A SPT based Liquefaction Analysis of Ramgarh Taal in Gorakhpur City

Nitish Kumar Chaudhary[1] Dr. S. M. Ali Jawaid[2] Ms. Sana Zafar[3]
[1]PG Student [2]Head of Department [3]Assistant Professor
[1,2,3]Department of Civil Engineering
[1,2,3]Madan Mohan Malaviya University of Technology, Gorakhpur, U.P., India, 273010

Abstract— Soil liquefaction has been a major cause of damage to soil structure, lifelines and building foundation. Liquefaction is one of the major types for ground failure. Liquefaction is a soil behavior phenomenon in which a saturated soil losses their strength and stiffness due to high excess pore-water pressure generated by during strong earthquake ground shaking. The devastating damage of liquefaction induced ground failures in the Alaska 1964 and Niigata 1964 earthquakes serve as a clear reminder of such events. Liquefaction is one of the main effects during an earthquake that is responsible to structural failure and damage to roads, pipelines and infrastructures. Liquefaction is one of the ground failures in potential earth science hazard. Zoning for liquefaction, therefore, has been an important goal for seismic hazard mitigation. Ramgarh Taal is situated to the southeast of Gorakhpur in Uttar Pradesh. It is a natural lake. Since Gorakhpur falls in the seismic zone IV so there is need for the assessment of liquefaction potential. So the study area is "Ramgarh Taal" to recognize the conditions that exist in a soil deposit before an earthquake in order to identify liquefaction. The main aim of this work is to analyse the liquefaction potential of "Ramgarh Taal" in Gorakhpur city using SPT data collected from the various sites of project by simplified procedure of Idriss & Boulanger. Determination of liquefaction potential due to earthquake is complex geotechnical problem. Many factors including soil parameters and seismic characteristics influence this phenomenon. To assess the liquefaction potential in an area, it is important to examine the geotechnical characteristics like grain size distribution, percentage of silt, water table, water table depth and SPT 'N' value. Here liquefaction potential analysis is done to determine the factor of safety at different depth. The liquefaction is severe in the "Ramgarh Taal" due to the presence of silt and poorly graded sand. So the assessment of liquefaction helps us to select a suitable ground improvement technique and foundation system for future correction in the region. This study helps us to mitigate the disastrous effect of liquefaction.

Key words: Liquefaction, SPT, CSR, CRR, Factor of Safety

I. INTRODUCTION

As India experiencing lots of major seismic threats and liquefaction is one of the major types for ground failure. Liquefaction is a phenomenon of soil behavior in which a saturated soil looses of strength due to high excess pore-water pressure generated and accumulated during strong earthquake ground shaking. The devastating damage of liquefaction induced ground failures in the Alaska 1964 and Niigata (Japan) 1964 earthquakes serve as a clear example of such events. Large numbers of liquefaction studies were conducted in all the earthquake prone areas of the world. After the 2001 Bhuj earthquake and recently 2015 Nepal earthquake attracted the great attention on liquefaction studies.

During earthquakes the shaking of ground may cause a loss of strength or stiffness those results in the settlement of buildings, landslides, and the failure of earth dams or other hazards.

Soil liquefaction has been a major cause of damage to soil structure, lifelines and building foundation. Zoning for liquefaction, therefore, has been an important goal for seismic hazard mitigation. This situation has created the necessity for carrying out a detailed seismic hazard assessment of the city and an awareness building measures to the people of Gorakhpur regarding the earthquake safety. It is also important to carry out more earthquake vulnerability reduction programs in Gorakhpur.

Ramgarh Taal is a natural lake and it is situated to the southeast of Gorakhpur in Uttar Pradesh. It covers an area of about 723 ha. The catchment area around the lake is approximately 1632 acres, out of which, 1235 acres land is under the Gorakhpur Development Authority (GDA). As we know that Gorakhpur is under seismic zone (IV) the need of liquefaction analysis requires the characterization of soil profile.

Liquefaction is one of the main effects of an earthquake that is responsible to structural failure and damage to roads, pipelines and infrastructures. In Gorakhpur region in spite of weak subsurface condition, many tall buildings have been built and the number is constantly rising. Most of these buildings (Except commercial, governmental and organizational buildings) have been constructed without adequate research on the subsurface sediment conditions and hence may run a high risk that they are not properly designed to withstand the particular accelerations at the site. Looking at this situation, the study on subsurface geology is very important, as it helps for the study of seismic hazard and hence for the earthquake vulnerability reduction program.

