Liquefaction Hazard In the Ap Capital Region, India

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Abstract: The new capital region of Andhra Pradesh state is in seismic zone III, and on the banks of Krishna River, with the expected population of 3 millions in the next 5 years. The liquefaction potential of new capital region of Andhra Pradesh is assessed based on Standard Penetration Test borehole data of 463 locations. The simplified approach is used to estimate the factor of safety against liquefaction. A moment magnitude of 5.8, Peak ground acceleration of 0.16g is considered for estimation of liquefaction potential. The map of the capital region is prepared from the G.O.MS.No.253, and the factor of safety against liquefaction at the locations are plotted with respect to their latitudes and longitudes using AUTOCAD-2015 at a scale of 1:796875. The region is categorized into 4 zones based on factor of safety, where 11 locations fall in the zone of less than 1.5 and have a tendency to liquefy, 45 locations in the zone 1.5-2.5, 25 locations in the zone 2.5-4 and 382 locations in the zone greater than 4. It has been observed that most of the region is having cohesive soils in the top 3 m to 6m at different locations, hence this analysis revealed that majority of locations in the capital region are safe against liquefaction and requires soil amplification studies and only 11 locations near the Krishna River stream are observed to be susceptible to liquefaction.

Index Terms: Liquefaction, Standard Penetration test, AP Capital Region, Peak ground acceleration, Factor of safety.

I. INTRODUCTION

The loss of ability to bear the loads by the soil underneath due to rapid loading like that of an earthquake is liquefaction. It is more of a fact that the soil underneath acts like liquid, mathematically explained by equating total stress and pore water pressure, thereby a zero effective stress. Liquefaction is prominent in soils of mediocre density with amounts of saturation. History shows a colossal damage is transpired due to causes of liquefaction in the mode of ground settlements, landslides, etc. (Borcherdt, R.D., 1991). Assessing the effect in prior to its occurrence can render necessary actions at times of earthquake. Many instances of liquefaction are noticed right from Niigata earthquake (1964), Alaska earthquake (1964), Loma-Prieta earthquake (1989), Kobe earthquake (1995), Chi-Chi Earthquake (1999), Bhuj (2001) to recent Christchurch (2010) and Canterbury (2011) earthquakes. Countries like India got stretchy coastal line, with high probability of liquefaction taking place. Also, the country got chances of over 50% susceptible to the earthquakes (Sreevalsa Kolathayar et al 2014). The Bhuj earthquake (2001) got incidents of failures due to liquefaction, causing sand boils, rail-road and highway damage. The areas that are placed near water bodies like rivers, oceans, etc. are found to be more open to liquefaction from the observations from the past earthquakes, damaging structures like bridges, retaining walls at the sites. Generally, the effect of liquefaction is observed in loose (rarely dense) cohesionless soils, as the concept of generating negative pore pressure while in shear may help dense soils. This effect of liquefaction is predominant up to a depth of 15m based on the literature as well as observed in the history. The present study area covering the new capital region of Andhra Pradesh is predominantly having high water table, which varies from ground surface to 5 m depth at various locations, Krishna river is flowing in the middle of the proposed area, based on the seismic Zone III as per IS 1893: 2002, and based on the Geological survey of India, seismotectonic map (2000), which shows more than 20 faults and lineaments in this region, with major thrust from Gundlakamma fault near Ongole, and Addanki-Nujiveedu fault, which is passing through the capital region. Also at present the population is 2 million and identified as most futuristic state capital of India, with the expectation of 3 million population in the next 5 years with major infrastructural facilities such as Government offices, high rise structures for both commercial and residential purposes, and industries in this region. By keeping in view the importance as given above, the borehole data is collected from 463 locations from various organizations and estimated the liquefaction potential map based on the well established cyclic stress approach developed by Seed and Idriss (1971) and Idriss and Boulanger (2005).

A. Study Area

The capital region of Andhra Pradesh, India is opted for the evaluation of liquefaction potential. the region with 7,068 km^2 dissolving 58 mandals both from Krishna and Guntur districts (G.O.MS.No.253).

