SHALLOW SUBSURFACE MAPPING IN RISHIKESH REGION

A DISSERTATION

Submitted in partial fulfilment of the requirements for the award of the degree of

INTEGRATED MASTER OF TECHNOLOGY

In

GEOPHYSICAL TECHNOLOGY

Submitted by,

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ENROLLMENT NO. : 10411022

INTEGRATED M.TECH. GEOPHYSICAL TECHNOLOGY

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ROORKEE.

CANDIDATE'S DECLARATION

I, hereby, certify that the work which is being presented in this dissertation entitled **"Shallow Subsurface mapping in Rishikesh Region."** in partial fulfilment of requirement for the award of **INTEGRATED M.TECH.** Degree in **GEOPHYSICAL TECHNOLOGY** submitted in the department of **Earth Sciences, Indian Institute of Technology Roorkee,** is an authentic record of my own work, carried out during the period of June 2015 to May 2016, under the supervision of Prof. Dr. Anand Joshi, Department of Earth Sciences, IIT Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree of this or any other institution.

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Place: IIT Roorkee.

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CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

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ABSTRACT

Garhwal region near Rishikesh lie in the seismic zone V and thus is prone to seismic risks. Stress gets accumulated as the constant thrust between Eurasian Plate and Indo-Australian Plate in always in action. The region I worked on is prone to seismic activities. The main objective of the presented work is to study the velocity structure in Rishikesh, Himalya by employing Multi Channel Analysis of Subsurface wave method and using it again for the estimation of bed thickness. The Rayleigh waves always show dispersive characteristics which are utilized for imaging the shallow subsurface layers. The accuracy of MASW method depends on the precision of the determined phase velocities for the Rayleigh waves. Multi-channel records are useful in identification and isolation of noise. The multi-channel record is then decomposed into time and frequency format thus permitting the real time maximization of the Signal/Noise ratio during the processing stages. Using "Seisimager", the MASW data were processed and finally interpreted that the shear wave velocity is in the range 320-700 ms^{-1}. Covering a depth range of 40-50 m.

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LIST OF FIGURES

1. Objective

The ultimate objective of the dissertation was **Multichannel Analysis of Surface Waves (MASW)** for the subsurface investigation. It is a technique employing non-destructive surface waves and are based fundamentally on the geometrical dispersion of Rayleigh waves. It's analysis helps in the determination of the vertical subsurface distribution of the S-wave velocity. S waves being very difficult to identify, are thus studied as a combination of P wave and vertical component of S wave i.e. Rayleigh wave. The S wave velocity is dependent on elasticity and stiffness of the medium.

In regular cases, subsurface investigation using seismic refraction method works well in conditions where we get a gradual increase in impedance contrast moving vertically downwards in a section. But this process limits where we encounter an impactful decrease in density (a weak zone), since the critical refraction is witnessed only where the density of second layer is more.

With the advancement of technologies in the recent past, the development of Multichannel Analysis of Surface Waves (MASW) has shown a transcendental complimentary aid in subsurface exploration and characterization, thus overcoming most of the limitations that were encountered by other geophysical techniques like the refraction seismic. Using high frequency is this method provides us with a very good resolution, but the depth of study is restrained to 30-40 m.
Depending upon the mechanical properties of the inherent subsurface layers, different frequencies/wavelength correspond to different phase velocity variations. For a vertically homogenous medium, phase velocity remains same and wavelength alters with depth; and for a heterogenous layer phase velocity varies in addition to wavelength. This process is known as Dispersion.

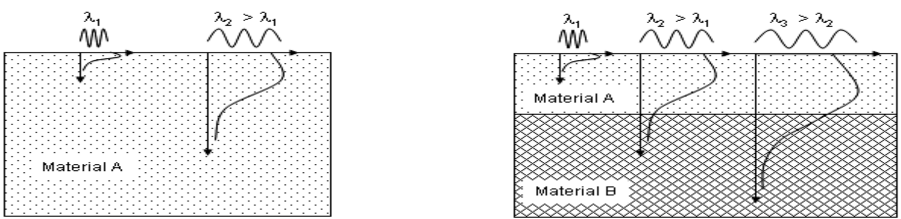

Figure 1: In a homogeneous medium: a) all the wavelengths sample the same material, and the phase velocity is constant, b) when the properties change with depth the phase velocity depends on the wavelength (Strobbia, 2003).

