Seismic Site Characterization using MASW of Sites along Srinagar Metro Rail Alignment, Jammu and Kashmir

Zahoor, F.[1,2 [0000-0002-1040-803X]], Rao, K. S.[1✉], Malla, S. A.[2[0000-0003-3748-9834]], Tariq, B.[2[0000-0003-2499-660X]] and Bhat, W. A.[2[0000-0002-7050-6774]]

[1] Indian Institute of Technology Delhi, Delhi, India
raoks.iitd@gmail.com
falaq.zahoor@gmail.com
[2] National Institute of Technology Srinagar, Jammu and Kashmir, India
sajadahmad2659@gmail.com
basittariq @gmail.com
bhatwaseem7860@gmail.com

Abstract. Srinagar metro rail is a part of the huge upcoming construction project proposed by the Government of India, aiming at the creation of a Mass Rapid Transport System in the state of Jammu and Kashmir. For this study, geophysical investigations using Multichannel Analysis of Surface Waves (MASW) have been conducted at 33 selected sites along the proposed alignment of the Srinagar metro. Shear Wave velocity profiles over 30 m depth have been generated at each location. Using the average value down to 30 m (V_{S30}), seismic site characterization of the locations has been carried according to National Earthquake Hazard Reduction Program (NEHRP) guidelines. V_{S30} is an important dynamic parameter of soils which is a critical input for evaluation of the seismic response of a soil deposit to earthquakes. Site classification using average N values up to 30 m (N_{30}) has also been carried. The values of N_{30} vary between 6 and 32 along the alignment of Srinagar metro. The range of V_{S30} for the sites varies from 139 to 451 m/s along Corridor-I, 151 to 410 m/s in Corridor-II and 189 to 428 m/s in Corridor-III. Site characterization revealed that most of the sites fall within D and E categories, with only a few sites in C category. Site conditions in Srinagar city vary drastically owing to the topographic changes and influence of water bodies. It is thus imperative to conduct site specific geophysical tests for the purpose of site characterization and earthquake resistant design of structures associated with the Srinagar metro rail.

Keywords: Multi-channel Analysis of Surface Waves · Srinagar (Jammu and Kashmir) · Shear Wave Velocity · Seismic Site Characterization

1 Introduction

1.1 MASW

Multichannel Analysis of Surface waves is a low cost, non-invasive geophysical technique to determine shear wave velocity of soil deposits [1]. The dispersive nature of the surface waves is utilized to determine the subsoil characteristics which is a critical dynamic parameter of soils. Different soil layers having varying densities and thicknesses, exhibit varying fundamental frequencies. Thus, surface waves being dispersive, travel at varying velocities in the layers. This is captured by the shot records in a seismograph with the help of multiple receivers/geophones. Analysis of data involves extraction of dispersion curves and their inversion to develop the velocity models with depth [2]. Shear wave velocity is an important dynamic parameter of soil deposits which is used as an input in various other studies like liquefaction analysis [3], ground response analysis and generation of response spectrum for the site [4, 5].

IS: 1893 (2016) gives design spectra for three categories of soil: soft, medium and hard rock [6]. However, this is a highly generalized form of classification. Response of a site to earthquakes is dependent on the characteristics of the local soil deposit. Local site effects were first observed in 1985 Mexico earthquake and 1989 Loma Prieta earthquake [7]. Soil layers modify ground motion parameters (amplitude, frequency content and duration) of the seismic waves reaching a site. Shear wave velocity is a measure of soil stiffness which is the main property of soil affecting its response to dynamic loading. Most of the modern seismic codes [4] suggest the consideration of local site effects in earthquake resistant design of structures through sites specific evaluation. The particular ground motion for which a structure needs to be designed is generated by ground response analysis. Codes suggest the use of V_{S30} as the input dynamic parameter for ground response analysis to generate site specific response spectrums and design spectrums for important constructions to incorporate the effects of soils at the site. This gives peak ground acceleration and spectral acceleration values at the ground surface which are different from those at bedrock and are representative of the local soil conditions.

