Local Site Effects and Liquefaction Analysis of Multilayered Soil

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Abstract

Earthquakes are one of the natural disasters that cause a huge amount of loss in terms of economy and human life. To achieve safety against natural disasters like Earthquake, it is necessary to construct the building considering geotechnical problems and structural safety against dynamic forces. The site effects, landslides, liquefaction are dangerous in regards to scale of damage. In the present study, 1D earthquake response analysis has been carried out in different sites of Andhra Pradesh capital seed area of 16.5 km^2 in Amaravathi city in Guntur district. To evaluate site effects, borehole data up to a depth of 15 m has been collected. The Earthquake time histories were used as input motion. The site amplification at surface has been assessed by using the equivalent linear approach in DEEPSOIL software. In addition to that, Response spectra and PGA with depth, Fourier Amplitude were assessed. The surface PGA values at surface obtained have been used for liquefaction assessment using SPT based method. As the study area has high rise buildings of national importance, findings from the study will be helpful in analysis and design of structures, therefore, solving practical challenges in Geotechnical and structural Engineering

Keywords: Earthquake, Ground Response Analysis, Liquefaction Analysis, Amplification, Guntur.

1. Introduction

1.1 General

Earthquakes are one of the devastating hazards in the world. Latur earthquake on 30th September 1993 (M 6.3), Jabalpur earthquake on 22nd May 1997(M 6.0), Koyna Earthquake on 11 Dec 1967 (M 6.5) and Bhuj earthquake on 26th January 2001(M 7.9). This recent seismicity has revealed that the Indian peninsular shield is no longer considered to be a 'stable land' or seismically inactive region. Earthquake causes huge damage to the regions by ground shaking, landslides, tsunamis etc., Therefore there is a need for amplification studies to analyze the amount of destruction caused due to earthquake .Seismic waves are the reasons for major destructions during Earthquake. These waves travel several kilometers in rock and few meters in soil. Therefore, soil plays a key role in determining the ground response analysis and its characteristics. It is evident from past earthquakes response of soil is different at different locations to ground motions imposed due to earthquake loading. Therefore, there is a need to model the soil to characterize and analyze the cyclic behavior of soil. Ground response analysis are generally analyzed by 1D responses assuming that seismic waves will travel in vertical directions through soil layers.1D response modeling can be analyzed by linear, Equivalent linear, and non- linear approach. In this, Equivalent linear approach is mostly used and it is approximation of non linear behavior of soil .This analysis is carried out in SHAKE, DEEPSOIL computer softwares which are popularly used. 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 [1] and based on the Geological survey of India, seismotectonic map, 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. By keeping in view the importance as given above, the borehole data is collected from 24 locations from various organizations and estimated the liquefaction potential based on the well established cyclic stress approach developed by Idriss and Boulanger [2]. These results obtained can be used to Construct Earthquake resistant Buildings and liquefaction analysis and various dynamic analysis.

1.2 Site Characterisation

The study area under scope is a location in Guntur District having an area of 16.5 km^2, consists of villages Lingayapalem, Udandarayapalem, Thalayapalem in Thullur Mandal and map view of area is shown in figure 1 representing the locations of boreholes. It is located between 16.31°N latitude and 80.33°E longitude and is the third most populous area in Andhra Pradesh. Krishna river also partly flowing in the district and there are other small rivers and channels flowing in the district.
Different seismic sources (~22) in and around the city have been identified for getting borehole data includes Andhra Pradesh Capital Region Development Authority(APCRDA),Vijayawada. Also different seismic events that occurred from 1800-2012 in the regions near to city have been detailed. Site characterization can be either by geological data, geophysical testing or by using geotechnical data. About 24 borehole data have been collected; the data is well scattered along the study area. Soil classification based on the borehole data has been suggested which consisted of four major soil strata in the city namely- sandy silt, silty/sandy clay, silty/clayey sand, rock. Major part of the city is covered by silty clay of thickness varying from 2 to 8 m. SPT–N values for every strata of entire soil depth were given in figure 2. Groundwater level influences the ground response significantly and hence cannot be neglected for site effect analysis. Water table is at shallow depths (0-4 m) in the study area.

