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Site Characterization Using Masw and Mapping of Average Shear Wave Velocity for Jammu, Jammu and Kashmir

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ABSTRACT- Jammu is a fast-growing and major city in northern India, in UT Jammu & Kashmir. Jammu, the winter capital, is a city of temples, a symbol of ancient values, and has a distinct image due to its legacy, geography, and connections. The present study focuses on Site Characterization through geophysical testing i.e., (Active) Multi-channel Analysis of Surface Waves. Multi-channel analysis of surface wave (MASW) is used for measuring the shear wave velocity (V_S) at twenty-one (21) locations within Jammu city using TROMINO. Shear Wave velocity profiles over 30 m depth have been generated at each location using Grilla Software. Using the V_{S30} values seismic site characterization of the locations has been carried according to National Earthquake Hazard Reduction Program (NEHRP) guidelines. V_{S30} is a significant input for evaluating the seismic response of a soil deposit to earthquakes because it is a dynamic property of soils. The value of V_{S30} for the sites is varying from 271 m/s to 475 m/s. Site characterization revealed that most of the sites fall under C and D categories. From the V_{S30} values further a map was generated using a GIS platform that can be used for hazard estimation.

KEYWORDS- Multi-channel Analysis of Surface Waves (MASW) · Jammu (Jammu and Kashmir) · Shear Wave Velocity · Seismic Site Characterization.

I. INTRODUCTION

In Earthquake Geotechnical Engineering, geophysical tests based on the creation and propagation of seismic waves are commonly utilized [1]. In sedimentary basins, shallow shear-wave velocity has long been recognized as a critical element in the research of changing ground motion amplification and site response. Shear wave velocity (V_S) is a key parameter in building regulations, and it is commonly used in earthquake engineering design applications. Borehole logging is the standard method for acquiring shear wave velocity (V_S) data, but drilling and logging to the depths required for seismic ground motion investigations is extremely expensive, and it is becoming increasingly difficult in densely populated areas [2]. The SASW method has been frequently utilized to characterize shallow shear wave velocity. The SASW method has been frequently utilized to characterize shallow shear wave velocity[3]. The Multichannel Analysis of Surface Waves (MASW) method addresses the limitations of the SASW method. The MASW approach has gained a lot of traction among professionals and scholars all around the world in recent years. The multichannel analysis of surface waves (MASW) approach examines the dispersion properties of specific types of seismic surface waves (fundamental-mode Rayleigh waves) travelling horizontally along the measurement surface directly from the impact site to the receivers[4]. It provides shear wave velocity (or stiffness) data in a cost-effective and time-efficient manner in either 1-D (depth) or 2-D (depth and surface location) format. The MASW method's underlying foundation is based on a multichannel recording and processing strategy that has long been employed in seismic exploration surveys[5]. This paper presents the site characterization on the basis of NEHRP site classes using average shear wave (V_{S30}) values and also mapping of average shear-wave velocity through the assessment of s-wave velocity profiles for 21 locations in Jammu region[6].

II. STUDY AREA

Jammu is a fast-growing and major city in the northern Indian state of Jammu & Kashmir. Jammu, the state's winter capital, is a city of temples and historical values, with a particular image owing to its history, geography, and relationships. Situated at an altitude of 400m above MSL on a sub hilly area between 32.7266° N and 74.8570° E. The Tawi River, a tributary of the Chenab River, runs through the city on both sides. The historic city is restricted to the right bank, whereas the city's later expansions have mostly occurred on the left side[7]. Large-scale urbanization and industrialization have given rise to what is now known as Greater Jammu in the last two decades [8]. The southern part of the city has a large deposit of sediments. The thick sediments that cover the underlying Jammu city (southern portion of the city) can potentially intensify earthquake shaking, whereas the central part of the city has a thinner sedimentary layer, which can have an impedance contrast effect. Figure 1 shows the map of study area Jammu divided by Tawi river.

