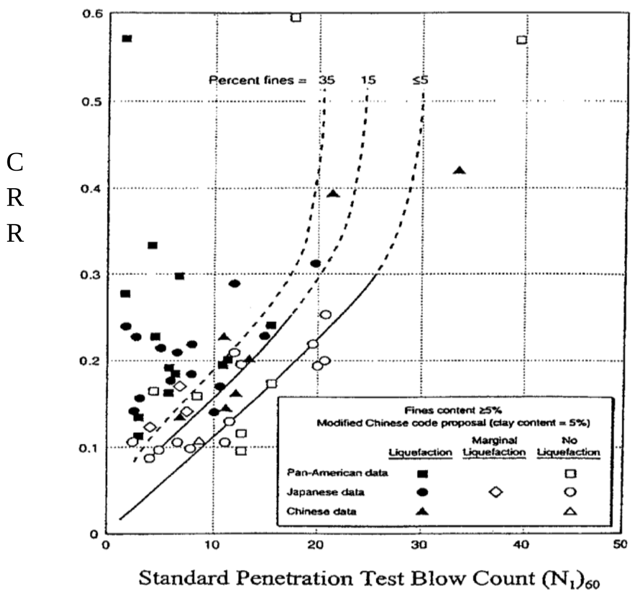

Fig6:- $(N_1)_{60}$ vs. CRR curve

Finally, factor of safety was calculated by:-

$$\mathbf{FOS = \frac{CRR}{CSR}}$$

If FOS is less than 1, soil will undergo liquefaction.
If FOS is more than 1, soil will not undergo liquefaction.

B. **Procedure of IS code Procedure for Evaluation of Liquefaction Potential (2016)**

The procedure allows the factor of safety (FOS) against liquefaction to be calculated for soil structure at a given depth.
With the help of specific gravity and void ratio, the saturated unit weight and submerged unit weight was found out by:-

$$\gamma_{sat} = (\frac{g+e}{1+e})\gamma_w$$

$$\gamma_{sub} = \gamma_{sat} - \gamma_w$$

Then total vertical stress(σ_v) and effective overburden pressure(σ'_v) was found out by:

$$\sigma_{v1=\gamma_{sat\times}H_1}$$

$$\sigma'_{v1=\gamma_{sat\times}H_1}$$

Then, value of stress reduction factor ($\mathbf{r_d}$) was calculated for depth H by:-

$$\mathbf{1-(0.00765 \times H)}$$

Peak ground surface acceleration ($\mathbf{a_{max}}$) is considered as 0.36g.
Now, cyclic stress ratio (CSR) is given by:-

$$\mathbf{CSR = 0.65 \times \frac{a_{max}}{g} \times \frac{\sigma_v}{\sigma'_v} \times r_d}$$

Observed value of no. of blows ($\mathbf{N_{60}}$) is taken from bore log chart.
Now, the value of $(\mathbf{N_1})_{60}$ is calculated by:-

$$\mathbf{(N_1)_{60} = C_N \times N_{60}}$$

Then, the value of CRR was found out from the $(N_1)_{60}$ vs. CRR curve.
Finally, factor of safety was calculated by:-

$$\mathbf{FOS = \frac{CRR}{CSR}}$$

If FOS is less than 1, soil will undergo liquefaction.
If FOS is more than 1, soil will not undergo liquefaction

Here,γ_d = dry unit weight of soil in KN/m³,γ_{sat} = saturated unit weight of soil in KN/m³, γ_w = unit weight of water in KN/m³, **H** = depth of bore hole in m, σ_V = vertical stress in KN/m², σ'_V= effective overburden pressure in KN/m², $\mathbf{a_{max}}$ = peak ground surface acceleration, **g** = acceleration due to gravity, $\mathbf{r_d}$ = value of stress reduction factor, **CSR** = cyclic stress ratio, $\mathbf{N_m}$ = observed values of number of blows, $\mathbf{C_N}$ = overburden correction factor, **Em** = actual hammer energy, E_{eff} = theoretical free fall energy, $(N_1)_{60}$= corrected values of number of blows normalised for 100kPa overburden pressure and hammer efficiency of 60%., **CRR** = cyclic resistance ratio, **FOS** = factor of safety.
FOS is calculated by using the same method as above for all the depths for borehole data collected which is represented in the table below.

The factor of safety calculations of 8 boreholes out of 95 are shown below.

