Liquefaction Analysis of Taramandal Area in Gorakhpur City

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Abstract— Liquefaction is defined as the strength and stiffness of soil is decrease by earthquake shaking or other sudden loading due to increment of pore water pressure. Liquefaction is main effects of an earthquake which is responsible for failure of structures, damages of roads, water retained structure such as dams etc. This project report is provides knowledge and ideas about liquefaction of soil. In this paper, some methods have been studied, empirical method of calculation of soil is liquefaction potential based method for analysis of soil liquefaction. Liquefaction analysis of Taramandal area using these three method and compare the factor of safety (FOS) obtained in the liquefaction analysis. A comparative study has been done using all above mentioned methods and using Geotechnical data (such as:- Depth, Soil type, SPT-N value, Grain size, Density, Depth of water table, etc.) and Seismic or Earthquake data (such as: - Magnitude of earthquake and Maximum horizontal acceleration).

Keywords: Liquefaction, Seismic Hazard, SPT, CSR, CRR, FOS

I. Introduction

Soil liquefaction is cause of building foundation and soil structure damage. For assessment of seismic hazard, India has been divided in four parts of zoning (Zone II, III, IV & V).

By this division easily execute the assessment of seismic hazard and provide safety for people from earthquake. Liquefaction is defined as strength and stiffness of soil decrease by earthquake shaking or Other sudden loading due to increment of pore water pressure. Liquefaction is mainly appears in saturated soils and these soils in which the distance between separate particles is fully filled with water.

Occurrence of movement between soil particles the because of increment of pore water pressure in the soil particles. That is cause of liquefaction when earthquake shaking.

- Condition for occurrence of liquefaction:-
  - In the ground surface 15 m. deep the ground water.
  - The soil required be excitable to liquefaction.
  - Duration of shaking- shaking to continue for some time.

A. Study Area

1) Liquefaction potential assessment of Taramandal city Gorakhpur:-

Taramandal is the study area, where analyze the liquefaction potential of that soil. Taramandal is comes in Gorakhpur city, Uttar Pradesh. Study are is comes under the authority of Gorakhpur Development (GDA). Area of this place is highly flood prone area. So the possibilities of liquefaction of this area is more. Gorakhpur is comes under seismic zone IV.

B. About Gorakhpur City

1) Geology of Gorakhpur

The geology of Gorakhpur district lies between
Lat. 26°13′N and 27°29′N and
Long. 83°05′E and 83°56′E.

Gorakhpur is a semi metropolitan city in Uttar Pradesh. The region covers the north eastern corner of Deoria. It is surrounded by Ghaghara River near north, on the west side it is surrounded by Basti. It is also touches the territory of Nepal.

Gorakhpur is highly flood prone and earthquake prone area. Twenty percent population of Gorakhpur are highly effected by floods. Underground water level becomes high at the time of monsoon. The majority of area will be effected by the natural disaster like flood, cyclone and earthquakes.

Gorakhpur is ranked in zone four in the earthquake zonal map of India. The earthquake which occurred in Nepal on April 25, 2015, also affected vast portion of Gorakhpur. The major impact of this earthquake was soil liquefaction.

