STUDY ON INFLUENCE OF LOCAL SOIL CONDITIONS ON GROUND MOTION AMPLIFICATION

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ABSTRACT: The peak ground acceleration is one of the major deciding factors in triggering liquefaction of a soil deposit and in earthquake geotechnical engineering. In the microlevel evaluation peak ground acceleration, the effects of local soil condition and influence of soft grounds are to be estimated. In this study, the one-dimensional equivalent nonlinear seismic model for horizontally layered soil deposit is used to estimate the ground motion parameters. From the analysis, it is observed that the loose sand and soft clay deposits amplify the acceleration while dense sand and stiff clay deamplify it. The increase in number of layers of different soil types decreases the acceleration. The response spectrum for soft soil which is recommended by IS code, is modified to accommodate the local site effects.

1. INTRODUCTION

Evaluation of seismic hazard potential of Coromandal Coast is an urgent need. Ground motion parameters are not considered by any planner or design engineer for the design of structures and for preparation of master plan. For the better understanding of the seismic hazard potential of any region, knowledge of seismicity, which is the data on the occurrence of past earthquakes and seismotectonics, which include details of various tectonic features of the region, are essential. Seismicity and seismotectonic data provide the necessary support for the evaluation of historical occurrence of earthquakes and future potential for earthquakes. The seismic microzonation process will be successful, if site characterization viz. both the seismic site classification and site response studies, is taken into account. Seismic microzonation is the essential and prime initial need for earthquake mitigation. Site characterization should include the details of subsurface materials, material properties and underground structures.

Mapping of site characterization plays a key role in planning development and protecting the built environment in important sites. The ground motion, which lasts for a few seconds, is strongly influenced by the local soil conditions at the site. Thus, it is very important to study the seismic hazards including the local site conditions, present condition of fault system and its influence. Fault map has been prepared based on the seismotectonic data available in the published work. In addition, for the study area, acceleration contour map and site-specific response spectra have been proposed as guidance for any design.

In the study area, Nagapattinam Coastal line of Tamil Nadu, India, the SPTs and CPTs are conducted as per the standard procedure in confirmation with Indian and ASTM Standards. The observed SPT and CPT values are corrected for field procedures, overburden pressures, sloping ground, fines content, etc., as described by Idriss & Boulanger (2006) and Robertson & Wride (1998). The Peak Ground Acceleration (PGA) is determined from equivalent nonlinear analysis computer software EduSHAKE. Ground surface motion, which is nearest to the target value described in IS1893-Part 1 (2002) for specific seismic zone was given as input ground motion for this analysis. In addition, peak ground surface acceleration contour map has been generated in GIS. Besides, the design response spectra are developed for different types of soil.

2. SITE AMPLIFICATION CHARACTERS

The Peak Ground Accelerations (PGA) that were estimated using attenuation relations are yielding unrealistic values compared to the observed seismicity of the same area (Boominathan & Suganthy 2007). The previous research in
the surrounding region of the study area (around 300 km distance) reveals that thicker deposit of low shear wave velocity soil amplifies the PGA by 1.5 times higher than the rocky and dense sandy deposits.

It is a well known fact that the soft ground amplifies the earthquake motion and causes severe damages than hard ground. The earthquake motions and its amplification or attenuation characteristics at ground surface are most important in the study of severity of damage due to earthquake for the built environment. The site amplification mechanism consists of surging, ground reflection and base reflection. It is clear that the boundary conditions like free boundary, fixed boundary, etc. are important features in site amplification studies. The site amplification mechanism consists of surging, ground reflection and base reflection. It is very clear that the boundary conditions are important features. The amplification, in San Francisco, at the soft deposit is in the order of 0.2 g, whereas that of hard deposits is in the order of 0.1 g during 1989 Loma Prieta earthquake (Yoshida 2007). It is also noted that the amplification of soft ground is mostly nonlinear which reduces the stiffness and strength of soil due to increase in strain. The liquefaction related cyclic mobility causes amplification of acceleration and behaves nonlinearly (Yoshida 2007).

Soft bay-shore deposits predominantly contributed for the amplification of Peak Ground Acceleration (PGA) and the subsequent damages to structures, compared to rock outcrop, in many of the past earthquakes (Seed et al. 1990). Soft grounds, such as soft clay and loose sand deposits amplified the acceleration due to earthquake. The softer site amplified the low frequency bedrock motions more than the stiff site (Kramer 1996). The thickness of the soft layers also significantly increased the Peak Ground Acceleration (PGA) by a factor of three to five. Idriss (1990) developed an empirical correlation between rock outcrop and soft soil peak accelerations for the San Francisco bay area. However, the structural response is greatly influenced by the layering and localized hidden soft patches in a dense soil (Ghosh & Madabhushi 2003). The site amplification characters were studied by many researchers like Borcherdt et al. (1991), Tamura et al. (2000), Kataoka & Yamamoto (2002) etc. and these groups proposed many equations for the calculation of amplification factors.

