SEISMIC LIQUEFACTION ANALYSIS OF CAPITAL REGION OF ANDHRA PRADESH STATE, INDIA

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ABSTRACT

Liquefaction is a phenomenon happens in a loose, fully saturated cohesionless soil in undrained condition subjected to cyclic loading. During liquefaction of the soil lost its shear strength when the mean effective stress is made equal to zero due to the progressively increasing excess pore water pressure. Liquefaction may cause failure of foundations, resulting in collapse of structure, even if the structure is designed as an earthquake-resistant. Liquefaction depends on characteristics of subsurface soil. Amaravathi is a new capital of Andhra Pradesh State, India. The construction activities in the capital region are swiftly increasing. It is essential that the new structures constructing in capital should be assessed for liquefaction susceptibility. In the present investigation an attempt has been made to assess the liquefaction susceptibility of various sites in the capital of Andhra Pradesh State, India. The liquefaction analysis is carried out by using simplified method which mainly relies on Standard Penetration Test (SPT) value.

KEYWORDS

Liquefaction, SPT, Susceptibility, Magnitude of Earthquake

INTRODUCTION

Earthquakes are most powerful natural disasters which are unavoidable. The hazards associated to earthquakes are referred to as seismic hazards. During an earthquake there is release of energy which reaches to the ground surface and to the structures by means of seismic waves. One of the major causes of destruction during an earthquake is the loss of strength & stiffness of cohesionless soils. This phenomenon called liquefaction occurs mainly in loose & saturated sand. When an earthquake shakes loose saturated sand, the grain structure of soil tends to consolidate into more compact packing. The soil liquefaction depends on the magnitude of earthquake, intensity & duration of ground motion, the distance from the source of the earthquake, site specific conditions, ground acceleration, type of soil and thickness of the soil deposit, relative density, grain size distribution, fines content, plasticity of fines, degree of saturation, confining pressure, permeability characteristics of soil layer, position & fluctuations of the ground water table [1, 2]. The purpose of the study is to evaluate the liquefaction susceptibility of various locations in the capital of Andhra Pradesh state, India using penetration resistance value from standard penetration test after necessary corrections. Firstly Cyclic Shear Stress Ratio (CSR) that would be induced due to earthquake was computed. In calculating CSR, the peak horizontal ground acceleration value (a_{max}) was selected based on region as mentioned in [3]. Seismic zoning map of India prepared based on the peak ground acceleration (PGA) induced by the maximum considered earthquake. Secondly determine the Cyclic Resistance Ratio (CRR) using the corrected penetration resistance value. Finally factor of safety against liquefaction (FOS) susceptibility is also determined which is the ratio of CRR to CSR. Variation of factor of safety versus depth for various magnitudes of earthquake is also studied.

REVIEW OF LITERATURE

There are two general approaches for the assessment of liquefaction. One is the laboratory testing of undisturbed samples and other is the use of empirical relationships developed mainly based on field tests [4]. The later approach is the dominant approach and is common in practice. The main reason for the selection of later approach is due to the experimental difficulties and high cost in the former approach. In India, most widely used in-situ test carried as a part of sub-soil exploration is SPT. Liquefaction susceptibility assessment using SPT value is the most common empirical method. [5, 6, 7] have evolved a method for liquefaction susceptibility using SPT based on both laboratory and field based data. Liquefaction susceptibility analysis of Kathmandu valley was carried by [8]. Liquefaction potential prediction of Coimbatore city was done by [9]. A liquefaction analysis of alluvial soil deposit for Kolkata city has been carried by [10, 11].

STUDY AREA

Amaravathi is the new capital of Andhra Pradesh State, India. Map of Andhra Pradesh with Capital Region Development Authority (CRDA) region is presented in Figure 1 [12]. Seed capital has land area about 121.4 square kilometres. The seed capital development area will comprise the Andhra Pradesh State Legislative Assembly, Legislative Council, High Court, Secretariat, Raj Bhavan, quarters for the ministers and officials, and the township for government officials.