Because of the movement of the Indian plate towards the Eurasian plate, the Himalayan area has an active tectonic configuration [9]. 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 and the recent seismic activity in the region, especially the Mw 7.6 2005 Kashmir earthquake and Mw 7.5 2015

Hindukush earthquake, reflect the region's vulnerability to big earthquakes and the resulting destruction[10]. These earthquakes have resulted in significant loss of lives and property. Due to this reason, IS: 1893 (2016) designates Jammu as seismic zone IV. Fig 1 showing the map of study area considered for field testing

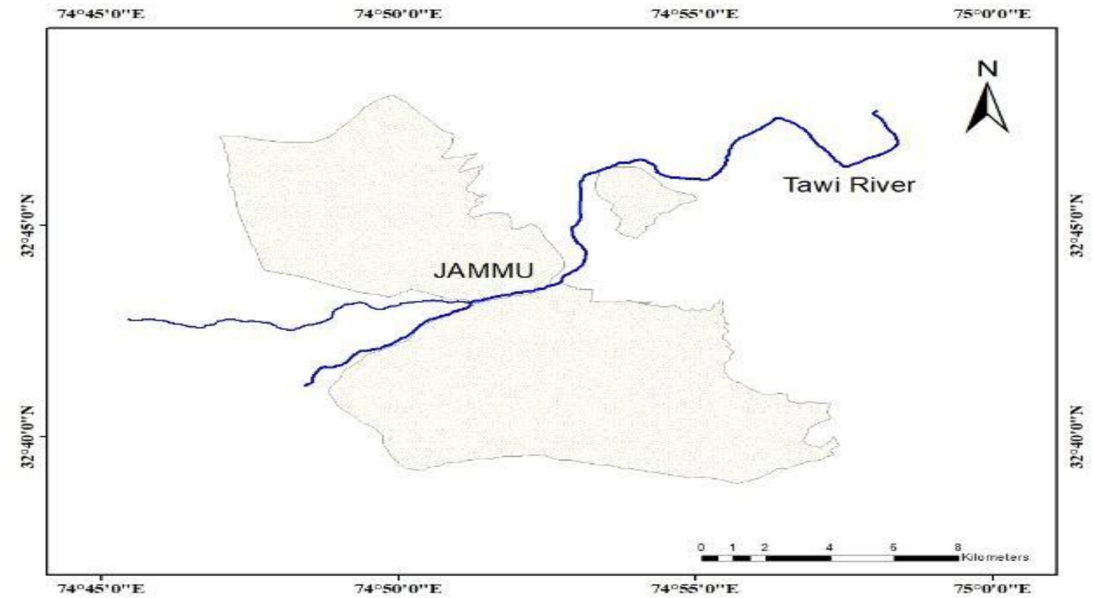

Figure 1: Showing the map of study area considered for field testing

III. DATA ACQUISITION AND ANALYSIS

In the present work, the MASW tests were performed at 21 locations in Jammu City with TROMINO (The Reactive Tomograph). The first all-in-one instrument for the dynamic characterization of soils, structures and more by MOHO Science and Technology, ITALY. The equipment consists of TROMINO (to record and process data), wireless trigger (to record wave energy), hammer (8 Kg) with 200 x 200 mm aluminum plates (to create seismic energy). Trigger was inserted in ground in a straight array 3 m away from TROMINO, seismic energy was created by striking hammer on the aluminum plate at 1.5 meters offset from the trigger[11]. The process was repeated up to 30 meters, by removing trigger and placing it in ground 2 meters from its current location. Trigger records the seismic energy and transfers it to TROMINO wirelessly, where the data is stored. Hammer of 8 Kg weight was used as trigger source to create seismic energy[12].

Surface wave seismic data is collected and sent to a computer, where it is processed. using *Grilla* software through spectral inversion to obtain 1D and 2D MASW shear wave velocity profiles, *Grilla* follows the European SESAME project directives (2004). The dispersion curve is obtained at different depths which after analysis gives us the values of shear wave velocity at the particular depth. Dispersion curves at 30m depth at some of the sites in Jammu area are shown in figure 2 below [13-14]. Fig 2 shows the Dispersion Curves at 30m depth of some sites, Jammu