1.2 Study Area

Srinagar is located in a depression in the north eastern flank of the Kashmir valley within the Himalayas, bounded by the Zanskar range in the north eastern margin and Pir Panjal range in the south western margin. The elevation contours in Figure 1 indicate drastic variations in elevations within small distances due to highly varying topography. Rivers, lakes and the associated areas form a part of the depressions. A few hills like Hari Parbat and Shankaracharya are located within the city. The lowest elevation of around 1555 m above M.S. L is in the center of Srinagar in the region lying around the Jhelum river. Due to the proximity to the river and as a result of being low lying, this area has an inflow and subsequent retention of water. Fluvial sediments are deposited in this region by the river and thus the soils here are young and unconsolidated. The topography merges with the Zankar range in the NE and thereby a rise in elevation is observed from the center towards the north. In the SW of the Kashmir valley, tectonic activity has uplifted the Pir Panjal range and the south western margin of the valley along with it, resulting in deposition of sediments from the mountains along the margin [8]. As a result, the elevation in Srinagar city increases towards the south western end. The combination of tectonic activity, deposition of sediments from the mountains, activity of the rivers, contributes to the overall geomorphological setting of the basin. These factors lead to huge changes in properties of the soils within short distances in Srinagar city. The study area mainly forms a part of the alluvial formations in Kashmir Valley.

The Himalayan region has an active tectonic setup which is a result of movement of the Indian plate towards the Eurasian plate. This has manifested in a complex pattern of faulting which includes strike slip faults as well as major thrusts like Main Frontal Trust (MFT), Main Wadia Thrust (MWT), Main Boundary Thrust (MBT) and Main Central Thrust (MCT) in the region. The record of past earthquakes (e.g. 1555 Kashmir earthquake, 1885 Pattan earthquake) and the recent seismic activity in the region, especially the M_w 7.6 2005 Kashmir earthquake and M_w 7.5 2015 Hindukush earthquake, reflect the high susceptibility of the region to major earthquakes and consequent damage. Huge loss of life and property has been experienced in these earthquakes. Due to this reason, IS: 1893 (2016) designates Srinagar as seismic zone V.

1.3 Srinagar and Jammu Metro Rail Project

Jammu is the winter capital and Srinagar is the summer capital of the Jammu and Kashmir state. Both cities are thus densely populated with ever increasing population and inflow of residents from other districts. Owing to the exponential increase in traffic volume over the last few decades, the capacity of roads to accommodate high traffic demand is now inadequate. Government of India has thus approved a plan to construct a Mass Rapid Transport System (Metro rail) in the Jammu and Kashmir state in order to enhance transport facilities and provide connectivity within the two cities respectively.

The construction firm handling this project, Economic Reconstruction Agency (ERA), engaged the railway agency Rail India Technical and Economical Services (RITES Limited) for preliminary and detailed investigation of the proposed routes. Based on the Preliminary Project Report (PPR) submitted by RITES limited in January 2017, it was decided to include only elevated corridors in the metro rail and avoid underground tunnel construction. The final form of the Detailed Project Report (DPR) for the alignment is in the process of getting finalized.

Three corridors have been proposed for the Srinagar metro rail passing through the heart of the city and covering over a total length of about 50 km. Figure 1 shows the alignment to be followed for the three corridors, which has been decided in order to interlink all important destinations.

Corridor-I (C-I) is proposed to extend from HMT Junction, through areas like Qamarwari, Lalchowk, Sonwar, Badamibagh, Panthachowk in Srinagar city up to Pampore in Pulwama having a total length of about 25 km. Corridor-II (C-II) is supposed to connect Airport (Humhama) to Osmanabad, passing through locations like Hyderpora, Barzulla, Karannagar Hawal, Soura and covering a total length of 12.5 km. Finally Corridor-III (C-III) over a total length of 12.5 km, is proposed to extend from Dalgate to Batpora, through destinations like Saidakadal, Nigeen, Habak and Zukura. The corridor alignment connects the far ends with the city center. As is observed from Figure 1, the metro rail passes through areas having varying topography and relief. Hills, mountain ranges, rivers, lakes and wetlands lie in its proximity.