The main aim of the thesis is to analyse the liquefaction potential of "Ramgarh Taal" in Gorakhpur city using SPT bore holes data collected from the various sites of project by procedure of Idriss & Boulanger. The geological, geotechnical, and seismological details of this area have to be studied which forms important parameters and information to analyse Liquefaction potential of this region.

The objectives of this work is to-

1) Estimate the maximum or equivalent cyclic shear stress ratio (CSR).
2) Estimate the liquefaction resistance of soils using SPT data (CRR).
3) Estimate the liquefaction potential of soil by calculating factor of safety by Idriss & Boulanger method.

II. SOIL LIQUEFACTION & ITS MECHANISM

The phenomenon by which, soil particles below the water table temporarily lose their strength and behave as a viscous liquid rather than a solid known as soil liquefaction. Liquefaction is the phenomena when there is loss of strength in saturated and cohesion-less soils because of increased pore water pressures and hence reduced effective stresses due to dynamic loading. The phenomenon due to which, the stiffness and strength of a soil is decreased by earthquake shaking or other rapid loading called liquefaction.

Liquefaction occurs in saturated soils and saturated soils are those types of soils in which the void between the soil particles is completely filled with water. A pressure on the soil particles exerts due to this water. The water pressure is however relatively low before the occurrence of earthquake. But earthquake shaking increases the water pressure to the point at which the soil particles can readily move with respect to each other.

During the liquefaction, the water available in the soil voids exerts a pressure upon the soil particles. If the pressure is low enough then the soil become stable. Pore water pressure exerts a pressure on the soil particles that influences how tightly the particles themselves are pressed together. The water pressure is however relatively low before the occurrence of earthquake. But earthquake shaking increases the water pressure to the point at which the soil particles can readily move with respect to each other.

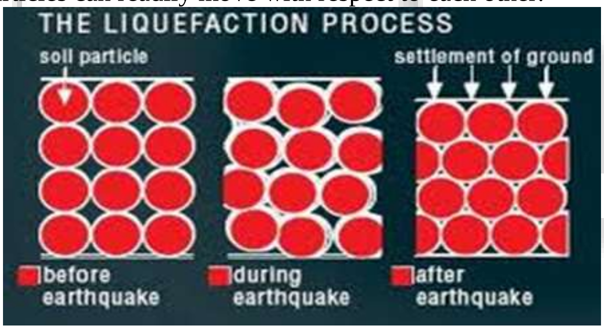


Fig. 1: Mechanism of soil liquefaction

A. Flow Liquefaction

It occurs when the static shear stress is greater than the shear strength of the soil in its liquefied state. When liquefaction occurs in such case the strength of the soil reduces and the ability of soil deposit to support for the structure is reduced. Flow liquefaction failures are characterized by the sudden nature of their origin, the speed with which they develop and the large distance cover over which the liquefied materials often move.

B. Cyclic Mobility

It occurs when the static shear stress is less than the shear strength of the liquefied soil. During earthquake shaking, it produces unacceptably large permanent deformation, which is also known as lateral spreading. It can occur on very mild sloping ground or on virtually flat ground adjacent to bodies of water.

Flow liquefaction occurs much less frequently than cyclic mobility but its effects are usually far more severe. Besides these two types, Ground oscillation, loss of bearing strength and sand boils are common phenomena of Liquefaction.

1) Geology of Gorakhpur

The district of Gorakhpur lies between Lat. 26°13′N and 27°29′N and Long. 83°05′E and 83°56′E. Gorakhpur has also a lake Ramgarh Taal Lake, which is 18 km bigger. It is bigger than Dal Lake of Kashmir which is of 15.5 km Ramgarh Taal. It's vast and provides home to various types of fishes. Geography the peak of Dhaulagiri, some 8,230 meters above sea-level, is visible under favourable climatic conditions as far south as Gorakhpur itself. The district geology is primarily river born alluvium. This impasses a very high risk of an earthquake disaster in Gorakhpur resulting into great damage. To determine the potential hazard due to an earthquake appropriate site characterization and determination of the soil properties are essential in order to suitably design a structure.

Ramgarh Taal is a natural lake and it is situated to the south-east of Gorakhpur in Uttar Pradesh. It covers an area of about 723 ha. The catchment area around the lake is approximately 1632 acres, out of which, 1235 acres land is under the Gorakhpur Development Authority (GDA). As we know that Gorakhpur is under seismic zone the need of liquefaction analysis requires the characterization of soil profile. So my work is to analyse the liquefaction potential of an area and the liquefaction potential map.

