Application of Refraction Microtremor (ReMi) for Seismic Site Characterisation

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SUMMARY:
Refraction Microtremor (ReMi) Survey was conducted for geotechnical site characterization based on non destructive testing method to evaluate shear wave velocity of substrata at selected locations in Bangalore city, India and to classify the site according to International Building Code 2006 (IBC 2006).The measured shear wave velocities have been used to conduct seismic site response analysis with an objective to find peak ground acceleration distribution, amplification and response spectrum at the measured sites. It is also focused to evaluate the potential of site for possible liquefaction in the study area. Results indicate that selected sites of Bangalore City can be classified as Class C for which shear wave velocity range from 360m/s to 750m/s. Further, these selected sites are free from occurrence of liquefaction during earthquakes.

Keywords: Shear wave velocity, Amplification, Liquefaction, Peak ground acceleration

1. INTRODUCTION

The need for a simple effective method of determining on site analysis of shallow subsurface shear wave velocity structure has become more important. Existing conventional methods for determining the shallow shear wave velocity structure of a given subsurface requires drilling to determine shear wave velocity of a site. Such drillings are laborious, time consuming and becomes uneconomical. Further the process becomes increasingly difficult in populated areas where there will be several constraints to carryout experimental investigations. To overcome this problem, a method has been developed to use the “seismic noise” or “microtremor” to map the shallow shear wave velocity structure. This is known as ReMi (Refraction Microtremor) method. For a proper design of earthquake –resistant structure and other infrastructures a good estimation of the ground amplification level during the expected earthquake is required. The level of shaking is mostly described in terms of peak ground acceleration and amplification, and visualized by response spectra. In order to determine the ground response during earthquake excitations several input parameters are required for each site. These include sub soil conditions and bed rock level, shear strength and other geotechnical properties of sub soils and the design earthquake. In most cases, many of these input parameters are very poorly known. Shear wave velocity may be obtained directly or indirectly using variety of methods. Indirect methods like Standard penetration tests (SPT) or Cone penetration test (CPT) results may be less reliable and provides limited depth of exploration compared to results obtained by measuring seismic energy directly.

Direct shear wave velocity measurements obtained by performing cross hole or down hole seismic surveys requires boreholes which adds the time and expense to the project as well. The major benefit in using the ReMi method includes the ability to collect the data quickly with a two person crew and ability to collect the seismic data in a noisy urban environment.

2. METHODOLOGY

2.1. Shear Wave Velocity by ReMi Method

Shear wave velocities are characterized at the site using ReMi technique. The essence of this technique is that ambient noise contains usable signals that are predictable from velocity structure that may be presumably caused by human activities; the vertical component of ambient noise dominated by Rayleigh waves is recorded by geophones/seismographs array. These Rayleigh waves are separated from other wave arrivals using two dimensional slowness frequencies (p-f) transforms of noise records energy propagating in both directions is analyzed. The fundamental mode phase velocity of Rayleigh wave dispersion is picked along the minimum velocity envelope of energy within the slowness frequency spectral image. The spectrum is normalized as the ratio of power spectrum at a particular frequency and slowness over the average value for all slowness values at that frequency. Louie [1] demonstrated that picking along the minimum edge of contours on p-f (Slowness-frequency) plots, where the slope is steepest is the best procedure for picking the dispersion curve to obtain the best estimate of true phase velocities. These Rayleigh wave dispersion picks are then interactively modeled using trial and error adjustments of velocity depth model, to obtain the shear wave velocity versus depth profile, Modelling was done using SeisOpt ReMi.

2.2 Field Data Collection

The method uses surface waves recorded on standard multi-geophone seismic refraction equipment. The records are collected in similar style to shallow refraction surveys, but emphasis is on recording the entire surface waves rather than primary and secondary wave refraction and reflection. The following fig. 1, 2 and 3 shows the typical slowness –frequency image obtained for the three locations such as Vijaynagar, Yeshwanthpur and Mahalaxmi layout respectively at Bangalore city, Karnataka, India which were used to model the Shear wave velocity structure.