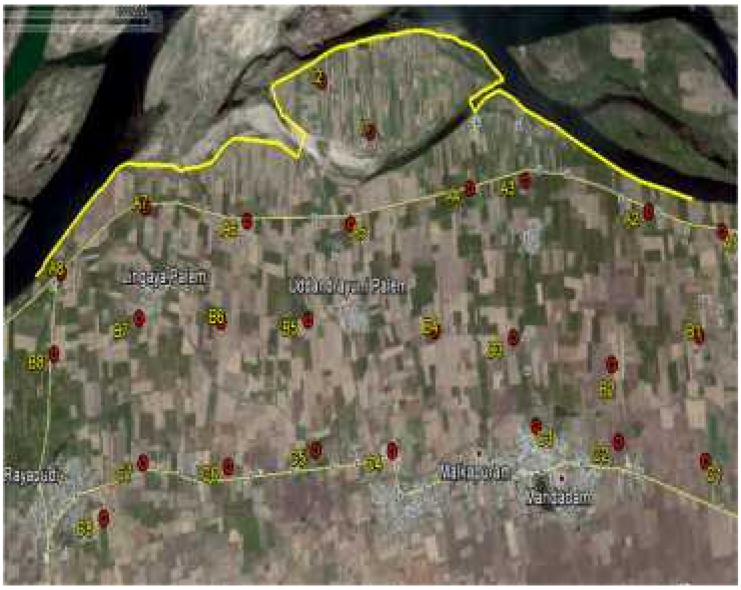


Figure. 1. Map view of study area with borehole locations

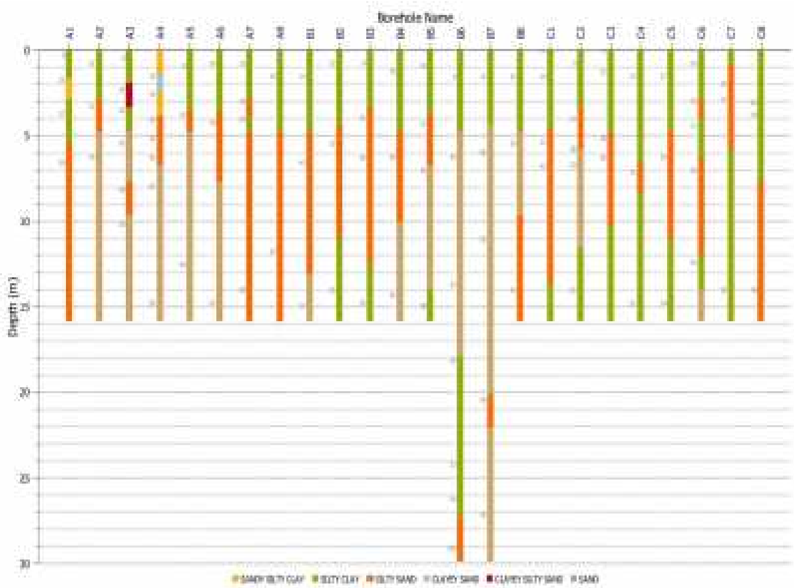


Figure. 2. Soil profile and SPT-N value along depth

2 Methodology

2.1 Ground Response Analysis

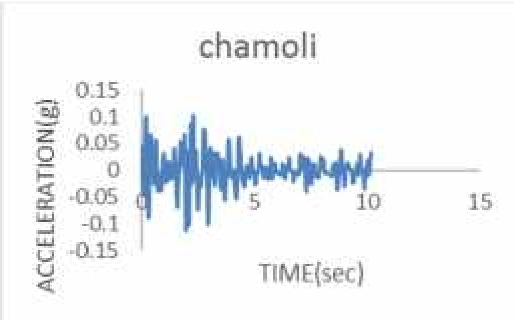
Propagation of seismic waves through soil column during earthquake alters the amplitude, frequency and duration of ground motion by the time it reaches the surface. The effects of ground motion are propagated in the form of waves from one medium to another. So, physically it is problem of prediction of ground motion characteristics whereas mathematically it is a problem of the wave propagation in continuous medium. The evaluation of such response of the site to dynamic loading is termed as ground response analysis. Site effects can be quantified by empirical correlations between rock outcrop motion and motion at soil sites. Different correlations are used for stiff soils and deep cohesionless soils. Depending on the geometry and loading conditions different analysis i.e., one, two and three dimensional are suggested. Idriss [3] developed a correlation between peak acceleration at rock outcrop and soft soil which is independent of earthquake magnitude. It is an empirical relationship developed from the recordings during Loma Prieta earthquake, 1989 in San Francisco bay and Mexico city in 1985 [4]. It can be inferred that sites subjected to low values of PGA had more amplification than those compared to higher values. We used attenuation relationships developed for the USA eventhough there are several such relations developed for peninsular India. The reason is that the authors have used Attenuation Relationships for the analysis given by Hanumantha Rao et.al [5] which is for peninsular India only. Also for very strong ground motion the amplitude of vibration at soft soil sites is lower compared to rock sites. Various empirical relationships have also been discussed in detail for the estimation of site effects. Ground response analysis also termed as soil amplification study comprises the calculation of site natural periods, ground motion amplification, evaluation of liquefaction potential, stability analysis etc. The important features that are considered for analysis are characteristics of soil overlying bedrock, bedrock location and inclination, topography of bedrock and soil deposits, faults in the soil deposits. A complete ground response analysis considers source, path and site amplification effects. Damping factors of the soil are difficult to be assessed. Important steps in site specific ground response analysis are dynamic characterization of the site and selection of rock motions.

