Site Characterization at Ekambareswara Temple Complex, Kanchipuram, Tamil Nadu

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ABSTRACT

Seismic site characterization of a particular location is prerequisite in ground response studies for providing realistic ground motions needed in seismic analysis of structures. Site characterization includes an evaluation of subsurface material types and their properties. In this study, a comprehensive site investigation campaign has been conducted at the Ekambareswara temple complex, Kanchipuram, Tamil Nadu. Multichannel analysis of surface waves (MASW) test and Refraction microtremor (ReMi) test using MASW test set-up are carried out at the temple complex. Shear wave velocity profiles are obtained by MASW tests. Shallow shear wave velocities beneath the temple complex are characterized using the ReMi test. The standard penetration tests are also carried out at different depths in the five boreholes drilled for the purpose of comparing the subsurface profile obtained using the MASW test. Comparative plots are provided for the shear wave velocity profiles of a few boreholes and a good correlation is observed.

1. INTRODUCTION

The overall performance of a structure founded on geologic material depends on the subsoil conditions, ground surface features, type of construction and sometimes the meteorological changes. Site characterization includes an evaluation of subsurface features, geologic material types and their properties. The field and laboratory studies are required to be carried out for obtaining the necessary information regarding the subsoil characteristics. Subsurface conditions can be explored by drilling and sampling, seismic surveying, excavation of test pits, and by the study of existing data. Much of the site investigation depends on the experience and good judgment of the field engineer. A well planned and properly executed site investigation programme will provide information about the stratigraphic and physical properties of the geologic materials at a site including groundwater table and its fluctuation.

This paper outlines the seismic site characterization carried out for the temple complex at Kanchipuram. The site characterization activity was divided into two categories. The first one was the geophysical seismic testing, which included multichannel analysis of surface waves (MASW) and refraction microtremor (ReMi) tests. The second one was the conventional geotechnical testing, which included geological surveys, standard penetration test and laboratory testing. Based on these test results, shear wave velocity profiles are provided for the borelogs of the temple complex at Kanchipuram, Tamil Nadu.

2. SITE CHARACTERIZATION

MASW Test

Multichannel analysis of surface waves (MASW) test is one of the most widely used techniques in geotechnical engineering for measurement of dynamic soil properties and identification of subsurface material boundaries. The MASW test consists of an in situ experiment to determine the dispersion curve of the soil and solution of an inverse problem where the corresponding soil profile is identified. The MASW test is a nondestructive seismic method used to evaluate thickness and shear wave velocity of the soil column (Park et al. 1999, Xia et al. 1999). The MASW test is commonly employed to estimate the shallow shear wave velocity structure. The test is based on the measurement of Rayleigh waves. The shear wave velocity
profiles are obtained by Rayleigh wave dispersion curves. Both the dispersion curve and the ellipticity of Rayleigh waves are controlled by the subsurface velocity structure. In principle, one can invert either of them for shear wave velocity determination. Multichannel data displayed in a time-variable frequency format allow identification and rejection of non-fundamental mode Rayleigh waves and other coherent noise from the analysis. Soil is assumed to be homogenous and isotropic in each layer. The theoretical dispersion curves are developed for layered medium using the developed MATLAB program.

The frequency-dependent properties of Rayleigh-type surface waves can be utilized for imaging and characterizing the shallow subsurface. Most surface wave analysis relies on the accurate calculation of phase velocities for the horizontally travelling fundamental mode Rayleigh waves acquired by stepping out a pair of receivers at intervals based on the calculated ground roll wave lengths. Interference by coherent source-generated noise inhibits the reliability of shear wave velocities determined through inversion of the whole wave field. The degree to which each of these types of noise contaminates the dispersion curve and, ultimately, the inverted shear wave velocity profile is dependent on the frequency as well as distance from the source. The locations of the MASW test arrays numbering Lines 1 to 5 are depicted in Figure 1, which also shows the schematic view of the Ekambareswara temple complex. The receiver spacing used is 2 m for all the acquired lines. Line 1 (Fig. 1) was processed 2 times using a stack of five shots of a sledgehammer. The processed data for Line 1-1 are depicted in Figure 2.