A.BOREHOLE I

Depth	σ'_VkN/m²)	σ_VkN/m²)	r_d	CSR	N_{60}	$(N_1)_{60}$	CRR	FOS	Liquefaction
1.5	28.74	28.74	0.988	0.231	6	11.22	0.19	0.82	Yes
3	44.95	57.68	0.977	0.293	8	12.01	0.22	0.750	Yes
4.5	59.38	86.81	0.965	0.330	16	20.90	0.5	1.51	No
6	74	116.14	0.954	0.350	21	24.57	0.5	1.42	No
7.5	88.7	145.5	0.942	0.361	22	23.51	0.5	1.381	No
9	103.52	175.06	0.931	0.368	23	22.75	0.5	1.358	No
10.5	118.55	204.79	0.919	0.372	20	18.48	0.21	0.566	Yes
12	133.72	234.55	0.908	0.372	22	19.15	0.4	1.07	No
13.5	148.74	264.31	0.896	0.372	25	20.63	0.5	1.344	No
15	163.84	294.071	0.885	0.371	27	21.23	0.5	1.347	No

Table1:-FOS by Seed and Idriss

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Depth	σ'_VkN/m²)	σ_VkN/m²)	r_d	CSR	N_{60}	$(N_1)_{60}$	CRR	FOS	Liquefaction
1.5	28.74	28.74	0.988	0.231	6	11.22	0.19	0.82	Yes
3	44.95	57.68	0.977	0.293	8	12.01	0.22	0.750	Yes
4.5	59.38	86.81	0.965	0.330	16	20.90	0.5	1.51	No
6	74	116.14	0.954	0.350	21	24.57	0.5	1.42	No
7.5	88.7	145.5	0.942	0.361	22	23.51	0.5	1.381	No
9	103.52	175.06	0.931	0.368	23	22.75	0.5	1.358	No
10.5	118.55	204.79	0.919	0.372	20	18.48	0.21	0.566	Yes
12	133.72	234.55	0.908	0.372	22	19.15	0.4	1.07	No
13.5	148.74	264.31	0.896	0.372	25	20.63	0.5	1.344	No
15	163.84	294.071	0.885	0.371	27	21.23	0.5	1.347	No

Table2:-FOS by IS Code Procedure

B. BOREHOLE II

Depth	σ'_VkN/m²)	σ_VkN/m²)	r_d	CSR	N_m	C_N	$(N_1)_{60}$	CRR	FOS	Liquefaction
1.5	29.04	29.04	0.998	0.234	3	1.82	6.552	0.12	0.512	Yes
3	43.29	57.96	0.982	0.307	8	1.49	14.30	0.25	0.814	Yes
4.5	57.67	87.07	0.954	0.337	11	1.29	17.028	0.29	0.860	Yes
6	72.19	116.29	0.95	0.358	12	1.154	16.61	0.26	0.726	Yes
7.5	86.82	145.62	0.94	0.368	14	1.052	17.67	0.32	0.869	Yes
9	101.61	175.11	0.91	0.366	15	0.97	17.48	0.31	0.846	Yes
10.5	116.44	204.64	0.89	0.366	18	0.909	19.63	0.39	1.065	No
12	131.28	234.18	0.85	0.354	21	0.856	21.57	0.5	1.41	No
13.5	146.145	263.74	0.825	0.348	20	0.811	19.46	0.38	1.091	No
15	161.01	293.31	0.754	0.321	23	0.773	21.33	0.5	1.55	No

Table3:-FOS by Seed and Idriss

Depth	σ'_VkN/m²)	σ_VkN/m²)	r_d	CSR	N_{60}	$(N_1)_{60}$	CRR	FOS	Liquefaction
1.5	29.04	29.04	0.988	0.231	3	5.60	0.11	0.47	Yes
3	43.29	57.96	0.977	0.306	8	12.23	0.23	0.751	Yes
4.5	57.67	87.07	0.965	0.340	11	14.58	0.25	0.735	Yes
6	72.19	116.29	0.954	0.359	12	14.21	0.249	0.69	Yes
7.5	86.82	145.62	0.942	0.369	14	15.12	0.26	0.704	Yes
9	101.61	175.11	0.931	0.354	15	14.97	0.258	0.728	Yes
10.5	116.44	204.64	0.919	0.349	18	16.79	0.35	1.002	No
12	131.28	234.18	0.908	0.379	21	18.44	0.39	1.029	No
13.5	146.145	263.74	0.896	0.320	20	16.65	0.32	1.00	No
15	161.01	293.31	0.885	0.377	23	18.24	0.38	1.007	No