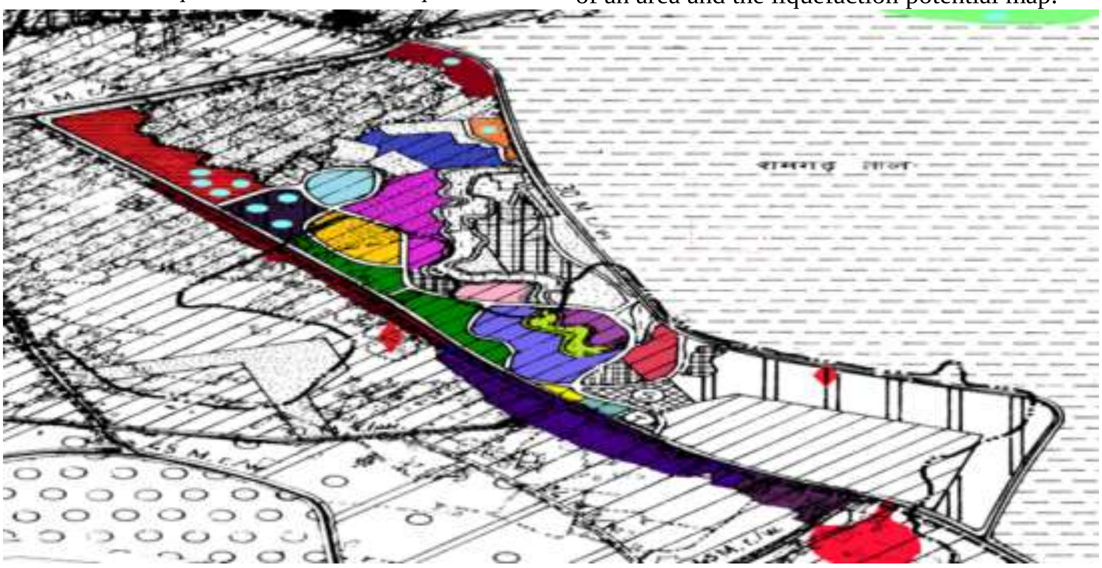


Fig. 2: Map of Ramgarh Taal Project representing Location of Bore Hole

2) Generation and Management of Data

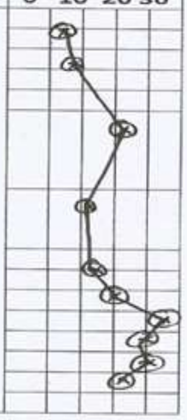
Collection and organization of data-extensive borehole data is collected from various locations of Ramgarh Taal Project and 10 borehole data were collected at different sites shown in fig 3 for liquefaction zonation.

All the data managed in a same platform so as to easily accessible. Data used to analyse liquefaction potential of a soil, Microsoft Excel 2007 and Microsoft Access were used to store the borehole data which was collected during the SPT test. Firstly the collected data were entered in the Excel sheets. After the data acquisition was completed, all the boreholes were grouped according to their types and source as shown in the tables given in appendix.

The deep bore holes samples and data are also used to study the geological evaluation of the site. Three tables are generated in this research work. One containing the information such as: borehole id, site location, depth range, geological information, Soil type, thickness of the strata, SPT 'N' value, corrected N-value and corrected SPT curve. The second table includes the geotechnical information such as: borehole-id, site location, depth range, particle size distribution, consistency limit and soil classification. Third table also contains the geotechnical information such as moisture content, bulk density, unit weight and shear characteristics.

C. Appendix-1

SOIL TYPE	I.S. SOIL GROUP	DEPTH BELOW G.L. in meter 0m	LOG	RECORDED N- VALUE	CORRECTED N- VALUE	SPT CURVE No. Of blows N-value (corrected) 0 10 20 30
Inorganic Silts	ML	1m 2m 3m		8	11	
Highly compressed silt with occasional organic content	MH/OH	4m 5m 6m		12 23	16 22	
Med. Compressed silt	MI	7m		11	12	
Poorly graded sands	SP	8m 9m 10m 11m 12m 13m 14m 15m		13 25 49 49 49 38	14 20 32 30 30 24	



Position of water table =2.00m

Table 1: Borelog Chart and SPT Curve

Site: G.D.A. Office Building, Siddharth Enclave Scheme, Gorakhpur. Bore Hole No-1