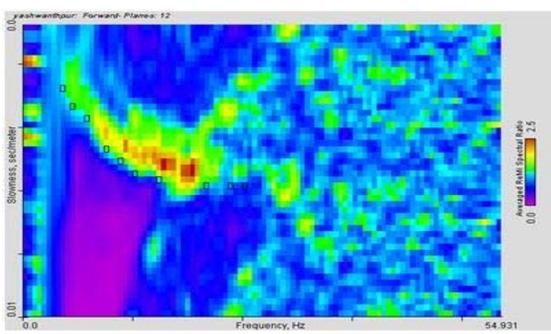


Figure 1. P-f Image for Vijaynagar Site

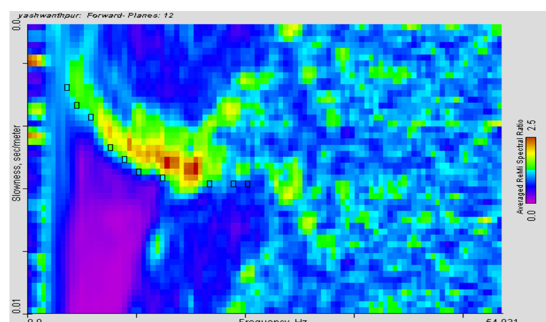


Figure 2. P-f Image for Yeshwanthpur **Site**

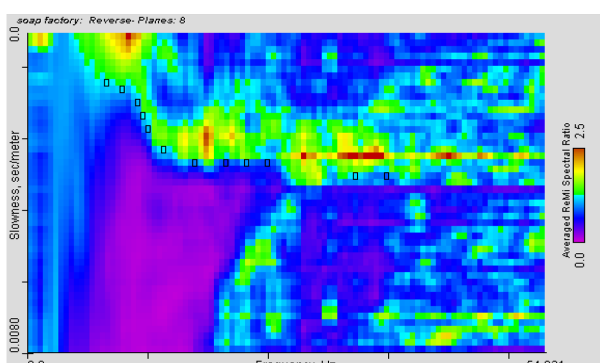


Figure 3. P-f Image for Mahalaxmi layout Site

Different sources used for surface wave measurement may produce a clearer dispersion trend in differing frequency ranges. In general, the best low frequency dispersion can be achieved with the help of dynamite source, however running a vehicle along the length of array also proved good sources of low frequency surface waves for determining deeper structure. Hence in this study the vehicular movement is used as a source of vibration.

3. RESULTS

3.1. Velocity Analysis

The Shear wave velocity profiles obtained from refraction microtremor method has been compared with Shear wave velocity (V_s) values obtained from Standard Penetration test values (SPT), based on empirical relations proposed by JRA (Japanese Road Association).

Table 3.1. Test Parameters for Recording Ambient Noise at Different Locations

Location	Recording Interval (Sec)	Geophone type (Hz)	Geophone Spacing (m)
Vijaynagar	30	4.5	8
Yeshwanthpur	30	4.5	6
Mahalaxmi layout	30	4.5	5
Baiyappanahalli	30	4.5	8

Table 3.2. V_S values for Vijaynagar Site

Depth (m)	Vijayanagar Site	
	Vs from ReMi m/s	Vs from SPT(N)
1.5	174	172
3.0	314	193
6.0	683	295
10.5	683	750
30	1957	-

Table 3.3. V_s values for Yeshwanthpur Site

Depth (m)	Yeshwanthpur Site	
	Vs from ReMi (m/s)	Vs from SPT(N)
3.6	246	237
8.1	278	240
10.6	278	267
15.1	321	299
30.0	617	-

Table 3.4. V_s values for Mahalaxmi layout Site

Depth (m)	Mahalaxmi layout Site	
	Vs from ReMi (m/s)	Vs from SPT(N)
3.0	402	229
4.5	402	267
7.5	313	246
10.5	560	249
13.5	924	750
30.0	1905	-

Figures 4, 5 and 6 shows the variations of shear wave velocities from both methods for different sites.