Table4:-FOS by IS Code Procedure

C. BOREHOLE III

Table5:-FOS by Seed and Idriss

Depth	σ'_VkN/m²)	σ_VkN/m²)	r_d	CSR	N_m	C_N	$(N_1)_{60}$	CRR	FOS	Liquefaction
1.5	29.13	29.13	0.998	0.233	5	1.81	10.86	0.18	0.772	Yes
3	43.41	58.11	0.982	0.307	6	1.48	10.65	0.19	0.618	Yes
4.5	57.82	87.22	0.954	0.336	8	1.290	12.38	0.22	0.654	Yes
6	72.36	116.46	0.95	0.357	11	1.15	15.18	0.25	0.700	Yes
7.5	87.07	145.87	0.94	0.368	13	1.051	16.39	0.29	0.788	Yes
9	101.88	175.98	0.91	0.367	14	0.971	16.31	0.285	0.776	Yes
10.5	116.77	204.97	0.89	0.365	17	0.970	19.78	0.34	0.931	Yes
12	131.745	234.64	0.85	0.354	16	0.854	16.39	0.29	0.819	Yes
13.5	146.85	263.45	0.825	0.347	19	0.809	18.44	0.34	0.97	Yes
15	161.98	294.28	0.754	0.320	18	0.770	16.63	0.30	0.937	Yes

Depth	σ'_VkN/m²)	σ_VkN/m²)	r_d	CSR	N_{60}	$(N_1)_{60}$	CRR	FOS	Liquefaction
1.5	29.13	29.13	0.988	0.231	5	9.32	0.14	0.606	Yes
3	43.41	58.11	0.977	0.306	6	9.16	0.18	0.184	Yes
4.5	57.82	87.22	0.965	0.340	8	10.59	0.19	0.196	Yes
6	72.36	116.46	0.954	0.359	11	13.01	0.21	0.220	Yes
7.5	87.07	145.87	0.942	0.369	13	14.02	0.23	0.244	Yes
9	101.88	175.98	0.931	0.376	14	13.69	0.22	0.236	Yes
10.5	116.77	204.97	0.919	0.378	17	15.88	0.27	0.293	Yes
12	131.745	234.64	0.908	0.378	16	14.031	0.23	0.253	Yes
13.5	146.85	263.45	0.896	0.376	19	15.78	0.18	0.20	Yes
15	161.98	294.28	0.885	0.376	18	14.23	0.15	0.16	Yes

Table6:-FOS by IS Code Procedure

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D. BOREHOLE IV

Depth	σ'_VkN/m²)	σ_VkN/m²)	r_d	CSR	N_m	C_N	$(N_1)_{60}$	CRR	FOS	Liquefaction
1.5	28.53	28.53	0.998	0.233	6	1.836	13.21	0.22	0.94	Yes
3	42.75	57.45	0.982	0.310	10	1.500	18	0.36	1.16	No
4.5	57.54	86.94	0.954	0.337	11	1.293	17.06	0.27	0.801	Yes
6	72.28	116.38	0.95	0.357	12	1.152	16.58	0.28	0.78	Yes
7.5	87.15	145.95	0.94	0.368	13	1.049	16.36	0.25	0.67	Yes
9	102.16	175.66	0.91	0.366	13	0.960	14.97	0.24	0.65	Yes
10.5	117.22	205.42	0.89	0.364	15	0.900	16.20	0.28	0.76	Yes
12	132.28	235.18	0.85	0.353	17	0.850	17.34	0.34	1.01	No
13.5	147.36	264.96	0.825	0.347	18	0.800	17.28	0.31	0.89	Yes
15	162.43	294.73	0.754	0.320	19	0.760	17.32	0.33	1.03	No

Table7:-FOS by Seed and Idriss

Depth	σ'_VkN/m²)	σ_VkN/m²)	r_d	CSR	N_{60}	$(N_1)_{60}$	CRR	FOS	Liquefaction
1.5	28.53	28.53	0.988	0.231	6	11.30	0.17	0.73	Yes
3	42.75	57.45	0.977	0.307	10	15.39	0.33	1.07	No
4.5	57.54	86.94	0.965	0.341	11	14.59	0.19	0.5	Yes
6	72.28	116.38	0.954	0.359	12	14.20	0.14	0.38	Yes
7.5	87.15	145.95	0.942	0.369	13	14.01	0.23	0.62	Yes
9	102.16	175.66	0.931	0.374	13	12.94	0.21	0.56	Yes
10.5	117.22	205.42	0.919	0.376	15	13.94	0.23	0.61	Yes
12	132.28	235.18	0.908	0.340	17	14.87	0.34	1.00	No
13.5	147.36	264.96	0.896	0.376	18	14.92	0.34	0.64	Yes
15	162.43	294.73	0.885	0.354	19	15.01	0.35	1.01	No