S. NO	DEPTH OF SAMPLING M	PARTICLE SIZE DISTRIBUTION							CONSISTENCY LIMIT			SOIL CLASSIFICATION
		GRAVEL		SAND			SILT 0.075-0.002 mm (%)	CLAY >0.002 mm (%)	LL (%)	PL (%)	PI (%)	IS:1498 -1970
		Coarse 80-20 mm (%)	Fine 20-4.75 mm (%)	Coarse 4.75-2.0 mm (%)	Medium 2.0-0.425 mm (%)	Fine 0.425-0.725 mm (%)						
	1.65-1.95	0.0	0.0	0.5	0.5	9.0	90.0	0.0	35	25	10	M.I.
	2.80-3.35	0.0	0.0	0.2	0.8	5.0	94.0	0.0	31	24	7	M.L.
	3.50-3.80	0.0	3.5	0.5	0.5	0.2	95.3	0.0	51	29	22.	M.H/OH
	4.75-5.05	0.0	3.0	0.4	0.5	0.5	95.6	0.0	50	29	21	M.H/OH
	6.50-6.80	0.0	2.6	2.8	1.4	3.2	90.0	0.0	36	29	7	M.I.
	7.80-8.10	0.0	0.3	0.0	0.5	95.2	4.0	0.0	-	-	N.P.	S.P
	9.30-9.60	0.0	0.2	0.0	0.2	95.6	4.0	0.0	-	-	N.P.	S.P.
	10.75-11.05	0.0	0.0	0.0	0.0	97.0	3.0	0.0	-	-	N.P.	S.P.
	12.30-12.50	0.0	0.0	0.0	0.5	96.5	3.0	0.0	-	-	N.P.	S.P
	13.60-13.90	0.0	0.0	0.0	0.7	97.0	2.3	0.0	-	-	N.P.	S.P
	14.00-14.30	0.0	0.0	0.0	0.4	96.0	3.6	0.0	-	-	N.P.	S.P
	15.00-15.30	0.0	0.0	0.0	0.5	96.5	3.0	0.0	-	-	N.P.	S.P

Table 2; Summary Of Mechanical Grading And Consistancy Limit

Site: G.D.A. Office Building, Siddharth Enclave Scheme, Gorakhpur. Bore Hole No -1

S.NO	DEPTH OF SAMPLING m	BULK DENSITY t/m³	MOISTURE CONTENT %	DRY DENSITY t/m³	SHEAR CHARACTERISTICS		REMARKS
					C Kg/cm²	Φ deg	
1.	1.65-1.95	1.98	24.56	1.59	0.12	7	
2.	2.80-3.35	1.98	21.83	1.62	0.15	7.5	
3.	3.50-3.80	1.90	-	-	0.10	7	
4.	4.75-5.05	1.97	25.00	1.57	0.12	7	
5.	6.50-6.80	1.98	-	-	0.12	8	
6.	7.80-8.10	1.89	-	-	0.00	34.5	
7.	9.30-9.60	1.97	-	-	0.00	35	
8.	10.75-11.05	1.99	-	-	0.00	34	
9.	12.30-12.60	1.98	-	-	0.00	34	
10.	13.60-13.90	1.97	-	-	0.00	34.5	
11.	14.00-14.30	1.95	-	-	0.00	34	
12.	15.00-15.30	1.99	-		9.00	34	

Table 3: Summary of Laboratory Results
Site: Proposed G.D.A. Office Building, Siddharth Enclave Scheme, Gorakhpur Bore Hole No-1

III. METHODOLOGY

A. *Idriss & Boulanger Method*

The methodology is used to determine the liquefaction potential of Ramgarh Taal using procedure of Idriss & boulanger. The following steps are followed to determine the liquefaction Potential.

1) Step 1:

The borehole data used to assess liquefaction susceptibility included the location of the water table, SPT N value, soil grain size, unit weight and fines content of the soil (percent by weight passing the IS Standard Sieve No. 76µ).

2) Step 2:

Summary of mechanical grading, consistency limits and other laboratory test results such as (bulk density, moisture content, dry density and shear characteristics) were obtained.

3) Step 3:

The total vertical stress (σ_{vo}) and effective vertical stress (σ'_{vo}) for soil layers were evaluated.

4) Step 4:

The following equation can be used to evaluate the stress reduction factor r_d:

For $Z \leq 34$m

$r_d = \exp(\alpha(z) + \beta(z)M)$

$\alpha(z) = -1.012 - 1.126 \sin((z/11.73) + 5.133)$

$\beta(z) = 0.106 + 0.118 \sin((z / 11.28 + 5.142)$

For $Z > 34$m

$r_d = 0.12 \exp(0.22M)$

Where "z" is the depth below the ground surface in meters

M- Magnitude of the earthquake.

5) Step 5:

The Critical stress ratio induced by the design earthquake, CSR was calculated as:

$$CSR = 0.65 \,(a_{max} / g)\, r_d \,(\sigma_{vo}/ \sigma'_{vo})$$

Where, σ_{vo} and σ'_{vo} are the total and effective vertical stresses, respectively, at depth z, a_{max} is the peak horizontal ground acceleration (PHGA), and g is the acceleration due to gravity.

