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K Rakesh
PG Student, Department of Civil Engineering, B.V.C. Engineering College, Odalarevu, East Godavari District, Andhra Pradesh, India.

Dr. GV Rama Subba Rao
Associate Professor, Department of Civil Engineering, SRK Institute of Technology, Vijayawada, Andhra Pradesh, India.

Dr. DSV Prasad
Professor & Principal, B.V.C. Engineering College, Odalarevu, East Godavari District, Andhra Pradesh, India.

Correspondence
K Rakesh
PG Student Department of Civil Engineering, B.V.C. Engineering College, Odalarevu, East Godavari District, Andhra Pradesh, India.

Seismic soil liquefaction susceptibility assessment of District Krishna, Andhra Pradesh

K Rakesh, Dr. GV Rama Subba Rao, Dr. DSV Prasad

Abstract
Liquefaction is a soil behaviour phenomenon in which a saturated fine and medium sandy soil loses a substantial amount of strength due to abrupt increase in pore water pressure and leads to decrease in effective stress during strong ground shaking. 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. Subsurface characteristics can be evaluated from Standard Penetration Test (SPT). Krishna District is an important District in Andhra Pradesh, India. The construction activities in the district are rapidly increasing. It is essential that the new structures in Krishna District should be analyzed for Liquefaction susceptibility. In the present investigation an attempt has been made to determine the liquefaction susceptibility of various sites in Krishna District of Andhra Pradesh State, India based on in-situ SPT. The analysis is carried out on simplified method as proposed by Seed and Idriss (1971). It was found from present study that factor of safety against liquefaction falling less than 1 for most of the sites in Krishna District when magnitude of earthquake above 6.

Keywords: Liquefaction Susceptibility, SPT, Krishna District, Magnitude of Earthquake.

Introduction

Earth quakes 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. The term *liquefaction* originally coined by Mogami and Kubo in 1953. 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.

There are two general approaches for the assessment of liquefaction. One is the use of laboratory testing of undisturbed samples and other is the use of empirical relationships based on correlation of observed field behavior with various in-situ tests for identifying the index properties (Cetin *et al*. 2004) [3]. 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 test of soil exploration is SPT. Liquefaction susceptibility assessment using SPT value is the most common empirical method. Seed and Idriss (1971) [15] developed a method for liquefaction susceptibility using SPT based on both laboratory and field based data. The method was called simplified method. Vijayawada is the major city in Krishna District which has experienced important seismic events including earthquakes M6 in 1900, and M5.4 in 1972. Map of Krishna district is given in plate 1.3.

Plate 1: Map of Krishna District

The purpose of the study is to evaluate the liquefaction susceptibility of various locations in Krishna District 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 chosen based on region as mentioned in IS: 1893-2002. Secondly determine the Cyclic Resistance Ratio (CRR) using the corrected penetration resistance value. Finally factor of safety against liquefaction 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

The case histories are abundant in the seismically active areas of the world. Ground failure induced by liquefaction is a major cause of damage in past earthquake and posse's considerable hazard to structure & their occupants (Chakraborty *et al*., 2003) [4]. In the last four decades a lot of research work has been done on soil liquefaction. This soil liquefaction depends on several factors such as fines content, mean grain size (D_{50}), Relative Density, Magnitude of Earthquake etc (Saran, 1999; Kramer, 2003; Sitharam *et al*., 2004; Yadav, 2004; Gulhati and Datta, 2006.) [14, 10, 17, 18, 6] Liquefaction Potential analysis of Kathmandu valley was done by Ramesh and Suzuki (2010) [13]. Prediction of Liquefaction potential of soil for Coimbatore city Corporation was carried by Kumar and Arumairaj (2014) [11]. Determination of liquefaction potential of a local sub soil for a site near Kolkata was made by Bandyopadhyay *et al.* (2014) [2]. Das and Ghosh (2015) [5] carried a liquefaction analysis of alluvial soil deposit for Kolkata city.

