Multi-channel Analysis of Surface Waves for shallow subsurface studies in Garhwal Himalayas, India - A case study

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Summary

The Garhwal Himalayas lie in the seismic zone V, the most prone zone to seismic risks. Himalayan fold thrust movement causes high seismic activity in this region. Hence, the shallow subsurface studies become very important for this region in the present study, Multi-channel Analysis of Surface Waves (MASW) is used to acquire the field data and SeisImager software is used for processing and interpretation. The site classification as per NEHRP (National Earthquake Hazards Reduction Program) is used to group sites into different classes according to calculated V_{s30}.

Introduction

Since long, human mankind has been trying to explore what lies beneath the subsurface. Seismic exploration has played a key role in the subsurface investigations, using passive sources (E.g. earthquakes, aftershocks, foreshocks, micro tremors, ambient noise) and active sources (E.g. explosives). Over past few years, geophysical research has witnessed a rapid progress with various state-of-art technologies being developed related to subsurface imaging. Hence, with new generation portable equipment, it has become relatively easier to conduct detailed seismic studies in the hilly regions like Himalayas.

V_{s30} is an important factor for the strong ground motion studies and therefore used for the estimation of earthquake hazard. For site classification, V_{s30}, shear wave velocity up to 30 m, is a key parameter. Since 30 m is a typical depth of borings and detailed site characterizations in engineering site investigation, hence, most of the site-effect studies in earthquake ground motions are based on the properties in the upper 30 m ***(Anderson et. al, 1996).*** To estimate V_{s30}, the entire seismological community is focused on the analysis of the fundamental mode of

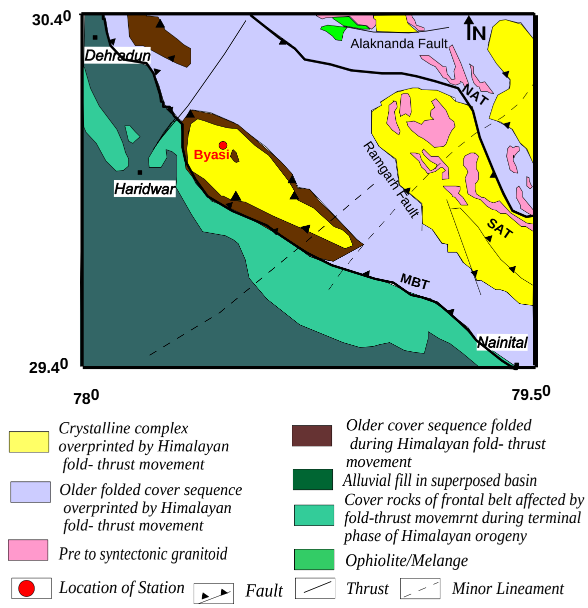

Figure 1: The present area of study belongs to Garhwal Himalayas, India. MBT = Main Boundary Thrust, SAT = South Almora Thrust and NAT = North Almora Thrust. Red Source of the tectonics and geology of the region is GSI (2000).

Rayleigh waves considering their highly dispersive property. Spectrum of surface waves can enormously benefit the domain of geophysics ***(Bullen, 1963, Mitchell, 1973; Mooney et. al, 1966; Tsai et. al, 1969)***. Also, V_{s30} estimate can be used to suggest the possible amplification and de-amplification of energy at such sites ***(Dobry et. al, 2000)***.

Objective of the study

The objective of the present study is to estimate 2D shear wave velocity model up to 30 m i.e. V_{s30} of Byasi village. MASW is generally utilized for geotechnical characterization of shallow subsurface properties ***(Park et. al, 1999; Xia et. al, 1999; Miller et. al, 1999)***.

