Seismic Hazard Assessment by Microzonation Mapping

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Abstract—Seismic hazard and Microzonation of cities enable to identify the seismic areas that need to be considered for designing of new structures. Study of seismic hazard and preparation of microzonation map will provide an effective solution for city planning and input to earthquake resistant design of structures in an area. Microzonation is identification of area having different earthquake hazard. It is the process of subdivision of region into to number of zones based on the earth quake effect in a local scale. The latest version of seismic zoning map of India is given in the earthquake design code [IS 1893 (PART 1) 2002] assign four level of seismicity in terms of zone factor (ZONE 2, 3, 4, 5). According to the present zoning map of India, zone 5 is associated with maximum seismicity whereas zone 2 is associated with lowest level of seismicity.

The scope of this project is to carry out microzonation of a particular region using surface parameters like Liquefaction, Shear wave velocity, Peak ground acceleration etc. The microzonation is done by compiling geotechnical parameters of bore log data collected from different region.

Keywords—Liquefaction, Microzonation, Seismic hazard, Shear wave velocity.

I. INTRODUCTION

India is the developing country and the developments are seen in various field, but often prone to natural hazards like earthquake. Earthquake is one of the most destructive natural hazards of the world. This natural hazard causes massive damages to structure and life on earth. Earthquake is caused due to the seismic waves generated from plain bed region. The effect of the earthquake depends upon local site condition. It is found that the presence of an unconsolidated soil profile can amplify the seismic waves at the time of earthquake. They are highly prone zones to earthquake. The presence of hard strata reduces the magnitude and frequency of the seismic waves. The major earthquake occurred in India over recent years include the following:

Uttarkashi in Uttarakhand – 1991 (magnitude of 6.6)
Latur in Maharashtra – 1993 (magnitude of 6.1)
Jabalpur in Madhya Pradesh – 1997 (magnitude of 5.8)
Chamoli in Uttarakhand – 1999 (magnitude of 6.8)
Bhu in Gujarat – 2001 (magnitude of 7.6)

The seismic hazard analysis is carried out by determining the ground motion at the time of earthquake and liquefaction of the soil present.

A. Study area

Some location of Chennai and Pondicherry are been taken as the study area for microzonation. For Chennai, latitude is 13°04′57.65″ of North Latitude and 80°16′14.99″ of East Longitude and for Pondicherry Latitude is 11°52′56″ and 11°59′53″ for North Latitude and between 79°45′00″ and 79°52′43″ East Longitude. According to census of 2011, the population of Chennai is about 4.9 million and it is 12,47,953 for Pondicherry. Both Chennai and Pondicherry is bounded by Bay of Bengal. The total area is 426 sq. Kms for Chennai and 293 sq. Kms for Pondicherry. Chennai comes under zone 3 Pondicherry comes under risk zone 2. But according to the latest macrozonation map of the Bureau of Indian Standards, the region is figured out in the moderate risk zone of 3. There have been about 189 earthquake events from 1858 to 2008. Maximum of 5.8 magnitude of earthquake have been recorded based on the data. In Pondicherry, there have been 189 earthquake events from 1858 to 2008.
II. ASSESSMENT OF LIQUEFACTION POTENTIAL

The liquefaction of the soil happens when the water pressure within the soil causes the soil particles to come in contact with each other thereby generating the seismic waves that propagate through the soil causing an earthquake.

A. Liquefaction potential

Liquefaction potential denotes the resistance of liquefaction of the soil. Liquefaction is the state at which soil changes its character from solid to liquid state due to increased pore water pressure. The cyclic stress induced within the soil causes increase of water pressure thereby it reduces the effective pressure of the soil resulting in liquefaction. Hence reducing strength and stiffness of the soil.

B. Liquefaction potential by Seed and Idriss

There are many conventional methods available for determining liquefaction potential of the soil. But the simplified procedure was given by Seed and Idriss in 1971.

It includes two terms Cyclic Stress Ratio (CSR) and Cyclic Resistance Ratio (CRR). The various parameters like SPT N value, density, specific gravity, effective stress etc are required for calculating these two terms is obtained from Bore log data of a particular location. The factor of Safety (FOS) is finally calculated for different magnitude of the particular location.