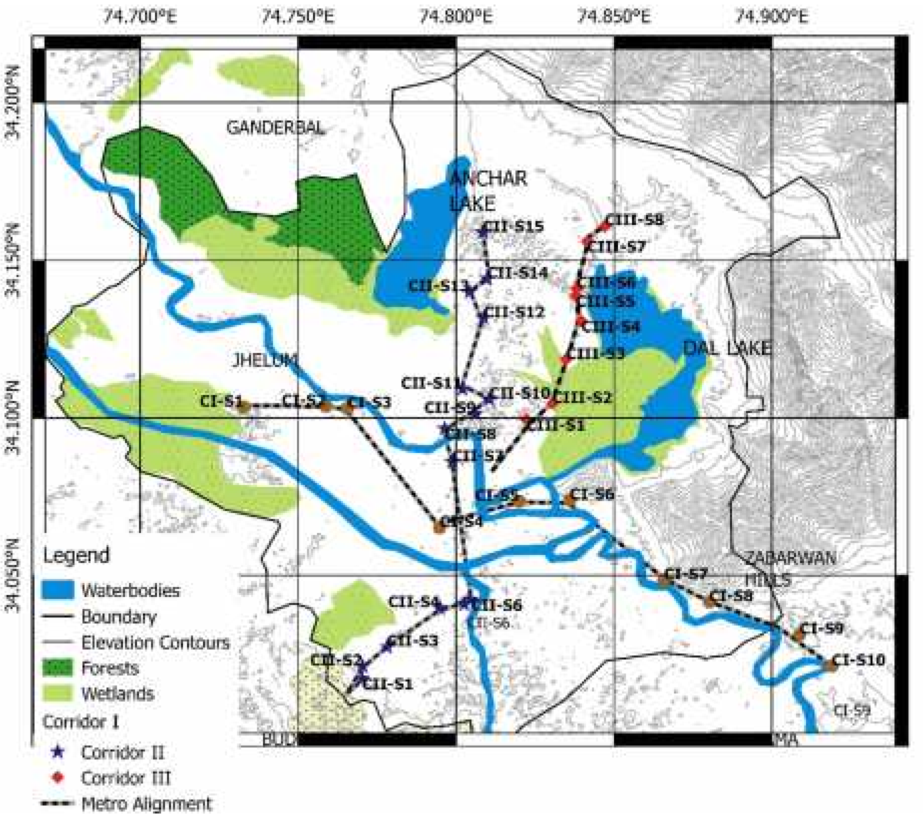

Fig. 1. The alignment of Srinagar metro through Corridors I, II and III along with MASW site locations superimposed on map of Srinagar City.

2 Data Acquisition and Analysis

2.1 Data Acquisition and Field Testing

Standard Penetration Test data for about 43 locations along all three corridors of the Srinagar metro alignment were obtained from RITES Ltd. Sites for MASW testing were selected along the alignment of the three corridors making sure that they are as near as possible to SPT test locations. This was done to allow a comparison between SPT data and MASW test results. However, as MASW requires a larger space for layout of geophone spread (around 60 m), this criterion could not be fulfilled in a few congested areas. MASW test could be performed at a total of 33 sites out of the 43 SPT test locations. The three corridors along the Srinagar metro alignment and the locations of MASW test sites in each corridor have been superimposed on the map of Srinagar city shown in Figure 1. Table 1 presents the sites selected and the corresponding labels for each site adopted for the present study. C stands for 'corridor' and S stands for 'sites' in the labels.

Table 1. Sites selected for MASW tests along the alignment of Srinagar Metro.

Label	Location	Label	Location
CI-S1	HMT	CII-S1	Friends Enclave Humhama
CI-S2	Parimpora	CII-S2	Railway Station Humhama
CI-S3	Qamarwari	CII-S3	Peerbagh
CI-S4	Batmaloo	CII-S4	Hyderpora
CI-S5	Polo Ground	CII-S5	Baghat
CI-S6	Sonwar	CII-S6	Barzulla
CI-S7	Pandrethan	CII-S7	GMC
CI-S8	Panthachowk	CII-S8	Nawakadal
CI-S9	Sempora	CII-S9	Rajourikadal
CI-S10	Pampore	CII-S10	Hawal
CIII-S1	Rainawari	CII-S11	Zadibal
CIII-S2	Saidakadal	CII-S12	Nowshera
CIII-S3	Nigeen	CII-S13	Soura
CIII-S4	Hazratbal	CII-S14	90 feet Road
CIII-S5	Naseembagh	CII-S15	Osmanabad
CIII-S6	Habak		
CIII-S7	Zukura		
CIII-S8	Batpora		

A 24-channel seismograph 'GEA24' from PASI srl, Italy purchased by the Geotechnical division of NIT Srinagar was employed for the Multichannel Analysis of Surface Waves testing in Srinagar. The acquisition layout consisted of an array of 24 vertical geophones of 4.5 Hz frequency placed at 3m spacing, resulting in a total linear spread of 69m. A 15 kg hammer was used as the source in order to generate seismic waves by hitting the ground through an Aluminium plate of size 200 mm x 200mm. The depth of investigation attained is assumed to be half of the spread length i.e. about 30m in this study [9]. An offset of 5m from the nearest geophone at the end of the array was considered. A total of 14 shots were taken between alternate geophones with a stacking number of 3 at each shot location to enhance the signal to noise ratio [9]. Raw data in the form of shot gather consisting of 24 channels was recorded at the sites.