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The area of study is located 35 km from Rishikesh, Uttarakhand, India besides the river Ganges i.e. Byasi Village (30°04'09.7"N 78°27'13.7"E) (Fig. 1). The village is well known for various rafting camps. Byasi is positioned between MBT and NAT over Lansdown Klippe in Garhwal Himalayas. Stratigraphically, it falls in Nathuakhan Formation of Ramgarh Group. The Nathuakhan Formation contains quartzite interbedded with schists, phyllites and slates ***(Valdia, 1980).***

Methodology

The data was acquired with a close geophone and source spacing of 2 m with 24 geophones of 4.5 Hz resulting into the spread length of 48 m (Fig 2). Since the said geographical region is highly mountainous, therefore it is very tough to find a large flat area for the survey. The data is recorded using McSeis-SX Seismograph (Fig 3).

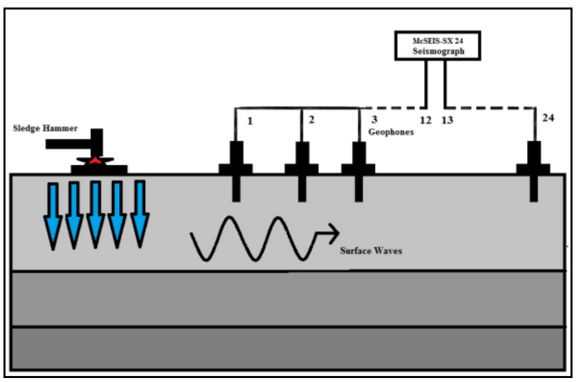

Figure 2: Schematic layout used for data acquisition.

Data processing of the seismic data has been carried out using SeisImager software. The key stages of the processing are explained in sequential manner (Fig-4).

A fifteen layered model of earth with layer thickness gradient 0.5 and bottom layer multiplier as 3 has been generated. In forward modeling, the multichannel record is processed to generate dispersion curves. From these dispersion curves, velocity ranges are obtained (Fig-5).In inverse modeling, the observed dispersion curve which is matched with synthetic dispersion curve is used to obtain the average shear wave velocity model of the soil column of 30 m.

Figure 3: McSeis-SX Seismograph

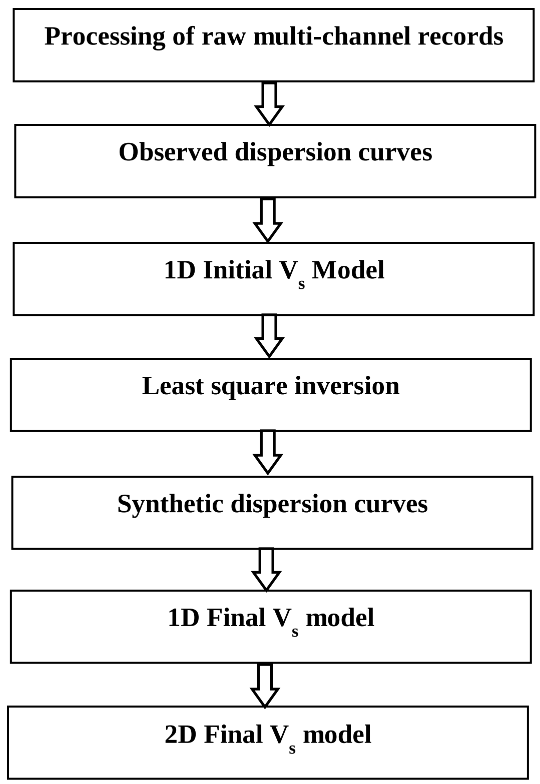

Figure 4: Detailed data processing workflow.

Following equation has been used to estimate average value of V_{s30}.

$$Vs30 = \frac{30}{\sum_{i=1}^{n}\left[\frac{h_i}{v_i}\right]}$$

Where, h_i is the thickness of the i^{th} soil layer in m; v_i is the shear wave velocity for the i^{th} layer in ms^{-1} and n is the no. of layers above 30 m.

The predominant frequency is corresponding to the highest value in amplitude spectrum of soil column which can be estimated by the following relation:

$$Fp = \frac{Vs30}{4h}$$

Where, F_p is the predominant frequency of the soil column in Hz, V_s is shear wave velocity of the soil column in ms^{-1} and h is the thickness of the soil column i.e. 30 m.