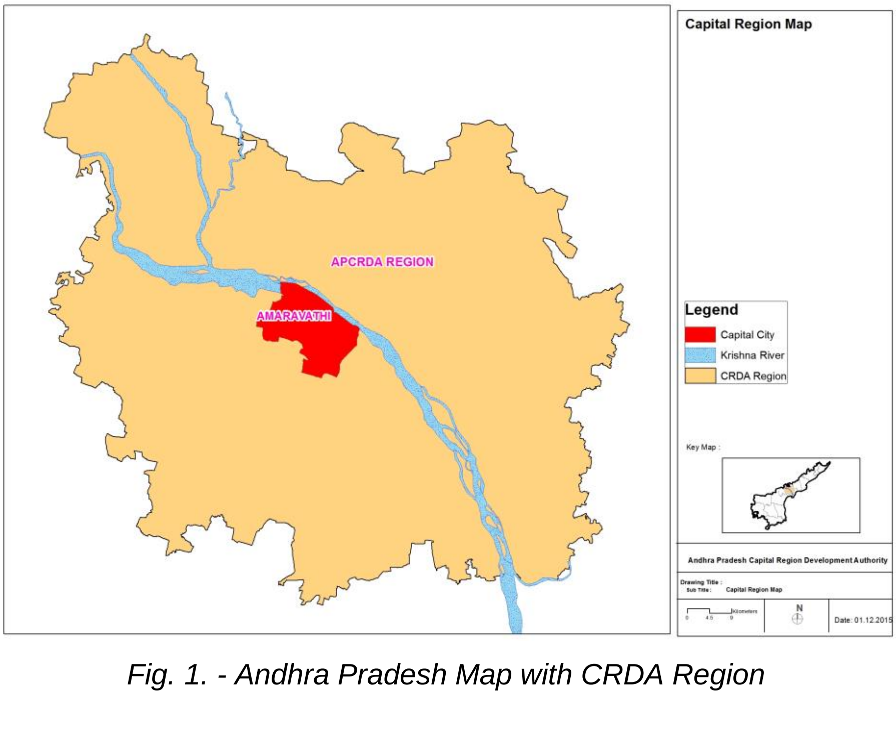

Fig. 1. - Andhra Pradesh Map with CRDA Region

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LIQUEFACTION SUSCEPTIBILITY ANALYSIS

The liquefaction susceptibility analysis was carried out using simplified method proposed by [5, 6, 7]. In the beginning in the simplified procedure, the CSR that would be induced due to earthquake was computed. Subsequently using SPT, the CRR of in-situ soil was determined. Further, factor of safety against liquefaction was computed which is the ratio of CRR to CSR.

The CYCLIC SHEAR STRESS RATIO (CSR) is calculated from the following equation:

$$CSS = 0.65\left(\frac{a_{max}}{g}\left(\frac{\sigma_{v0}}{\sigma'_{v0}}\right)\times r_d\right) \tag{1}$$

Where, a_{max} is the Peak ground acceleration

g is the acceleration due to gravity

$\frac{a_{max}}{g}$ = z is the Zone factor

Seismic zoning map of India prepared based on the peak ground acceleration (PGA) induced by the maximum considered earthquake [3].

σ_{v_0} is the total overburden pressure (in kPa)

σ'_{v_0} is the effective overburden pressure at the same depth (in kPa)

r_d is the stress reduction Coefficient

$$r_d = e^{[\alpha(z)+(\beta(z)\times M)]} \tag{2}$$

M is magnitude of the earthquake

$$\alpha(z)=-1.012 - 1.126\,sin\left[\frac{z}{11.73} + 5.133\right] \tag{3}$$

$$\beta(z)=0.106 + 0.118\,sin\left[\frac{z}{11.28} + 5.142\right] \tag{4}$$

In the above two equations Z is the depth of the soil stratum

The CYCLIC SHEAR RESISTANCE RATIO (CRR) is calculated from the following equation:

$$CRR = e^{\left[\frac{(N1)_{60cs}}{14.1}+\left[\frac{(N1)_{60cs}}{126}\right]^2+\left[\frac{(N1)_{60cs}}{23.6}\right]^3+\left[\frac{(N1)_{60cs}}{25.4}\right]^4-2.8\right]} \tag{5}$$

Where $(N1)_{60CS}$ is the corrected SPT value including correction for fines

Factor of Safety against Liquefaction (FOS) is ratio of CYCLIC SHEAR RESISTANCE RATIO (CRR) to CYCLIC SHEAR STRESS RATIO (CSR).