2.2 Data Processing and Analysis

Required information from SPT test data regarding soil layers has been extracted, homogenized and processed. Borelogs have been plotted in Groundhog Desktop software [10] to represent the soil profiles with depth at each SPT test site (Figs. 2, 3 and 4). SPT N values have also been extracted and plotted with depth for each site in order to understand the variation of N values with depth (Fig. 5). Variation of N values along the alignment of corridors is also clearly visible in the plots. SPT N represents the resistance of a soil to penetration. Higher the value of N, higher is the resistance.

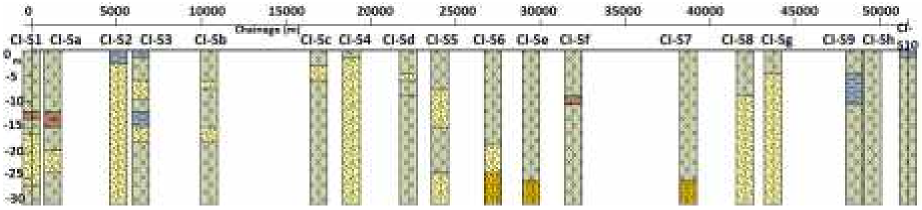

Fig. 2. Soil profile in boreholes at sites along Corridor I. (Clay , Silt , Sand , Gravel)

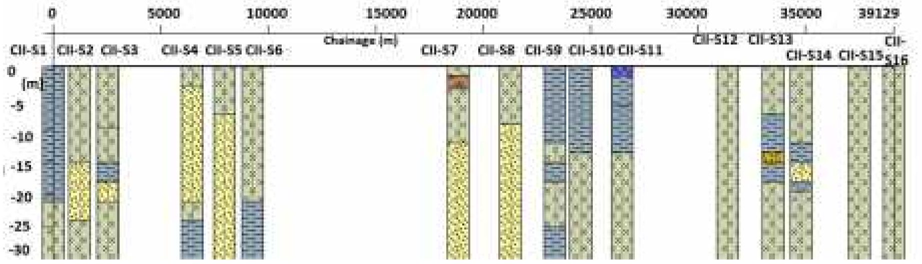

Fig. 3. Soil profile in boreholes at sites along Corridor II. (Clay , Silt , Sand , Gravel)

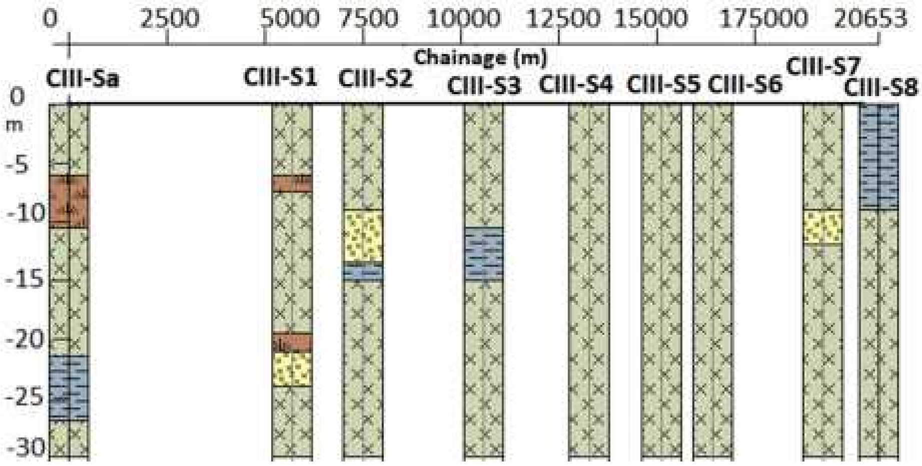

Fig. 4. Soil profile in boreholes at sites along Corridor III. (Clay , Silt , Sand , Gravel)

Shot records collected from MASW tests have been analyzed and processed in SeisImager software for each location [11]. Dispersion analysis followed by inversion analysis of the shot records has been conducted in the software. Results in the form of 1D and 2D shear wave velocity (V_S) profiles giving the variation of V_S with depth have been generated at each site. Higher shear wave velocity indicates higher stiffness of soil and thus better response earthquake ground shaking.