Table8:-FOS by IS Code Procedure

E. BOREHOLE V

Depth	σ'_VkN/m²)	σ_VkN/m²)	r_d	CSR	N_m	C_N	$(N_1)_{60}$	CRR	FOS	Liquefaction
1.5	28.57	28.53	0.998	0.233	6	1.83	13.17	0.21	0.901	Yes
3	42.74	57.45	0.982	0.308	11	1.499	19.78	0.39	1.266	No
4.5	57.41	86.82	0.954	0.337	30	1.294	46.5	0.5	1.48	No
6	72.17	116.28	0.95	0.358	13	1.154	18.00	0.28	0.78	Yes
7.5	87.01	145.81	0.94	0.368	12	1.051	15.13	0.26	0.706	Yes
9	101.96	175.47	0.91	0.366	15	0.971	17.47	0.29	0.792	Yes
10.5	117.02	205.23	0.89	0.365	19	0.906	20.65	0.45	1.23	No
12	132.13	235.03	0.85	0.353	20	0.853	20.47	0.49	1.38	No
13.5	147.26	264.87	0.825	0.347	18	0.808	17.45	0.28	0.80	Yes
15	162.50	294.81	0.754	0.320	20	0.769	18.45	0.29	0.377	Yes

Table9:-FOS by Seed and Idriss

Depth	σ'_VkN/m²)	σ_VkN/m²)	r_d	CSR	N_{60}	$(N_1)_{60}$	CRR	FOS	Liquefaction
1.5	28.57	28.53	0.988	0.231	6	11.29	0.18	0.77	Yes
3	42.74	57.45	0.977	0.307	11	16.93	0.33	1.07	No
4.5	57.41	86.82	0.965	0.341	30	39.85	0.5	1.46	No
6	72.17	116.28	0.954	0.359	13	15.40	0.22	0.61	Yes
7.5	87.01	145.81	0.942	0.369	12	12.94	0.23	0.62	Yes
9	101.96	175.47	0.931	0.374	15	14.95	0.24	0.64	Yes
10.5	117.02	205.23	0.919	0.327	19	17.67	0.35	1.07	No
12	132.13	235.03	0.908	0.327	20	17.51	0.33	1.009	No
13.5	147.26	264.87	0.896	0.376	18	14.93	0.24	0.63	Yes
15	162.50	294.81	0.885	0.375	20	15.79	0.33	0.81	Yes

Table10:-FOS by IS Code Procedure

F. BOREHOLE VI

Depth	σ'_VkN/m²)	σ_VkN/m²)	r_d	CSR	N_m	C_N	$(N_1)_{60}$	CRR	FOS	Liquefaction
1.5	28.96	28.96	0.998	0.233	2	1.82	4.36	0.08	0.34	Yes
3	43.37	58.07	0.982	0.307	7	1.48	12.43	0.18	0.58	Yes
4.5	57.94	87.34	0.954	0.336	9	1.28	13.82	0.24	0.71	Yes
6	72.61	116.71	0.95	0.355	11	1.15	15.04	0.28	0.78	Yes
7.5	87.41	146.21	0.94	0.367	13	1.04	16.22	0.3	0.81	Yes
9	102.24	175.79	0.91	0.366	10	0.97	11.64	0.21	0.57	Yes
10.5	117.21	205.42	0.89	0.364	11	0.906	11.95	0.22	0.60	Yes
12	132.16	235.06	0.85	0.353	14	0.853	14.33	0.25	0.70	Yes
13.5	147.11	264.71	0.825	0.347	15	0.80	14.4	0.26	0.74	Yes
15	162.07	294.38	0.754	0.320	16	0.77	14.78	0.27	0.84	Yes

Table11:-FOS by Seed and Idriss

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Depth	σ'_VkN/m²)	σ_VkN/m²)	r_d	CSR	N_{60}	$(N_1)_{60}$	CRR	FOS	Liquefaction
1.5	28.96	28.96	0.988	0.231	2	3.74	0.08	0.34	Yes
3	43.37	58.07	0.977	0.306	7	10.69	0.16	0.52	Yes
4.5	57.94	87.34	0.965	0.340	9	11.90	0.21	0.61	Yes
6	72.61	116.71	0.954	0.358	11	12.99	0.23	0.64	Yes
7.5	87.41	146.21	0.942	0.315	13	13.99	0.25	0.79	Yes
9	102.24	175.79	0.931	0.374	10	9.95	0.18	0.48	Yes
10.5	117.21	205.42	0.919	0.376	11	10.22	0.2	0.53	Yes
12	132.16	235.06	0.908	0.377	14	12.25	0.22	0.58	Yes
13.5	147.11	264.71	0.896	0.377	15	12.44	0.22	0.58	Yes
15	162.07	294.38	0.885	0.376	16	10.00	0.19	0.50	Yes