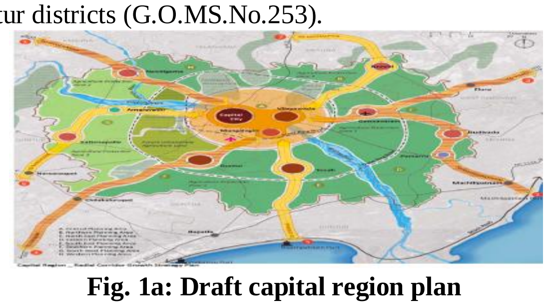

Fig. 1a: Draft capital region plan (www.crda.ap.go.in)

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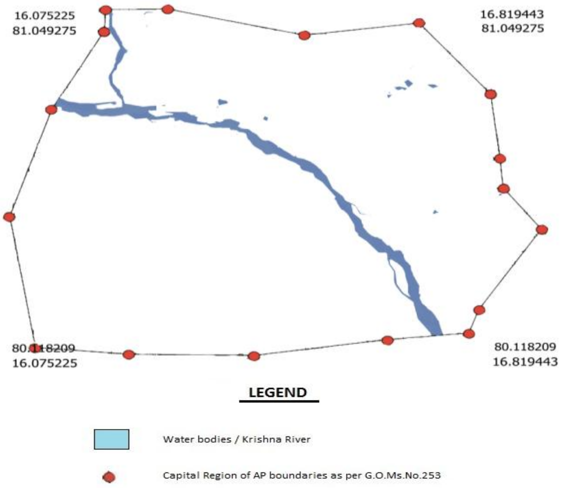

Fig. 1b: Boundary of capital region of Andhra Pradesh as per G.O.Ms.No.253

II. METHODOLOGY

In the present study Seed& Idriss (1971) simplified approach has been used for evaluating the cyclic stress ratio (CSR) of in situ soil. Bore hole data of 463 locations has been collected for assessment of liquefaction potential in capital region of Andhra Pradesh.

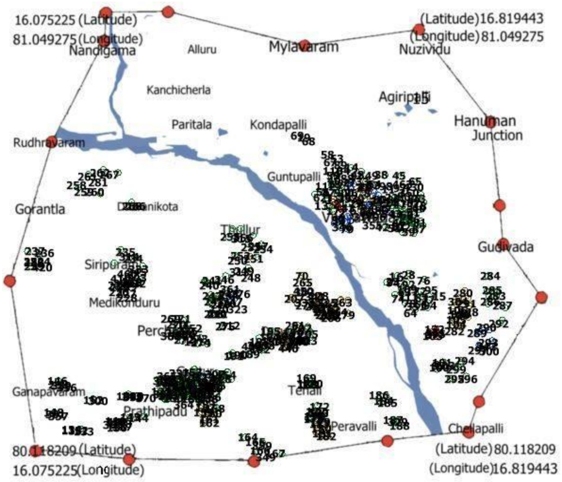

Fig. 2: Bore hole locations map.

$$CSR = 0.65 \left(\frac{\sigma vo}{\sigma vo'}\right)\left(\frac{amax}{g}\right) rd \quad (1)$$

Total stress, effective can be computed from SPT-borehole data based on water table depth, soil profile. Since the soil column is not rigid body during earthquake but rather the soil is deformable r_d depth reduction factor was suggested by Liao and Whitman (1986)

$$r_d = 1.0 - 0.00765z \text{ for } z<9.15m \quad (2)$$

$$r_d = 1.174 - 0.0267z \text{ for } 9.15<z<23m \quad (3)$$

Where z is depth in m, a_{max} refers to peak ground acceleration, according to IS 1893:2002 our region of interest falls under zone III corresponding PGA is 0.16g,From the technical report by National Disaster Management Authority "Probabilistic Seismic hazard map of India" (2011) constituted by Raghukanth and Iyenger the PGA values for return periods of 500,2500 and 5000 years are 0.07g,0.13g,0.15g of all critical being 0.16g by IS 1893-2002 used for computing cyclic stress ratio. From Seismicity parameters for important urban agglomerations in India Raghukanth (2011) Moment magnitude(Mw) for a region depends on the seismic parameters b-value and seismic activity rate λ, which can be estimated from the past earthquake study for a control region with radius of 300 Km, given by Kijko and Graham (1998). A moment magnitude of 5.8, with the seismic parameters b and λ being 0.09±0.1 and 0.35±0.05 was given by Raghukanth (2011). Cyclic resistance ratio was computed using equation given by Idriss and Boulanger (2005).