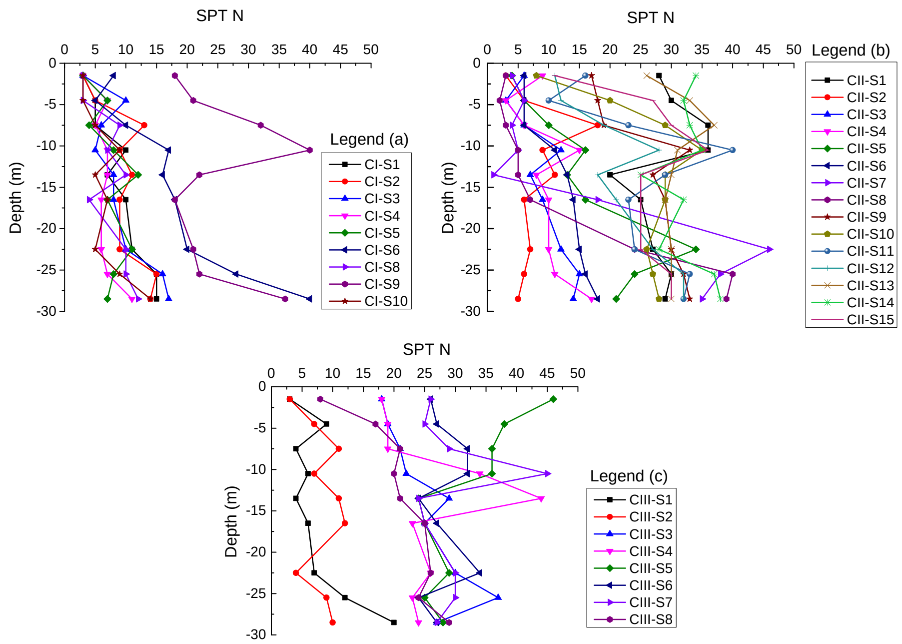

Fig. 5. Variation of SPT N with depth for boreholes at locations along the alignment for a) Corridor I b) Corridor II c) Corridor III.

The average shear wave velocity (V_{S30}) and average N value (N_{30}) down to a depth of 30m was then calculated at each site using the harmonic mean formula given by the International Building Code [12] for '*i*' number of layers of soil (Equation 1).

$$V_{S30} = \frac{30}{\sum_{i=1}^{30} h_i / V_{Si}} \qquad and \qquad N_{30} = \frac{30}{\sum_{i=1}^{30} h_i / N_i} \tag{1}$$

V_{S30} and N_{30} values determined from the equations were compared with the criteria provided in the National Earthquake Hazards Reduction Program. The sites were then characterized into various classes (A, B, C, D, E) following NEHRP guidelines (Table 2).

Table 2. NEHRP site classification guidelines [4].

Site Class	Remarks	N_{30}	V_{S30}
A	Hard rock	>50	>1500
B	Rock	>50	760-1500

C	Very dense soil or soft rock	>50	360-760
D	Stiff soil	15-50	180-360
E	Soft soil	<15	<180

3 Results and Discussion

3.1 SPT Data

The borelogs developed at each location reveal that soils extend down to 30 m depth, with gravel in only a few locations at deeper depths, like Panthachowk and Sonwar, which may be attributed to their proximity to the mountains. In corridor C-I, silty soils have been found to be dominant, with a few locations like Parimpora, Batmaloo and Panthachowk where sandy soils form a significant portion. Silty and sandy soils are found in corridor C-II, with a few locations with significant thicknesses of clayey soil layers. In corridor C-III however, silty soils have been found in almost all the locations.

Figures 2, 3 and 4 clearly indicate that SPT N ranges between 3 and 15 in most of the locations in C-I, except sites like Sonwar and Sempora where stiff soils with values up to 40 have been observed. In C-II, a wide range (3-50) of N has been observed, with comparatively lower N (soft soils) for locations in the south and higher N (stiff soils) for locations towards the north. In C-III, N values are in the range of 10-45 for most of the locations except Rainawari and Saidakadal where lower values between 3 and 15 were observed.