$$\text{FOS} = \frac{CRR}{\left({CSS}/{MSF}\right)} \tag{6}$$

Where CRR is the Cyclic Shear Resistance Ratio

CSR is the Cyclic Shear Stress Ratio

MSF is the Magnitude Scaling Factor

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$$MSF=\frac{10^{2.24}}{M^{2.56}} \tag{7}$$

In which M is the Magnitude of the Earthquake

If the value of Factor of Safety against Liquefaction is less than or equal to 1, the soil is susceptible to liquefaction (L). If the value of Factor of Safety against Liquefaction is greater than 1, the soil is not susceptible to liquefaction (NL). Standard Penetration Test (SPT) was conducted as per the guidelines of [13]. The SPT is carried out in drilled boreholes, by driving a standard 'split spoon' sampler using repeated blows with a 63.5kg hammer falling through 750mm. The bore holes have been drilled using rotary hydraulic drilling of 150mm diameter up to the rock depth. The hammer is dropped on the rod head at the top of the borehole, and the rod head is connected to the split spoon by rods. The split spoon is lowered to the bottom of the hole, and is then driven for a depth of 450mm, and the blows are counted normally for each 150mm of penetration. The penetration resistance (N) is the number of blows required to drive the split spoon for the last 300mm of penetration. The penetration resistance during the first 150 mm of penetration is ignored. The 'N' values measured in the field using SPT procedure have been corrected for various corrections recommenced for evaluating the seismic borehole characteristics of soil.

First, corrected 'N' value i.e., $(N_1)_{60}$ are obtained using the following equation:

$$(N_1)_{60} = C_N C_{ER} C_B C_R C_S \, N \tag{8}$$

Where

C_N is the Correction for Overburden Effect

C_{ER} is the Correction for Hammer Effect

C_B is the Correction for Borehole Effect

C_R is the Correction for Rod Length

C_S is the Correction for Sampler

Then corrected 'N' values (N) is further corrected for fines content based on the revised boundary curves derived by [14] as described below:

The N value for soil shall be corrected for overburden is extracted from [11].

$$\mathrm{C_N} = 0.77 \log_{10}\left[\frac{2000}{\sigma_0'}\right] \tag{9}$$

Where σ_0' is the effective overburden pressure.

Correction for Hammer Effect [C_{ER}] can be taken as follows:

For Doughnut hammer : 0.5 to 1.0

For Safety hammer : 0.7 to 1.2

Automatic Doughnut hammer : 0.8 to 1.3

Correction for Borehole Effect [C_B] can be taken as follows:

C_B = 1.00 for diameter of the bore hole = 65mm to 115mm

C_B = 1.05 for diameter of the bore hole = 150mm

C_B = 1.15 for diameter of the bore hole = 200mm

Correction for Rod Length [C_R] can be taken as follows:

C_R = 0.75 for l < 3m

C_R = 0.8 for l = 3m to 3.99m

C_R = 0.85 for l = 4m to 5.99m

C_R = 0.95 for l = 6m to 9.99m

C_R = 1.00 for l = 10m to 30m

Correction for Sampler [C_S] can be taken as follows:

C_S = 1.00 for Standard sampler

Correction for Fines $\Delta\,(N_1)_{60}$ can be taken as follows:

Liquefaction, in the past, was primarily associated with medium to fine grained saturated cohesion less soils and soils with fines were considered non-liquefiable. [13] studied the liquefaction behaviour of silts and silt clay mixers over a range of plasticity values of interest by conducting cyclic tri axial tests on undisturbed as well as reconstituted samples and their behaviour was compared with that of sand. Saturated silts with plastic fines were found to behave differently from sands both with respect to rate of development of pore water pressure and axial deformations. Later on it was found by several investigators that certain soils with fines may be susceptible to liquefaction.

$$\Delta(\mathrm{N_1})_{60} = \mathrm{e}^{\left[1.63+\left(\frac{9.7}{\mathrm{fc}+0.001}\right)-\left(\frac{15.7}{\mathrm{fc}+0.001}\right)^2\right]} \tag{10}$$

Where fc is the fines content

Corrected SPT value including correction for fines [$(N1)_{60CS}$] is given by

$$(\mathrm{N_1})_{60CS} = (\mathrm{N_1})_{60} + \Delta(\mathrm{N_1})_{60} \tag{11}$$

Authors attended SPT conducting at Mandadam site (shown in Figure 2). The fines content present in soils was measured. Vulnerability of liquefaction evaluation in light of experimental approach with SPT value (N value) was done at 107 locations those covers all the area of capital region of Andhra Pradesh.

