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QUANTIFICATION OF LIQUEFACTION TRIGGERING SUSCEPTIBILITY: USING GEOLOGICAL, GEOMORPHOLOGICAL AND GEOTECHNICAL CHARACTERISTICS

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ABSTRACT: The damages patterns from the Bhuj earthquake (2001,7.6 M_w) observed within the 250km radial distance from the epicenter due to regional surface and sub-surfaces settings. In order to estimate the damage level from future earthquakes in the current study, an attempted to evaluate the various compositional aspects in the fields of geological, geomorphological and geotechnical characterization of the Amaravati capital region, Andhra Pradesh (AP) state, India. The selected study area lies between latitudes of 16°01" N to 16°09" N and longitudes of 80°00" E to 80°08" E. The results from all the aspects presented in the form of thematic maps, developed by using Geological Information System (GIS). The various types of data like spatial data (satellite image), attributes data and field data collected during the study. To characterize the soils within the study area, soil samples collected from 250 boreholes by conducting the Standard Penetration Test (SPT) at different locations within the study area. In addition to this, basic laboratory tests like index properties and grain size analysis were conducted to identify the nature of soils and to classify the soils according to the size of the grain. The obtained laboratory results compared with existing methodologies like Chinese Criteria by Wang (1979), Seed (1982) and modified Chinese Criteria by Andrews & Martin (2000). Based on the results, liquefaction prone areas identified in the study area and depending upon the susceptibility to liquefaction entire study area has been divided into three groups namely i) susceptible ii) partially susceptible iii) not susceptible.

Keywords: Amaravati Capital Region, Geology, Geomorphology, Geotechnical Characterization, Liquefaction Susceptibility.

1. INTRODUCTION

Earthquakes are very strong and unexpected natural disasters which are unavoidable and unpredictable in nature [1]. India has experienced with high frequency earthquake magnitude greater than 8.0, during 1897 to 1950 including [Assam-1897 (Mw = 8.7), Kangara 1905 (Mw= 8.6), Bihar-Nepal-1934 (Mw= 8.4), Bhuj - 2001 (Mw=7.6), Muzaffarabad-Kashmir 2005 (Mw= 7.6), Sikkim-India 2011 (Mw= 6.9), Chamoli-1999 (Mw= 6.8), Latur-1993 (Mw= 6.4), New Delhi - 2012 (Mw= 4.9) and Koyna Nagar-2012 (Mw= 4.9)] [2]. Geographical statistics of India shows about 54% of the land is under vulnerable to earthquakes, which contend on the necessity for carrying out seismic hazard analysis and microzonation studies throughout the country [3]. Liquefaction one of the grounds induced failures mostly occurs at the time of earthquakes, which cause huge damage to the structures [4]. The phrase liquefaction formerly invented by Mogami and Kubo (1953) [5]. The phenomenon of liquefaction drawn attention by many researchers after Alaskan and Niigata earthquakes (1964) [6]. The phenomenon of liquefaction is described as the reduction of shear strength of soil followed by decreases in bearing capacity of soils due to the generation of excess pore water pressure within the soil skeleton [7,8,9]. The Phenomenon of liquefaction is shown in Fig. 1.

1.1 Significance of the Present Investigation

Wang (1979), an attempt made for evaluation of liquefaction potential from Haicheng (1975) and Tangshan (1976), earthquakes. In order to assess the liquefaction potential Wang (1979), has considered constraints like. Clayey content <15-20% of the particles smaller than 0.005mm by weight and ratio of water content to liquid limit >0.9 [4,10]. The method which was proposed by Wang (1979), is slightly revised by the Seed (1982), by considering plasticity characteristics of clayey soils, which was not considered by the Wang studies earlier [4,11]. Many researchers all

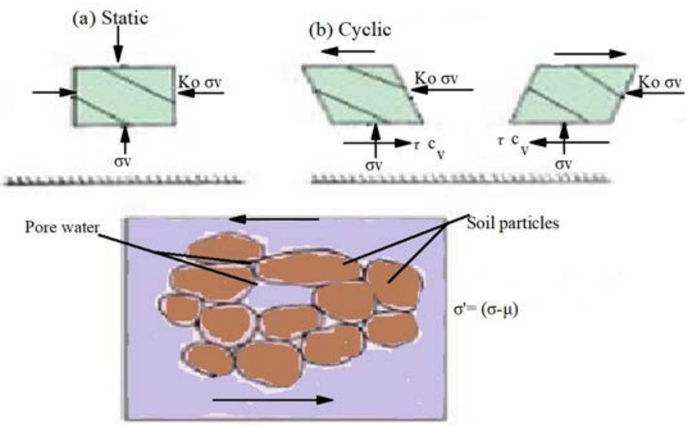

Fig.1 Phenomenon of liquefaction [1].

over the world, stated that clayey soil could be susceptible to liquefaction if the soil deposit meets the following criteria [4, 11, 12].