2. Methodology

2.1. Generation of Surface waves and Data Procesing

The layout on field for data acquisition employs a mechanical source (hammer/weigh drop) for generating the seismic waves. A linear array of geophones (vertical geophones) is placed in a nearly horizontal 100 metre ground spread and then connected to a **multichannel seismograph recorder**. In the acquisition the two important parameters are the source spacing (4m) and the geophone spacing (4m here): The source offset is taken according to the depth of probing and receiver spacing is taken on the basis of desired vertical resolution.

The data acquisition and analysis of Surface wave method are accomplished by SeisImager/SW software on McSEIS-SXW and computer. The '**energy accumulation pattern recognition technique**' is employed to get the fundamental mode Rayleigh wave and thus generating the dispersion curves by picking highest energy part in the spectrum to draw curves which represents the relationship between frequency and Rayleigh wave phase velocity.

Finally, the S- wave velocity is calculated by doing inversion of dispersion curves by **least square method** using pattern recognition algorithm or by simply employing inversion tab in McSEIS-SXW after picking bound points for the dispersion curves.

2.2. Workflow

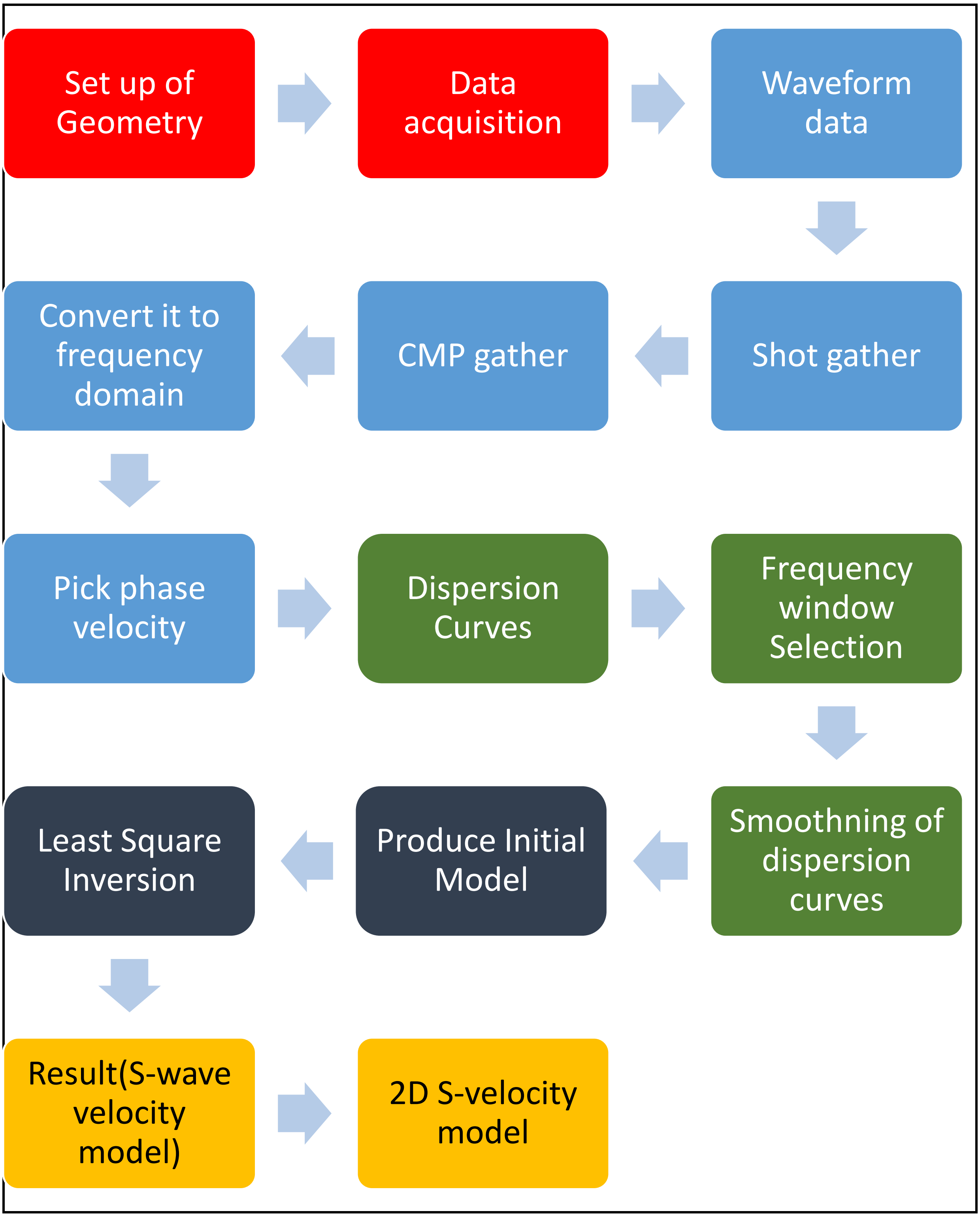

Figure 2: The Workflow of the procedure for surface wave analysis.

3. Data and Processing:

3.1. Geometry

An array of 24 geophones is set up. The geophone interval is kept as 4 metres. First shot is fired at -2m and a total of 25 shots are fired.

Data Acquisition

Shots are fired using a weight drop/hammer on a plate. And the data was recorded on McSEIS SW instrument. 3 shots were fired and the instrument stacked them to get a unique data for that shot point.

3.2. Shot Gather

The traces are recorded by one shot are taken together as a common shot gather(CSG).

3.3. CMP Gather