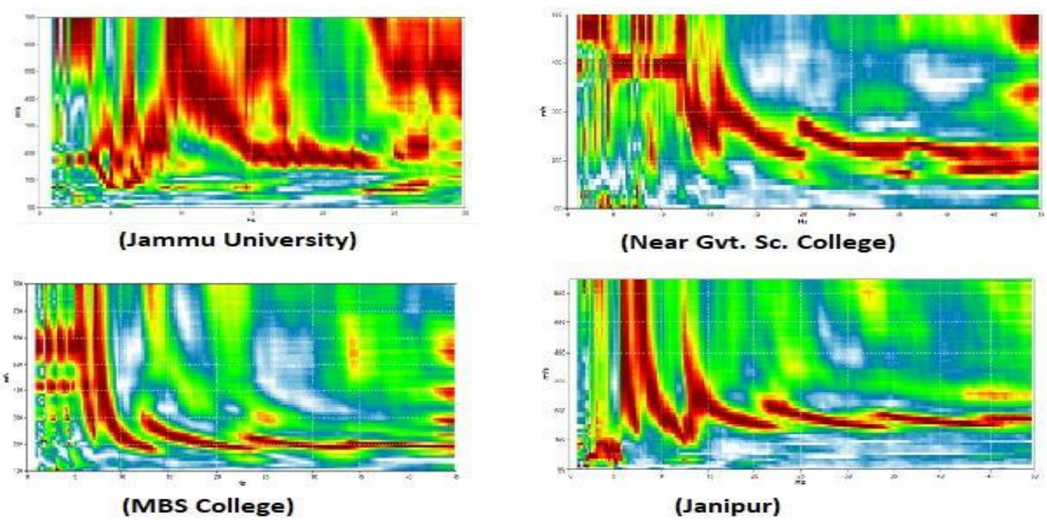

Figure 2: Dispersion Curves at 30m depth of some sites, Jammu

From the Shear velocity values at different depths the average shear wave velocity at 30 meters, is calculated. The V_s values acquired at different depths can be used to calculate the average shear wave velocity (V_{s30}).
The parameters of TROMINO for the MASW tests are shown in Table 1.

Table 1: Parameters of TROMINO, for MASW Tests

Acquisition Length	Free
Sampling Rate	1024
Mode	Wireless
Amplifier Test	Set
Acquire	Save
Geophone	Wireless Trigger
Source	8 Kg Hammer
Offset distance	First 3m then 2m up to 30m

A. Average Shear Wave Velocity (VS30)

The V_{S30} is the average shear wave velocity across the top 30 meters of soil. It is computed by dividing 30m with the shear wave velocity from the surface to 30m as given in following equation.

$$V_{S30} = \frac{30}{\sum_{i=1}^{N} \frac{h_i}{V_i}} \quad (1)$$

where, h_i and vi denotes the thickness and shear wave velocity of the N layers existing in
the top 30 meters.
Modern seismic codes like NEHRP, UBC97, IBC200 and Eurocode8 use V_{S30} for seismic site characterization. These codes were created in response to recent large earthquakes in the United States, Europe, Japan, and other countries [15-16]. In general, the soil characterization and spectral amplification factor are used to express the parameters describing site impacts in seismic codes [17-18].
The V_{S30} for all the 21 test sites have been calculated using the above equation and the values were compared with criteria provided in the National Hazard reduction Program. The sites were then characterized into various classes (A, B, C, D, E) following NEHRP site classification guidelines (Table 2).

Table 2: NEHRP Site Classes Based on VS30, BSSC (2001)

Site Class	**Soil Profile**	**V_{S30} (Min) m/s**	**V_{S30} (Max) m/s**
A	Hard rock	> 1500	-
B	Rock	> 760	1500
C	Very dense soil and soft rock	> 360	760
D	Stiff Soil	180	360
E	Soft Soil	-	<180

The V_{S30} for all the locations have been worked and are used to generate map on GIS platform ArcGIS. V_{S30} values of the sites with NEHRP site classification is given in Table 3 below.

Table 3: Average Shear Wave Velocity VS30 with Proposed and NEHRP Site Classes

S.No	**Location**	**Lat.**	**Long.**	**V_{S30}**	**Site**
1	Janipur	32.7598	74.8491	**362.71**	**C**
2	MBS College	32.6679	74.8510	**370.66**	**C**
3	G.Sc. college	32.7251	74.8524	**448.24**	**C**
4	GCET	32.7940	74.8340	**233.26**	**D**
5	Jammu University	32.7155	74.8643	**369.21**	**C**
6	Near Bagh.EBahu	32.7253	74.8778	**339.9**	**D**
7	Near Kali Mata Mandir	32.7040	74.9000	**298.24**	**D**
8	Near Army Public School	32.6740	74.9210	**418.9**	**C**
9	Trikuta Nagar	32.7036	74.8766	**475.31**	**C**
10	Shastri Nagar	32.6966	74.8525	**324.79**	**D**
11	Gandhi Nagar	32.7106	74.8618	**428.72**	**C**
12	Satwari	32.6872	74.8431	**337.6**	**D**
13	Near Swami Vivekanand Hospital	32.7464	74.8650	**312.4**	**D**
14	Near Railway Station	32.7073	74.8777	**438.02**	**C**
15	Near Shiksha Niketan Hr. Sec School	32.6841	74.8519	**402.4**	**C**
16	Sector 13	32.6991	74.8688	**435.6**	**C**
17	Near Nav Durga Temple	32.7712	74.8227	**271.8**	**D**
18	Near Nagbani Resorts	32.7560	74.7487	**298.24**	**D**
19	Udheywala	32.7429	74.8146	**381.7**	**C**
20	Near J&k Bank Karan Bagh	32.6641	74.8385	**320.3**	**D**
21	Near Kanjwani Chowk	32.6666	74.8777	**298.24**	**D**