$\tau = \sigma' \tan \phi'$ (1)
$\sigma' = \sigma - u$ (2)
Where,
τ = shear strength,
σ'=effective normal stress
ϕ'=angle of internal friction
σ=total normal stress
u=angle of internal friction

●Percentage finer than 0.005 mm < 15%
●Liquid Limit (LL): < 35% and
●water content (WC %): > 0.9 x LL

As the method is evolved from Wang (1979), and this method recognized as Chinese Criteria. Further by Andrews & Martin's (2000) criterion, to identify the soils which prone to liquefaction the percentage of fineness is reduced to 0.002mm instead of 0.005mm and clay content is taken as 10% constant throughout the criteria. From the Koester in (1992) and by Andrews & Martin (2000) it is observed that, if the clay content present in the soils is less than 10% by the liquid limit is < 32, then the soils are treated as susceptible to liquefaction. In other cases, soils are not treated as susceptible, if the clay content is ≥10% by the liquid limit is > 32 [13,14]. From the Loma Prieta earthquake (1989), it has been observed that clayey soil deposit might be contributed to surface deformation and leads to liquefaction effects of the sites [15]. It has been strongly recommended by Idriss and Boulanger (2004), from their studies and from the comprehensive report, evaluation of liquefaction potential with laboratory equipment is the best method and stated that the soils are classified as "sand-like" fine-grained soil if the plasticity index is (PI <7), treated as susceptible to liquefaction [5,16]. On the other side, soils are categorized as "clay-like" fine-grained soil that may undergo cyclic failure if the plasticity index is (PI ≥7). Vijayawada in Krishna district of Andhra Pradesh, India, and its adjoining areas are known to have experienced more than fifty seismic events during the past four decades with low intensity to medium moderate. In the process of evaluation of liquefaction potential, all the existing case histories and theories are considered collectively and an attempt made to identify the liquefaction prone locations in the capital region by considering the following constraints with respect to existing conditions.

- Percentage of fineness (D ≤ 0.005 mm) content < 10%
- Coefficient of uniformity(D60/D10) < 10
- Liquid limit (LL) >32 ≤ 35
- Relative density Dr ≤ 75%
- Plasticity index PI < 7≤ 10

1.2 Description of the Study Area

Amaravati and adjoining areas have been selected as new capital to the state of Andhra Pradesh after bifurcation Telangana state from Andhra Pradesh in the year of 2014. The capital region of Amaravati is coming up in an area of 217.23sq.km in that 16.26 sq.km as a seed capital region [17,18]. As per BIS [1893 (part 1):2016], the selected study region falls under seismic zone III, which means seismically the area classified as low to a medium moderate risk zone from the seismic hazards.

The geographical coordinates of the study area starts from northwest 16°09'80" N to 80°00'9" E and from southwest 16°01'3" N to 80°01'8" E from southeast 16°01'3" N to 81°00'6" E from northeast 16°08'6" N to 80°08'9" E. The location of study area from India is shown in Fig.2. River Krishna flows along the southern part of the capital region due to this more alluvial soil formation taking place in adjoining areas of the river Krishna.

2. OBJECTIVES OF THE PRESENT STUDY

I. To evaluate the different compositional aspects in the fields of geological, geomorphological and geotechnical characterization of the study area.