The Root Mean Square Error (RMSE) is calculated using following equation

$$RMSE = \sqrt{\frac{1}{N}\left(\sum_{i=1}^{N}(d_i^M - d_i^T)\right)}$$

Where, N is the total number of data points and d_i^T and d_i^M are phase velocity of theoretical and measured dispersion curve respectively.

Results and Discussion

The raw dispersion curves at Byasi are calculated and edited. The dispersion curves are extracted by keeping 4.5 Hz as minimum frequency. The frequency range of the phase velocity is within 8.54-39.04 Hz and phase velocity is varying from 300 ms^{-1} to 420 ms^{-1} (Fig 5).

After performing approximately 1000 iterations of least square inversion, the initial RMSE of 6.3% is reduced to 0.35 % and RMS velocity error is reduced to 2.20 ms^{-1} from 22.20 ms^{-1}. The RMSE is plotted against the number of iterations (Fig 6).

The shape of dispersion curves ranging from source 0 m to 48 m fall in line with each other which signify the good quality of data acquisition and data processing. Thus, an optimum initial model is

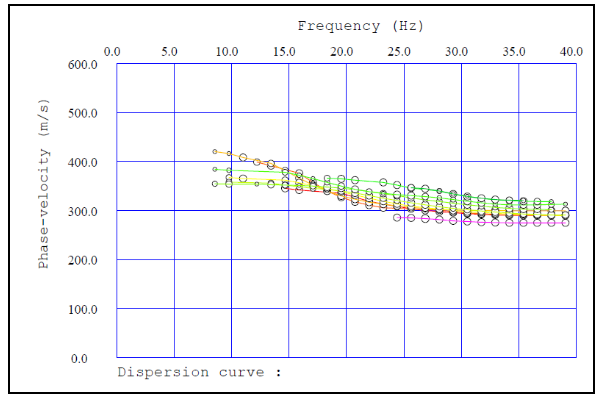

Figure 5: Calculated dispersion curves

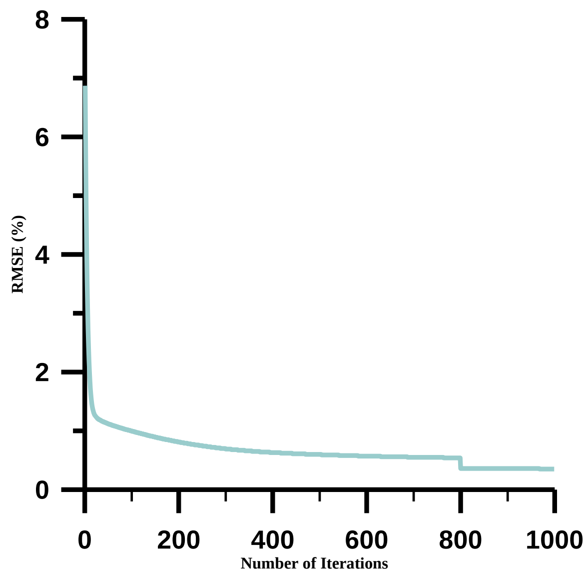

Fig 6: RMSE plot against the number of iterations

generated which is inverted using least square inversion method. The observed (red) and synthetic dispersion (black) curve gives good match between the two (Fig 7) resulting into final 1D Shear Wave Velocity Model (Fig 8). These velocity functions are interpolated to produce 2D Shear Wave Velocity Model. The 2D Shear wave velocity models can be used for the geotechnical purposes and for the investigation of earth's crust as well for model based predictions for strong ground motion in the area of interest (Fig 9).

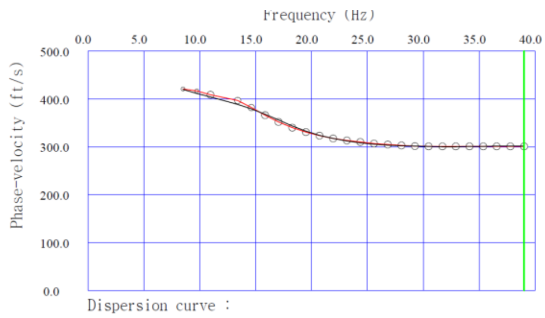

Figure 7: The observed (red) and synthetic dispersion (black) curve.