Study Methodology

In this chapter, methodology for liquefaction susceptibility using SPT was presented. The analysis was carried out using simplified method as proposed by Seed and Idriss (1971) [15]. At beginning in the simplified procedure the CSR that would be induced due to earthquake was computed. In calculating CSR, the peak horizontal ground acceleration value (a_{max}) was chosen based on region as mentioned in IS: 1893-2002. 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. Seed and Idriss (1971) [15], Seed *et al*, (2003) [16] given simplified method for liquefaction susceptibility assessment using SPT.

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

$$CSS = 0.65\left(\frac{a_{max}}{g}\left(\frac{\sigma_{v_0}}{\sigma'_{v_0}}\right) \times r_d\right) \text{--------------------------------} (1)$$

a_{max} =Peak ground acceleration
g =acceleration due to gravity
$\frac{a_{max}}{g}$= z = Zone factor

Seismic zoning map of India (IS: 1893-2002) prepared based on the peak ground acceleration (PGA) induced by the maximum considered earthquake (Das and Ghosh, 2015) [5].
σ_{v_0}=Total overburden pressure (in kPa)
σ'_{v_0}=Effective overburden pressure at the same depth (in kPa)

r_d =Stress Reduction Coefficient

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

M is magnitude of the earthquake

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

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

In the above two equations Z is Depth of the soil stratum
THE CYCLIC SHEAR RESISTANCE RATIO (CRR) is calculated from the following equation:

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

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

Factor of Safety against Liquefaction is ratio of CYCLIC SHEAR RESISTANCE

RATIO to $[CRR]$ CYCLIC SHEAR STRESS RATIO $[CSR]$ FS

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

Where CRR=Cyclic Shear Resistance Ratio
CSR=Cyclic Shear Stress Ratio
MSF=Magnitude Scaling Factor

$$\frac{10^{2.24}}{M^{2.56}} \text{-- (7)}$$

In which M=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 IS: 2131-1981. 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 (Youd *et al*., 2001; Cetin *et al*., 2004) [1, 3] First, corrected 'N' value i.e., (N) are obtained using the following equation:

$$(N_1)_{60} = C_N \times C_{ER} \times C_B \times C_R \times C_S \times N \text{--------------------- (8)}$$

Where
C_N = Correction for Overburden Effect
C_{ER} = Correction for Hammer Effect
C_B = Correction for Borehole Effect
C_R = Correction for Rod Length
C_S = Correction for Sampler

Then this corrected 'N' values (N) is further corrected for fines content based on the revised boundary curves derived by Idriss and Boulanger (2004) for cohesion less soils as described below:

The N value for soil shall be corrected for overburden is extracted from IS: 2131.

$$C_N = 0.77 * \log_{10}\left[\frac{2000}{\sigma_0'}\right] \text{-- (9)}$$

σ_0' = 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 trip 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
C_S = 1.1 to 1.3 for samplers without liners

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. Prakash and Puri, 2010 investigated the liquefaction behavior 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 behavior 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.

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

Where fc = Fines Content

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

$$(N_1)_{60CS} = [(N_1)_{60} + \Delta (N_1)_{60}] \text{--------------------------------- (11)}$$

The author himself attended SPT conducting at Prasadampadu, Vijayawada Rural, and Krishna District. Author keenly observing SPT procedure and it was presented in Plate 2. Fine content of soil was measured as per I.S: 2720-Part IV.

Plate 2: Author Observing Lifting of Drop Hammer for applying blows

Discussion on test results

Liquefaction susceptibility analysis was carried out using simplified method as proposed by Seed and Idriss (1971) [15]. 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 IS: 1893-2002 for Krishna District. 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 Krishna district, throughout the analysis water table was assumed to be presented at ground level. A typical calculation for factor of safety against liquefaction for different magnitudes of earthquake is presented in Tables 1 (Gudlavalleru area). Depth versus factor of safety against liquefaction for different Magnitudes of Earthquake at locations-Gudlavalleru, Benz circle and Hanumanpet of Krishna district are shown in Fig. 1, 2 and 3 respectively. Liquefaction susceptibility assessment based on empirical approach with SPT value (N value) was carried out at 115 areas of Krishna district.