Fig. 2. - Lifting of drop hammer for applying blows

DISCUSSION ON TEST RESULTS

Liquefaction susceptibility analysis was carried out using simplified method as proposed by [2, 3] based on SPT value. In the simplified procedure the Cyclic Shear Stress Ratio (CSR) that would be induced due to earthquake was computed. In calculating CSR, the peak horizontal ground acceleration value (a_{max}) was chosen as 0.16g as mentioned in [4] for capital region of Indian State Andhra Pradesh. Subsequently using SPT, the Cyclic Shear Resistance Ratio (CRR) of in-situ soil was determined. Factor of safety against liquefaction is the ratio of CRR to CSR. Further, factor of safety against liquefaction for different magnitudes of earthquake (=4, 5, 6, 7, 7.5) was computed. Since the River Krishna is flowing through the capital region of Andhra Pradesh, throughout the analysis water table was assumed to be presented at ground level. A typical calculation of factor of safety against liquefaction for a magnitude of earthquake is presented in Table 1.

Tab. 1 - Liquefaction Analysis of Mandam Site for an Earthquake Magnitude 4

Depth of Ground Water Table=					AT GL							
Peak Ground Horizontal Acceleration(a_{max}/g)=					0.16							
Depth, Z (m)	Depth, Z (m)	Observed SPT Value	Saturated Density (kN/m^3)	Submerged Density (kN/m^3)	Fines (%)	Corrected SPT [(N1) 60] (Eqn. 8)	Correction for fines(fc) [Δ(N1)60] (Eqn. 10)	Corrected SPT Value [(N1)60cs] (Eqn.11)	Cyclic Shear Stress [CSS] (Eqn. 1)	Cyclic Shear Resistance [CRR7.5] (Eqn.5)	Factor of Safety (FS) (Eqn. 6)	Conclusion
2	3	2	19.68	9.87	97	1.64	5.49	7.14	0.19	0.10	2.57	NL
3	4	9	19.8	9.99	96	6.81	5.50	12.31	0.19	0.13	3.63	NL
4	5	12	20.08	10.27	94	8.26	5.50	13.77	0.18	0.15	4.11	NL
5	6	15	20.29	10.48	92	10.72	5.51	16.23	0.17	0.17	4.91	NL
6	7	15	20.6	10.79	98	10.08	5.49	15.57	0.16	0.16	4.99	NL
7	8	18	20.66	10.85	97	11.46	5.49	16.95	0.15	0.17	5.65	NL
8	9	16	20.74	10.93	97	9.71	5.49	15.21	0.15	0.16	5.42	NL
9	10	17	20.99	11.18	97	10.39	5.50	15.89	0.14	0.16	5.94	NL

Liquefaction analysis has been conducted for other earth quake magnitudes also. Analysis carried in various locations of capital region of Andhra Pradesh State, India. Depth versus factor of safety against liquefaction for different Magnitudes of Earthquake at various locations of capital of Andhra Pradesh State is shown in Figures 3 to 10. It was observed from Figures 4 to 11, the Factor of Safety against Liquefaction is greater than 1 for Earthquake Magnitudes of 4 and 5 irrespective of depth for various locations. It was also noticed that when Magnitude of earthquake 6 and above, many of sites in the capital region of Andhra Pradesh State, India was prone to Liquefaction. At some locations (as depicted in Figure 7, 8 and 10) higher factor of safety against liquefaction was obtained due to presence of hard gravel (SPT value is more than 50) at lower depths.