6) Step 6:

The standardized SPT blow count (N_{60}) which is the standard penetration blow count for a hammer with an efficiency of 60 percent is now evaluated. The standardized SPT blow count is obtained from the equation:

$$N_{60} = N.C_{60}$$

Where, C_{60} is the product of various correction factors.

Now the normalized standardized SPT blow count, $(N_1)_{60}$ are calculated using

$$(N_1)_{60} = C_N N_{60}$$

Where, Stress normalization factor C_N is calculated from the following expression:

$C_N = (P_a / \sigma'_{vo})^m \leq 1.7$

Where, $m = 0.784 - 0.0768 \sqrt{(N_1)_{60}}$

The equivalent clean sand SPT penetration resistance $(N_1)_{60cs}$ value for cohesionless soils is developed by Idriss and Boulanger 2004, 2008

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

$\Delta (N_1)_{60}$ is the equivalent clean-sand adjustment empirically derived by Idriss and Boulanger 2004, 2008. It is used to account for the effects of fine content on CRR.

$\Delta (N_1)_{60} = \exp(\,1.63 + (\,9.7 / FC) - (\,15.7 / FC)^2\,)$

FC = fines content

7) Step 7:

Now for assessing liquefaction susceptibility using the SPT we compute cyclic resistance ratio, CRR

$CRR = \exp\{((N_1)_{60cs} / 14.1) + ((N_1)_{60cs} / 126)^2 - ((N_1)_{60cs} / 23.6)^3 + ((N_1)_{60cs} / 25.4)^4 - 2.8\}$

8) Step 8:

The factor of safety against initial liquefaction, FS, is calculated as:

$$FS = (CRR_{7.5}/CSR)\, MSF$$

Where,

CRR= Cyclic Resistance Ratio

CSR= Cyclic Stress Ratio

MSF= Magnitude Scaling Factor

CRR of soils is affected by the magnitude scaling factor, MSF. It is calculated based on the relation recommended by Idriss (1999).

$$MSF = 6.9 \exp(-M / 4) - 0.058$$

Where,

M = Magnitude of Earthquake

Liquefaction is predicted to occur when FS ≤ 1.0, and liquefaction predicted not to occur when FS > 1.

IV. LIQUEFACTION POTENTIAL ANALYSIS

As mentioned that our first aim is to analyse liquefaction potential of soil of "Ramgarh taal" using SPT borehole data. Liquefaction phenomena have been recorded in many parts of the world, where ground shaking is frequent and soils consist of loose fine sand where the water table is shallow. Liquefaction of saturated loose sands and silty sands induce flow slides, differential settlement, and subsidence, leading damage to buildings and infrastructure and eventually to loss of life. Determination of liquefaction potential due to earthquake is complex geotechnical problem. Many factors including soil parameters and seismic characteristics influence this phenomenon To assess the liquefaction hazard in an area, it is important to examine the geotechnical characteristics like grain size distribution, percentage of silt, water table ,water table depth and SPT 'N' value. The percentage of silt and poorly graded sand is high in the area under "Ramgarh Taal" indicating that there is a great chance of soil liquefaction. Here liquefaction potential analysis is done to determine the factor of safety at different depth. The liquefaction potential of "Ramgarh Taal" in Gorakhpur city using SPT data collected from the various sites of project is estimated by simplified procedure of Idriss & Boulanger.

The methodology used to estimate the liquefaction potential is given as example for one borehole Excel spread sheet used to calculate the Factor of Safety with depth and enclosed in tables shown below