II. To develop the thematic maps of geological, geomorphological and soil classification by using RS & GIS.

III. To identify the liquefaction prone areas within the study area and to generate the liquefaction susceptible map.

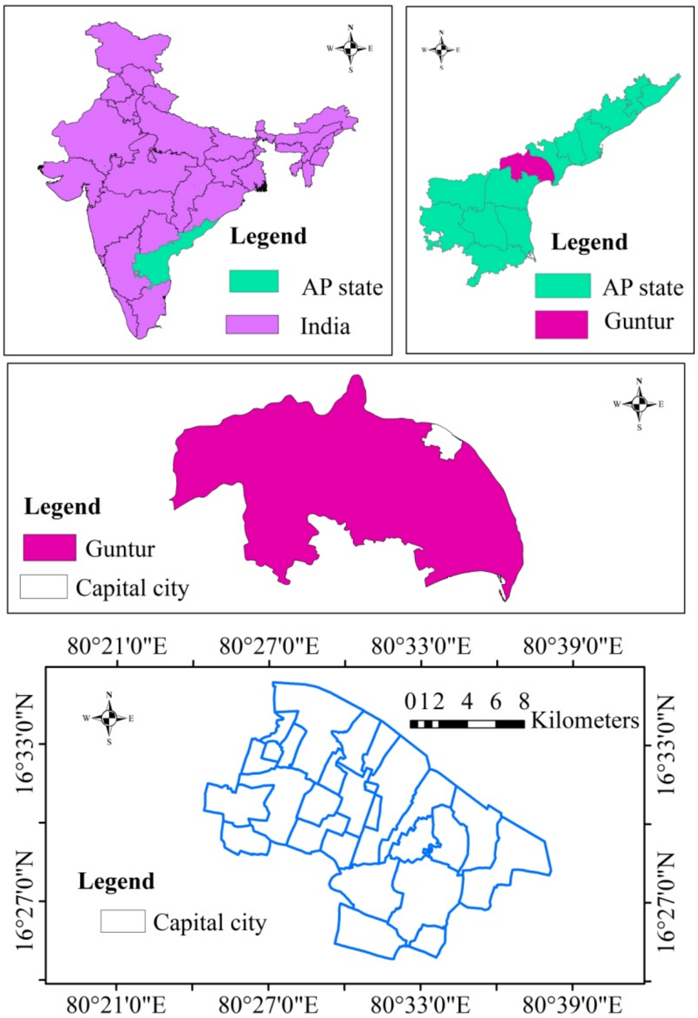

Fig. 2 Location of the study area (village boundaries) from the India map.

3. METHODOLOGY

The methodology adopted in the present investigation to evaluate the liquefaction potential is presented in Fig.3. During the data collection, the toposheets related to study area (65D/6, 65D/7, 65D/10 and 65D/11 on 1:50,000 scale), are collected from Survey of India (SoI) and the geology maps (including geomorphology characteristics), of Guntur and Krishna districts of AP state, has been collected from Geological Society of India (GSI), Hyderabad. Various parameters like rock types, rock formations, alluvium formations and water bodies considered in geological field and in geomorphologically the type of structural plains, topographical features been considered. To identify the liquefaction susceptibility according the geomorphological classification the method given by Iwasaki (1982) has been considered in this study and in geotechnical point of view mainly Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI) are considered as basic parameters to analysis of liquefaction potential in the study area [19].

4. RESULTS AND DISCUSSION

4.1 Geology of the Study Area

Geological formations of different age groups ranging from Precambrian to the latest were observed during the preliminary studies. The

Archaean basement complex comprising of Khondalites, Charnockites and basic barrier of dolerites from the predominant rock types in this region. The southern part of the capital region is comparing sandstone belonging to the Nallamalai group of upper Cuddapahs, these rock shores underlain by the eastern ghats supper group comprising by Khondalites and Charnockites on the eastern side of the study area [19,20,21]. The geology map of the study area is drawn with the help of GIS software, as shown in Fig. 4. The Khondalite Group of rocks consists of quartz, feldspar, and garnet sillimanite, graphite, with or without corundum and are seen as prominent hill ranges. In the north-eastern part of the study area, with local swerves to NE-SW and NW-SE [20]. A number of calc granulite and quartzite bands are present within the Khondalites.The Khondalites, Charnockites rocks groups and the layered complex show foliation trending dominantly N-S.

4.2. Geomorphology of the Study Area

Geomorphologically, Amaravati capital region broadly classified into 3 units viz., I) Alluvial plain II) Fluvial plains III) Denudational plain, all this type of plains mostly formed in the southeast corner of the area. Alluvial plain forms a leading part of the geography of this region and runs on the northern side of the region. Geomorphology features of the Amaravati capital region are shown in Fig. 5.

