INTEGRATING GEOPHYSICAL STUDIES WITH ENGINEERING PARAMETERS FOR SEISMIC MICROZONATION

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ABSTRACT: Geophysical data along with the borehole information is used to delineate the National Capital Region of Delhi (including Gurgaon, Noida, Faridabad and Ghaziabad) for engineering purposes. A total of 199 geophysical tests (Refraction and MASW) were conducted in the study area. Primary and shear wave profiles were generated using common mid-point method and an attempt has been made to minimize the error between observed and calculated travel times to improve the velocity models. For refraction and MASW testing, geophones of frequency 28 Hz and 4.5 Hz were used respectively. The linear array of 24 geophones with a spacing of 3 m was adopted for the testing. The locations of geophysical tests are maintained at the exactly same location where borehole data is available. A number of shallow rock engineering parameters such as Concentration Index, Material Index, Density Gradient and Stress Ratio were calculated to assess the subsurface bedrock from a geophysical and engineering prospective. Subsurface information (rock/soil quality) is interpreted using seismic velocity values, consolidation and strength parameters. The study area is then divided into different zones based on the obtained results. The aim of the study is to integrate the geophysical studies with the engineering parameters to help in site characterization for seismic microzonation and hazard estimation.

1. INTRODUCTION

Seismic refraction surveying is a geophysical method traditionally used in many civil engineering projects. Seismic refraction is considered as one of the main geophysical techniques used to investigate the subsurface layering and/or local anomalies. This technique is routinely used in many applications such as engineering, environmental, groundwater, hydrocarbon, and industrial-mineral exploration (Lankston 1989; Hodgkinson & Brown 2005; Bridle 2006; Yilmaz et al. 2006).

In the present study, traditional seismic profiles are conducted, interpreted, and then a common mid-point technique is applied to improve the resulting velocity-depth models. The ultimate goal of the present study is to recommend the suitable methodology for the seismic microzonation, based on measured and calculated shallow engineering characteristics of the near surface. In the study area, analysis of the shallow seismic refraction velocities (P-wave and S-wave) could tangibly delineate the shallow subsurface layering as well as determine the following shallow soil engineering parameters; Bulk Density, Poisson's Ratio, Young's Modulus, Lame's Constants, Concentration Index, Material Index, Density Gradient, and Stress Ratio.

2. GEOLOGY OF THE AREA

The National Capital Region of Delhi occupies an area of 2000 sq. km and geographically located between latitude 28º24'01" and 28°53'00" and longitude 76°50'24" and 77°20'37". The geological map of Delhi region is shown in Figure 1. The historic Delhi is bound in the North, South and West by Faridabad and Gurgaon (Haryana) and in the East by Ghaziabad (Uttar Pradesh). Delhi and its adjoining region are surrounded in the north and east by Indo-Gangetic plains, in the west by the extension of the great Indian Thar desert and in the south by the Aravali ranges. The terrain is generally flat except for a low NNE-SSW trending Delhi ridge in the central portion of the region with river Yamuna flowing towards south direction in the eastern side of Delhi (Naqvi & Roger 1986). The south eastern side of Delhi has a natural depression in the surface topography, which is called as Najafgarh basin.
3. DATA ACQUISITION

Seismic refraction and Multi channel Analysis of Surface Waves (MASW) profiles were conducted at 199 locations in order to cover the study area. Each profile extends for a total length of 69 m. The inter-geophone spacing was 3 m and the shot-to-1st geophone spacing was 1.5 m with a total of 24 geophones per profile. The total record length for P-waves was 750 ms with sample interval of 0.2 ms, while for S-waves total recorded length was 2000 ms, sample interval was 0.5 ms.

A 36 kg accelerated weight drop system, propelled energy generator (PEG40) and sledgehammer (11 kg) was used to generate the seismic P and S waves respectively. To generate the P-waves aluminum plate (46 × 46 × 2 cm) was used to receive the impact from PEG. A total of 5 shots were recorded at each test location and 3 stacks were made per shot location for P-wave (Fig. 2). To generate the S-waves a circular aluminum plate (20 cm diameter) was used to receive the sledgehammer strikes. A total of 25 shots were recorded at each test location and 3 stacks were made per shot location for S-wave (Fig. 3). For refraction and MASW testing, 28 Hz and 4.5 Hz frequency geophones were used respectively.