The CSG are then reorganized, so that they form a common midpoint gather, where any trace taken in a CMP gather has exact same source-receiver midpoint as other traces in the Gather. We search and extract all pairs that have a common mid-point (CMP) from all the traces and calculate the cross-correlation to generate cross-correlation CMP gathers. Bin size is taken as double the geophone spacing.

Conversion to Frequency Domain

Phase velocity frequency transformation is then done. The maximum frequency of the Wave is approximately 40 Hz.

3.4. Dispersion Curves

Dispersion is a process in which, depending upon the elastic properties of the layers, different frequencies/wavelength have different variations in phase velocity.

Frequency Range Selection

We remove the low frequency region containing noise and high frequency region consisting of dispersion curves of higher mode. This is accomplished either by setting the minimum and the maximum frequency for removing unwanted data or by manually removing undesired frequencies.

3.5. Initial Model

An initial velocity model of S wave is then created, assuming that the velocity increases with depth.

3.6. Least Square Inversion

This Geophysical inversion technique involves the estimation of the mechanical parameters of a postulated earth model from the set of observations. Since the associated model responses are mostly nonlinear functions of the model parameters, nonlinear least-squares techniques thus prove to be fruitful for performing the inversion (L.R. Lines and S. Treitel)

Data and Results

Data Acquisition and Field

Figure 3: Location on the google map. (Ohni – Barkot Range (30.138, 78.265)

It was a bright sunny day on 27th Feb,2016. When we went to the field, the location was approximately 9 kms from Rishikesh. It was somewhat plane area on a mountain, where we did our survey.

Figure 4: Set up geometry of Geophones array. East-West Profile.

Figure 5: Field Equipment and layout.

DATA:

The data was then gathered along the profile with a total of 25 shots. The first being at -2 m from the first geophone. The data in the area was quite clear and low and high frequency noises were absent.