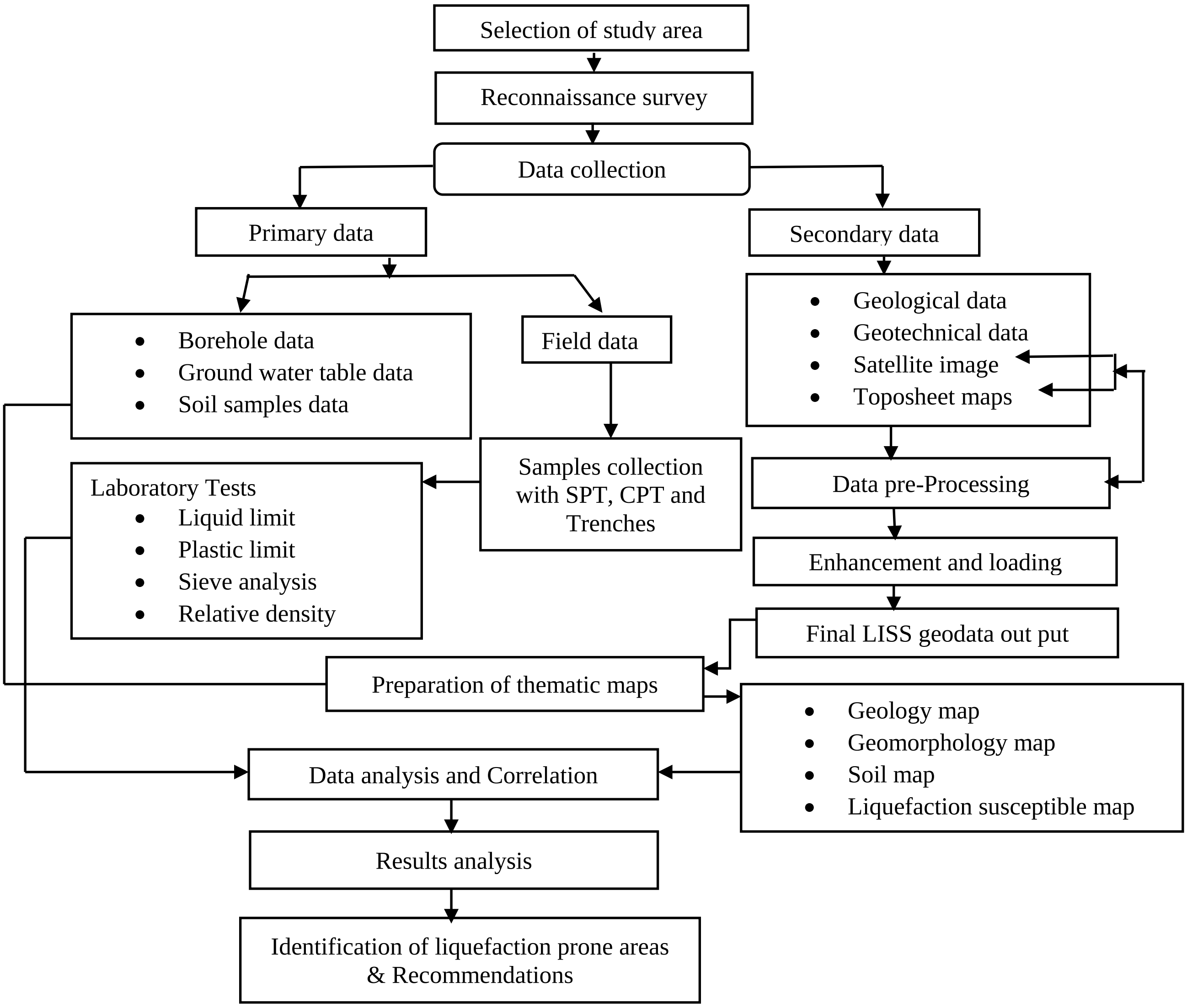

Fig. 3 Methodology adopted in the present investigation to evaluate the liquefaction prone area.