$$CRR = \exp\left\{\frac{(N1)60cs}{14.1} + \left(\frac{(N1)60cs}{126}\right)^2 - \left(\frac{(N1)60cs}{23.6}\right)^3 + \left(\frac{(N1)60cs}{25.4}\right)^4 - 2.8\right. \quad (4)$$

The N values measured in the field using standard penetration test procedure have been corrected for various corrections, such as Overburden Pressure (C_N), Hammer energy (C_E), Bore hole diameter (C_B), presence or absence of liner (C_S), Rod length (C_R) and (f) fines content (C_{fines}) (Seed et al: 1983, Skempton: 1986, Schmertmann).Corrected "N" value i.e., $(N_1)_{60cs}$ is obtained using the following equation:

$$(N_1)_{60cs} = N \times (C_N \times C_E \times C_B \times C_S \times C_R \times C_{fines}) \quad (5)$$

However this estimation is proposed for a magnitude of 7.5 on the Richter scale. Since the earthquake magnitude considered in this study is 5.8, this correction has been applied using magnitude scaling factor (MSF).

$$MSF = \left[\frac{10^{2.24}}{Mw^{2.56}}\right] \quad (6)$$

The above equation holds good for Mw less than 7.5. Factor of safety against liquefaction can be evaluated from the methods based on deterministic as well as probabilistic analysis. In either of these methods, liquefaction expected to occur during the earthquake if the cyclic stress ratio caused by the earthquake is higher than the cyclic resistance ratio of in situ soil. The factor of safety against liquefaction is defined as follows:

$$FS = \left(\frac{CRR7.5}{CSR}\right) MSF \quad (7)$$

Here subscript 7.5 denotes that CRR values calculated for the earthquake moment magnitude of 7.5. MSF is the magnitude scaling factor and this term is used to adjust the CRR values if the earthquake magnitude differs from 7.5. Liquefaction hazard can be classified as no liquefaction (FL ≥4), moderate (2≤ FL <4), high (1.5≤ FL <2), and very high (FL <1.5).

III. RESULTS & DISCUSSIONS

The estimation of liquefaction potential is done via both the old and new methods, and the results obtained by the 1971 approach tend to be more conservative then the modified approach. So, the outcomes from the earlier approach are considered for plotting the map.

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A scale of 1:796875 is selected for the purpose of covering entire region of the capital. The latitudes and longitudes of the locations where boreholes are made are collected with high accuracy. With the help of google maps a. kml file the region is created. This file is edited according to the prevalence in Adobe Photoshop CS6. Autocad-2015 is employed for plotting the map.