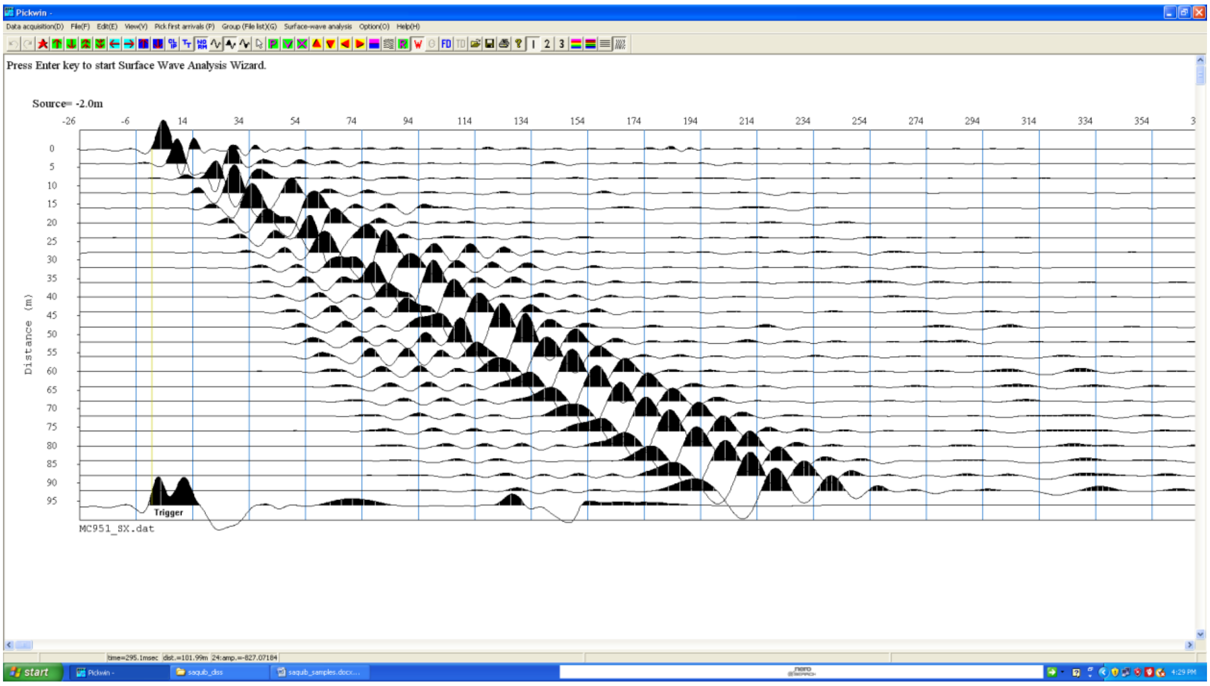

Figure 6: Shot gathers for the shots at -2m.

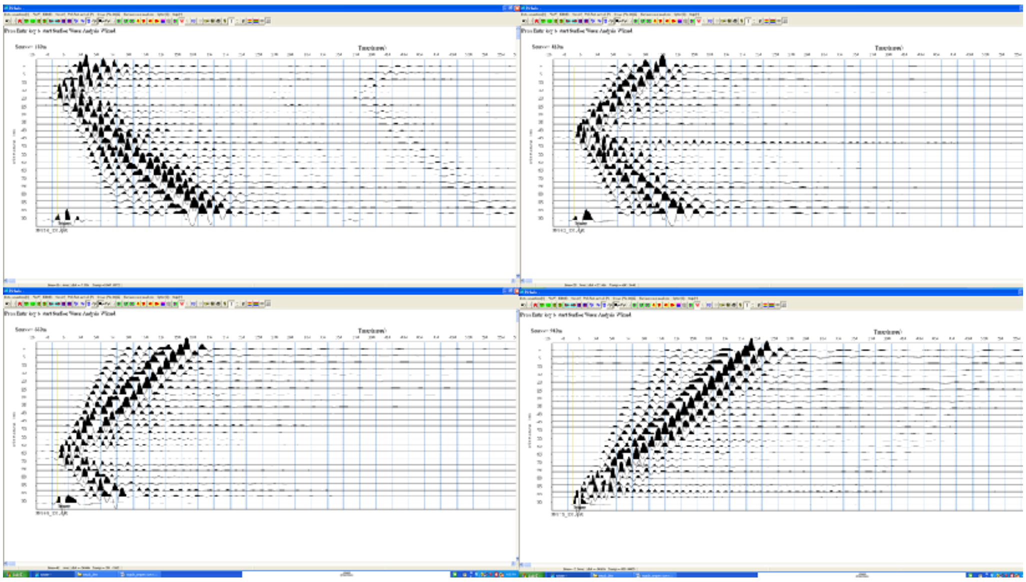

Figure 7: Shot gathers for shots at (a) 18m (b) 42m (c) 66m and (d) at 91m respectively. Source and receiver intervals were 4m for each case. Fixed receiver configuration was employed.

Set up of Geometry.