Location: D. No. 7/107, R.S. No. 182/1, Gudlavalleru, Krishna District

Table 1: Liquefaction Analysis of Gudlavalleru Site for Earthquake Magnitude 4

Depth of Ground Water Table=					AT GL							
Peak Ground Horizontal Accelaration(amax/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
0	1.5	----	----	----	----	----	----	----	----	----	----	----
1.5	2	2	16	6.19	97	1.87	5.49	7.37	0.26	0.10	1.95	NL
2	3	3	16	6.19	96	2.49	5.50	7.99	0.25	0.10	2.09	NL
3	4	4	16	6.19	94	3.19	5.50	8.70	0.24	0.11	2.26	NL
4	5	8	16	6.19	90	5.94	5.51	11.46	0.23	0.13	2.76	NL
5	6	11	17	7.19	87	8.55	5.52	14.08	0.22	0.15	3.4	NL
6	7	2	15	5.19	98	1.49	5.49	6.99	0.21	0.10	2.3	NL
7	8	2	16	6.19	97	1.43	5.49	6.93	0.20	0.10	2.4	NL
8	9	2	16	6.19	97	1.38	5.49	6.88	0.19	0.10	2.51	NL
9	10	2	16	6.19	97	1.41	5.49	6.90	0.18	0.10	2.64	NL

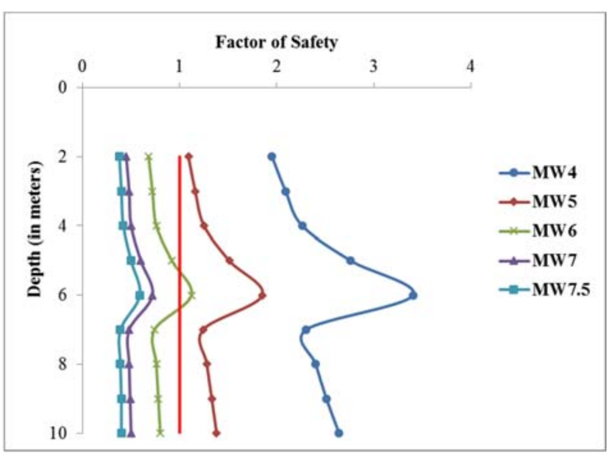

Fig 1: Depth Vs. Factor of Safety (D. No. 7/107, R.S. No. 182/1, Gudlavalleru)

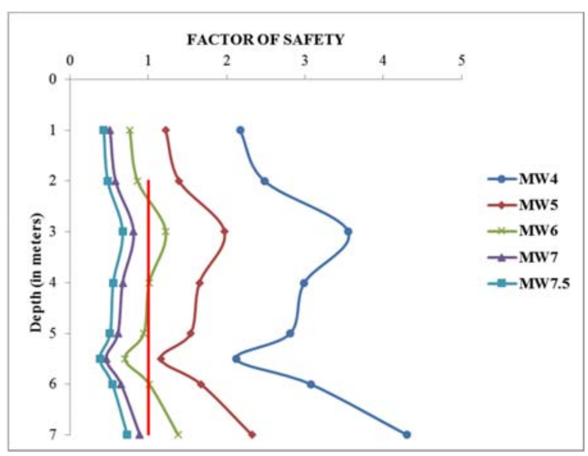

Fig 2: Depth Vs. Factor of Safety (D.NO. 40-14-5/2, Benz Circle)