3. GEOLOGICAL SETTINGS OF STUDY AREA

The study area along the Coromandal Coastal line at Nagapattinam, Tamil Nadu, India lies between the latitudes of 10°44'50" and 10°49'30" North and longitudes of 79°49'40" and 79°51'10" East. Even though, this region is not seismically active as in the northern and western parts of the country, small to moderate magnitude earthquakes have occurred in the past. Several active faults have been identified in the Nagapattinam region out of which many show the evidence of movement during the Holocene period (Dasgupta et al. 2000). The east-west trending Cauvery fault and Thirukkovilur-Pondicherry fault are some of them and run close to major urban centers like Coimbatore, Nagapattinam, Vailankanni, Thanjavur and Pondicherry. The active faults on the tectonic plates of South India oriented along the north east-south west in between N51-60°E and N71-80°E. Their intersection with an angle of 10–30° is more vulnerable to seismic hazards in South India (Ramasamy 2006). The 10°45°N fault is running along the study area. Very active faults of North India like north-south, north east-south west and north west-south east faults have connectivity with these South Indian faults. For that reason, many earthquakes that occurred in north India were experienced in few parts of south India also. In the ancient period, the frequency of earthquakes was low. However, seismic activity in the recent past has occurred in clusters (Dasgupta et al. 2000). In 1679, severe earthquake had occurred in the Bay of Bengal and the north end of Tamil Nadu was affected (iyengar et al. 1999). Similarly, the same part of Tamil Nadu near Bay of Bengal was affected by earthquakes in 1807 and 1816 with intensity of MSK-VI (Dasgupta et al. 2000). A moderate earthquake (magnitude of M-5.5 in Richter scale and focal depth of 10 km) occurred in the Bay of Bengal, off the coast of the union territory of Pondicherry and Cuddalore (Tamil Nadu) on 25 September 2001. That earthquake resulted in three deaths and minor damage to property in Pondicherry and coastal Tamil Nadu (Martin 2008). The December 2004, Sumatra-Andaman earthquake (M-9.1) was experienced at various parts of east coastal line of Tamil Nadu.

4. PEAK HORIZONTAL GROUND ACCELERATION

In this study, the one-dimensional equivalent nonlinear seismic model for horizontally layered soil deposit is used to estimate the ground motion parameters. The available EduSHAKE software is used and ground motion parameters are evaluated. The shear wave velocities are estimated from SPT and CPT values. The estimated results are used as input parameters for the EduSHAKE analysis. In addition, densities of soil layers and location of water table, which are synthesized to represent the values at the center of the layers, are given as input. The ground motion, which was observed in the Yerba Buena Island in San Francisco bay during 1989 Loma Prieta Earthquake, is given as input motion. The peak ground acceleration of this model (PGA = 0.07 g) is very close to the zone factor (Z = 0.1) described in IS 1893-Part 1 (2002) for zone II. For the sandy layer Seed and Idriss (1970) models are chosen as input for modulus reduction curve and damping curve. For the clayey layer Vucetic and Doby (1991) models are chosen as input for modulus reduction curve and damping curve. From the EduSHAKE analysis, it is observed that the loose sand and soft clay deposits amplify the acceleration while dense sand and stiff clay deamplify it and influenced by thickness of layers, the underlying layer type, and water table location. The increase in number of layers of different soil types decreases the acceleration. Particularly, it is observed that even a small stiff clay layer very much reduces the acceleration due to damping effects of clay layers. The very soft clay layers are not
only amplifying the input motion much, but also shifting the peak towards the higher side of period. The loose sand and soft clay deposits amplify the input acceleration by a factor of 1.2 to 2.7. Similarly, dense sand and stiff clay deamplify the input acceleration by a factor of 0.6 to 0.96. The following Figures 1, 2 and 3 show clearly the effects of soil types in the study area.