Then all the shot records were then expressed as common shot gathers and Geometry for the survey was set up.

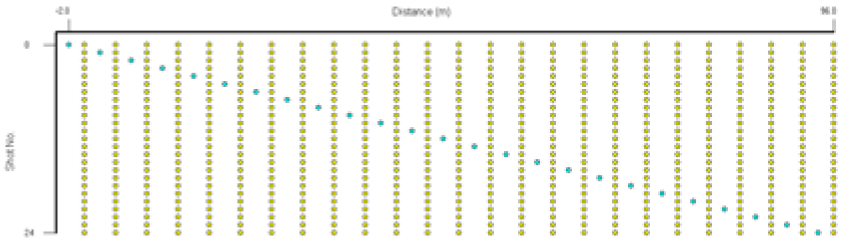

Figure 8: Shot Gather Geometry. Number of shot gathers are 625 with range of source/receiver geometry from -2 to 96m.

Then the common shot gather was converted to common mid point gather for further processing and the Geometry for common mid point gather was set up.

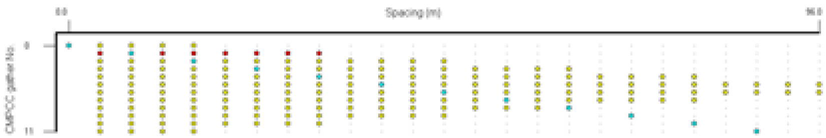

Figure 9: CMP Gather geometry.Total number of shot and receivers were 25 each. So, total number of CMP's are 49.

Dispersion Curves:

In physical sciences, dispersion relations do describe the effect of dispersion in a medium based on the properties of a wave traveling in the medium. A dispersion relation provides the relation between the wavelength or wavenumber of a wave and its frequency. From this relation the phase velocity of the wave has easier expressions which then determine the mechanical properties of the medium. More general than the material dependent and geometry dependent dispersion relations, there are overarching Kramers–Kronig relations that describe the frequency dependence of wave propagation.

Dispersion is caused either by geometric boundary conditions (waveguides, shallow water) or by confronting of the waves with the medium boundary.

When dispersion occurs, wave velocity is no longer defined uniquely, thus gives rise to the distinct phase velocity and group velocity.

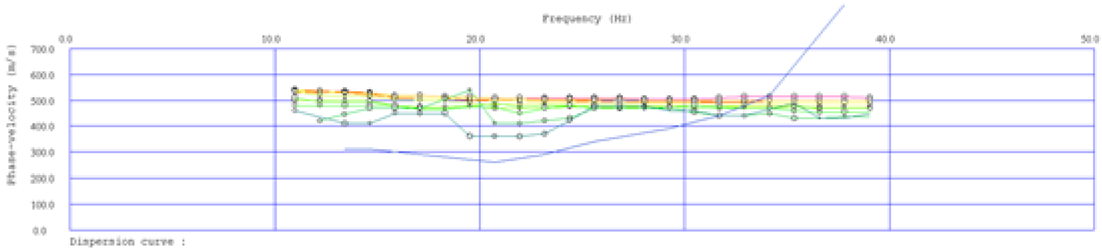

Figure 10: Dispersion Curves without Editing and Smoothing.

When we get the dispersion curves, the unwanted data is then removed and a continuous decreasing non-linear curve is aimed for. This process is known as smoothing.

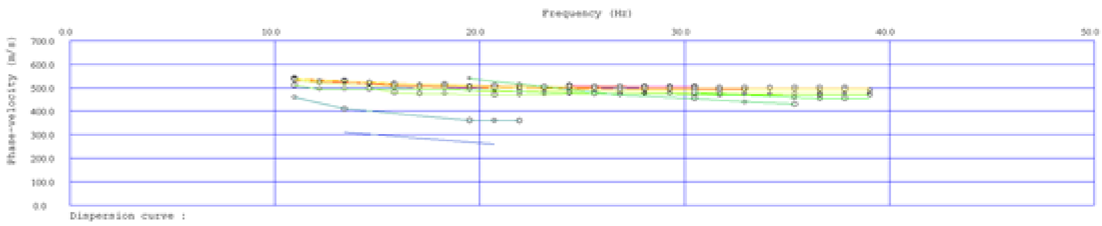

Figure 11: Dispersion Curves after Editing and Smoothing.