2.2 Analysis using Deep soil

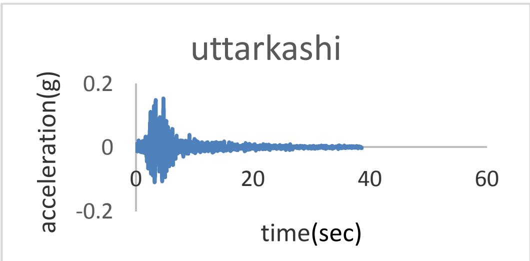
A computer program DEEPSOIL [6], for equivalent linear approximation of layered soils is used to compute the seismic response of horizontally layered soil deposits of the study area. It is a one-dimensional site response analysis program that can perform linear, equivalent linear and non-linear approach of analysis. The linear analysis can be done either in frequency domain or time domain. Frequency domain methods are the most widely used to estimate site effects due to their simplicity, flexibility and low computational requirements. However, in cases of high seismic intensities at rock base and/or high strain levels in the soil layers, an equivalent soil stiffness and damping for each layer cannot represent the behavior of the soil column over the entire duration of a seismic event. In such cases also ground motion propagation through deep soil deposits can be simulated using this tool. The equivalent linear approach implemented in DEEPSOIL is similar to that in SHAKE [7]. Any number of material properties and layers can be used and the user can choose frequency dependent or independent complex shear modulus formulations [7]. For performing 1D equivalent linear analysis following inputs about soil are required i.e., number of layers of the profile, thickness of layer, shear wave velocity/shear modulus, % of damping, unit weight and water table depth.

2.3 Input Motions

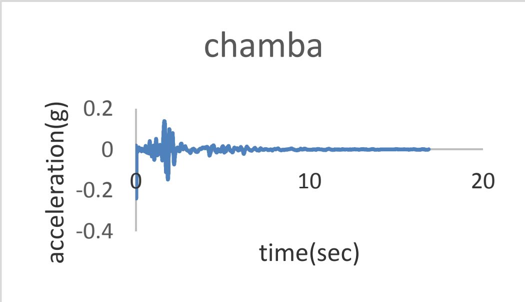
Input motions are selected based upon regional seismicity, PGA values. The study area comes under zone 3 having a maximum PGA value of 0.16g [IS-1893 part 1 (2016)]. Based on the importance of the structure considered we can decide the design of the structure by different magnitude of the Earthquakes. So analysis is also done for different magnitude Earthquakes. Chamoli earthquake (Mb = 5.4 and PGA = 0.11g) of 29th March 1999 is selected as the input ground motion to analyze soil effects and is applied at hard stratum shown in figure 3.It is analyzed with different motions of Bhuj, Uttarkashi, and Chamba from low to high magnitude based on importance of structures as shown in figure 3. From previous Earthquake data, the magnitude of earthquake was similar to the earthquakes considered in the analysis.



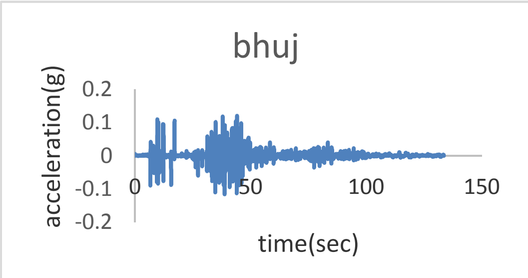
Chamoli



Uttarkashi



Chamba



bhuj

Figure.3. Different input motions

2.4 Liquefaction Hazard

In the city of Amaravathi, highest magnitude of earthquake (5.4 Mw) was recorded [8]. With reference to that the Chamoli Earthquake of M_w 5.4 was adopted in the present study. 0.16g is the maximum PGA for the region considered as per IS code 1893-2016. For Amaravathi region the value of peak ground acceleration is 0.16g as it falls in seismic zone III (IS 1893- 2016). From the collected bore log data, the water table is observed very high (<4m from ground surface) in nearby areas of Krishna river. In such situations it becomes essential to identify the liquefiable soil layers within upper 15 m strata, especially with loose soil pockets, which can be susceptible to liquefy in future. Amaravathi liquefy during a 5.4 magnitude earthquake because from the analysis shows that soils are liquefied representing that soils are having less SPT value(<10) from the data considered (as per soil Investigation Report). Soils liquefied are silty sand and silty clay. Silty Sand having major amount of silty and coarser nature which leads to liquefaction. Silty Clay due to its less SPT value may leads to Cyclic mobility. Factor of safety at 5m, 10m, and 15m depth were shown in figures 4, 5, 6.