Table12:-FOS by IS Code Procedure

G. BOREHOLE VII

Depth	σ'_VkN/m²)	σ_VkN/m²)	r_d	CSR	N_m	C_N	$(N_1)_{60}$	CRR	FOS	Liquefaction
1.5	28.7	28.7	0.998	0.233	2	1.831	4.39	0.12	0.51	Yes
3	42.09	56.83	0.982	0.31	2	1.512	3.62	0.1	0.32	Yes
4.5	55.37	84.77	0.954	0.341	3	1.318	4.74	0.13	0.38	Yes
6	69.06	113.16	0.95	0.422	4	1.180	5.66	0.14	0.33	Yes
7.5	83.27	142.07	0.94	0.357	10	1.075	12.9	0.23	0.61	Yes
9	97.50	171.0	0.91	0.373	15	0.99	17.8	0.29	0.77	Yes
10.5	111.42	199.62	0.89	0.373	10	0.929	11.14	0.21	0.56	Yes
12	125.57	228.47	0.85	0.361	20	0.875	21	0.45	1.24	No
13.5	139.25	256.85	0.825	0.356	19	0.831	18.9	0.4	1.12	No
15	152.78	285.08	0.754	0.329	13	0.793	12.3	0.22	0.66	Yes

Table13:-FOS by Seed and Idriss

Depth	σ'_VkN/m²)	σ_VkN/m²)	r_d	CSR	N_{60}	$(N_1)_{60}$	CRR	FOS	Liquefaction
1.5	28.7	28.7	0.988	0.231	2	11.2	0.2	0.86	Yes
3	42.09	56.83	0.977	0.30	2	3.103	0.09	0.3	Yes
4.5	55.37	84.77	0.965	0.345	3	4.05	0.12	0.34	Yes
6	69.06	113.16	0.954	0.365	4	4.84	0.13	0.35	Yes
7.5	83.27	142.07	0.942	0.376	10	11.03	0.19	0.50	Yes
9	97.50	171.0	0.931	0.382	15	15.2	0.25	0.65	Yes
10.5	111.42	199.62	0.919	0.385	10	9.41	0.14	0.36	Yes
12	125.57	228.47	0.908	0.386	20	17.96	0.39	1.01	No
13.5	139.25	256.85	0.896	0.386	19	16.2	0.389	1.00	No
15	152.78	285.08	0.885	0.436	13	10.5	0.18	0.41	Yes

Table14:-FOS by IS Code Procedure

H. BOREHOLE VIII

Depth	σ'_VkN/m²)	σ_VkN/m²)	r_d	CSR	N_m	C_N	$(N_1)_{60}$	CRR	FOS	Liquefaction
1.5	28.8	28.8	0.998	0.231	3	1.827	6.57	0.13	0.56	Yes
3	57.39	86.82	0.982	0.347	5	1.29	7.76	0.16	0.46	Yes
4.5	100.68	174.25	0.954	0.389	8	0.997	9.37	0.18	0.46	Yes
6	159.3	291.73	0.95	0.405	12	0.977	14.06	0.24	0.59	Yes
7.5	233.25	439.25	0.94	0.405	11	0.642	8.47	0.17	0.42	Yes
9	322.8	617.09	0.91	0.407	13	0.550	8.58	0.18	0.44	Yes
10.5	428.75	826.04	0.89	0.401	12	0.477	6.87	0.12	0.30	Yes
12	550.55	1051.83	0.85	0.384	14	0.418	7.02	0.16	0.42	Yes
13.5	687.71	1321.29	0.825	0.377	15	0.377	6.73	0.13	0.34	Yes
15	844.46	1625.04	0.754	0.37	15	0.338	6.08	0.12	0.32	Yes

Table15:-FOS by Seed and Idriss

Depth	σ'_VkN/m²)	σ_VkN/m²)	r_d	CSR	N_{60}	$(N_1)_{60}$	CRR	FOS	Liquefaction
1.5	28.8	28.8	0.98	0.23	3	5.63	0.11	0.48	Yes
3	57.39	86.82	0.97	0.45	5	7.67	0.15	0.33	Yes
4.5	100.68	174.25	0.97	0.69	8	10.62	0.2	0.30	Yes
6	159.3	291.73	0.95	0.90	12	14.22	0.24	0.26	Yes
7.5	233.25	439.25	0.94	1.11	11	11.87	0.22	0.19	Yes
9	322.8	617.09	0.93	1.31	13	12.96	0.24	0.18	Yes
10.5	428.75	826.04	0.92	1.51	12	11.16	0.17	0.11	Yes
12	550.55	1051.83	0.90	1.69	14	12.25	0.21	0.12	Yes
13.5	687.71	1321.29	0.89	1.88	15	12.43	0.18	0.09	Yes
15	844.46	1625.04	0.88	2.06	15	11.82	2.06	0.08	Yes

Table1 6:-FOS by IS Code Procedure

V. COMPARISION

Comparing the results of 8 boreholes obtained from both the methods.