Initial Model:

After the dispersion curves are smoothened an initial model is made, where for a specified number of layers and depths (here 30 and 15). At the earlier stage a model for layered earth model is made.

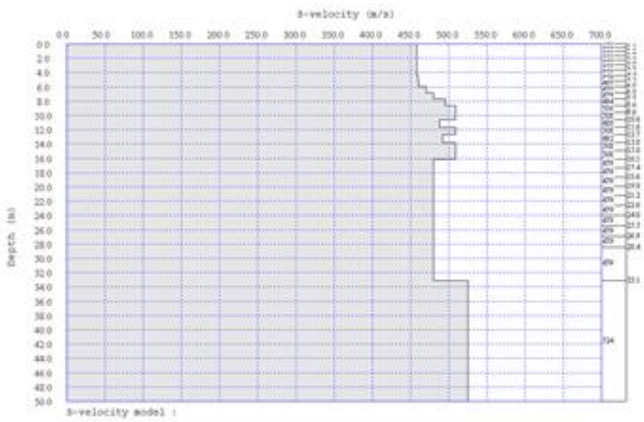

Figure 12: Initial S-wave velocity model with depth when dispersion curves are smoothed.

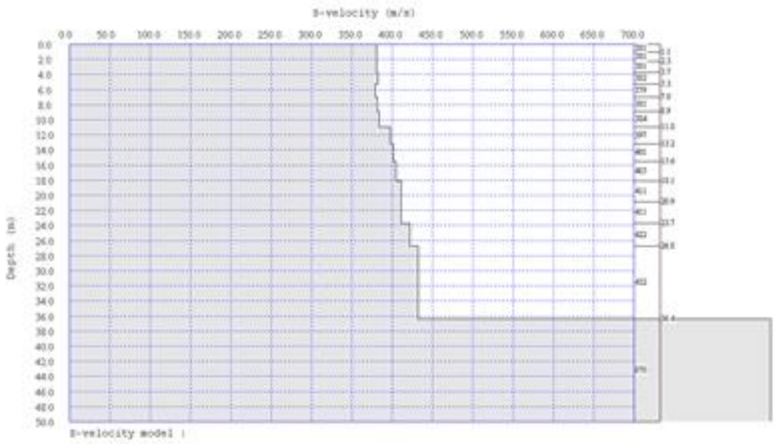

Figure 13: 1-D Velocity model for unsmoothed dispersion curves.

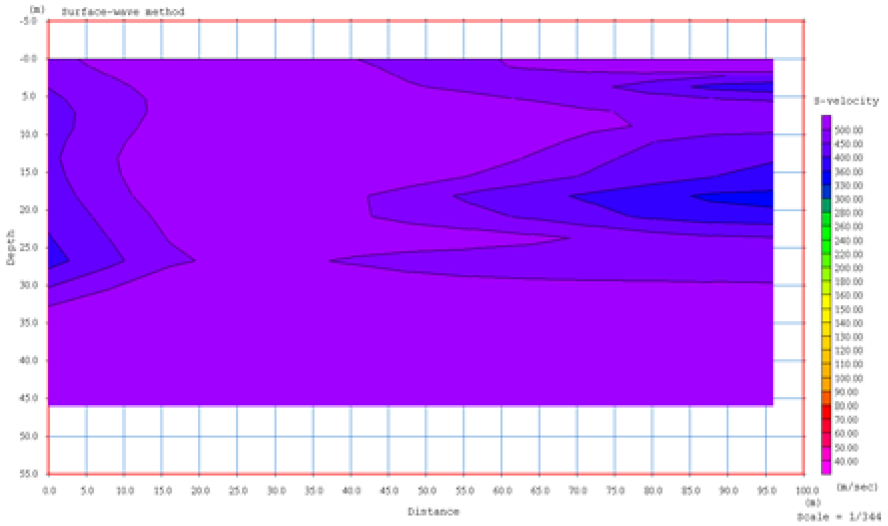

Figure 14: 2-D velocity model for unsmoothed dispersion curves.