The shear stress can be determined using the equation proposed by Seed and Idriss.

\[ \tau_{\text{max}} = (\gamma h/g) a_{\text{max}} \cdot \text{rd} \]

Where, \( \tau_{\text{max}} \) is the maximum shear stress \( \gamma \) is the unit weight of soil \( h \) is the depth at which actual shear stress acts g is acceleration due to gravity

\( a_{\text{max}} \) is peak ground acceleration rd is stress reduction factor

The average shear stress in soil is given by

\[ \tau_{\text{av}} = 0.65 (\gamma h/g) a_{\text{max}} \cdot \text{rd} \]

It is 65% of maximum shear stress

Cyclic Stress ratio is given by

\[ \text{CSR} = \left( \frac{\tau_{\text{av}}}{\sigma'} \right) = 0.65 \left( \frac{\sigma}{\sigma'} g \right) a_{\text{max}} \cdot \text{rd} \]

Where,

\( \sigma' = \) Effective overburden pressure
\( \sigma = \gamma h = \) Total overburden pressure

The equation for stress reduction coefficient is given by

\[ \text{rd} = \left( \frac{1.000 - 0.4113Z^{0.5} + 0.04052Z + 0.001753Z^{1.5}}{1.000 - 0.4177Z^{0.5} + 0.05729Z^{2} + 0.001210 Z^{2}} \right) \]

The evaluation of liquefaction resistance (CRR) can be found using the equations of curves as given by Youd et al.

\[ \text{CRR}_{7.5} = (1/(34-N_{1.60}) + (N_{1.60}/135) + (50/(10N_{1.60} + 45)) - (1/200)) \]

Where, \( N_{1.60} \) is the corrected N values.

The CRR\(_{7.5}\) equation is valid only for the earthquake with magnitude of 7.5

This equation is valid only when \( N_{1.60} \) is less than 30.

\( \text{CRR}_{7.5} = \frac{\text{CRR}_{7.5}}{\text{MSF}} \)

Where, N is actual N value

\( \text{CN} \) is correction for overburden pressure

\( \text{CE} \) is correction for energy ratio

\( \text{CB} \) is correction for bore diameter

\( \text{CR} \) is correction for rod length

\( \text{CS} \) is correction for sampling method

The same CRR equation can also be used for other magnitude by relating it with Magnitude Scaling Factor (MSF)

\[ \text{CRR} = \text{CRR}_{7.5} \cdot \text{MSF} \]

The factor of safety can be calculated from the relationship given below

\[ \text{Factor of safety (FOS)} = \frac{\text{CRR}}{\text{CSR}} \]

The factor of safety should be calculated for different locations. Based on the calculated factor of safety, a map can be created using ArcGIS software.
III. ASSESSMENT OF SHEAR WAVE VELOCITY

The major factors that control site effects depend on the shear wave velocity. The shear wave velocity is determined by Multichannel Analysis of Surface wave (MASW) or Spectra Analysis of Surface Wave (SASW).

In MASW method, an artificial shocking wave is generated to obtain profile of shear of velocity that contains Vs versus depth. This method is found to be very expensive. The shear velocity is found from SPT test and correlation between shear wave velocity (V) and SPT N values is made. This method is found to be easiest and economical.

A. Shear waves

During the time of earthquake, shocking waves will be generated will propagate through the surface of earth causing disturbance to surface and subsurface layers. These waves will create shear deformation along the surface and they are often referred as shear waves. If the earthquake magnitude is higher, larger shear wave velocity will be created resulting in higher deformation of soil surface.

B. Correlation between Vs and SPT N values

Using a statistical means a correlation between shear wave velocity and uncorrected SPT N is made. A database is collected consisting of correlation between Vs and a SPT N value framed by many researchers is shown in table 1.