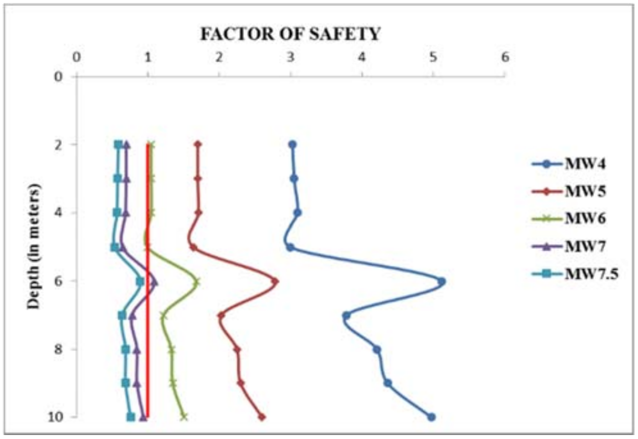

Fig 3: Depth Vs. Factor of Safety (D. No. 14-7-29, New Assessment No. 107518, Hanumanpet)

From Fig. 1, it was observed that Factor of Safety against Liquefaction is greater than 1 for Earthquake Magnitudes of 4 and 5 irrespective of depth. It was also noticed that when Magnitude of earthquake exceeds 6, considered site in Gudlavalleru of Krishna District was prone to be Liquefaction. Fig. 2 and 3 also shown similar trend.

Liquefaction Susceptibility of Krishna District for Different Earthquake Magnitudes

The Number of sites of Krishna district that are liquefiable for various magnitudes of earthquake are summarized & presented in Table 2 and the same is plotted in the Fig. 4. From the Table 2, it was noticed that most of the sites in the Krishna district are liquefiable at the magnitude of earthquake beyond 5. It was strongly identified that no site has shown liquefaction susceptibility for an earthquake magnitude of 4. Majority of the regions of Krishna district may not susceptible to liquefaction when a light earthquake happens. Most of the sites in the Krishna district may be susceptible to liquefaction even for moderate earthquakes. If a strong earthquake happens almost all the areas in the Krishna district are susceptible to liquefaction and there is a chance of huge loss for life and property.

Table 2: Number of sites of Krishna district liquefiable for various magnitudes of earthquake

Earthquake Magnitude	4	5	6	7	7.5
No. of sites liquefiable	0	5	103	112	113

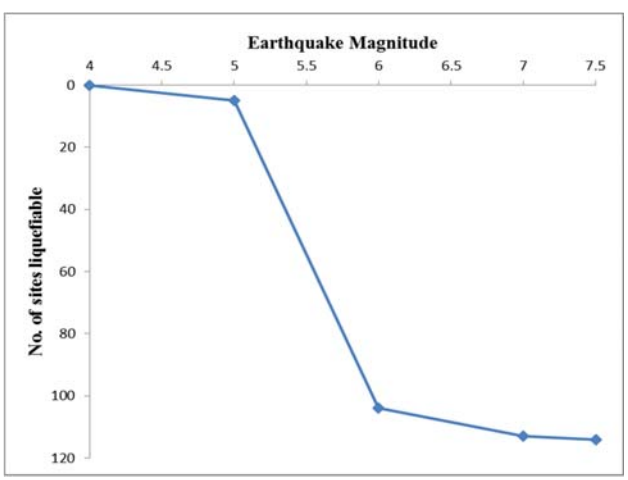

Fig 4: Plot between Magnitude and number of sites liquefiable

Conclusions

Liquefaction susceptibility assessment based on empirical approach with SPT value (N value) was carried out at 115 areas of Krishna district. The following conclusions were drawn from the analysis.

1. Liquefaction susceptibility by using empirical method showed 2 locations to be in safe zone while rest 113 was found to be unsafe.
2. It was observed from the current investigation that most of the sites in the Krishna district are liquefiable at the magnitude of earthquake beyond 5. It was strongly identified that no site has shown liquefaction susceptibility for an earthquake magnitude of 4.
3. Majority of the regions of Krishna district may not susceptible to liquefaction when a light earthquake happens.
4. If a strong earthquake happens almost all the areas in the Krishna district are susceptible to liquefaction and there is a chance of huge loss for life and property.
5. 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.
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.

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