Figure 2 shows the stacked seismogram on the upper left of the figure. The two plots on the right show the frequency (f) - wave length (k) spectra, whereas the lower left plot shows the depression curve. Figure 3 depicts the fitted dispersion curve and the best shear wave velocity profile for Line 1-1.

![Figure 1: Array Locations at Temple Complex, Kanchipuram](image1)

The Refraction Microtremor (ReMi) test (or technique) has been widely used to determine shear wave velocity profiles using ambient noise recordings. This test is faster and better for probing shear wave velocity profiles up to 100 m depth. The ReMi test results will add to the results of the MASW test. Pancha et al. (2008) have characterized the shallow shear wave velocities beneath a rock site using the ReMi technique developed by Louie (2001). Ground motion from a passing train enables capture of energy propagating parallel to the recording array. This allowed evaluation of the variation of the minimum phase-velocity of the dispersion curve envelope and better estimation of the true minimum velocity beneath the site. This study used a new method to image and evaluates the dispersion curve envelope via power-slowness profiles through the slowness–frequency plots introduced by Louie (2001). The data illustrates the frequency dependency of dispersion curve uncertainties, with greater uncertainty occurring at low frequencies. These uncertainties map directly into uncertainty of the inverted velocity–depth profile. Beyond 100 m depth, velocities are well constrained within 10% variability. The variability is greatly reduced when the energy propagation is along the geophone array. Greater velocity variation is observed below 100 m depth. In this study, ReMi data are acquired by recording ambient noise using 80 s time windows. A variable number of windows are acquired considering the time needed to move and put in place the active source. A total of five tests data were...
acquired and the steps taken to process the ReMi data are explained in the following paragraph.

Active data are contaminated by too strong noise level for active data processing. For Line 2, in all 10 shots have been acquired and stacked using the sledgehammer, but the acquisition has been disturbed by the continuous passage of people close to the receiver line, and the signal to noise ratio is hence too low to extract reliably a dispersion curve from active data. The noise analysis shows a strong dominance of the energy travelling with positive velocity (positive wave number). Even if the hypothesis of azimuthally homogenous noise is not fulfilled strictly, due to the nature of the noise sources, it is assumed that the positive quadrant can be analysed. The results are shown in Figure 4. The positive wave numbers have a much higher energy level than the negative ones, and the spectral section at constant frequency shows a strong asymmetry. The positive half can however be interpreted. The dispersion curve obtained with the positive half is shown in Figure 5. The Rayleigh wave phase velocity is almost constant, about 270 m/s for wave length shorter than 25 m.

Standard Penetration Test
The main purpose of drilling exercise is to provide an indication of the nature and disposition of the material formation, geological strata and lithology below the site. In the Ekambareswara temple complex, Kanchipuram, a total of five shallow boreholes, named BH-1, BH-2, BH-3, BH-4 and BH-5 were drilled, using a 150 mm diameter rotary hydraulic driller. The boreholes were located in such a way that they were distributed throughout the complex to represent the site characteristics.

Standard penetration test (SPT) is one of the most popular forms of in situ testing conducted for site characterization in geotechnical engineering. The main purpose of the test is to provide an indication of the relative density of granular deposits, such as sands and gravels from which it is virtually impossible to obtain undisturbed samples.

A shear wave velocity profile was obtained using the empirical correlation between the shear velocity and SPT ‘N’ value from the results of boreholes BH-1, BH-2 and BH-4. These boreholes were chosen, because the section that connects them goes through the main temple, thereby allowing a first approximation of the shear wave velocity at the site. The $V_s$ profiles have been estimated using Ohta & Goto (1976) empirical correlation and are shown in Figure 6. Comparative plots are developed for the shear wave velocity profiles of a few boreholes obtained using correlations along with that obtained from the MASW test. A good correlation is observed between the shear wave velocity profiles. Laboratory tests are conducted mainly to provide the modulus and damping characteristics of the geologic material explored as part of the site characterization.

### Fig. 4: ReMi Spectrum Computed Stacking 2s Time Windows

### Fig. 5: Dispersion Curve Obtained from the Positive Half of the Spectrum

### Fig. 6: Shear Wave Velocity Profiles for BH-1, BH-2 and BH-4

#### 3. MODELLING OF SUBSURFACE PROFILE

A proper definition and assessment of the seismic input and possible amplifications of the ground motion due to localized lithographic or geomorphological characteristics of the soil at the site of the temple complex are needed in the hazard analysis. In this regard, a reliable model of the subsurface profile is essential.