Fig. 1: Soil Liquefaction

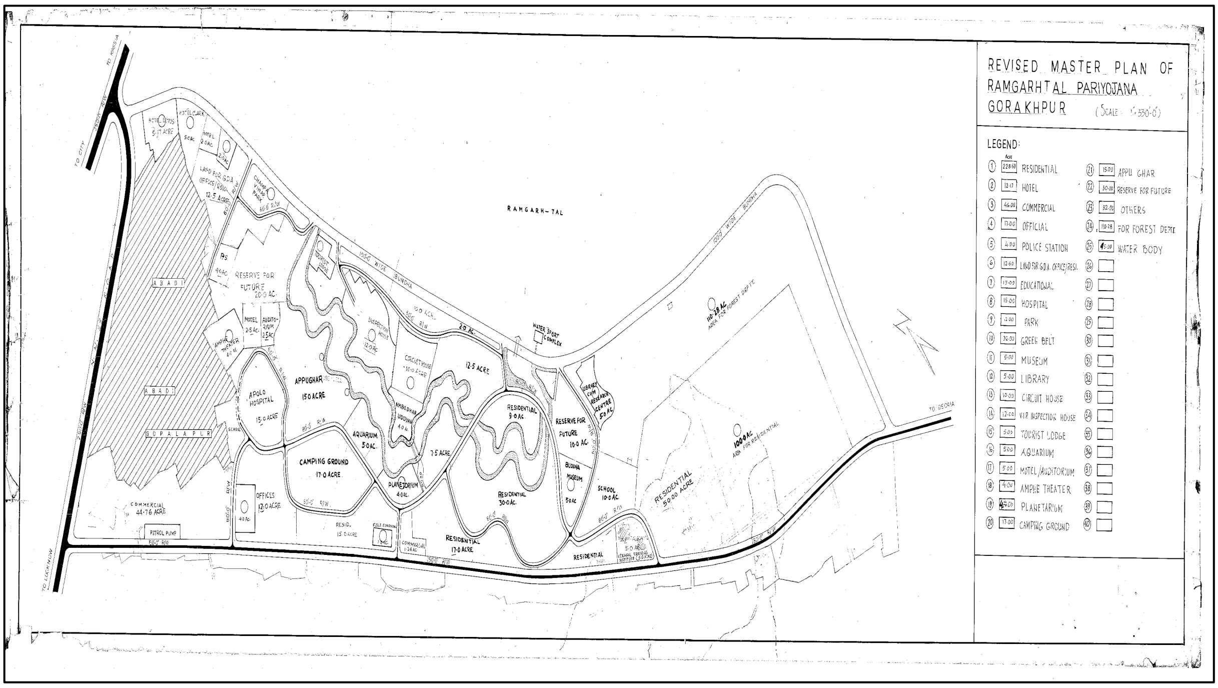

Fig. 2: Map of "Taramandal Project"

C. *Aim of Study*

Due to earthquake liquefaction occurs that is very harmful. The purpose of study of liquefaction is to provide knowledge about soil liquefaction which is a huge problem in civil engineering. Particularly under the branch of geotechnical in which studies the behavior of soils, occurrence of rapid loading forces and water interaction in the soil. Secondly to present the evaluation method for the potential of liquefaction in soil. Lastly to show various method in which mitigation of liquefaction hazards can be achieved and also present a few studies on soil liquefaction.

Appearance of liquefaction in different type earthquakes. Which has been recorded in geology and history.

There are so many past earthquake data (geotechnical and historical) are used to assessment of liquefaction by different –different method.

- Objectives

The main objectives of this work is:-

To carry out liquefaction analysis of Taramandal area using three different methods such as:

1) Seed & Idriss (1971)
2) Tokimatsu & Yamini (1983)
3) Idriss & Boulanger (2008)

To compare (FOS) factor of safety which is obtained from the assessment of liquefaction potential.

II. SOIL LIQUEFACTION

The soil particle move freely regarding to each other because of increment of stiffness and strength of soil deposit. When the liquefaction is appeared the pore water pressure become great high to oppose the gravitational pull on soil particles cause waft or suspended particle.

A. *TYPE OF SOIL LIQUEFACTION*

It can be classified as:-

1) *FLOW LIQUEFACTION*

In which Static equilibrium condition is ruined by static loading or dynamic loading with less remaining strength in a soil deposit. When static shear stress soil be the greater the shear strength of liquefied soil.

2) *CYCLIC MOBILITY*

When cyclic loading appears in soil deposits with shear stress.

Due to static and dynamic stress that during the earthquake during cyclic loading produced incensement.

Lateral spreading a common result of cyclic mobility can occure on gently sloping and on flat ground close to rivers and lakes.

B. *Contect Forces in Soil*

1) *Soil before Liquefaction*

In a soil deposits soil grains. The height of the blue column to the right represent the level of pore water Pressure in the soil.

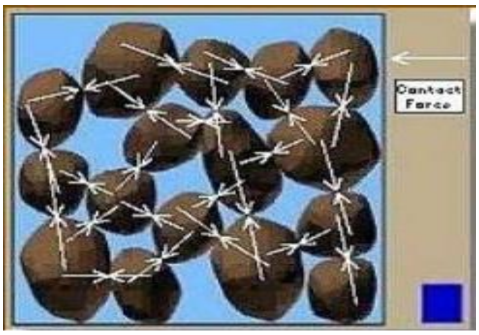

Fig. 3: Soil before liquefaction

2) *Soil after Liquefaction*

The arrow's length represents the size of the adjacent forces between individual soil grains. When the pressure is less in pore water the contact force are large.