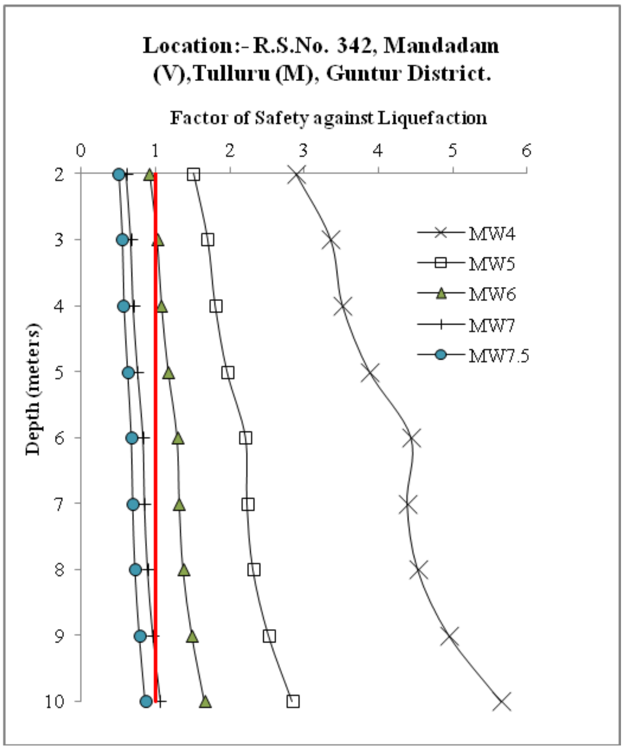

Fig. 3. - Depth vs. FOS (Location: R.S.No. 342, Mandadam (V), Tulluru (M), Guntur District)

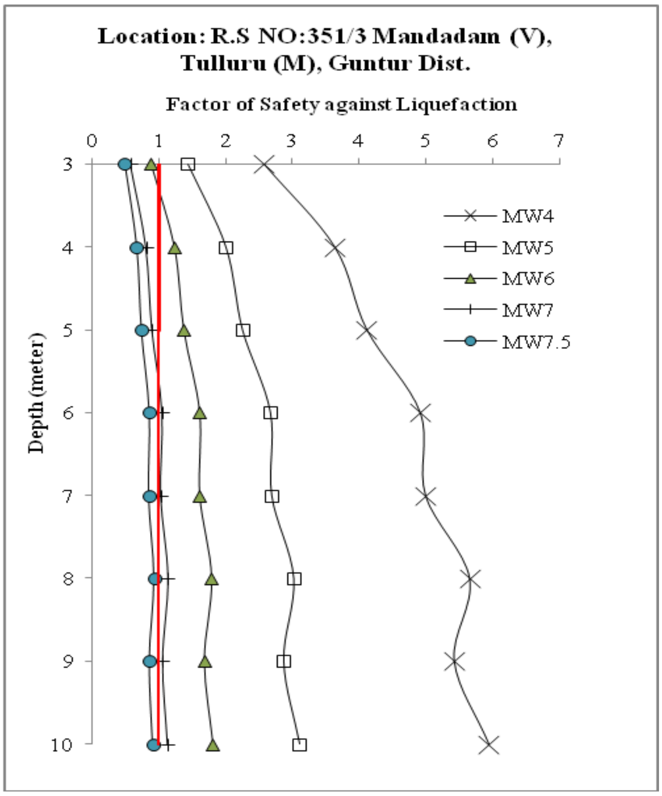

Fig. 4. - Depth vs. FOS (Location: R.S.No. 351/3 Mandadam (V), Tulluru (M), Guntur District)

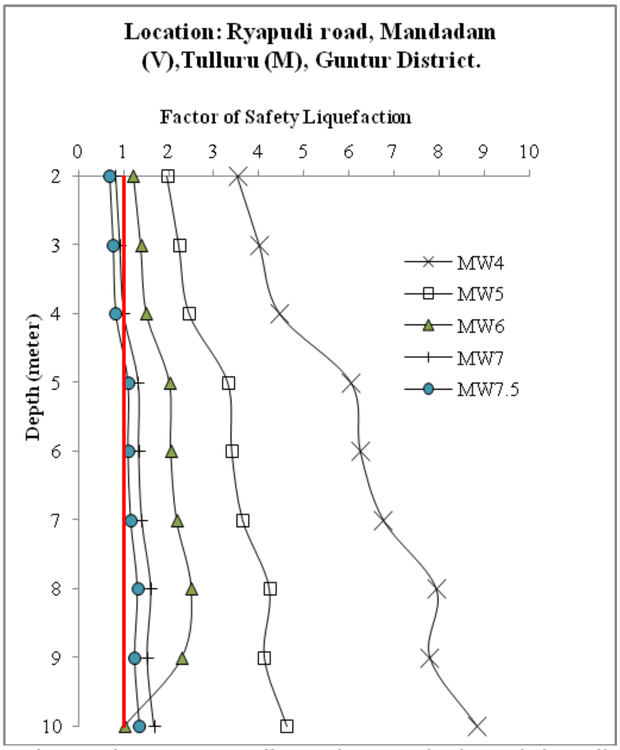

Fig. 5. - Depth Vs. FOS (Location: Ryapudi road, Mandadam (V),Tulluru (M), Guntur District