3.2 1D Shear Wave Velocity Profiles

Shear wave velocity profiles show variation of V_S with depth at each MASW test location. Velocity profiles have been generated for locations along C-I (Fig. 6), C-II (Fig. 7) and C-III (Fig. 8). Values of V_S determined for different locations at various depths ranges from as low as 120 m/s to as high as 586 m/s. Low shear wave velocity signifies less stiffness i.e. represents soft soil conditions. High velocity represents stiff soil conditions. It is clear from a comparison between N and V_S profiles with depth, that both follow a common trend along the alignments of the corridors. Sites with low shear wave velocity have in general low N values except for a few sites like CI-S1 CI-S8 and CII-S2. The difference in these three sites may be because MASW tests could not be performed at the exact location or near to the SPT test sites.

3.3 Site Characterization from N_{30} and V_{S30}

The calculated values of N_{30} and V_{S30}, and the results of NEHRP site characterization for all sites using these parameters have been compiled and presented in Table 3. Values of N_{30} vary between 6 and 32 at the sites in the three corridors. The range of

V_{S30} for the sites of interest varies from 139 to 451 m/s along C-I, 151 to 410 m/s in C-II and 189 to 428 m/s in C-III.

The sites have been characterized into classes D and E using the parameter N_{30}. Using V_{S30} as the parameter for classification, the sites fall under C, D and E categories. In general, it is observed that the site characterization obtained from both parameters agree well with each other. At a few locations, there is an apparent mismatch in the results obtained by the two methods. This can be attributed to the differences in the two methods of testing (MASW and SPT) which may yield varying results.

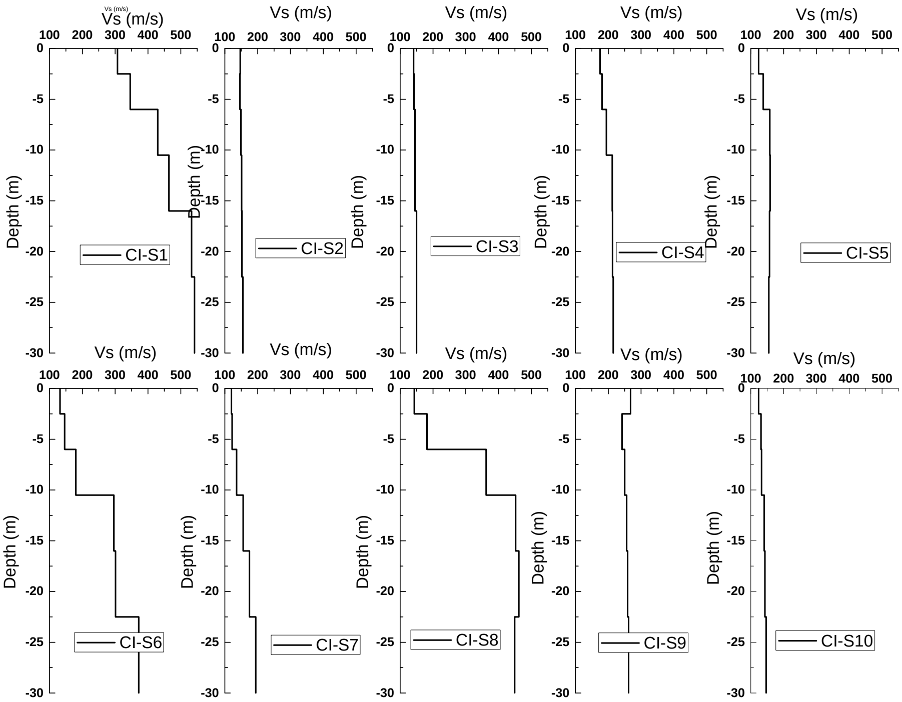

Fig. 6. Shear Wave Velocity vs. depth plots for sites along Corridor I.

Further, the classification of sites into categories has its own limitations. The range of values of the parameters is huge for each site category and thus values at the border of the categories may be misinterpreted, as in the case of CII-S7.

Interpretation. The variation of the parameters, V_{S30} in particular, can be interpreted by a comparison with the SPT N data and by understanding the topography of the region. Locations with high SPT N indicating dense, stiff soils have high shear wave velocity in general.