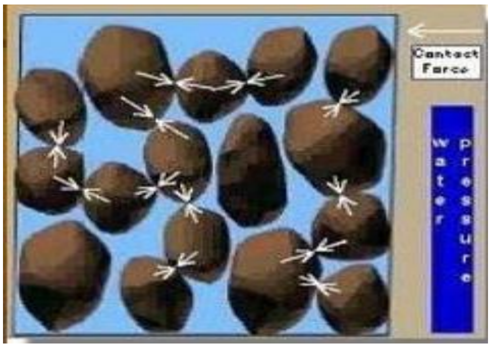

Fig. 4: Soil after liquefaction

Due to saturated sand, loose sand and the loosely-paced soil particle is result of quick loading the liquefaction is appeared. Under the quick and Earthquake loading forces, there are not any time to complete forces out of pore-water in the soil. In the place of existence force out, the soil particles are move with each other, by this they are obstructed.

C. Factor Which Affect the Soil Liquefaction

There are some factor which affect the soil liquefaction, such as:

1) Ground motion and surrounding faults
2) Soil Properties
3) Geological Conditions

D. Failure of Ground According to Soil Liquefaction

There are ground failure according to liquefaction of soil:

- Sand boiling
- Failure of retaining wall
- Ground settlement
- Flow failure
- Buoyant rise
- Lateral spreading
- Loss of bearing capacity
- Ground oscillation

III. FIELD DATA

A. Requirement of Data for Liquefaction potential assessment

For the liquefaction potential assessment there are two ways: -

1) Geotechnical data:-

Conventional Method governs data requirements. Therefore Geotechnical data required for Liquefaction potential assessment are as:

- Depth, Soil Type, SPT-N value, Grain size, Density, Depth of water table etc.

2) Seismic or Earthquake data:

In this way for analysis of Liquefaction potential data are required are Magnitude of earthquake and Maximum horizontal acceleration.

3) Field Data Collected

The data has been collected from Department Civil Engineering (Geotechnical Engineering), in M.M.M.U.T., GORAKHPUR. The field data organized and collected from various location of Taramandal City project. 7 borehole data were collected at different sites for liquefaction potential analysis. Standard Penetration Test (SPT) carried out in different location of Taramandal city. The collection of Geotechnical data are in different format depending upon source of constitutions and the individual plan.

IV. METHODOLOGY

A. Empirical procedure for calculation of liquefaction potential

There are four main steps for evaluating liquefaction potential. The most simple and common techniques using SPT blow count "N- value" follows procedures

1) To determine the ability of liquefaction of soil at the time of earthquake.
2) To calculate the CSR (cyclic stress ratio) at different depths in the soils.
3) To calculate the CRR (cyclic resistance ratio) by the use of SPT.
4) To calculate FS (factor of safety) of liquefaction potential of soil.

So, there are many empirical methods in presents research work. There are 3 methods used for evaluating of the liquefaction potential of Taramandal city during earthquake.

1) SEED & IDRISS (1971)
2) TOKIMATSU & YOSHIMI (1983)
3) IDRISS & BOULANGER (2006)

B. SEED & IDRISS (S & I) (1971) METHOD

1) The simplified procedure for calculating (CSR) Cyclic stress ratio

Seed & Idriss (1971) simplified method to use to calculate the CSR induced by ground motion at (z) depth below the ground surface by this equation:-

$$CSR = 0.65\left(\frac{a_{max}}{g}\right)\left(\frac{\sigma_{VO}}{\sigma'_{VO}}\right) r_d$$

Where,

σ_{VO} = total vertical stress

σ'_{VO} = effective vertical stresses

a_{max} = maximum horizontal acceleration (PHGA)

g = Acceleration due to gravity

r_d = reduction factor

2) Calculation of Stress Reduction Factor r_d

$r_d = 1 - 0.00765\,z$ for $z \le 9.15$ m

$r_d = 1.174 - 0.0267\,z$ for $9.15 < z \le 23$ m

3) Use of SPT-blow count for soil liquefaction characteristics

The SPT-blow count (N_{60}) in which 60 % of efficiency of SPT-blow count for a hammer is evaluated. Equation of this is as:

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

Where,

C_{60}= various correction factor product

Then SPT-blow $(N_1)_{60}$count is evaluated by this equation:

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

Where,

C_N = Stress normalization factor

This is calculated by using this equation:

$$C_N = (Pa/\sigma'_{VO})^{0.5}$$

Subjected to $C_N \le 2$

Where,

Pa= atmospheric pressure.
This expression proposed by Liao and Whiteman in (1986) also used:

$$C_N = 9.79(1/\sigma'_{VO})^{0.5}$$

4) Calculation of (CRR) cyclic resistance ratio

The CRR is calculated by this equation:-

$$CRR_{7.5} = \frac{1}{34-(N_1)_{60}} + \frac{(N_1)_{60}}{135} + \frac{50}{[10\cdot(N_1)_{60}+45]^2} - \frac{1}{200}$$

This Equation is for $(N_1)_{60} < 30$ for $(N_1)_{60} \geq 30$

5) Calculation of (MSF) Magnitude Scaling Factor

MSF = Magnitude Scaling Factor
In 2001 Youd and Idriss recommend the following equation for obtaining MSF

$$MSF = 10^{2.24}/M_w^{2.56}$$

Where,
Mw= Earthquake's Magnitude
When the Design grounds motion is conservative, earthquake related permanent ground deformation is generally small if FS ≥ 1

6) Calculation of Factor of Safety (FS)

The factor of safety FS is calculated as:-

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

C. TOKIMATSU & YOSHIMI (T & Y) (1983) METHOD

1) Calculation of CSR Cyclic Stress ratio

Cyclic stress ratio (CSR) defined by this method is:-

$$CSR = \frac{\tau_{avg}}{\sigma'_v} = 0.1\,(M-1)\,\frac{a_{max}}{g}\frac{\sigma_v}{\sigma'_v}(1-0.015z)$$

Where,
τ_{avg}= amplitude of uniform shear stress cycles equivalent to actual seismic shear stress time history.
a_{max} = The maximum horizontal acceleration at ground surface
M = magnitude of earthquake
σ'_v = initial effective vertical stress
σ_v = initial vertical stress contribution to the shear stress

$$\sigma_v = \int_0^z \gamma\, dz$$

Where,
γ = unit weight of soil,
z = depth below the ground surface

2) Calculation of CRR cyclic resistance ratio

CRR (cyclic resistance ratio) specified by Tokimatsu and Yoshimi is:

$$CRR = \frac{\tau_1}{\sigma'_v} = a\,c_r\left[\frac{16\sqrt{N_\alpha}}{100} + \left(\frac{16\sqrt{N_\alpha}}{C_S}\right)^n\right]$$

Where,
τ_1= shear stress on horizontal plane
a , c_r & n are correction factors and may be taken as 14, 0.57 & 0.45 respectively
C_a is between 80 & 90
N_α and subsequently N_1, may be calculated from the following pairs of equations:

$$N_\alpha = N_1 + \Delta N_f$$

$$N_1 = C_N N = \frac{1.7}{\sigma'_o + 0.7} N$$

Where,
ΔN_f is correction factor for SPT-N value and
σ'_o = effective vertical stress

$$\Delta N_f = 0 \quad \text{for } FC \leq 5$$
$$= FC - 5 \quad \text{for } 5 \leq FC \leq 10$$
$$= 0.1\,FC + 4 \quad \text{for } 10 \leq FC$$

Where FC is the fine content of soil.
From IS-(1893, 2000)
And Peak Horizontal Ground Acceleration (a_{max})

ZONE II	ZONE III	ZONE IV	ZONE V
0.10 g	0.16 g	0.24 g	0.36 g

D. IDRISS & BOULANGER (2006) METHOD

1) Calculation of CSR Cyclic Stress Ratio

For evaluation of CSR by Idriss & Boulanger (2006) is same as Seed & Idriss simplified method. Right after CSR calculated values of CSR is adjusted for the moment magnitude M=7.5.
.