The altitude of the above landforms varies with weathered outcrops of an average elevation about 13 meters above Mean Sea Level (MSL). Depending upon rock type and the geomorphology

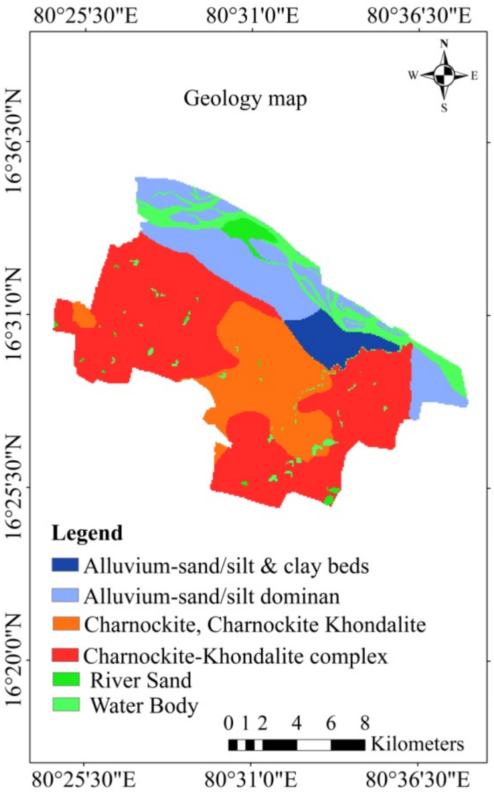

Fig.4 Geology map of the study area

units with groundwater levels the outcrops susceptible to liquefaction for the selected area classified into three categories viz., Geomorphological groups developed by the Iwasaki (1982), are used in the present study to evaluate the of liquefaction potential [19]. 1) Likely susceptible 2) Possibly susceptible 3) Not susceptible. Table 1, shows the liquefaction units of the study area as per geomorphology.

4.3. Geotechnical Characteristic of the Study Area

SPT based probabilistic liquefaction in the sand and silty sand deposits have been derived by the number of investigators including Christian and Swiger (1975), Liao (1988), Youd and Noble (1997), Juang (2010) and Cetin (2004) [22,23,24,25]. In order to understand the lithology of subsurface and groundwater levels, characterization of soils was carried out in two stages in the Amaravati capital region I) Field investigation II) Laboratory investigation [26]. In the first stage of the investigation, soil samples were collected in 250 different locations with the help of SPT and in addition to this 75 soil samples were collected from test pits up to a depth of 3 meters. SPT is conducted in different locations up to an average depth of 25m. The lowest SPT value recorded in majority adjoining areas of Krishna river including Rayapudi, Lingayapalem, Uddandarayanipalem, Venkatapalem, Undavalli, and Tadepalli the value of SPT observed 5 and below. The major soil complex of this region is loamy to clayey soils. Velgapudi and its adjoining areas the SPT counts increase and the consistency of the soils at these depths can be defined as low dense to medium dense. The spatial variation of the soil map of the capital region is shown in Fig. 6. In the second stage of the investigation, physical properties and various index properties like liquid limit, plastic limit, relative density and sieve analysis conducted for disturbed and undisturbed soil samples to differentiate the soils according to their composition. It is found that the alluvial soils are exposed on the eastern side and along the Krishna river and the maximum study area is compiled by block cotton, silty sand, clay loam, sandy alluvial, red gravel, and red loams.

The disposition of interlayered sequences of silty clay, silt and sand are found in most of the areas during the excavation of soils. Laboratory results revealed that 24 locations (shown in Fig.8), within the capital region including Rayapudi, liquefaction and based on the laboratory results (Geotechnical characteristics), the capital region has been divided into 3 groups with respect to the liquefaction susceptibility, as shown in Table 2. Liquefaction susceptibility map (shown in Fig.7), of the capital region developed by indicating the liquefication potentiality viz., I) susceptible to liquefaction II) partially susceptible and III) not susceptible.