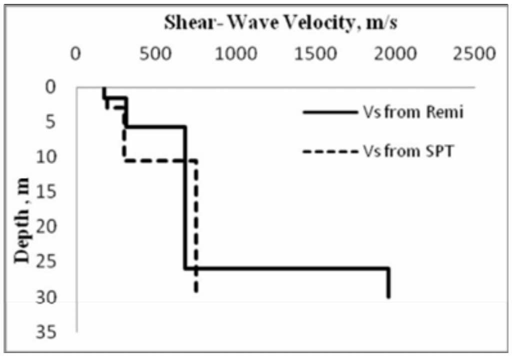


Figure 4. Vs profile for Vijaynagar Site

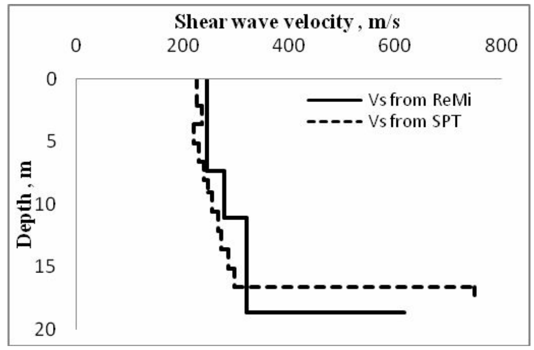


Figure 5. Vs profile for Mahalaxmi layout

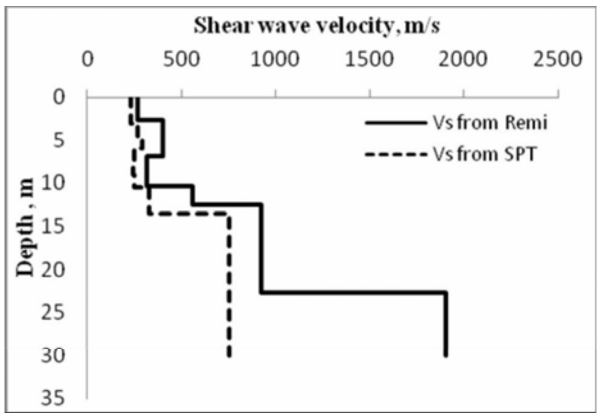


Figure 6. Vs profile for Yeshwanthpur Site

3.2. Liquefaction Potential Analysis

Evaluation of the liquefaction resistance of soils is an important step in many geotechnical investigations in earthquake prone regions. The simplified procedure was originally developed by Seed and Idriss (1971) using blow counts from the standard penetration test correlated with the parameter called cyclic Stress Ratio (CSR) that represents the cyclic loading on the soil is used in the present study.

3.2.1. Cyclic Stress Ratio

The cyclic stress ratio, τ_{av}/σ'_v, at a particular depth in a level soil deposit can be expressed (Seed and Idriss, 1971) as

$$CSR= \tau_{av}/\sigma'_v=0.65(a_{max}/g)\ (\sigma_v/\sigma_{v'})*r_d \quad (1)$$

where τ_{av} is the average equivalent uniform cyclic shear stress caused by the earthquake and is assumed to be 0.65 of the maximum induced stress, amax is the peak horizontal ground surface acceleration during earthquakes, g is the acceleration due to gravity, σ_v' is initial effective overburden stress at particular depth, σ_v is the total overburden stress at that depth and rd is shear stress reduction coefficient to adjust for flexibility of the soil profile.

3.2.2. Stress corrected Shear wave velocity

Shear wave velocity can be measured by several methods; the accuracy of their results can be sensitive to procedural details, soil conditions, and interpretation techniques. One important factor influencing V_s is the state of stress in soil.

Following is the traditional procedures for correcting SPT blow count and CPT tip resistance to account for overburden stress (Sykora 1987; Robertson et al. 1992)

$$V_{s1}=V_s*C_v=V_s*(P_a/\sigma_{v'})^{0.25} \quad (2)$$

Where V_{s1}= overburden stress-corrected shear wave velocity; C_v = factor to correct the measured shear wave velocity for overburden pressure; P_a= reference stress of 100 kPa or about atmospheric pressure; and $\sigma_{v'}$ = initial effective overburden stress (kPa).

3.2.3. Cyclic resistance ratio

The value of CSR separating liquefaction and non liquefaction occurrences for a given V_{s1}, or corrected penetration resistance, is called the cyclic resistance ratio (CRR). CRR given by Andrus and Stokoe (1999) for M_w = 7.5 earthquake is defined as

$$CRR= \{0.022*(V_{s1}/100)^2 + 2.8(1/(V_{s1}*-V_{s1})-(1/V_{s1}*))\}*MSF \quad (3)$$

Where $V_{s1}*$ is the limiting upper value of V_{s1} for liquefaction occurrence (which is assumed as 215 m/s in absence of fine content data). Idriss (1999) proposed Magnitude scaling factor (MSF) defined by

$$MSF= 6.9 \exp(-M_w/4)-0.06, \text{ for } M_w > 5.2 \quad (4a)$$

$$MSF= 1.82, \text{ for } M_w \leq 5.2 \quad (4b)$$

Magnitude scaling factors defined by equation (4a & 4b) and Reduction factor (r_d) proposed by Idriss (1999) should be used together when applying corrected shear wave velocity (eqn 2) and Cyclic resistance ratio (eqn 3) The difference in two proposed MSF and r_d relationships is not significant for earthquakes with magnitudes of about 7 to 7.5 (Andrus et.al.1999), as per range of the majority of the Shear wave velocity case history data. In order to assess the liquefaction risk at testing locations, estimations of CSR with depth are made at each location and plotted against V_{s1} calculated from the shear wave velocity profiles (see fig 7 and 8).