The Initial model changes its nature when the dispersion curves are smoothed, for shallow depths the unsmoothed initial velocity model gives much lower velocity having larger proportion of data as erroneous. Thus smoothing of dispersion curves is always carried out. The number of depths is kept at 30 and number of layers is kept at 15 for the correct initial model, when the number of depths is increased, so is the depth of our model and vice versa. When the number of depths is changed the initial model reflects the velocities of the given number of layers of the model.

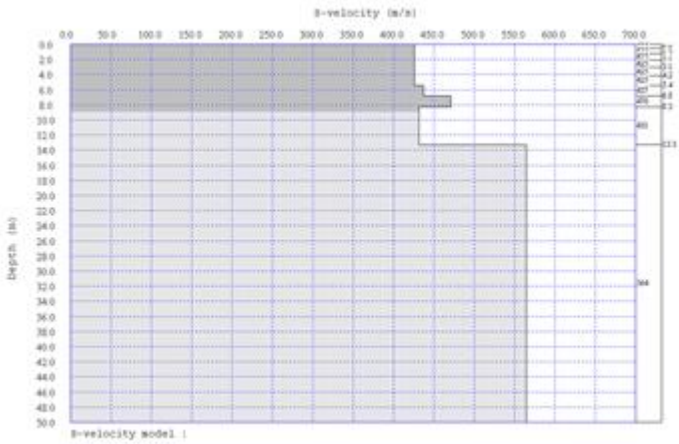

Figure 15: Initial velocity model when number of depths is taken as 10 and number of layers is taken as 10.

After the least square inversion, the velocity model that is arrived at is

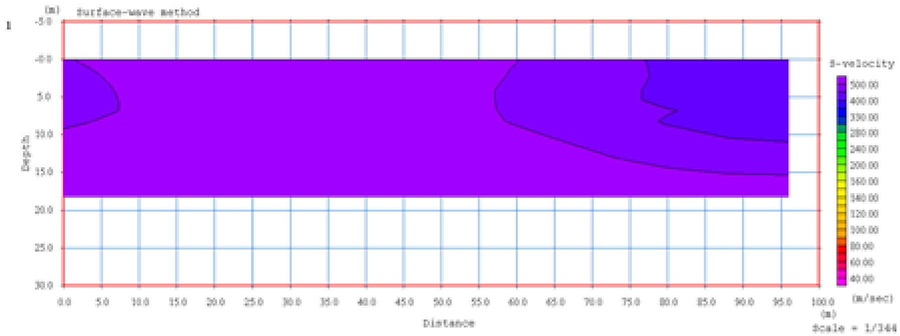

Figure 16: 2-D velocity model at 10 depths and 10 layers.

Thus by observing this arrived velocity model it can be said that increasing the number of layers the accuracy of our result also increases while the number of depths is to be taken as the same as that for number of layers for better results. As in the above figure it is confirmed that with lower depths, the results are for 18m depth only.

4. Results and conclusions:

After the initial model is made, least square inversion is employed with 10 number of cycles and regularisation weight being 0.5.

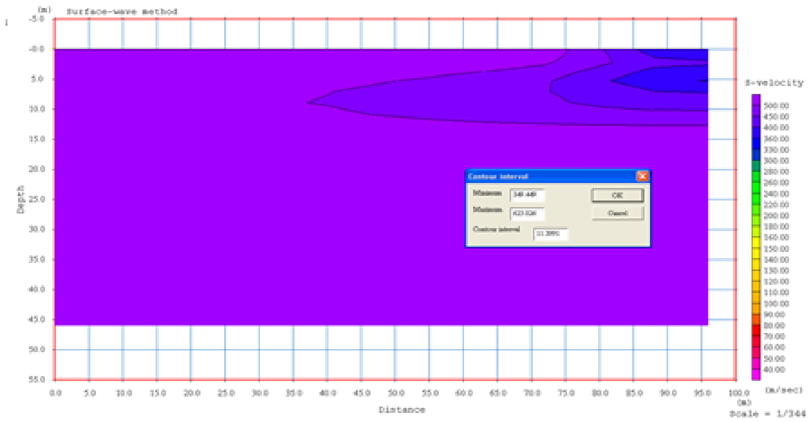

Figure 17: Velocity model when velocity contour is 12 ms^{-1}.