The ground motion analysis is carried out on the data from 276 SPT and 112 CPT test points. The output peak ground acceleration is normalized by input peak ground acceleration and correlated with various soil parameters, which influence the amplification characteristics of soil deposit using XLSTAT 2007. The soil density, SPT values, fines content, relative density of sand, thickness of soil layers, shear wave velocity are tested with normalized peak ground acceleration values. Since, the relative density, density and shear wave velocity are indirectly reflected by the SPT values, the obtained correlation coefficients are negligible and omitted from analysis. Finally the SPT resistance values, thickness of soil layers and fines content are selected and vigorously regressed using multivariable nonlinear regression analysis. Equation 1 is developed for the soil deposits in the study area.

\[
\frac{a_{\text{max, Output}}}{a_{\text{max, Input}}} = 1.622N^{-0.608} + 0.095T_h^{0.323} - 0.298F_c^{-0.334} \cdot 0.84
\]

where \(T_h\) is the thickness of the layer in \(m\), \(F_c\) is the fines content in percentage and \(N\) is the SPT value in blows. Nevertheless, the equation presented here is valid for similar soil properties elsewhere.
In the same way, the normalized PGA values are correlated with CPT resistance resulting in Equation 2, in which $q_c$ is in kg/cm², thickness $T_h$ is in m and normalized friction ratio $F_R$ is in percentage.

$$\frac{a_{\text{max, Output}}}{a_{\text{max, Input}}} = 2.771q_c^{-0.395}T_h^{0.227} \cdot 0.401F_R^{1.408} \cdot 0.377$$

where $F_R = \frac{f_s}{q_c} \times 100\%$.

Even though the input motion is 0.07 g, the range of peak ground acceleration values obtained from analysis is 0.06 g to 0.23 g.

The IS1893-Part 1 (2002) specifies the PGA in terms of response spectra. In order to verify the applicability of the response spectra, a site-specific response analysis is carried out. The amplification or attenuation character of the deposit is very much visualized from the comparative study of input and output response spectra as shown in Figure 4 with 5% damping. The loose sand deposits amplify the input response spectrum in the range of 1.1 to 1.22, while the dense sand deposits deamplify by factors of 0.65 to 0.9. Medium dense sand deposits and stiff clay deposits resulted in response spectra with very minimum changes. However, the soft clay deposits highly amplify the input response spectra by factors in the range of 1.5 to 3. The response spectra of similar sites are grouped for convenience and the average is used for developing the response spectrum for each case.

Figure 5 shows that the dense sand deamplifies the acceleration period. The stiff clay, sand and medium dense sand do not amplify very much. However, the soft soils, loose sand and soft clay, amplify very much and the peak is shifted to the period of 1.5 sec from 0.5 sec for input spectrum. The IS1893-Part 1 (2002) recommends the design response spectra for the rock, medium soil and soft soil for 5% damping, as a general guidance.

However, the local soil conditions may influence the acceleration spectrum depending upon the denseness or stiffness of the deposits. From this research study, it is concluded that compared to medium soil, soft soils highly amplify the response spectrum. Therefore, it is necessary to modify the code recommended response spectrum for soft soil, to accommodate the local site effects. The modified spectrum for soft soil deposits is presented in Figure 5. Table 1 gives the related data in arriving at Figure 5. These results are applicable only to the study area. Additionally this is valid for clay with SPT values less than 10 and CPT tip resistance values less than 22 kg/cm².

![Fig. 4: Comparison of the Trend of Response Spectrum of Different Type of Soil Deposits with 5% Damping](image)

![Fig. 5: Proposed Site Dependant Response Spectrum for Soft Soil with 5% Damping for the Study Area](image)
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Table 1: Recommended Design Response Spectrum
for Soft Soil

<table>
<thead>
<tr>
<th>S. No.</th>
<th>IS1893 Part 1 (2002) recommendations</th>
<th>Recommendations from this study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sa/g Period limit, Sec.</td>
<td>Sa/g Period limit, Sec.</td>
</tr>
<tr>
<td>1</td>
<td>1+15T 0.00 ≤ T ≤ 0.10</td>
<td>1 + 15T 0.00 ≤ T ≤ 0.10</td>
</tr>
<tr>
<td>2</td>
<td>2.5 0.10 ≤ T ≤ 0.67</td>
<td>2.5 0.10 ≤ T ≤ 0.80</td>
</tr>
<tr>
<td>3</td>
<td>1.67/T 0.67 ≤ T ≤ 4.00</td>
<td>2.074/T 0.80 ≤ T ≤ 4</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS
The following key points leading to improvement of the existing practice of planning and designing have been summarized. From the EduSHAKE analysis, it is concluded that the loose sand and soft clay deposits amplify the acceleration while dense sand and stiff clay deamplify the acceleration. However, the amplification or attenuation properties of any soil deposits are influenced by thickness of the layers, the underlying layer type and water table location. The loose sand and soft clay deposits amplify by a factor ranging from 1.2 to 2.7 and the peak ground acceleration is shifted towards higher side in the period. Dense sand and stiff clay deamplify by a factor of 0.6 to 0.96. The design response spectra recommended by IS1893-Part 1 (2002), are modified for the local soil conditions.

REFERENCES