A. Idriss & Boulanger Method

depth(m)	soil type	%gravel	%fines	SPT 'N'	SPT corrected (N1)60	γ(kN/m³)	γ'	σ_{vo}	σ'_{vo}	Mw	rd=(z<=34)	a_{max}	CSR	MSF	Δ(N1)60	(N1)60cs	CRR	FOS	Remark
1.8	inorganic silt	0	90	8	11	1.98	-	3.564	-	8	0.996673484	0.24	0.554134511	0.87581345	5.514312107	16.51431	0.16939078	0.267723308	Liquefaction
3.075	inorganic silt	0	94	8	11	1.98	0.98	6.0885	3.0135	8	0.988990168	0.24	0.311713554	0.87581345	5.50301092	16.50301	0.169287369	0.475642311	Liquefaction
3.65	highly compr. Silt with occasional organic content	0	95.3	12	16	1.9	0.9	6.935	3.285	8	0.985183637	0.24	0.324453811	0.87581345	5.499425387	21.49943	0.225633916	0.609064257	Liquefaction
4.9	highly compr. Silt with occasional organic content	0	95.6	23	22	1.97	0.97	9.653	4.753	8	0.97621016	0.24	0.309287532	0.87581345	5.498604184	27.4986	0.364100282	1.031027417	No Liquefaction
6.65	medium compr. Silt	0	90	11	12	1.98	0.98	13.167	6.517	8	0.962139186	0.24	0.303250563	0.87581345	5.514312107	17.51431	0.17885181	0.51653926	Liquefaction
7.95	poorly graded	0	4	13	14	1.89	0.89	15.0255	7.0755	8	0.950645552	0.24	0.314930713	0.87581345	1.17621E-05	14.00001	0.147901102	0.411308803	Liquefaction
9.45	poorly graded	0	4	25	20	1.97	0.97	18.6165	9.1665	8	0.936401136	0.24	0.296675049	0.87581345	1.17621E-05	20.00001	0.205852855	0.607697549	Liquefaction
10.9	poorly graded	0	3	49	32	1.99	0.99	21.691	10.791	8	0.92175443	0.24	0.289039844	0.87581345	1.65104E-10	32	0.644207295	1.951998761	No Liquefaction
12.45	poorly graded	0	3	49	30	1.98	0.98	24.651	12.201	8	0.905295766	0.24	0.285334445	0.87581345	1.65104E-10	30	0.484931568	1.488462396	No Liquefaction
13.75	poorly graded	0	2.3	49	30	1.97	0.97	27.0875	13.3375	8	0.890974651	0.24	0.282282814	0.87581345	2.01065E-18	30	0.484931568	1.504553485	No Liquefaction
14.15	poorly graded	0	3.6	38	24	1.95	0.95	27.5925	13.4425	8	0.88649077	0.24	0.283863676	0.87581345	4.15059E-07	24	0.268149599	0.827330322	Liquefaction
15.15	poorly graded	0	3	38	24	1.99	0.99	30.1485	14.9985	8	0.875152518	0.24	0.274426614	0.87581345	1.65104E-10	24	0.26814959	0.85578077	Liquefaction

Table 4: Liquefaction Assessment of Proposed G.D.A. Office Building, Siddharth Enclave Scheme, Gorakhpur (Bore Hole-1)

V. RESULTS AND ITS DISCUSSIONS

Result of liquefaction is shown with depth for of each site of bore holes and graph shows factor of safety vs. depth.

A. Bore Hole Number 1 (BH1)

The analysis of SPT results by idriss & boulanger method at Bore hole number-1 shows that the soil strata between depths 4.75-5.05 m & 10.75-13.90 m are Non-Liquefiable and the soil strata between 1.65-3.80 m, 6.50-9.60 m & 14.0-15.30 m are responsible to liquefy under seismic shaking corresponding to peak horizontal ground acceleration of 0.24g.