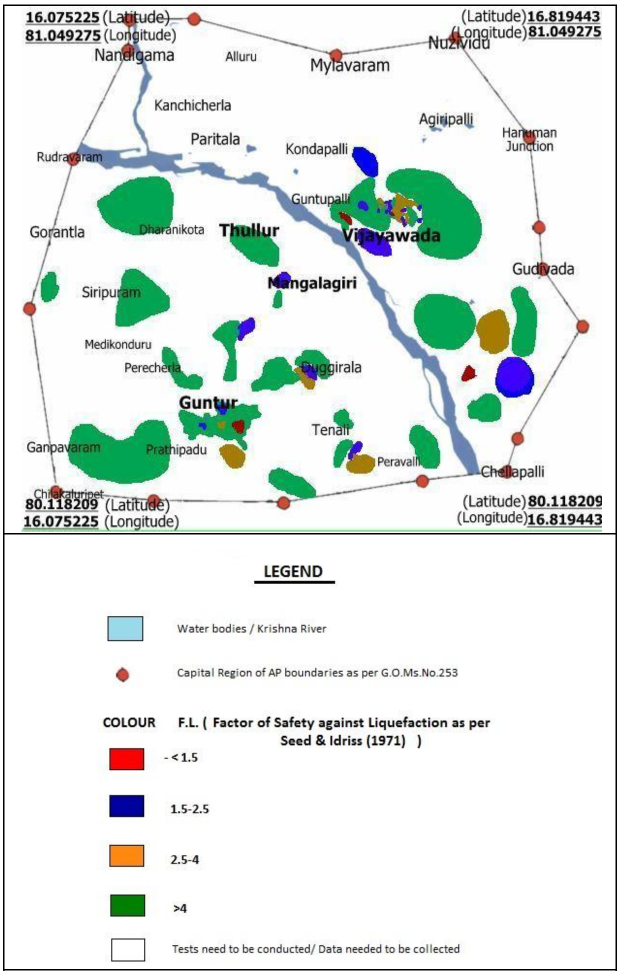

Fig. 3. Liquefaction Hazard Map for capital region of Andhra Pradesh for a moment magnitude of 5.8, PGA of 0.16g and using Seed & Idriss (1971) Method.

The Brahmin Street consists of sandy silt for 5.5m and water table at 3.5m, which explains the possibility of liquefaction failure below 3.5 meters. A similar case with the locations at Y.V.Rao Hospital, Gunadala Railway gate with water tables at 2.5m and 5.5m with silty sand combination, liquefaction may occur with good chance. Sufficient care needs to be taken in case of the foundation, as reaching much deeper levels, till it hits the non-liquefiable soils.

Jakkampudi, locations in sub-jail road, Jawahar Autonagar, Kondapalli, Bus-terminal in Autonagar, Sivalayam Street in Moghalrajapuram, High School Road in Patamata, KBN college, BPCL outlet in Autonagar, Geetha Mandir in Seetharampuram, Vidhyadhrapuram, Venkataratnam street in Dornakal Road, Amarvani estate in Patamata, Sanyasi Raju Street in Gandhinagar, 33/11 Kv-Substation, on National Highway near Vaddeswaram, Ajith Singh Nagar, Brundhavan Colony are the safe locations in regards to liquefaction, as they consists of clay all through. Sunnam battilu Centre in Moghalrajpuram with water table at 3m and top 5m being clay is safe for the top 5m, but underneath the sandy silt may cause liquefaction with little disturbance to the top layer.

Madhuranagar has its water table at 3.5m with top 5m being sand and silt. So the removal of this layer is suitable as underneath clay is safe from liquefaction. Similar with the case of banks of Budameru drain in Gunadala, top 2.5m sandy layer and filled up soil can be removed for safety against liquefaction. The top 2m of filled soil removal at Pantakaluva road may assure safety at this place, as water level also at 2m with clay underneath.

V.S.S.Road in Ayyappa Nagar, in spite of top layers being sand there is no water table existing. So the process of liquefaction is invalid for the regions like this. Jakkampudi, Ambapuram have similar situations.

The NH-9 near Kanakadurga temple, Journalist colony and Mallikarjunapet are having rock underneath making the sites safe from liquefaction.

Kanuru Panchayat is prone to liquefaction as the water table is at 2.4m with availability of sand. So reaching till clayey layers is one of the remedial measures. Even Kasturibaipet is having the water and sand combo at 2m, removal of the top layer helps safety as clay underneath avoids liquefaction. C.K.Reddy road in Kedhareswarapet, Mahanadu road are one such locations with same situation but with a suitability of 3.5m and 2.5m top layer removal respectively.

Narravari Street in Satyanarayanapuram is safe against liquefaction at top levels, at 5.5m where water meets sand liquefaction may occur. But the pressure is not sufficient to pierce the top clayey layers. Muthyalampadu also comes up with same circumstances. Gunadala also has the same situation with 7.7m of ground water availability.

Sub-collector's office in Bundar road is having sand available in top layers, but the water table is deep underneath at 6m with clay combination making the site safe from liquefaction.Same with case of Enkipedu.