A. **Borehole I**

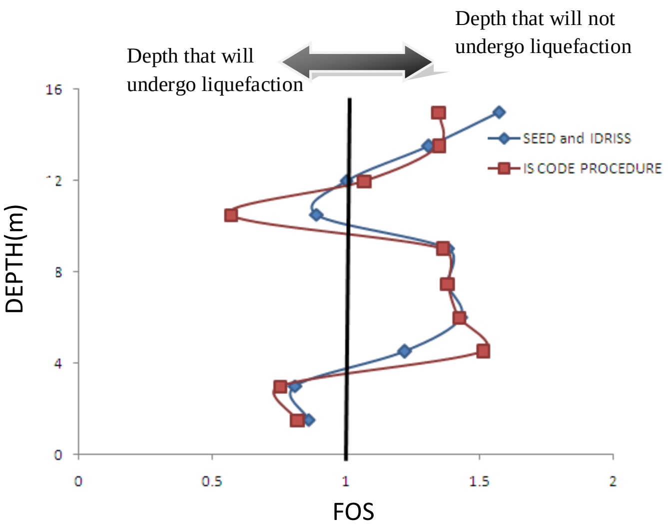

Fig 7:- FOS vs Depth

B. **Borehole II**

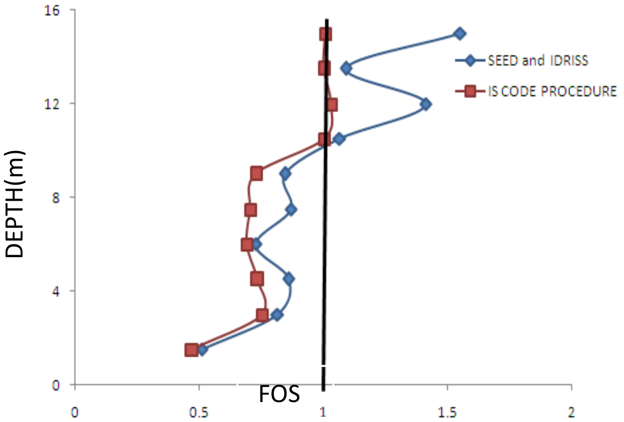

Fig 8:- FOS vs Depth

C.**Borehole III**

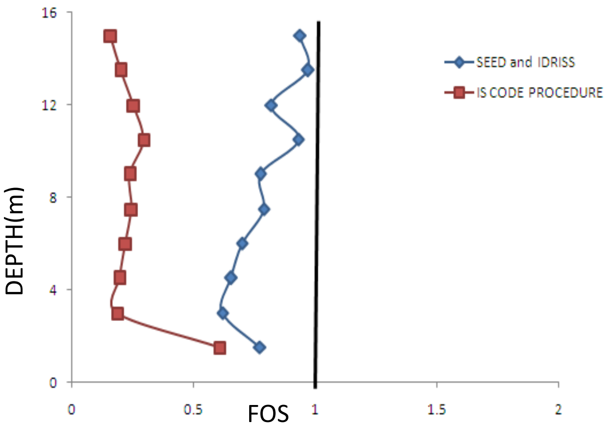

Fig 9:-FOS vs Depth

C. **Borehole IV**

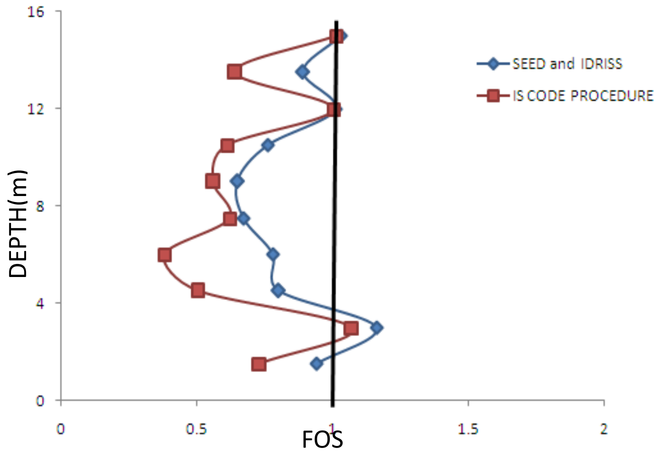

Fig 10:- FOS vs Depth

E.**Borehole V**

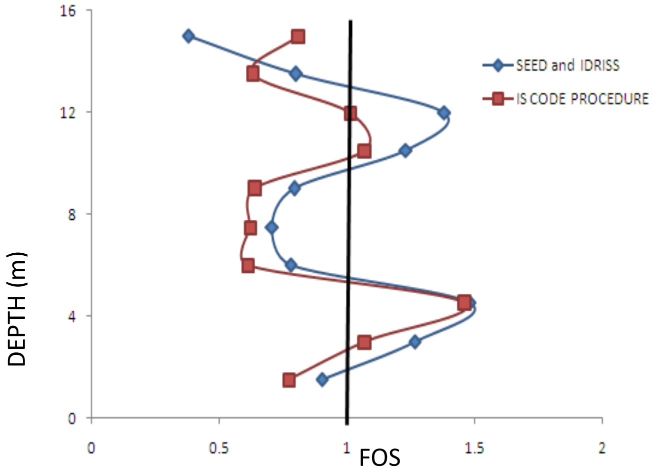

Fig 11:- FOS vs Depth

F.**Borehole VI**

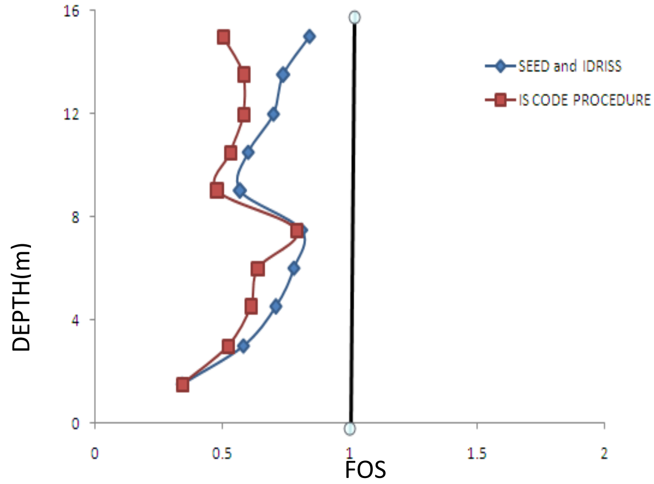

Fig 12:- FOS vs Depth

G. **Borehole VII**

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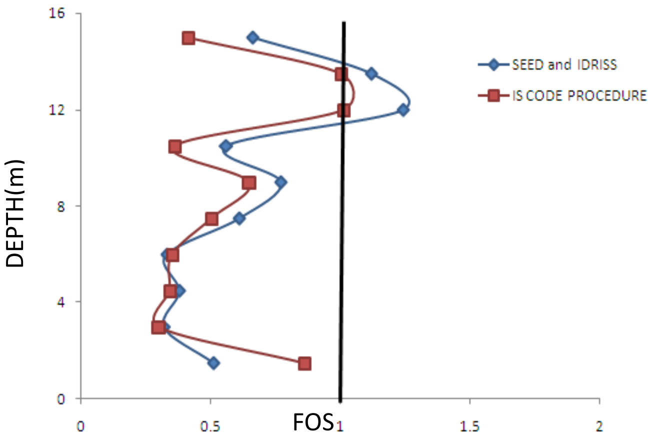