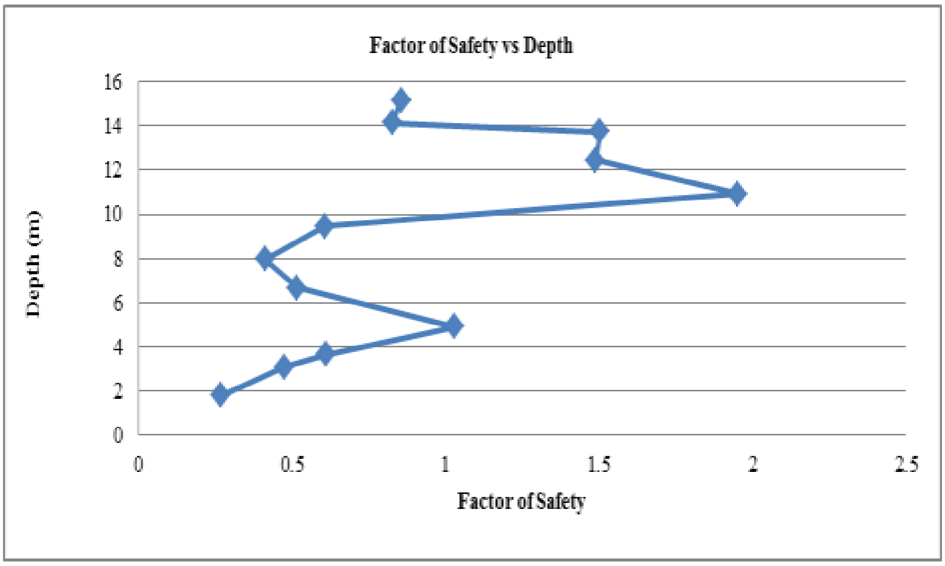


Fig. 3: Depth vs Factor of Safety Graph

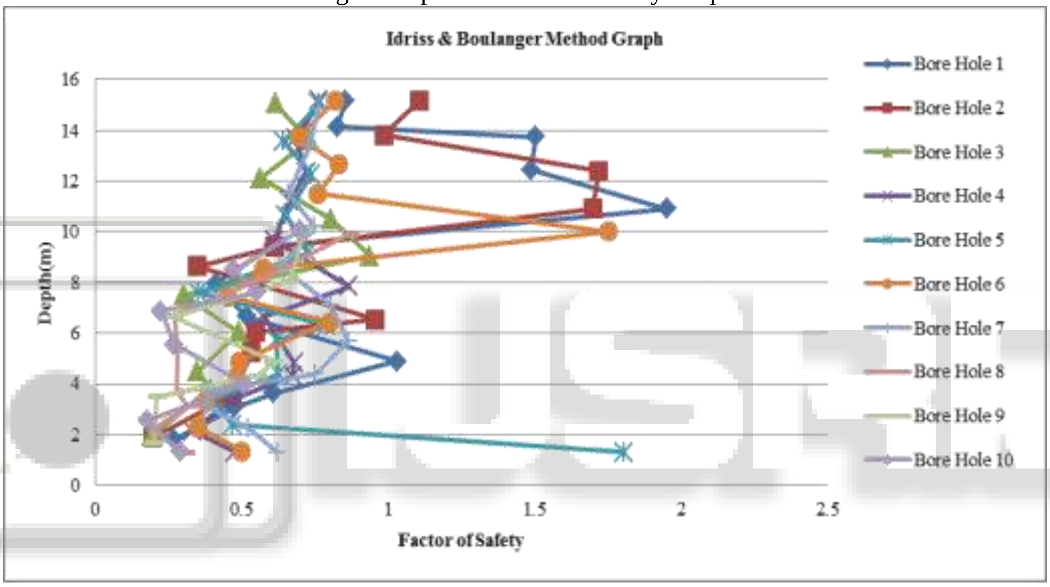


Fig. 4: Depth vs. Factor of Safety for all bore holes using Idriss & Boulanger method

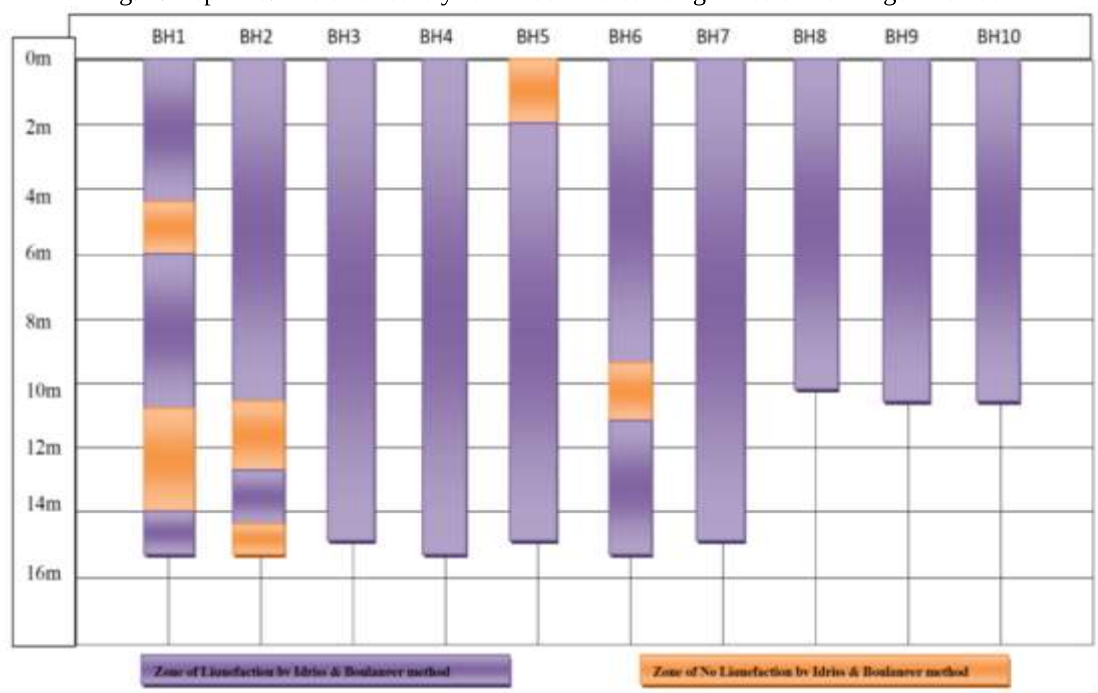


Fig. 5: Depth wise liquefaction of each bore hole

VI. CONCLUSION

Based on the study for assessment of liquefaction potential for "Ramgarh Taal", it is concluded that soil of study area is susceptible to liquefaction extra care should be taken against liquefaction during construction upon this type of soil. The Study area being a reclaimed area has a top layer of loose fine sand followed by soft to medium or loose sandy silt or clayey silt is also susceptible to liquefaction.