Autonagar has no level of water in ground, so it is safe from liquefaction, even if the water table raises the top layers being clay, the site is safe from liquefaction. SBI colony, Nethaji street in Seethrampuram, Kapula Ramalayam Street, Kreesthurajpuram, Nehru Nagar, Government Regional Press, Nunna also fall into the same category. Acharya Ranga Nagar in Benz circle, Technical nagar in Patamata have chances of liquefaction occurrence at 7m and 8m depth with ground water availability repectively. But the pressure is not sufficient to displace the top layers. Yanamalakuduru region, Old Bus stand, Tikkle Road, Bharati Nagar, Praja sakthi Nagar, Chandramoulipuram, Currency Nagar, M.G.Road in Patamata, Prasadampadu, Ramvarrapdu also exhibit the same circumstances. But they may face a problem at times of raise of ground water. Srinivasa nagar Bank colony is prone to liquefaction at a greater extent, as the water table being at 2m with entire region being sand extending up to 10 m underneath.

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Suitable care should be taken in designing the foundations for this cases. Even the locations of Municipal Corporation, Bhavanipuram, Sitarama Road in Patamatalanka are at stake with same conditions.

Ramachandra Rao nagar in Governerpet is safe even though the water level being at 4m, as the top layer are equipped with clay. S.E.R. Centre in Prasadampadu, Ibrahimpatnam, Machavaram, Maguntavari Street, Vemula Syamaladevi Road also are one such location.

The APSRTC Bus Terminal, Vijayawada is the location where water table is nil, but with sandy layer underneath. VMC office premises, Labbipet, Tikkle Road in Patamata are one such location.

The Airport at Gannavaram is higly prone to liquefaction with water table at 2m with clayey sans all through. More than 3.5m of the top layer should be removed for avoiding such damage.

The Vuyyuru Sivalayam Street is safe in terms of liquefaction due to availability of clay all through its base.Edepalli in Machilipatnam faces high risk of liquefaction due to 2m water level with sand all through. Suitable measure should be adopted, as reaching the non-liquefiable zone. In the locations covering Guntur and its surroundings, JKC College road, Sangadigunta, Amaravathi road, Gorantla, Near Ashok Layland Work Shop, Budampadu By-pass, Naaz centre, Lakshmipuram, Mangalagiri Road, Opp: Eenadu Office, NGGO Colony, Amaravathi main road, Brundavan Gardens, Pattabhipuram Main Road, Reddypalem,, Koritepadu, Guntupalli, Thullur, Peravalli, Dharanikota. Chilakaluripet Village border, Agraharam in Guntur, Krishna Nagar Park Road, Pandaripuram, Anjaneyapeta,Koritepadu, S.V.N. Colony, Vijayapuri Colony, Nalanda Nagar, Siripuram, Behinde Tagur Rice Mill, Mutyala Reddy Nagar Road, Balaji Nagar, Syamala Nagar, NGO's Colony, Turakapalem Road, Bhavanamvari Street in Tenali, Ganganammapet in Tenali, Vijeta Public School Road, Ankireddy Palem Road in Nallapadu, Challawariplalem, Pothavaram village, Sri lakshmi Narasimha Enclave, Ramachandrapura Agraharam, hirangipuram, Brodipet, Shop Employees Colony, Vetarnity Colony, Venkata Ramana Colony, Pattabisitaram Nagar, Nagaralu, Vidya Nagar, Koritipadu, Lambadi Colony, Pandu Ranga Nagar, Outer Ring Road in Reddypalem, Tarkarama Nagar B\beside Rama Chandra Mission, Alapativari Street, Gandhinagar in Tenali, Vengalayapalem,N.H.16 in Guntur, Krishna Nagar, Lakshmipuram, Sri Amarewara Swamy Temple in Amaravathi, Donka Road in Guntur, Pedda Palakaluru, Arundelpet, Brundavan Gardens in Guntur, Stambalagaruvu Ring Road in Guntur, Khaja Village, Vadlamudi, Auto Nagar in Guntur, Sitanagar in Guntur, Sankara Eye Hospital in Peda Kakani, South BMR Residency in Guntur, Naidupeta, Siddhartha Nagar, Vijayapuri Colony, Padmavathi Complex in Lakshmipuram, Old Pattabhipuram, Ankkireddy Palem, Near Chilakaluripet Bus Stand, Chinakakani, Obulunaidu Palem, Potturu Village, Housing Board Colony Extension in Guntur, Tadepalli, Annapurna Nagar, Inner Ring Road in Guntur, Kantheru village, Agathavarapadu, Krishna Babu Nagar, Palakaluru Road, Gujjanagundla, Ratnagiri Nagar, Navabharat Nagar, Duggirala, Prathipadu, Sai Nagar in Chuttugunta, Lalpuram Road, Venkata Ramana Colony in Guntur, Railpet, Venugopala Nagar, Challavaripalem, Ponnur Road, Vasantha Raya Puram, Devapuram, Kannavari Thota, Opp: Swamy Theater Road, Lakshmipuram Main Road, Potturu Gramapanchayat, Ramanna Pet, Vikas Nagar, Piduguralla, KMC & Hospital in Chinna Kondrupadu, Padmavathi Estate, Near Pedanandipadu bus stop in Chilakaluripet, Gunturvarithota, Navaluru Grama Panchayati, Ramireddy pet, Ganganammapet in Tenali, Near Railway Gate in Vinukonda, Eanugupalem road, Autonagar By-Pass Road, Nizampatnam, Venegandla Road in Pedakakani, Saibaba Road, Beside Over Bridge in Vinukonda Road, Behind XXX Soap Company in Gorantla, Kundul Road, Gaddipadu in Pedakakani, Thuraka Palem Road, Pedhapalakaluru, Penamaluru, Opp. Spinning Mill in Chebrolu, Budampadu, Vasantharayapuram, Hanumaiah Nagar Main Road, Chaitanyapuri, :Tsundur in Tenali, Ramireddy Thota in Guntur, Kothapet, Pillutla Road in Piduguralla, Chowdavaram, Kalyani Road, Kopparru, Ramalingeswarapet in Tenali., Karuchola, Jaggapuram, Nadendla, Sankurathipadu, contains black cotton soil, black clay, moorum with red and white variations all through. Though the ground water positions at most of these locations, due to the presence of clayey soils everywhere the liquefaction will not occur and these regions can be termed safe in regards to liquefaction potential.