Table 1: Peak Ground Acceleration values using Chamoli Motion.

Borehole name	PGA at surface	Borehole name	PGA at surface
a1	0.20	b5	0.18
a2	0.19	b6	0.26
a3	0.17	b7	0.16
a4	0.18	b8	0.18
a5	0.21	c1	0.18
a6	0.21	c2	0.20
a7	0.16	c3	0.21
a8	0.18	c4	0.20
b1	0.23	c5	0.18
b2	0.21	c6	0.16
b3	0.21	c7	0.17
b4	0.18	c8	0.19

Table 2: Peak Ground Acceleration values using different Motions.

Borehole	Chamba	Uttarkashi	Bhuj
a1	0.16	0.18	0.21
a2	0.18	0.2	0.22
a3	0.15	0.19	0.21
a4	0.16	0.2	0.22
a5	0.18	0.22	0.24
a6	0.19	0.23	0.25
a7	0.21	0.24	0.26
a8	0.16	0.2	0.23
b1	0.2	0.24	0.25
b2	0.19	0.23	0.24
b3	0.2	0.22	0.24
b4	0.16	0.2	0.22
b5	0.16	0.2	0.22
b6	0.23	0.28	0.3
b7	0.15	0.18	0.2
b8	0.16	0.2	0.23
c1	0.16	0.2	0.22
c2	0.18	0.22	0.25
c3	0.2	0.23	0.25
c4	0.19	0.22	0.24
c5	0.16	0.21	0.23
c6	0.14	0.19	0.21
c7	0.15	0.19	0.21
c8	0.17	0.21	0.23