In this study we concluded that if earthquake more than or equal to 8 ritcher scale occurs in Gorakhpur region, it will be extensively damaged due to liquefaction.

- In Fig 3. there is a graph between factor of safety and depth for bore hole 1, which show the factor of safety at different depth.
- In fig 4 combined graph is drawn between factor of safety and depth of all 10 bore holes using Idriss & Boulanger method. In this graph the soil strata whose factor of safety is less than 1 is susceptible to liquefaction and should be considered for mitigation before building a structure on it.
- In the fig 5, we have bore hole position wise combined data of all the studied bore holes and depth wise zone of liquefaction and zone of no liquefaction using Idriss & Boulanger method. In this figure, there is also a comparison of depth wise zone of liquefaction and zone of no liquefaction. Observation of combined graph shows liquefaction potential for each borehole and depth upto which soil may liquefy during an earthquake.
- The percentage of silt and poorly graded sand is high in the tested area under "Ramgarh Taal" indicating that there is a great chance of soil liquefaction. Here liquefaction potential analysis is done to determine the factor of safety at different depth.
- The construction should be avoided on liquefaction susceptible soils. There are various criteria to determine the soil's liquefaction potential in a site. According to these criteria, the soil of a particular building site is characterized.
- The construction of structure should be liquefaction resistant i.e., the foundation elements should be designed to resist the effects of liquefaction. Due to favourable location, space restriction and other reasons if it is necessary to the construction of structure on liquefiable soil, the foundation should be liquefaction resistant.
- Improvement of soil is an important method to mitigate the adverse effect of liquefaction hazards by improving the soil by improving the density, strength and drainage characteristics of the soil. This can be done by using various types of soil improvement techniques.

REFERENCES

[1] Chapter 2: soil liquefaction in earthquakes.
[2] IS: 1893-2002, "Criteria for Earthquake Resistant Design of Structures".
[3] Idriss I.M. and Boulanger R.W. (2004) "Semi-Empirical Procedures for Evaluating Liquefaction Potential During Earthquakes". Proc. of 11th SDEE and 3rd Conference. University of California, Berkeley
[4] Idriss I. M., and Boulanger R. W. (2006). "Semi-empirical procedures for evaluating liquefaction potential during earthquakes." Soil Dyn. Earthquake Eng., 26, 115–130.
[5] Idriss, I.M., R.W. Boulanger (2008), "Soil liquefaction during earthquake", Eq Engg. Research Institute, EERI Publication, Monograph MNO-12, Oakland, CA.
[6] Idriss, I.M., R.W. Boulanger (2010), "SPT-based liquefaction triggering procedures" Report No. UCD/CGM-10-02 Centre for Geotechnical Modelling Department of Civil and Environmental Engineering University of California Davis, California.
[7] I.M. Idriss,(1999) "An update to the Seed-Idriss simplified procedure for evaluating liquefaction potential", Proc., TRB Workshop on New Approaches to Liquefaction, January, Publication No. FHWA-RD-99-165, Federal Highway Administration.
[8] K. S. Rao, (2001), "Liquefaction Studies for seismic microzonation of Delhi region". In Indian Geotechnical Conference, vol. 2, pp. 44–51.
[9] K. S. Rao and D. Neelima Satyam (2007), "Liquefaction studies for seismic microzonation of Delhi region", Current Science, 646 Vol. 92, No. 5.
[10] Robertson, P.K. and Fear, C.E. (1996), "Soil liquefaction and its evaluation based on SPT and CPT", Liquefaction Workshop.
[11] Seed, H. B. and Idriss, I. M., (1971) "Simplified Procedure for Evaluating Soil Liquefaction Potential". J. Soil Mech. Found. Div. vol. 97, pp, 1249–1273.
[12] Seed, H.B. and Idriss, I.M. and Arango, I. (1983). "Evaluation of liquefaction potential Using Field Performance data". ASCE Journal of Geotechnical Engineering, 109(3), 458-482.