$$(CSR)_{M=7.5} = \frac{CSR}{MSF} = 0.65\left(\frac{\sigma_v a_{max}}{\sigma'_v}\right)\frac{r_d}{MSF}$$

Where,
σ_{VO} = total vertical stress
σ'_{VO}= effective vertical stresses
a_{max} = maximum horizontal acceleration (PHGA)
g = acceleration due to gravity
r_d = reduction factor
MSF = magnitude scaling factor

2) Calculation of Magnitude Scaling fuction (MSF)

It is calculated based on the relation recommended by Idriss (1999)

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

Where,
M = Earthquake's magnitude
It is predicted that liquefaction is appear when FS ≤ 1.0, and Predicted not to appeared liquefaction when FS > 1

3) Calculation stress reduction factor r_d

The equation for calculation of stress reduction factor r_d is given below:
For z ≤ 34m and
For z > 34m

$$r_d = 0.12\exp(0.22\,M)$$

Where,
"z"= depth below the ground surface in m
M= Earthquake's magnitude
Use of the SPT blow count for soil liquefaction characteristics
The SPT-blow count (N_{60}) in which 60 % of efficiency of SPT-blow count for a hammer is evaluated. Equation of this is as:

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

Where,
C_{60}= various correction factors.
Then SPT-blow count normalized standardized C_{60} are calculated using this formula given as:

$$(N1)_{60} = C_N N_{60}$$

Where,
CN= Stress normalization factor that is calculated using this formula:

$$C_N = x\left(\frac{P_a}{\sigma'_{vo}}\right)^m \leq 1.7$$

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

The equivalent clean sands SPT penetration resistance $(N_1)_{60CS}$value for cohesiionless soils is proposed by Idriss & Boulanger 2004, 2008

$$(N_1)_{60CS} = (N1)_{60} + \Delta(N1)_{60}$$

$\Delta(N1)_{60}$ is the equivalent clean-sand adjustment empirically derived by Idriss & Boulanger 2004, 2008.

$$\Delta(N1)_{60} = \exp\left(1.63 + \left(\frac{9.7}{FC}\right) - x\left(\frac{15.7}{FC}\right)^2\right)$$

FC = fines content

4) Calculation of CRR Cyclic Resistance Ratio

CRR is calculated by this formula:

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

5) Calculation of FS Factor of Safety

The FS is calculated by the formula:

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

Where,

CRR is knows as Cyclic resistance ratio

MSF is Magnitude Scaling factor MSF.

It is evaluated based on the relation given by Idriss in (1999).

V. RESULT AND ANALYSIS

A. RESULT

The analysis liquefaction potential by Seed & Idriss, Tokimatsu &Yoshimi and Idriss & Boulanger methods at 4 bore hole shows that the soil strata 0-9.45 &13.5-16.00 are responsible for liquefy under seismic shaking corresponding to PHGA of 2.4g.

And soil strata 9.45-13.75 are non-liquefiable.

B. ANALYSIS

Here graphical representation is given for analyzing factor of safety vs. Depth for 4 bore hole at different-different depth.

In all graph for all bore hole all three methods is presented by different colors

- Seed & Idriss Method by Blue Line
- Idriss & Bolounger Method by Orange Line
- Tokimatsu & Yamini Method by Grey Line

- Liquefaction Potential Analysis of Main Office of Purvanchal Gramin Bank at Budh Vihar Commercial Yojna, Ramgarh Tal Pariyojna, Gorakhpur