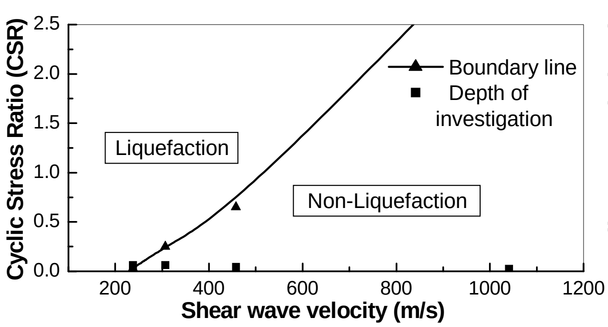


Figure 7. Estimation of Liquefaction potential for Vijaynagar site.

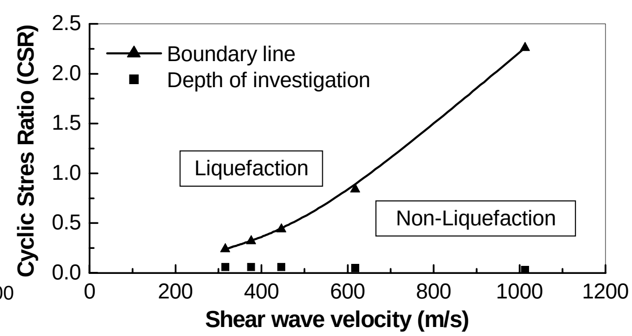


Figure 8. Estimation of Liquefaction potential for Mahalaxmi layout site

In figures 7 & 8 the boundary line separating liquefiable and non-liquefiable region is the cyclic resistance ratio (CRR) line suggested by Andrus and Stokoe (1999).

3.2.4. Ground response analysis

During earthquakes the ground motion parameters such as amplitude of motion, frequency etc. changes as the seismic waves propagate through overlying soil and reaches the ground surface. In this study, equivalent linear one dimensional ground response analysis has been carried out using the computer program SHAKE2000 developed by Idriss and Sun (2004).

As per IS1893-2002, Bangalore city lies in seismic zone II with a zone factor of 0.10 and expected earthquakes of magnitudes 6 to 7.5. Global Seismic Hazard Assessment Program (GSHAP) map, specifies the maximum peak ground acceleration of 0.12g for zone II. A wavelet based method has been used for generation of spectrum-compatible time history analysis of earthquakes. RSPMatch is one such wavelet based method developed and subsequently updated by Hancock et.al (2006).

As a basic step, the methodology requires use of strong motion records available from previous earthquakes, while selecting a suitable strong motion several important factors are considered which includes similar magnitude earthquakes, peak acceleration values and similar site conditions (Kramer 1996). Based on these factors, a coalinga earthquake of magnitude in the range of 6 to 7.5 recorded at rock sites were selected from the earthquake database (Fig.7). The rock motion obtained from synthetic ground motion model using RSPMatch2005 is assigned at bedrock level as input to conduct site response analysis.

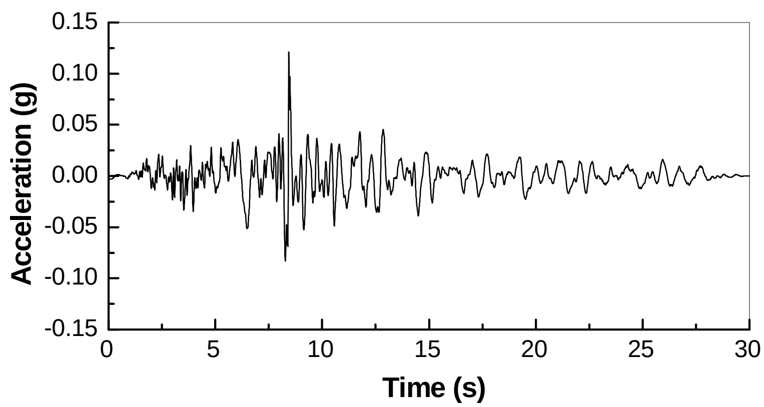


Figure 9. Input motion of Coalinga Earthquake

The following figures 10, 11 and 12 shows the amplification, peak ground acceleration (PGA) and response spectrum for Vijaynagar site respectively.