<table>
<thead>
<tr>
<th>Authors</th>
<th>All Soils</th>
<th>Sands</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imai &amp; Yoshimura (1970)</td>
<td>76.0N0.99</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ohba &amp; Toriumi (1970)</td>
<td>84.0N0.51</td>
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<td></td>
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<tr>
<td>Shibata (1970)</td>
<td>32.0N0.53</td>
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<tr>
<td>Ohta et al. (1972)</td>
<td>87.0N0.36</td>
<td></td>
<td></td>
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<tr>
<td>Fujiwara (1972)</td>
<td>92.10N0.33</td>
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<td></td>
</tr>
<tr>
<td>Ohsaki &amp; Iwasaki (1973)</td>
<td>82.0N0.39</td>
<td>59.4N0.47</td>
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<tr>
<td>Imai et al. (1975)</td>
<td>90.0N0.34</td>
<td></td>
<td></td>
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<tr>
<td>Imai (1977)</td>
<td>91.0N0.34</td>
<td>80.6N0.331</td>
<td>102.0N0.293</td>
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<tr>
<td>Ohta &amp; Goto (1978)</td>
<td>85.3N0.35</td>
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<td></td>
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<td>JRA (1980)</td>
<td>80.0N0.33</td>
<td>100N0.33</td>
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<tr>
<td>Seed and Idriss (1983)</td>
<td>61.0N0.50</td>
<td></td>
<td></td>
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<tr>
<td>Imai and Tonouchi (1982)</td>
<td>97.0N0.31</td>
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<tr>
<td>Seed et al. (1983)</td>
<td>56.4N0.50</td>
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<tr>
<td>Fumal &amp; Tinsley (1985)</td>
<td>152+5.1N 0.27</td>
<td></td>
<td></td>
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<tr>
<td>Jinan (1987)</td>
<td>116.1(N+0.31 85,0.202</td>
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<td>Okamata et al. (1989)</td>
<td>125N0.5</td>
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<tr>
<td>Lee (1990)</td>
<td>57.0N0.49</td>
<td>144N0.31</td>
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<td>Yokota et al. (1991)</td>
<td>121.0N0.27</td>
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<td>Kalteziotis et al. (1992)</td>
<td>76.20N0.24</td>
<td>76.6N0.45</td>
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<tr>
<td>Pitiklas et al. (1992)</td>
<td>76.20N0.24</td>
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<tr>
<td>Athanasopoulos (1995)</td>
<td>107.60N0.36</td>
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<tr>
<td>Raptakis et al. (1995)</td>
<td>100.0N0.24</td>
<td>184.2N0.17</td>
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<tr>
<td>Iyisan (1996)</td>
<td>51.5N0.336</td>
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<td></td>
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<tr>
<td>Kayabali (1996)</td>
<td>175+(3.75 N)</td>
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<tr>
<td>Jafari et al. (1997)</td>
<td>22.0N0.33</td>
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<tr>
<td>Okamoto et al. (1989)</td>
<td>120.0N0.38</td>
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<tr>
<td>Chein et al. (2000)</td>
<td>22.0N0.76</td>
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<td>Kiku et al. (2001)</td>
<td>68.3N0.292</td>
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<tr>
<td>Hasancabi &amp; Ulusay (2007)</td>
<td>90.0N0.309</td>
<td>97.89N0.209</td>
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<tr>
<td>Hanumantharao &amp; Ramana (2008)</td>
<td>82.6N0.43</td>
<td>79N0.448</td>
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<tr>
<td>Dikmen (2009)</td>
<td>58.0N0.39</td>
<td>73N0.13</td>
<td>44N0.48</td>
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<tr>
<td>Umanaheshwari et al. (2010)</td>
<td>95.64N0.305</td>
<td>100N0.263</td>
<td>89.31N0.358</td>
</tr>
<tr>
<td>Mhaske &amp; Choudhary (2011)</td>
<td>72.0N0.4</td>
<td></td>
<td></td>
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<tr>
<td>Anbazhagan et al. (2012)</td>
<td>68.96N0.51</td>
<td>60.17N0.56</td>
<td>106.63N0.59</td>
</tr>
<tr>
<td>Achmad et al. (2014)</td>
<td>105.03N0.285</td>
<td></td>
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</tr>
</tbody>
</table>
C. Deriving equations for shear wave velocity