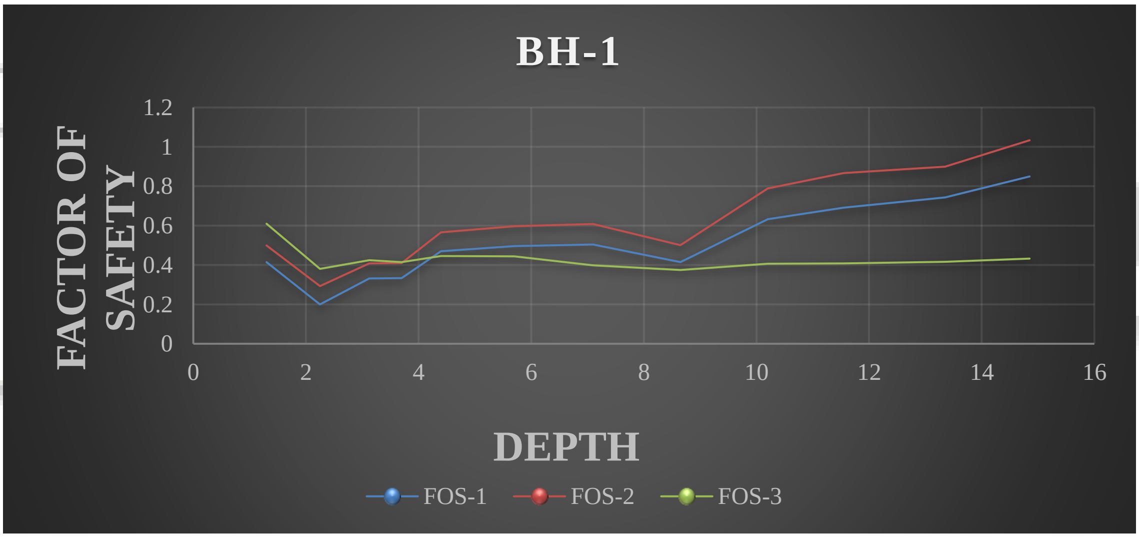

Fig. 5: Depth Vs. Factor of safety of Bore Hole-1 using all three method (S&I, T&Y, I&B Methods)

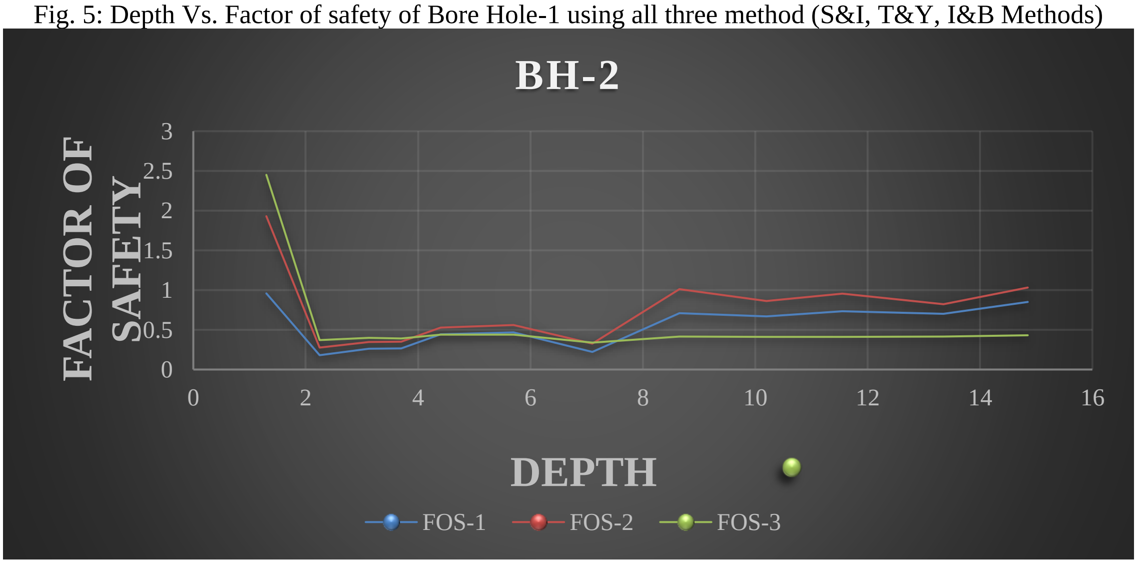

Fig. 6: Depth Vs. Factor of safety of Bore Hole-2 using all three method (S&I, T&Y, I&B Methods)