Fig 13:- FOS vs Depth

H.**Borehole VIII**

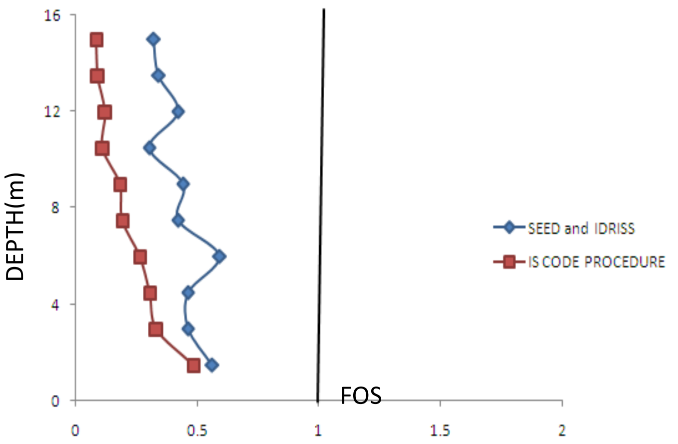

Fig 14:- FOS vs Depth

VI. RESULTS

As per IS code 1893 (2002) Guwahati lies in Zone V. The peak ground acceleration for Guwahati is 0.36g for an 8.1 magnitude earthquake. The factor of safety against liquefaction is determined for all the 95 boreholes using Seed and Idriss and IS Code Procedure. Out of the 95 boreholes 59 boreholes was found to be susceptible to liquefaction by both the methods. The lowest factor of safety against liquefaction among the layers is considered to be the factor of safety for that borehole.