4. DATA INTERPRETATION

The acquired refraction data (shot records) are analyzed using the software program SeisImager/2D software package. Figure 4 shows the travel time curves. These travel time curves are constructed based on the distance along the survey line, geophone spacing, source location and the first arrival times. Travel time curves are corrected and checked for the exact estimation of the P-wave velocity structure. Observed and calculated reciprocal times were checked for multiple shot locations and the Root Mean Square (RMS) error was calculated and found less than 5%. Although the low RMS error value indicates a best fit between the observed and calculated travel-times, it does not necessary mean that the resulted velocity depth model is geologically the correct model. Another verification tool such as outcrop, borehole, or other geophysical tool is always helpful. In this work, we used 3000 drilled borehole data as another source of information that verifies the resulted seismic velocity-depth models. The final depth-velocity models are represented in 2D forms. The number of layers present is determined on the basis of the number of changes in the slope of the travel time curve. Layer assignment is done by identifying crossover points that occur where the slope of 1/V changes. After the layer assignment, a time-term inversion model is done and the 2D velocity profile is obtained by analyzing the travel time curves adopting the reciprocal method in Figure 5.

Acquired surface wave seismic data is processed using SeisImager/SW software through spectral inversion to obtain 1D and 2D MASW shear wave velocity profiles. Common Mid Point (CMP) pairs from all traces were extracted and later its cross correlation CMP gathers were calculated. Then the dispersion curves are generated by converting it into frequency domain for each cross correlation CMP gathers and then checked. Dispersion curves are generally displayed as phase velocity versus frequency and shown in Figure 6. The 1D shear wave velocity profiles (Fig. 7) are calculated using the dispersion curves obtained from waveform data by non linear least square method and then the 2D velocity profile was generated and is shown in Figure 8.
No construction material has more variable engineering and physical parameters than the ground’s soil. These parameters vary both laterally and vertically and often the variations are strong (Bowles 1982). In order to evaluate the competence of the subsurface for construction, some of the shallow soil engineering parameters are calculated. Four parameters were calculated: the Concentration Index ($C_i$), the Material Index ($V$), the Density Gradient ($D_i$), and the Stress Ratio ($S_i$). Integration of these four parameters can be used for seismic microzonation and hazard estimation.

To calculate these parameters the values of P-wave velocity ($V_p$), S-wave velocity ($V_s$), density ($\rho$), Poisson’s Ratio ($\nu$), Young’s Modulus ($E$), Lamé’s Constant ($\mu$), and the Shear Modulus ($\mu$) are required. Both P-wave and S-wave velocities are obtained from the acquired seismic refraction and MASW profiles. The density values are obtained from collected boreholes, and the elastic moduli values are calculated at all 199 test locations from the equations listed in Table 1. The elastic moduli results for the bedrock layer can be summarized in the following points: 1. Bulk Density ($\rho$): ranges from 1.66 to 1.86 g/cc. The central, southwest and southern part of the study area is characterized by relatively high rock densities. 2. Poisson’s Ratio ($\nu$): ranges from 0.21 to 0.43. The northern and northwest part of the area is characterized by relatively low Poisson’s Ratio, which indicates a relatively more competent...
soil in this part of the study area (Salem 1990). 3. Young’s Modulus (E): ranges from 1323 to 3602 MPa. The south and south-western part is characterized by relatively high values of Young’s Modulus. 4. Lame’s Constants (?): ranges from 297 to 1631 MPa. The northwestern part and north-central part are characterized by relative low ”?” values. 5. Shear Modulus (µ) or Rigidity: ranges from 406 to 1341 MPa. The south west and south-central parts are characterized by relative high rigidity or shear modulus “µ” values.

Using the seismic velocities and elastic moduli values, the shallow soil engineering parameters are calculated. These parameters include the Concentration Index (Ci), the Material Index (V), the Density Gradient (Di), and the Stress Ratio (Si). The description and ranges of these parameters is well explained by Adams 1951; Birch 1966; Gassman 1973; Bowles 1982; Tatham 1982; Sheriff & Geldart 1986; Abd El-Rahman 1989; Abd El-Rahman 1991. Ranges of these calculated parameters are given in Table 2.