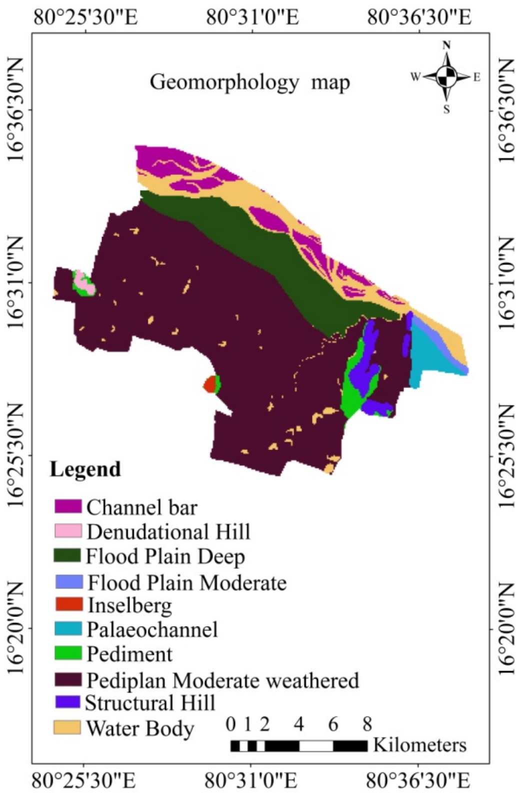

Fig.5 Geomorphology map of the study area

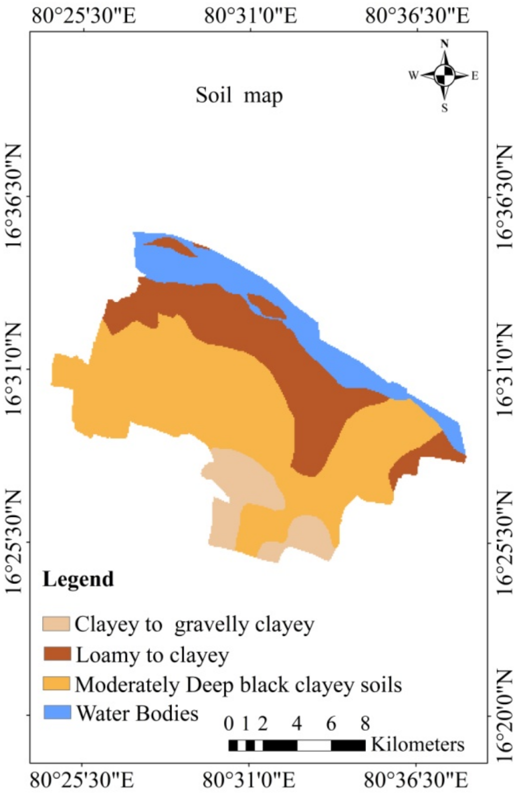

Fig.6 Soil map of the study area

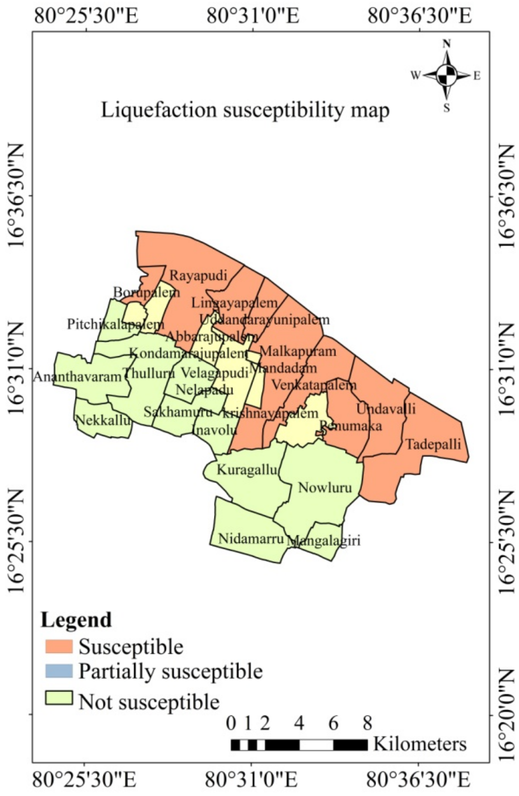

Fig.7 Liquefaction susceptibility map

Table 1. Criteria for liquefaction susceptible according to geomorphological units

Category	Rock type	Depth in meters	Geomorphological classification	Liquefaction susceptible
I	Sand & Hard rock	Ground-level at 25m &25 to 35 m and below 35 m	Older deposits	Not susceptible
II	Silty sand	Ground-level at 5m and between 5 to 25 and below 25m	Alluvial plain moderate	likely susceptible
III	Silty clay & clay	Ground surface level and up to 5m	Alluvial plain shallow	Possible to susceptible

5. CONCLUSION

In the current study based on the laboratory results, the selected study area has been divided into 3 groups such as susceptible to liquefaction (Uddandarayunipalem, Tadepalli, Undavalli, Rayapudi, Borupalem, Lingayapalem, Mandadam, Penumaka, Venkatapalem), partially susceptible to liquefaction (Abbarajupalem, Dondapadu, Velagapudi, Malkapuram, krishnayapalem, Kondamarajupalem) and not susceptible to liquefaction (Inavolu, Ananthavaram, Kuragallu, Mangalagiri, Nekkallu, Nelapadu, Nidamarru, Nowluru, Pitchikalapalem, Sakhamuru, Thulluru). Since the liquefaction susceptible map can be considered as a first level source for future studies. As it is recommending that, further detailed investigation is required in order to understand the scale of hazard due to the earthquakes and to understand the seismicity of this region it is required to prepare the earthquake catalogue and seismotectonic map Seismic Hazard Analysis (SHA), ground response studies and liquefaction analysis and microzonation studies.