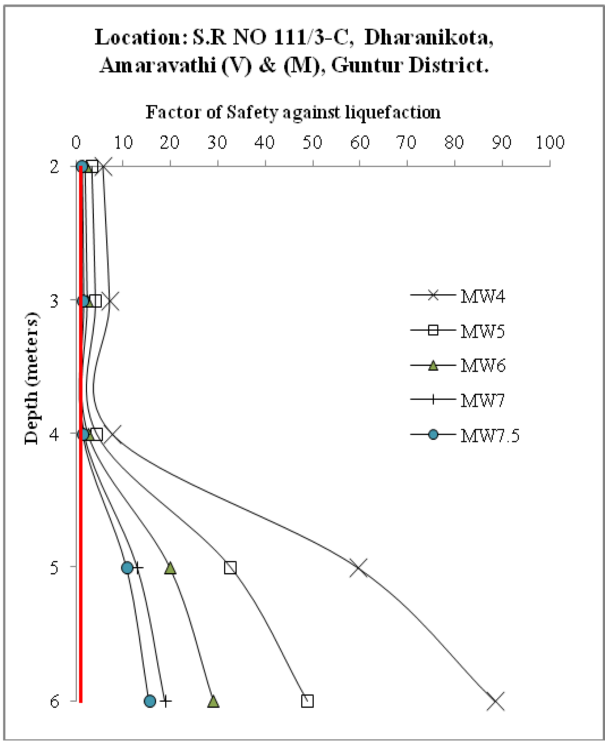

Fig. 6. - Depth vs. FOS (Location: S.R. No. 111/3-C, Dharanikota, Amaravathi (M), Guntur Dist.)

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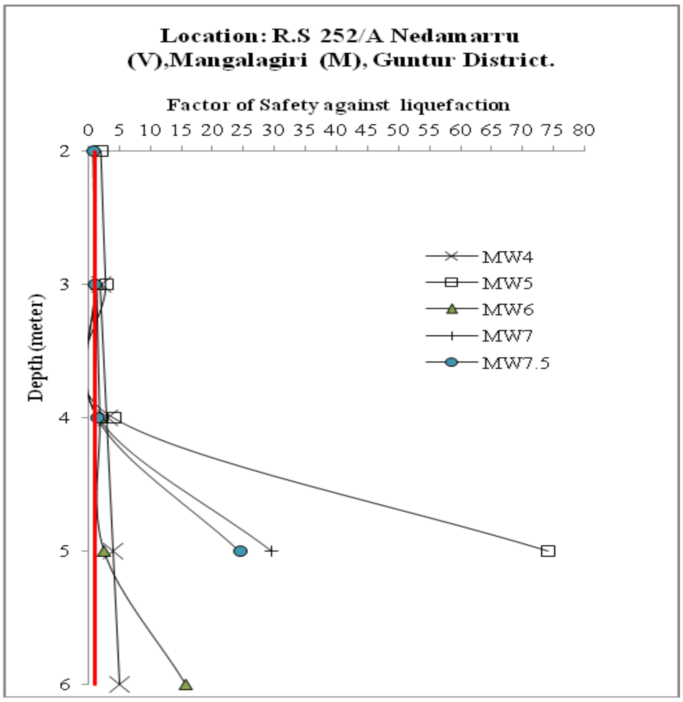

Fig. 7. - Depth Vs. FOS

(Location: R.S 252/A Nedamarru (V), Mangalagiri (M), Guntur District)