**Subsoil Model Definition**

The characteristics of the subsoil model adopted to perform the site response analysis are defined based on the knowledge of the site. Figure 7 depicts the subsurface profile obtained using the borelogs of BH-1, BH-2 and BH-4. This is used to study the lateral variations of soil properties below the main temple. The shear wave velocity profiles found for the boreholes BH-1, BH-2 and BH-4 using Ohta & Goto (1976) empirical relationship were compared with those obtained from the MASW tests for Lines 1, 3, 4 and 5. It is noted that
the \( V \) profiles obtained from the SPT `N' values follow the trend found with the MASW test results. The thickness and shear wave velocity of each layer were defined using the mean of the results shown in Figure 8 and are presented in Table 1 (Kalyan Kumar, 2010). The figure shows the mean \( V \) profile to be used in the site response analysis and includes the interval of variation of the shear velocity.

![Fig. 7: Subsurface Profile from Borehole Data (BH-1, BH-2 and BH-4)](image)

![Fig. 8: Mean \( V \) Profile and Range of Variation for Shear Wave Velocity in Each Layer of the Subsurface Model](image)

**Table 1:** Values of Thickness and \( V \) Evaluated from Geophysical Tests

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness Range (m)</th>
<th>Thickness (m)</th>
<th>( V_s ) (m/s)</th>
<th>( V_r ) Range (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.8-1.2</td>
<td>1.0</td>
<td>150</td>
<td>100-200</td>
</tr>
<tr>
<td>2</td>
<td>2.0-3.0</td>
<td>2.5</td>
<td>200</td>
<td>150-250</td>
</tr>
<tr>
<td>3</td>
<td>6.6-12.0</td>
<td>9.0</td>
<td>250</td>
<td>220-275</td>
</tr>
<tr>
<td>4</td>
<td>15.0-35.0</td>
<td>25.0</td>
<td>480</td>
<td>416-630</td>
</tr>
<tr>
<td>5</td>
<td>Bedrock</td>
<td>–</td>
<td>750</td>
<td>660-850</td>
</tr>
</tbody>
</table>

The boreholes drilled at the site reached a maximum depth of 25 m. The estimated shear wave velocity at that depth is 480 m/s. Therefore, it cannot be considered as rock. There is no reliable data beyond 25 m to define the depth at which the rock stratum can be found. Due to the lack of information, one can vary the thickness of the fourth layer from 15 to 35 m, hence allowing for the uncertainty associated with the position of the bedrock. Based on the data provided by the Public Works Department of Tamil Nadu State Government, it is noted that the hard surface can be found at a depth varying from 25 to 50 m, thereby justifying the range of values chosen to represent the thickness variability of the last layer of the subsurface profile.

Table 2 presents the values of unit weight for the different layers identified in the study. The shear modulus and damping curves for each of the soil layers have been obtained from the laboratory experiments. All the above information is used in the construction of the subsoil model to be used in the ground response analysis.

**Table 2:** Values of Unit Weight of Soil Adopted for Each Layer

<table>
<thead>
<tr>
<th>Layer</th>
<th>Unit Weight, ( \gamma ) (kN/m(^3))</th>
<th>Range for ( \gamma ) (kN/m(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>15-17</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>16-19</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
<td>16-19</td>
</tr>
<tr>
<td>4</td>
<td>19</td>
<td>18-21</td>
</tr>
</tbody>
</table>

4. CONCLUSIONS

The reliable and dependable subsurface profile is obtained from the geotechnical and geophysical exploration for the Ekambareswara temple complex at Kanchipuram. This study is carried out as part of the comprehensive seismic hazard analysis for the Kanchipuram region. The MASW and ReMi tests have been conducted to characterize the subsurface profile for ground response analysis. The MASW test is much faster and simpler technique because of its multi-channel recording that eliminates the necessity of repeated measurements by changing field configuration. The standard penetration tests are conducted at the temple complex in order to compare the shear wave velocity profiles obtained from the MASW tests. The ReMi test results will add to the results of the MASW test. All these data have been used in the modelling of subsurface profile and this profile is used in the ground response analysis so as to derive the surface design ground motions at the temple complex.

**REFERENCES**