### Table 1: List of Equations used to Calculate Elastic Moduli

<table>
<thead>
<tr>
<th>Elastic parameters</th>
<th>Used equation</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poisson’s Ratio</td>
<td>( \sigma = \frac{1}{2} \left[ 1 - \frac{1}{\left( \frac{v_S}{v_P} \right)^2 - 1} \right] )</td>
<td>Adams (1951), Salem (1990)</td>
</tr>
<tr>
<td>Young’s Modulus</td>
<td>( E = \rho \left[ \frac{3v_P^2 - 4v_S^2}{\left( \frac{v_S}{v_P} \right)^2 - 1} \right] )</td>
<td>Adams (1951)</td>
</tr>
<tr>
<td>Lame’s Constants</td>
<td>( \lambda = \frac{\sigma E}{(1 + \sigma)(1 - \sigma)} )</td>
<td>King (1966), Toksoz et al. (1976)</td>
</tr>
<tr>
<td>Shear Modulus</td>
<td>( \mu = \frac{E}{2(1 + \sigma)} )</td>
<td>King (1966), Toksoz et al. (1976)</td>
</tr>
</tbody>
</table>

### Table 2: The Ranges of the Calculated Engineering Parameters of the Bedrock Layer

<table>
<thead>
<tr>
<th>Parameter range</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poisson’s Ratio, ( s )</td>
<td>0.21–0.43</td>
</tr>
<tr>
<td>Shear Modulus, ( \mu )</td>
<td>406–1341 MPa</td>
</tr>
<tr>
<td>Concentration Index, ( Ci )</td>
<td>3.81–5.90</td>
</tr>
<tr>
<td>Material Index, ( V )</td>
<td>-0.30 to 0.55</td>
</tr>
<tr>
<td>Density Gradient, ( Di )</td>
<td>-0.47 to -0.83</td>
</tr>
<tr>
<td>Stress Ratio, ( Si )</td>
<td>0.23–0.52</td>
</tr>
</tbody>
</table>

The southwestern and central part is characterized by relative high Concentration Index (Ci) values ranging between 4.3 and 5.9, which, according to Abd El-Rahman (1989), reflects fairly competent soil. The calculated Material Index (V) for the bedrock layer reveals values ranging from 0.30 to 0.70. The southeastern part is characterized by relative low Material Index values ranging between -0.27 and 0.10, which reflects a slightly competent soil. The calculated Density Gradient (Di) reveals values ranging from -0.47 to -0.83. The southeastern part is characterized by relative low Density Gradient (Di) values ranging between -0.47 to -0.62. In the study area, the calculated Stress Ratio (Si) for the bedrock layer reveals values ranging from 0.23 to 0.59. The western and southwestern part is characterized by the lowest Stress Ratio (Si) with values ranging between 0.23 and 0.34, which, according to Abd El-Rahman (1991), reflects fairly to good competent soil.

### 6. RESULTS

The area of study is divided into three zones according to the seismic P-wave and S-wave velocity values and the engineering parameter values. The first zone is the northeastern parts, where the subsurface bedrock is characterized by less competent rock quality. This zone has a bedrock P-wave velocity of 300 to 600 m/s and S-wave velocity of 120 to 250 m/s. The Concentration Index, Material Index, Density Gradient, and Stress Ratio are ranging between 3.8 to 4.4, -0.3 to -0.1, -0.47 to -0.51, and 0.6 to 0.5, respectively. The second zone is located in the central part of the study area, where the subsurface bedrock is characterized by competent rock quality. The P-wave and S-wave velocities are ranging between 400–800 m/s and 250–370 m/s, respectively. These velocity values are higher than those of the northeastern parts. The Concentration Index, Material Index, and Stress Ratio are ranging between 4.8 to 5.5, -0.2 to 0.3, and 0.5 to 0.4, respectively. The third zone is located in the southern part of the study area, where the subsurface bedrock is characterized by highly competent rock quality. These zones have a bedrock P-wave velocity of 470 to 1700 m/s and S-wave velocity of 400 to 480 m/s. The Concentration Index, Material Index, and Stress Ratio are ranging between 5.0 to 5.9, 0.3 to 0.61, and 0.23 to 0.30, respectively. The calculated engineering parameters for the whole region are indicated in Table 2.

### 7. SUMMARY AND CONCLUSIONS

The purpose of this work is to delineate the NCR of Delhi for seismic microzonation. For that purpose a total of 199 shallow seismic refraction and MASW profiles were acquired and interpreted. The reciprocal and common mid point method is used to generate a preliminary depth velocity model. A number of shallow rock engineering parameters such as Concentration Index, Material Index, Density Gradient, and Stress Ratios were calculated to assess the subsurface bedrock from a geophysical and engineering
prospective. Integration between different engineering elastic, consolidation, and strength parameters indicates a high competent of the bedrock in the south part of the site. The implication of this work is to integrate the geophysical studies with the engineering parameters to help in site characterization. The results will help to estimate seismic hazard and to design land-use maps that avoid critical and dangerous zones at the unseen bedrock layer.

REFERENCES