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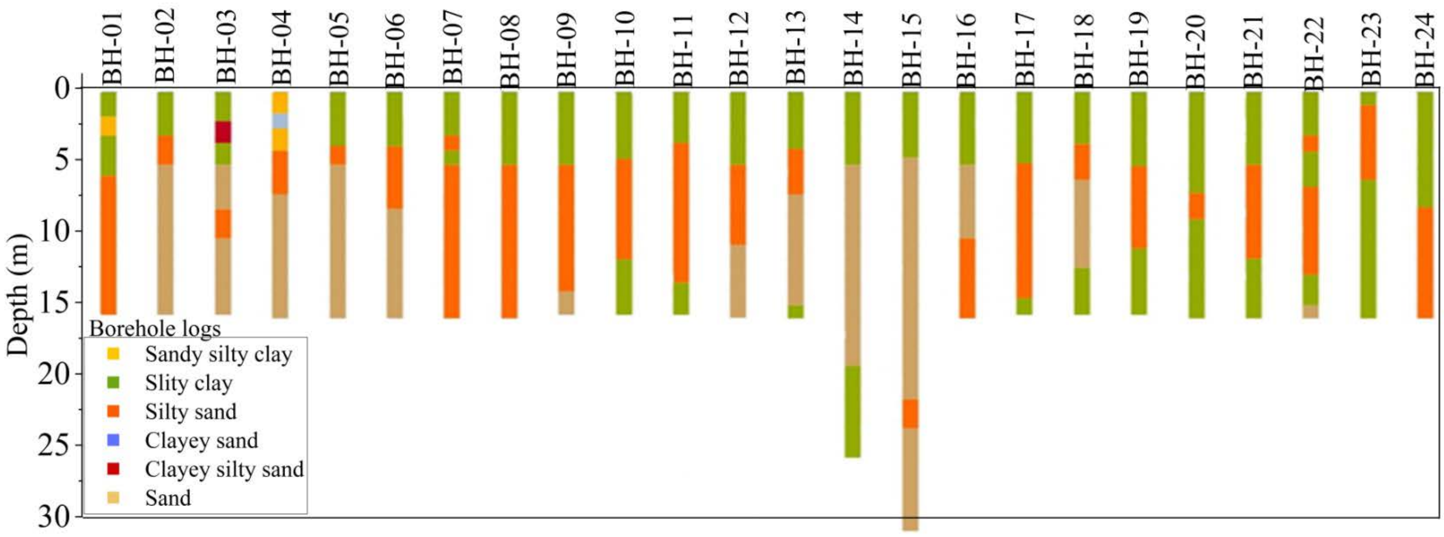

Fig.8 Sub-surface soil profiles with major soil classification at different depth.

Table 2. Laboratory test (Index properties and grain size analysis) results verses liquefaction susceptibility analysis.

Result analysis	Soil nature	Group A	Group B	Group C
Grain size Analysis	Depth in (Meters)	1.5 to 2.45	1.8 to 5	>5
	Gravel	0.4 to 3	0.8 to 2.3	25to 75
	Sand	1.6 to 15.25	2.2 to 14.7	5 to 25
	Fineness (< 75μ)	82 to 98	84 to 97	1 to 5
Liquefaction analysis	Relative Density in%	54 to 63	55 to 60	75 to 95
	Liquid limit (LL) in %	18 to 25	17 to 28	NA
	Plastic limit (PL) in %	8 to 10	8 to 12	NA
	Plasticity index (PI)	8 to 16	17.8 to 9.85	NA
	Remark	Susceptible to liquefaction	Partial susceptible to liquefaction	Not susceptible to liquefaction

enhanced and vivid explanation happened even to a layman. Clarity occurred in our research paper after corrections.

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