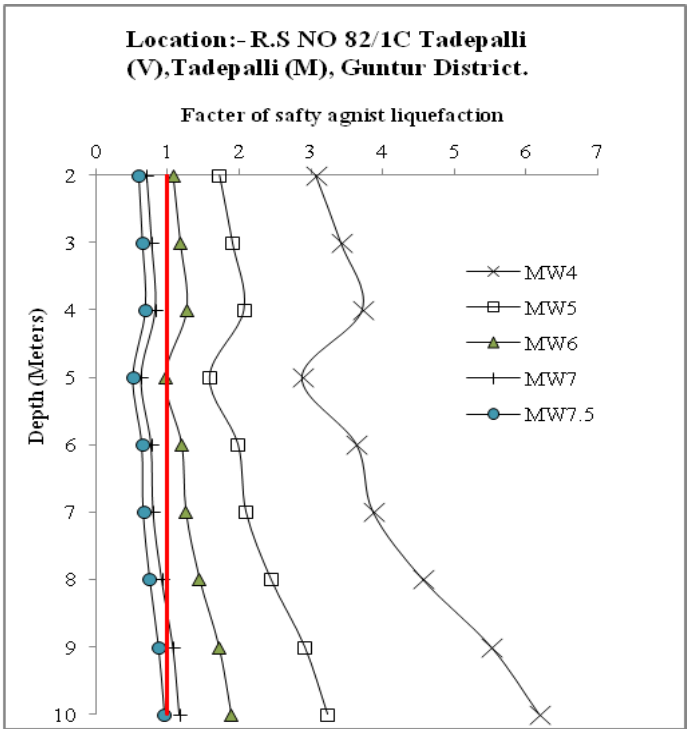

Fig. 8. - Depth vs. FOS (Location: R.S. No. 82/1C, Tadepalli (V), Tadepalli (M), Guntur District)

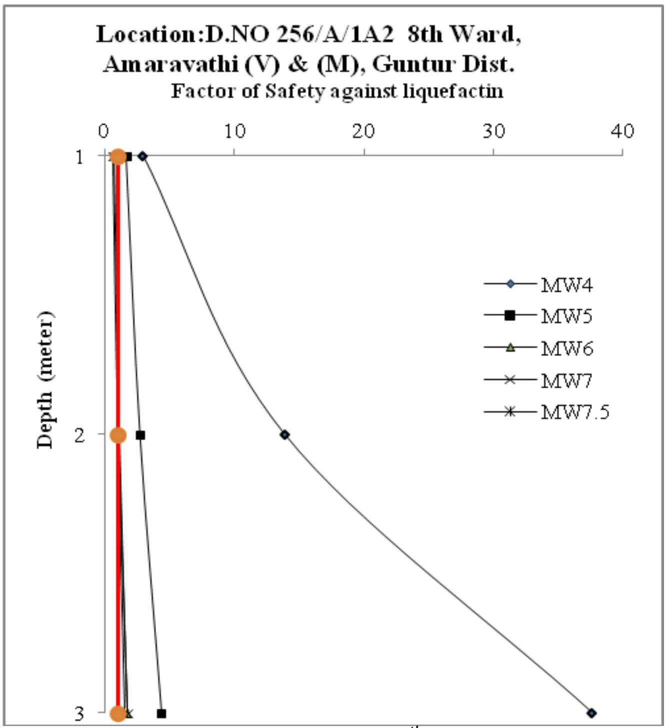

Fig. 9. - Depth Vs. FOS (Location: D.No. 256/A/1A2, 8th Ward, Amaravathi (V)&(M), Guntur Dist.)