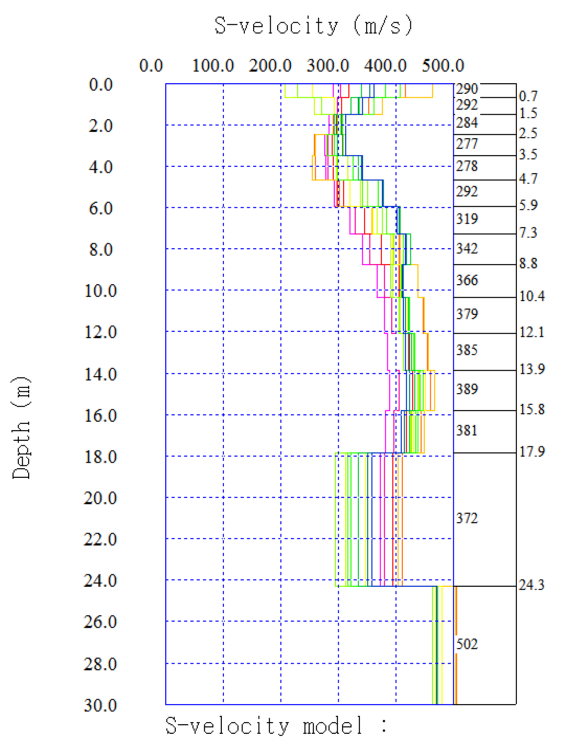

Figure 8: 1D Shear Wave Velocity Model after inversion.

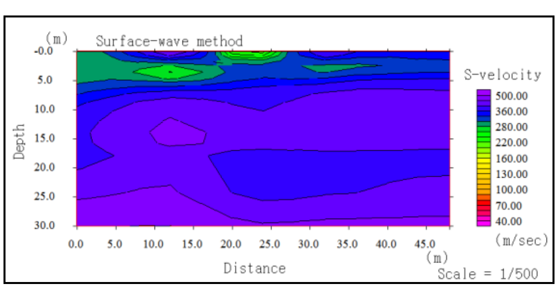

Figure 9:2D Shear Wave Velocity Model at Byasi.

Such 2D Shear Wave Velocity models play an important role in earthquake engineering. According to Building Seismic Safety Council (BSSC), 2003 has classified the sites with respect to N- value, thickness, shear strength, water content and V_{s30} (Table 1).

Site classification	**Description**	**Average shear wave velocity up to 30 m(V_{s30})**
A	Very hard rocks	>1500
B	Rocks	$760 < V_{s30} < 1500$
C	Very hard soil and soft rock	$360 < V_{s30} < 760$ Or N > 50, S_u >100 Kpa
D	Hard soil (sands, clays and gravels)	$180 < V_{s30} < 360$ or 50 > N > 15,100 > S_u > 50 Kpa
E	Soft clay of thickness about H in site profiles	$V_{s30} < 180$ or H > 3m (PI > 20),W > 40%, S_u < 25 Kpa
F	Soils requiring site – specific evaluations	

H: Thickness;
S_u: Undrained shear strength;
N: Standard Penetration Test Blow Count
PI: Plasticity Index;
W: Water Content

Table 1: NEHRP site classes ***(BSSC, 2003)***

Conclusions

It has been observed that geological setting and lithology of the area has a major influence on predominant frequency of the ground. In the present study area, Shear wave velocity ranges are varying from 200 ms^{-1} to 502 ms^{-1}. Average V_{s30} of Byasi is 382 ms-1 hence it can be classified in class C i.e. hard to very hard soil category. Its estimated average predominant frequency is 3.19 Hz. The results reveal that the quartzite interbedded with schists , phyllite and slate is not suited for high rise structures such as dams and multi-story buildings however the site is more suited for low height buildings e.g. schools , primary health centers etc. Such analysis should be done for other sites of the Himalayas to obtain the better image of the subsurface. The velocity information is also important for the simulation of earthquake strong ground motions.

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