From the calculation it is observed that areas like Chandmari, zoo road, Sixmile, Beltola, Dispur, G.S. Road, Uzanbazar, jalukbari and Bharalamukh are most susceptible to liquefaction.

Although the factor of safety are calculated for all 95 boreholes but tables 1 to 16 shows factor of safety withdepth of only 8 boreholes for both the methods. A comparison of factor of safety between the two methods is shownin figs7 to 14. It is observed that for all the 95 boreholes both the methods gives almost the same results. Hence the IS code procedure may be preferred as it is a much simpler method as compared to Seed & Idriss for evaluation of liquefaction potential.

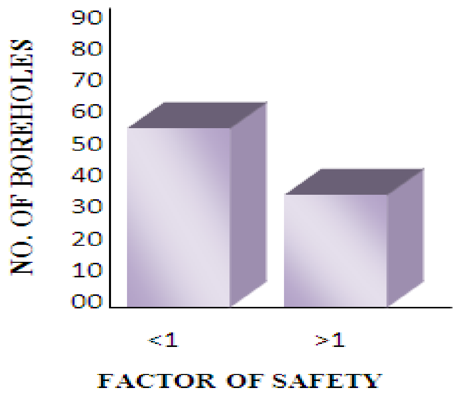

Fig 15:- Bar diagram representing factor of safety against the number of boreholes

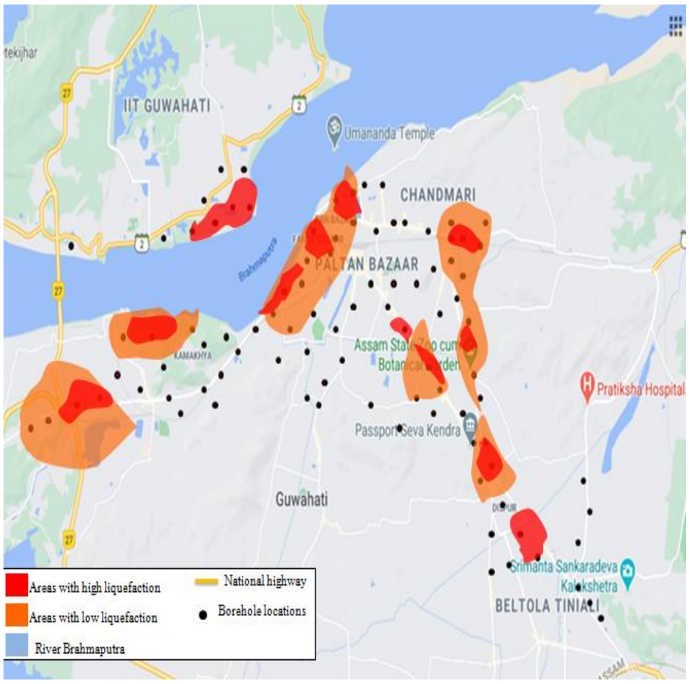

Fig 16:- Liquefaction potential map of GUWAHATI city.

VII. CONCLUSION

In this paper the liquefaction potential of Guwahati city is assessed with the help of Seed and Idriss method (1971) and IS Code Procedure (2016). The factor of safety is calculated using 95 borelog datas, and it is found that the factor of safety is less than 1.0 for 59 boreholes. It is also observed that the total thickness of soil up to 15m is susceptible to liquefaction, which means that Guwahati city area is most vulnerable to liquefaction related hazards during future earthquakes of magnitude more than 8. From the map it is observed that the areas areas like Chandmari, Zoo Road, Sixmile, Beltola, Dispur, G.S. Road, Uzanbazar, Jalukbari and Bharalamukh

are most susceptible to liquefaction. Both the northern and southern bank of the city is susceptible to liquefaction.
Also, a relative comparison of factor of safety using Seed & Idriss and IS Code Procedure method is also made.
Thus it is hoped that this paper contributes in making a broader microzonation map of Guwahati.

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