Using regression analysis, all the equations mentioned under table 1 were analysed and new equations are found for all soils, sand, and clay. LINEST function is used for performing regression analysis. The resultant curve equation is transformed in the form of \( V_s = AN^B \)

### Equation

\[
Y = MX + C
\]

Taking log on both sides

\[
\log Y = \log X^m + \log C
\]

\[
\log Y = C \log X^m
\]

\[
Y = CX^m
\]

Therefore the equation is in the form of \( V_s = AN^B \)
Figure 3, 4, 5 represents the correlations between the SPT–N values and shear wave velocity formed by many authors mentioned in table 1 and results of the regression analysis for various soil conditions is obtained and mentioned in below table.

### TABLE 2
RESULTS OF THE REGRESSION ANALYSIS FOR VARIOUS SOIL CONDITION

<table>
<thead>
<tr>
<th>Soil condition</th>
<th>Equations</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>All soil</td>
<td>$94.255N^{0.3144}$</td>
<td>0.7413</td>
</tr>
<tr>
<td>Sand</td>
<td>$87.439N^{0.791}$</td>
<td>0.995</td>
</tr>
<tr>
<td>Clay</td>
<td>$110.46N^{0.2998}$</td>
<td>0.9998</td>
</tr>
</tbody>
</table>

Using equations mentioned in table 2, shear wave velocity for various locations can be determined.

### IV. MICROZONATION

The microzonation is defined as the subdivision of a region into a number of zones based on some geophysical characteristics like amount of shaking of a ground, liquefaction susceptibility, flooding caused due to earthquake etc. It is the analysis of specific risk of a site. It involves the detailed analysis of seismic hazard and assessment of region which is not done in the macrozonation map of IS 1893. At first, mapping of the liquefaction was started in USA during early 1970s. Based on different liquefaction potential and seismic hazard, the entire region was divided into a number of individual areas. The engineering designing, urban town planning was carried out by making use of this map.

**A. Different methods adopted for microzonation**

- Multichannel Analysis for Surface Waves (MASW)
- Spectral Analysis of Surface Waves (SASW)
- Microtremor Analysis (MA)
- Standard Penetration Test (SPT)
- Cone Penetration Test (CPT)
- Becker Penetration Test (BPT)

**B. Significance of map**

In this study, Standard Penetration Test (SPT) is being used for performing the microzonation of Chennai and Pondicherry location and map showing different zones for different magnitude of factor of safety is plotted using ArcGIS.

From figure 6, it is clear that for zone 1, the FOS for magnitude 5.5 is between 0.89 to 1.23, which implies that this zone is prone to liquefaction more, when compared with zone 4, which has a value between 1.90 to 2.24.

Figure 6 - Factor of safety map (Chennai) for magnitude 5.5

Figure 7 - Factor of safety map (Pondicherry) for magnitude 5.5
Similarly from figure 7, it is clear that for zone 1, the FOS for magnitude 5.5 is between 0 to 2.74, which implies that this zone is prone to liquefaction more than zone 4, which has a value between 8.24 to 10.99.

V. CONCLUSION

Using the bore log details of 22 location of Chennai and 62 location of Pondicherry, liquefaction potential has been determined for the city. FOS for different earthquake magnitude of 5.5, 6, 7 and 7.5 were found and corresponding FOS map are drawn. It is clear from the maps that southern part of Chennai is highly susceptible of liquefaction of higher order magnitude. For Pondicherry, most of the areas having high population density were found to be in risk zone for an earthquake with magnitude 7.5.

Correlation was made between SPT N value and shear wave velocity \( V_s \) using regression analysis for different soil conditions and equations for various soil condition has been derived.

Using ArcGIS, FOS map for various magnitudes of Chennai and Pondicherry has been plotted.

REFERENCES


[10] T.G. Sitharam, P. Anbazhagan, K.S. Vipin, -Principle And Practice of Seismic Microzonation: Case Studies In Indial, Fifth International Conference on Recent Advance in Geotechnical Earthquake Engineering and Soil Dynamics and symposium in honor of professor I.M. Idriss