In Figure 1 the alignment of the Srinagar metro is shown along with the elevation contours. The contours help to understand the variation of topography within the region. From a close survey of the map, it is observed that Corridor I starts from HMT (CI-S1) which lies near a wetland at a low elevation, but shows a variation to a relatively higher elevation locally. Hence, the parameters may change drastically within short distances. The observed high value of V_{S30} corresponds to this location with stiff soils at higher elevation. The corridor then passes through the depression around the Jhelum river in the center of the city. This area has young loose and unconsolidated fluvial deposits and also greater inflow of water from the surrounding water sources making the soils soft. As the soils are silty clay and clayey silts, the shallow water table may affect the stiffness of the soils and consequently the shear wave velocities. This is reflected in the low values of V_{S30} in this whole belt (CI-S2, CI-S3, CI-S4). It further passes through locations which have Jhelum on one side and the Shankaracharya hill and Zabarwan hills on the other side. The close proximity to the hills may be a reason for high V_{S30} in CI-S6, CI-S8 and CI-S9. Low values in the other sites may possibly be due to the effect of the river sediments and water.

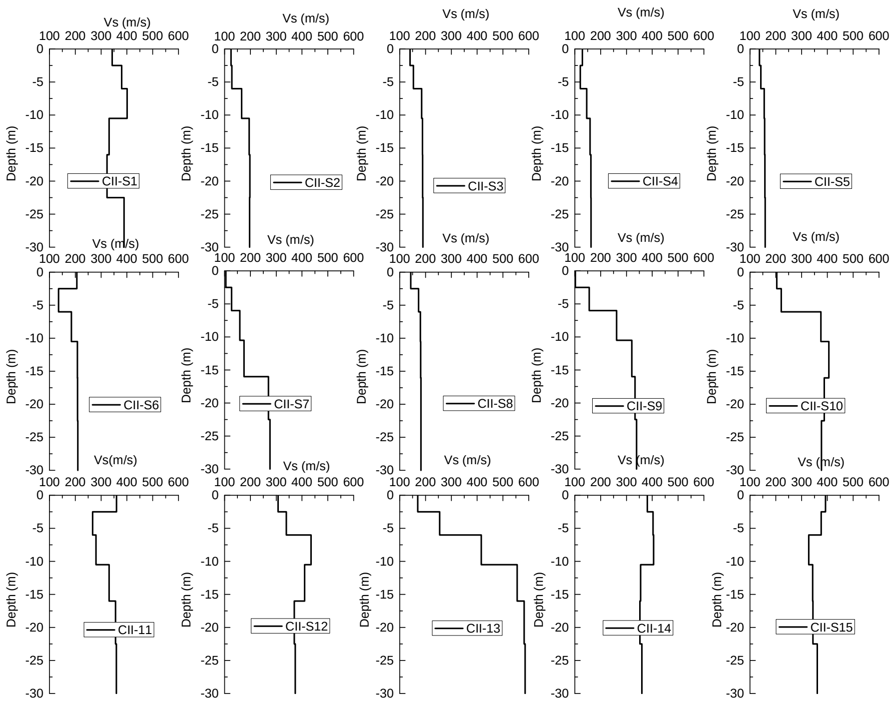

Fig. 7. Shear Wave Velocity vs. depth plots for sites along Corridor II.

In corridor CII, site CII-S1 which is located at the foot of the uplifted region of the Pir Panjal range in the South, has high V_{S30}. The values change to a drastic low in sites located in the central depression up to CII-S8. Then, towards the north in the corridor, as is clearly visible in Figure 1, the region is somewhat elevated and hence has stiffer soils and thus higher N and V_{S30}. Moreover, sites like CII-S9, CII-S10 and CII-S11 are located near the Hariparbat hill. The same reasoning can be applied to the observed variation of V_{S30} in the sites along C-II.

Low shear wave velocity means higher vulnerability of the site to earthquakes. This indicates high liquefaction potential, high chances of ground deformation, amplification of seismic waves and hence higher chances of damage to structures on the site. Seismic site characterization helps to identify vulnerable sites where construction of structures must be done with caution. Seismic design of structures must be carried out by incorporating the response of soil deposit at the site.