IV. RESULTS AND DISCUSSION

Geophysical investigations to estimate the shear wave velocity structure for dynamic site Characterization which is carried out using MASW investigation. The entire procedure in MASW testing consists of three steps i.e., acquiring multichannel records (shots gathers), extracting the fundamental mode dispersion curves and inverting these curves to obtain one dimensional V_S m/s profiles. Acquired surface wave seismic data is processed using *Grilla* software through spectral inversion to obtain 1D and 2D MASW shear wave velocity profiles. It is observed that the value of V_S determined for different locations at various depths is ranging as low as 102 m/s to 498 m/s in the city. Low shear wave velocity signifies less stiffness (soft soil conditions). High velocity represents stiff soil conditions.

The value of V_{S30} for the Jammu region is ranging from 271 m/s to 475 m/s in the city. The whole Jammu city falls into site class of D and C of NEHRP site classification. This C and D, site class represents the soil is Very dense soil and soft rock for class C and Stiff soil for class D. The northern and southern part of the city is falling in the D Site class category indicating the soil present there is mostly stiff soil. The centre of the city also has D class sites but also the C class sites indicating that the soil present there is very dense soil with soft rocks. With the average shear wave velocity calculated from the sites a map was generated using ArcGIS Software (Figure 3), this map can be used for hazard estimation.

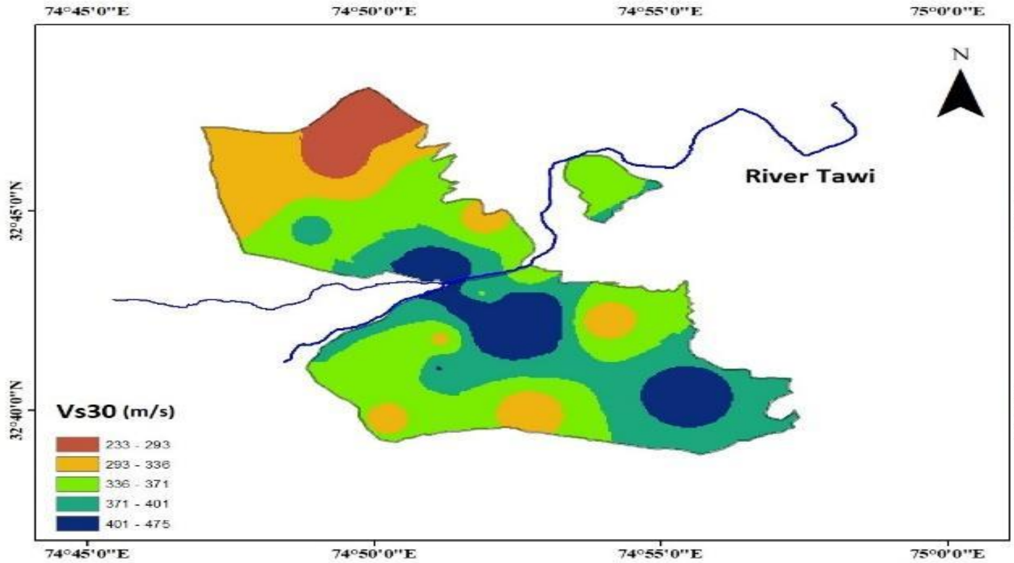

Figure 3: Mapping of Average Shear Wave Velocity (VS30) for Jammu Region

V. CONCLUSION

One of the first steps in quantifying the effect of soil parameters on seismic waves is site characterization. V_{S30} is an important parameter utilized to study the site effects during earthquakes. Site characterization at 21 locations in the Jammu city has been conducted in this study using V_{S30} through elaborate field tests using Multichannel Analysis of surface waves method at each location. Soil sites with high sedimentary thickness and low shear wave velocities were evaluated in these locations (102 to 250 m/s) in upper strata, increasing up to around 498 m/s at 30 m. The V_{S30} values are varying between 271 m/s to 475 m/s. site characterization has revealed most of the sites fall under C and D site class.

Following conclusions are derived from the above study. The huge variation in site parameters may be attributed to highly varying topography and influence of water bodies on the soils in nearby locations. 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 Jammu area. Also, the map on the basis of Average Shear Wave Velocity has been prepared in ArcGIS and presented, that can be used for hazard estimation of the region.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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