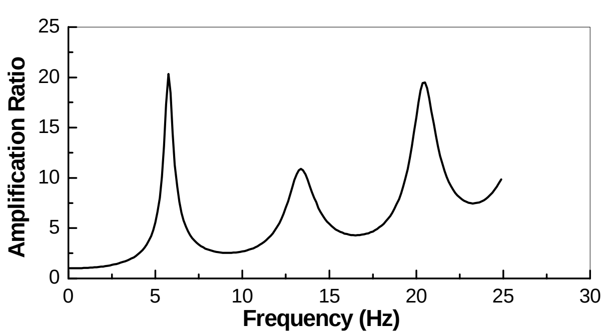


Figure 10. Amplification ratio for Vijayanagar site

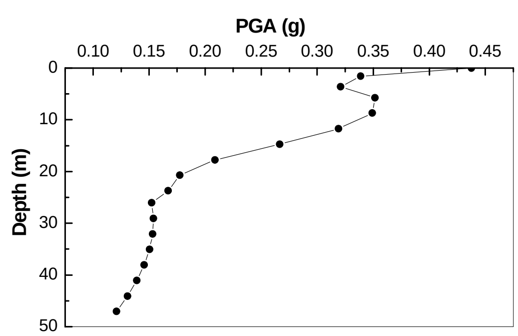
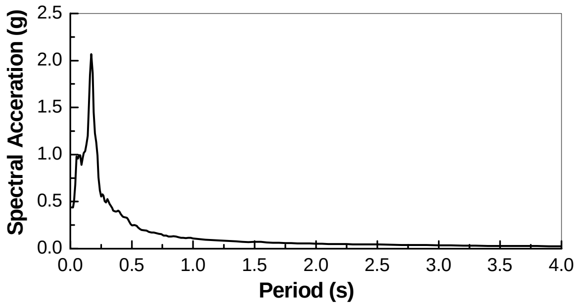


Figure 11. Variation of PGA with depth for Vijayanagar site

Table 8 shows the results of ground response analysis of all the locations.



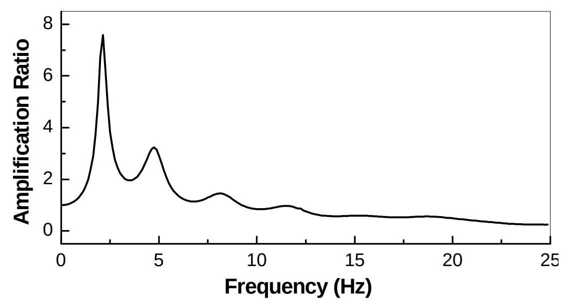


Figure 12. Spectral acceleration for Vijaynagar site

Figure 13. Amplification ratio for Yeshwanthpur site

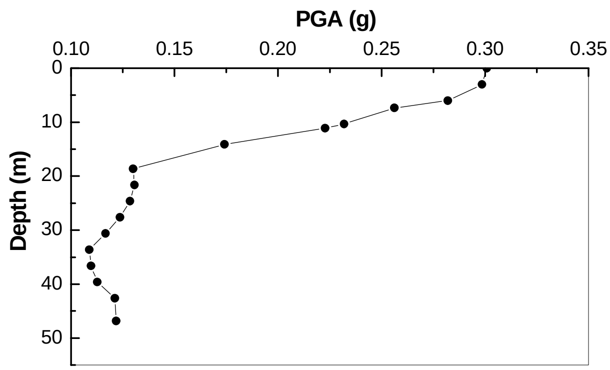


Figure 14. Variation of PGA withdepth for Yeshwanthpur site.

Table 8. Summary of the Results of Site Response analysis of all the sites

Parameter	Site 1 Vijaynagar	Site2 Yeshwanthpur	Site3 Mahalaxmi Layout	Site4 (Baiyappanahalli)		
				BH1	BH2	BH3
Peak ground surface acceleration (g)	0.44	0.3	0.36	0.34	0.44	0.32
Maximum amplification of ground motion parameter	20.32	7.60	15.21	6.17	9.0	6.13
Frequency of maximum amplification (Hz)	5.75	2.13	12	4	11.37	3.25
Maximum spectral acceleration(g)	2.07	1.32	1.33	1.15	1.19	1.05
Period at max.spectral acceleration (S)	0.17	0.45	0.18	0.26	0.26	0.3

4. CONCLUDING REMARKS

In the present study an attempt has been made to measure shear wave velocity at selected locations using ReMi method. The average shear wave velocity for the top 30m depth of soil/rock strata ranges from 378m/s to 603m/s thus representing site class C indicating very dense soil and soft rock as per International Building Code 2006. The measured shear wave velocity is in close agreement with the shear wave velocity computed from Japanese Road Association based on corrected Standard Penetration Test Values (N). An assessment of liquefaction potential at the selected sites based on measured Shear wave velocity values indicate that these sites are free from occurrence of liquefaction. One dimensional ground response analysis carried at different locations reveals the peak ground acceleration at surface range from 0.30g to 0.44g. A maximum spectral acceleration of 2.07g has been observed at Vijaynagar site at corresponding period of 0.17sec (5.48 Hz).

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