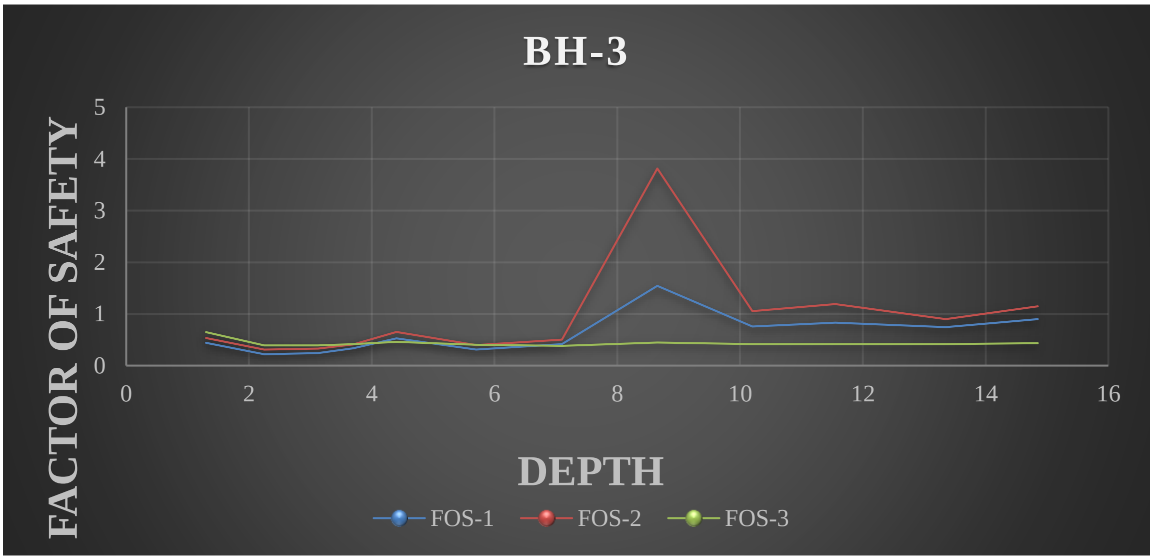

Fig. 7: Depth Vs. Factor of safety of Bore Hole-3 using all three method (S&I, T&Y, I&B Methods)

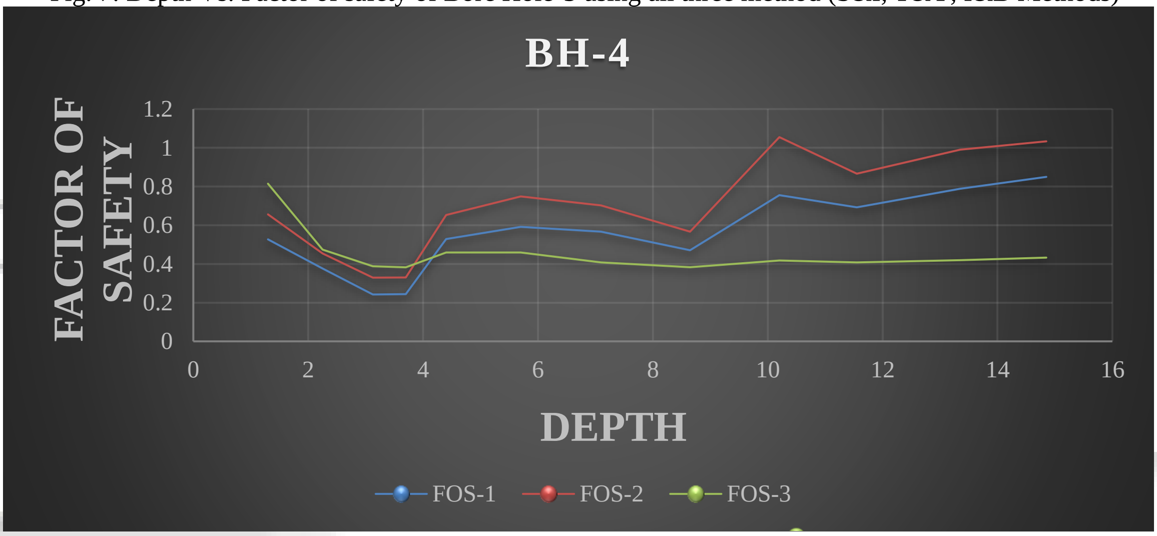

Fig. 8: Depth Vs. Factor of safety of Bore Hole-4 using all three method (S&I, T&Y, I&B Methods)

VI. CONCLUSION

It is based on the study for the analysis of liquefaction potential of Taramandal city project. The soil of that area is susceptible to liquefaction. The project work area is reclaimed area top layer of loose fine sand and loose sandy silt and clayey silt is soil which is susceptible to liquefaction. After this study it is clear that if earthquake appeared in Gorakhpur area at the magnitude more than 8 Richter scale then it damaged huge due to liquefaction.