Few regions in Undavalli region, Ramalingeswarpet in Tenali need to be taken care of in aspects of liquefaction potential, as the water table is at 2m from ground with sandy soils predominant to greater depths.

Marrispet, Ganganammapet in Tenali have sandy soil layers covered by clayey ones with water table at 2m depth. Sufficient care should be adopted at these regions if the foundations are going deep underneath.

Amaravathi temple region is one such region where the excavation of top layers is necessary. The water table of 2m with fines content in top layers till 3.45m may be a threat in terms of liquefaction.Nizampatnam area in Guntur District, also needs a heavy excavation till 5.45m for avoiding liquefaction. The 2m ground water level combined with silty sand may cause liquefaction at times of earthquake.

Agatavarappadu in Pedakakani, Venkateswara Colony, Ayyappa Nagar Road in Guntur have sandy soils at greater depths but water table at 2m. The top layers being clayey soil for a greater depth, the effect of liquefaction is ruled out at this location.

IV. CONCLUSIONS

A map with scale of 1.796975 is created using the G.O.Ms.No.263 google maps and AUTOCAD 2015, and categorized into 4 zones based on factor of safety against Liquefaction, as less than 1.5, 1.5 to 2.5, 2.5 to 4 and greater than 4, as shown in figure 3.

Amongst the 463 locations evaluated for liquefaction potential, there are 11 locations identified having a factor of safety less than 1.5, and have a tendency to liquefy. Suitable measures needed to be adopted for these regions.

And 45 locations are having a 1.5 to 2.5 factor of safety, 25 between 2.5 to 4 and 382 which are having factor of safety over 4 and hence safe.

Amongst the pga's used, the pga provided by IS-1893 (2002) is prevalent and more conservative than the other pga's used. So, it is employed for the estimation of liquefaction potential.

The liquefaction potential is estimated using the simple approach of Seed and Idriss (1971) and the revisions in the method from Youd et. al (2001). The earlier one proved to be more conservative than the later, and hence used for plotting the map of liquefaction potential in the capital region of Andhra Pradesh.

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