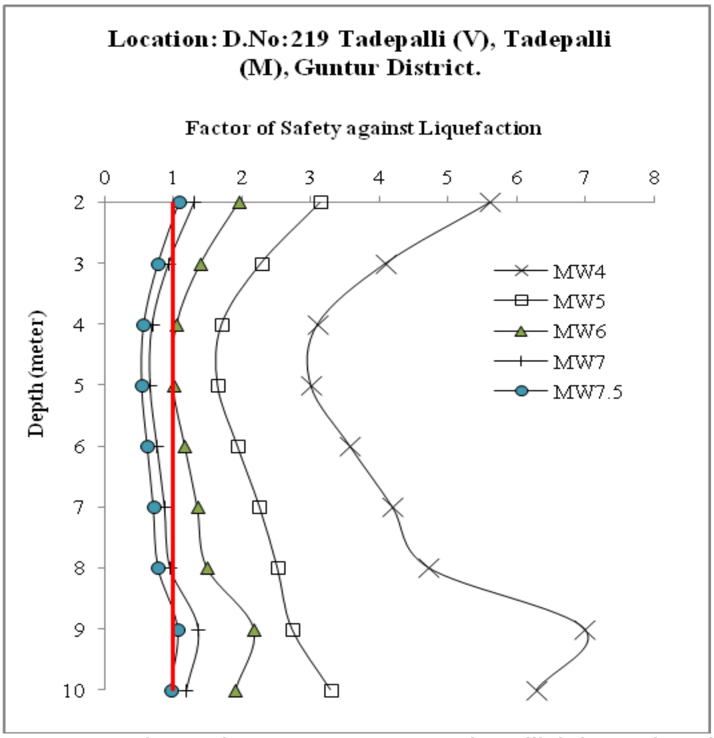

Fig. 10. - Depth Vs. FOS (Location: D.No:219, Tadepalli (V), Tadepalli (M), Guntur District)

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The number of sites suceptible to liquefaction with increase in earthquake maginitude is plotted in the Figure 11. By observing the Figure 11, it was noted that the majority of the locations in the region are liquefiable when the magnitude of quake exceeds 5. It was unequivocally distinguished that no site has indicated liquefaction vulnerability for a seismic quake for maginitude of 4. It can be inferred that the greater part of the capital region of Andhra Pradesh may not liquefiable when a light seismic quake happens.

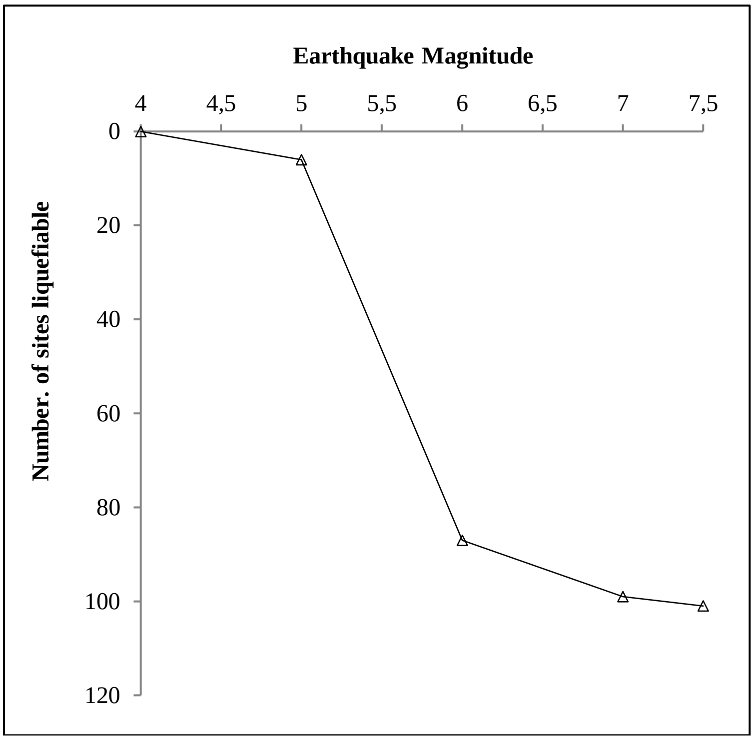

Fig. 11. - Graph represents Earthquake magnitude and Number of sites liquefiable

CONCLUSION

Liquefaction susceptibility assessment based on empirical approach with SPT value (N value) was carried out at various places in capital of Andhra Pradesh state, India. The following conclusions were drawn from the analysis.

1. Liquefaction analysis should be carried for the all the structures and mainly for structures of national importance.
2. Many of the liquefaction susceptibility studies need to be considered in early stages of planning and design in order to select the most appropriate sites and also to improve sites for mitigating liquefaction susceptibility.
3. Liquefaction susceptibility assessment based SPT value is quite feasible. Since SPT was most widely used method soil exploration in India.
4. Most of the sites in the capital region of Andhra Pradesh are susceptible to liquefaction at the magnitude of earthquake 6 and above.
5. Majority of the sites of capital of Andhra Pradesh may not susceptible to liquefaction when a light earthquake happens. If a strong earthquake happens almost all the areas in the capital of Andhra Pradesh are susceptible to liquefaction and there is a chance of huge loss for life and property.

6. The findings would help the designers in taking suitable decisions for design of foundations, resistant to liquefaction and to adopt appropriate ground improvement techniques for rapidly developing capital of Andhra Pradesh.

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