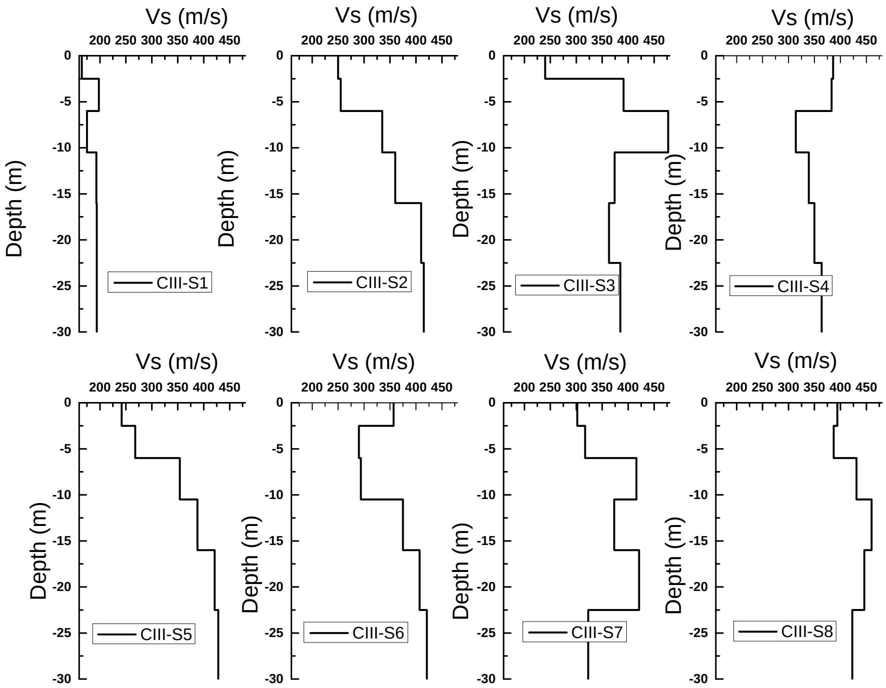

Fig. 8. Shear Wave Velocity vs. depth plots for sites along Corridor III.

4 Conclusions

In order to quantify the effect of soil properties on seismic waves, site characterization is one of the first steps. V_{S30} is an important parameter utilized to study the site effects during earthquakes. Site characterization at 33 locations along Srinagar metro line has been conducted in this study using V_{S30} and $N_{S30.}$ SPT N values have been obtained from RITES Ltd. and shear wave velocity was determined through elaborate field testing using Multichannel Analysis of Surface Waves method at each location.

Values of N_{30} vary between 6 and 32 along the alignment of Srinagar metro. The range of V_{S30} for the sites varies from 139 to 451 m/s along the alignment of the metro. Site characterization revealed that most of the sites fall under classes E and D, with a few sites in class C. Soft soil conditions exist in class E sites, stiff soil conditions in class D sites and very dense soil conditions in class C. The huge variation in site parameters may be attributed to highly varying topography and influence of water bodies on the soils in nearby locations. Change in site conditions along the alignment signifies the importance of site specific evaluation for earthquake resistant design of associated structures of the Srinagar metro. As specified by earthquake codes like NEHRP and Eurocode, response spectrums and design spectrums must be generated by utilizing site specific dynamic properties (V_{S30}) determined by geophysical tests like MASW in order to accomplish safe design of important structures against earthquake forces in seismically active regions like Kashmir valley.

Table 3. Results of site classification using N_{30} and V_{S30} according to NEHRP standard.

Site	N_{30}	Site Class	V_{S30}	Site Class	Site	N_{30}	Site Class	V_{S30}	Site Class
CI-S1	07	E	451	C	CII-S1	29	D	359	D
CI-S2	09	E	151	E	CII-S2	07	E	173	E
CI-S3	08	E	147	E	CII-S3	08	E	179	E
CI-S4	07	E	203	D	CII-S4	09	E	151	E
CI-S5	07	E	152	E	CII-S5	12	E	153	E
CI-S6	13	E	234	D	CII-S6	11	E	193	D
CI-S7	-	-	155	E	CII-S7	11	E	185	D
CI-S8	07	E	326	D	CII-S8	06	E	177	E
CI-S9	24	D	257	D	CII-S9	26	D	244	D
CI-S10	06	E	139	E	CII-S10	24	D	332	D
CIII-S1	07	E	189	D	CII-S11	24	D	327	D
CIII-S2	07	E	348	D	CII-S12	21	D	376	C
CIII-S3	25	D	371	C	CII-S13	31	D	410	C
CIII-S4	25	D	352	D	CII-S14	32	D	370	C
CIII-S5	31	D	361	C	CII-S15	26	D	353	D
CIII-S6	29	D	362	C					
CIII-S7	29	D	360	C					
CIII-S8	21	D	428	C					

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