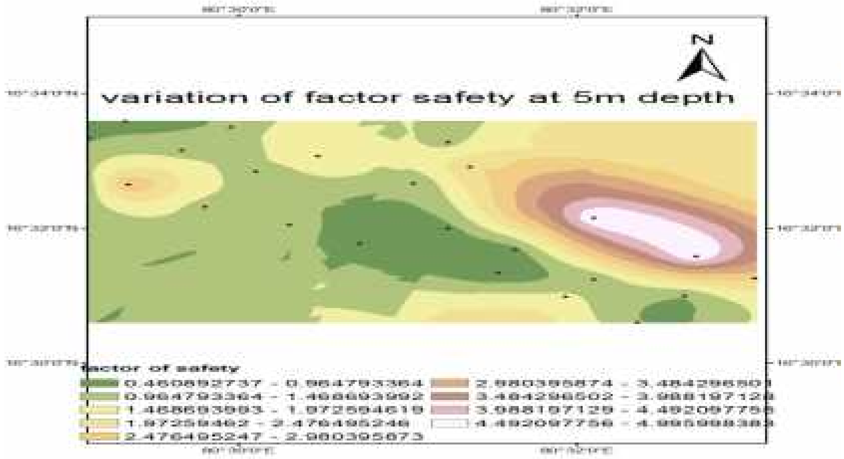


Figure. 4. Map Showing Factor of Safety at 5m Depth

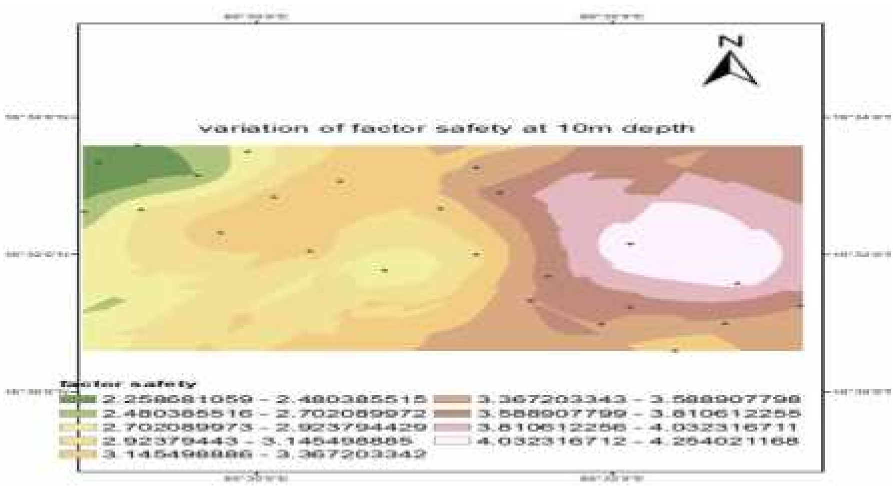


Figure. 5. Map Showing Factor of Safety at 10m Depth

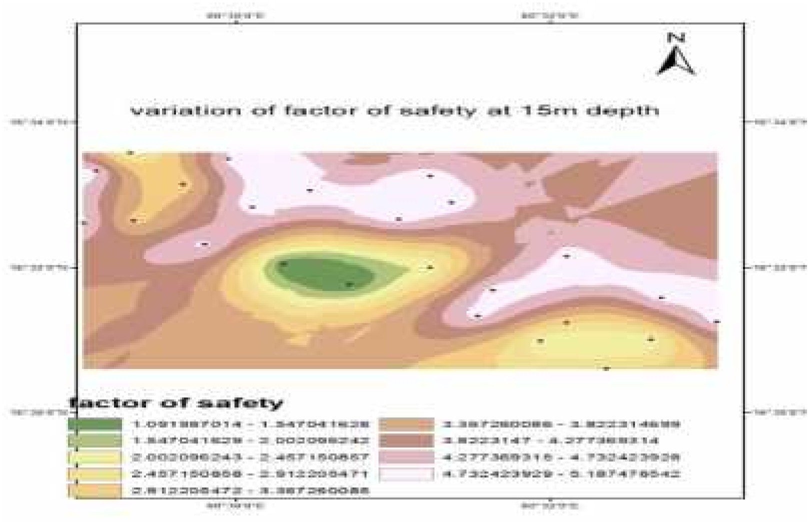


Figure. 6. Map Showing Factor of Safety At 15m Depth

The factor of safety against liquefaction is computed by a software LIQIT which will use field data and evaluate cyclic resistance ratio (CRR) and cyclic stress ratio(CSR). Thus, the factor of safety (FS) against liquefaction may be defined as, FS = CRR/CSR. Thus, the factor of safety (FS) against liquefaction may be defined as, FS = CRR/CSR. It is observed that factor of safety at 5m depth in all the boreholes were greater than 1. But at few locations like a5, a6, b3, b4, b6, c3, c4, b8, c8 the factor of safety was less than 1 and factor of safety at 10m and 15m depth is greater than 1 at all the borehole regions. It is due to presence of dense silty sand and stiff silty clay layers having high spt-N values (>30-50).

3 Results and Analysis

The Peak Ground Acceleration values at surface obtained at these boreholes in response to Chamoli earthquake motion shown in table1. The values varies from 0.16g to 0.26g for the Chamoli bedrock motion of 0.11g. The Surface acceleration values have been very high (>0.2g) at b6, a5, a6, c2, c3, b1, b2, b3. These boreholes are having water table depth ranging between 2-4m and having predominant soil of high plastic silty clay at larger depths with mixture silty sand layers. Different earthquake input motions were also used in DEEPSOIL software and analyzed peak ground acceleration shown in table 2. From the results, it is evaluated that PGA values for Chamba motion ranges from 0.14g to 0.23g which are slightly lower when compared with Chamoli motion (5.4 Mw), (0.16g to 0.26g) which have explained in table 1. For Uttarkashi motion the values ranges from 0.18g to 0.28g which are higher compared to Chamba motion and Chamoli motion. For Bhuj motion, the values ranges from 0.21g to 0.3g which are very high when compared with the three motions. Therefore, it is analyzed that the amplification is based on the magnitude of the earthquake. More the magnitude, more the amplification of the soil layers at the surface.

4 Conclusions

i. It is observed that local soil sites alters the bedrock motion and has a profound influence in modifying the ground response.
ii. The higher amplification were found (greater than 0.2) which shows the effect of local site effects on the seismic waves.
iii. It is found essential to consider local site effects in seismic design at all these locations.
iv. It is evaluated that amplifications at surface is based on the magnitude of the Earthquake at bedrock level.
v. At few locations like a5,a6,b3, b4, b6,c3,c4,b8,c8 the factor of safety was less than 1 (ranging 0.8-0.9) which are almost at the verge of safety against liquefaction.
vi. It is analyzed that factor of safety at 10m and 15m depth is greater than 1 at all the borehole regions.

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