After doing the liquefaction hazard assessment of Gorakhpur region it is concluded after comparing the lab results that is the soil of zones will be highly liquefied susceptible.99 percent of soil of this region will be susceptible to liquefaction. Suggestive measures and precautions will be taken during construction for that type of soil. According to Wang criteria each and every will not follow the rule of this theory. This Gorakhpur zone is highly liquefied zone. At the time of earthquake there will be much possibility of it. Constructions on liquefaction susceptible soils is to be avoided. The construction should be according to earthquake resistant design of structures for this type of soil. Plastic limit, liquid limit will be zero that type of soil that means the soil has no any property of plasticity and liquidity.

- There is graphical comparison between (S &I, I & B and T &Y) methods.
- The percentage of silty and poorly graded soil is high in the area under Taramandal City. Indicated that there is a huge chances of soil liquefaction.
- Analysis of Liquefaction potential is to determine the (FS) factor of safety at various depth (z).
- On the liquefaction susceptible soil construction should not performed.
- If construction of structure is performed at that place (liquefaction susceptible soil) then foundation of that place should be liquefaction resistance.
- To moderate the adverse effects of liquefaction risk by improving the density, strength and drainage characteristics of soil. There are so many type of soil improvement techniques.

VII. FUTURE SCOPE

1) Economical point of view we will be safe from the hazards of liquefaction.

2) We will know easily the type and property of soil with the help of this. We can easily perform the construction on that site.
3) We can know about the highly earthquake prone area.
4) For further construction that will be according to earthquake resistant design of structures.
5) Gorakhpur is in the earthquake zone 4 therefore it will be highly earthquake prone area.
6) For future and further constructions we will be safe from the damages of civil engineering structures by the effect of liquefaction.
7) The constructions that will be done on that type of soils will be according to ground improvement techniques.
8) All the fourteen zones of that region will be highly susceptible according to liquefaction.
9) Therefore construction should be avoided in these zones. If the construction is necessary it will be done according to various ground improvement techniques and earthquake resistant design of structures.
10) Percentage possibility of damages will be improved with liquefaction hazard assessment.

REFERENCES

[1] 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.
[2] Seed, H. B., (1979) “Soil Liquefaction and Cyclic Mobility Evaluation for Level Ground During Earthquakes”. J. Geotech. Eng. Div.,105, 210–255.
[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] Seed, H.B., Idriss, I.M. and Arange, I. (1983), “Evaluation of liquefaction potential using field performed Data,”J. of the Geotechnical Engineering Division, ASCE, Vol. 109, pp. 458–482.
[8] Tokimatsu, K. and Yoshimi, Y. (1983), “Empirical correlation of soil liquefaction based on SPT N-value andfine content,” Soils and Foundations, JSSMFE, Vol. 23, No. 4, pp. 55–74.
[9] Robertson, P.K. and Fear, C.E. (1996), “Soil liquefaction and its evaluation based on SPT and CPT”, Liquefaction Workshop.
[10] Robertson, P. K. _1990_. “Soil classification using the cone penetrationtest.” Can. Geotech. J., 27_1_, 151–158.
[11] Robertson, P. K. _1999_. “Estimation of minimum undrained shearstrength for flow liquefaction using the CPT.” Proc., 2nd Int. Conf. on Earthquake Geotechnical Engineering, Balkema, Rotterdam, TheNetherlands.
[12] Robertson, P. K. _2009a_. “Discussion of ‘CPT-based probabilistic soilcharacterization and classification’ by K. Onder Cetin and CemOzan.” J. Geotech. Geoenviron. Eng., 135_1_, 84–107.
[13] Robertson, P. K. _2009b_. “Interpretation of cone penetration tests—Aunified approach.” Can. Geotech. J., 46, 1337–1355.
[14] Robertson, P. K. _2009c_. “Performance based earthquake design usingthe CPT.” Tokyo Conf., CRC Press/Balkema, Taylor & Francis Group, Tokyo.
[15] Robertson, P. K. _2010_. “Estimating in situ state parameter in sandy soils from the CPT.” Proc., 2nd Int. Symp. of the Cone Penetration Test, CPT ‘10, Omnipress Publishers, Madison, Wis.