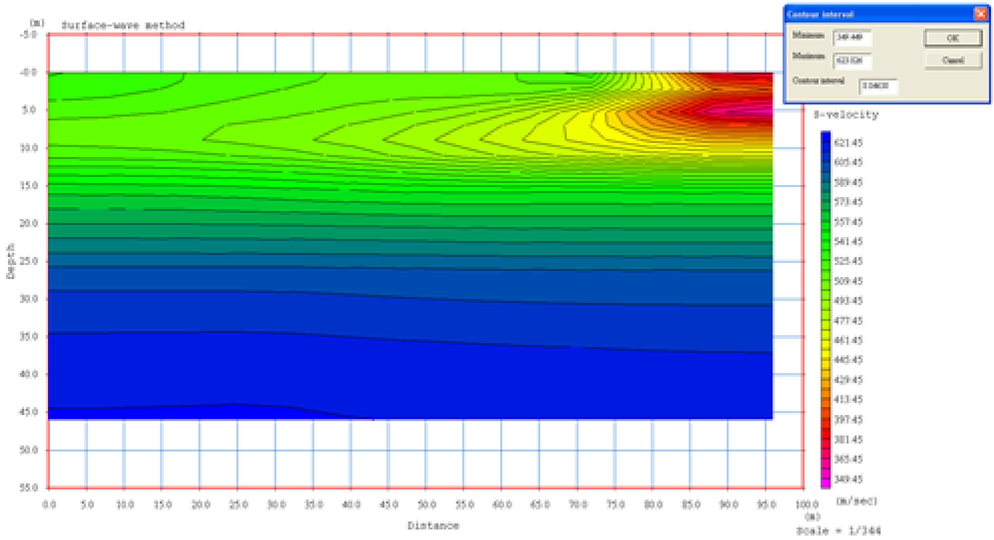

Figure 18: Velocity model when velocity contour interval is 8 ms^{-1}.

By viewing the S-wave velocity model, it can easily be concluded that on going downslope of the mountain the low velocity layer is thickening and sandy regions are observed and thus extremely low velocity is observed thus loose packing of grains are there. Which is also confirmed by the resistivity survey results that are already done in the area.

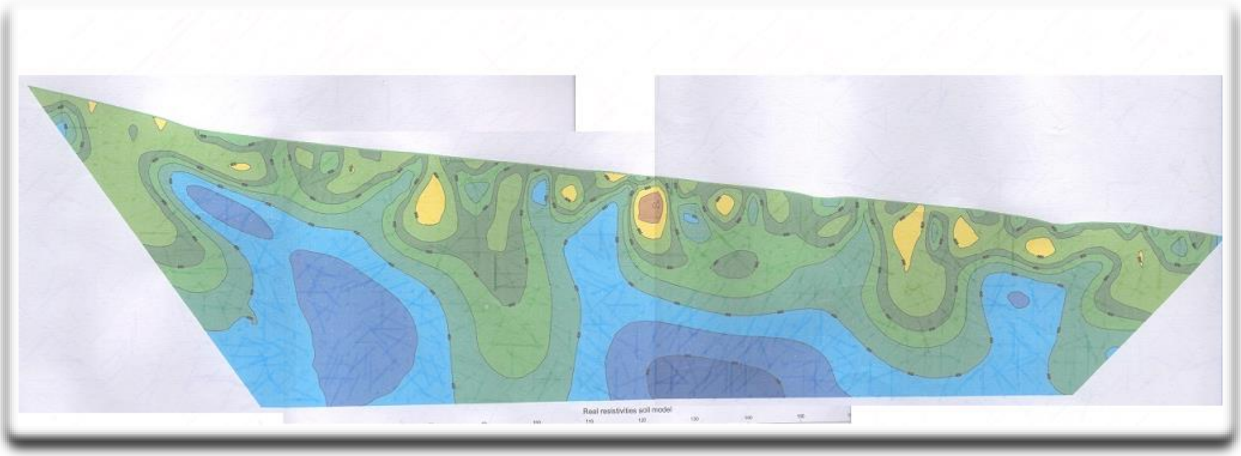

Figure 19: Resistivity profile of a nearby area. (*ref: RVNL report for resistivity survey)*

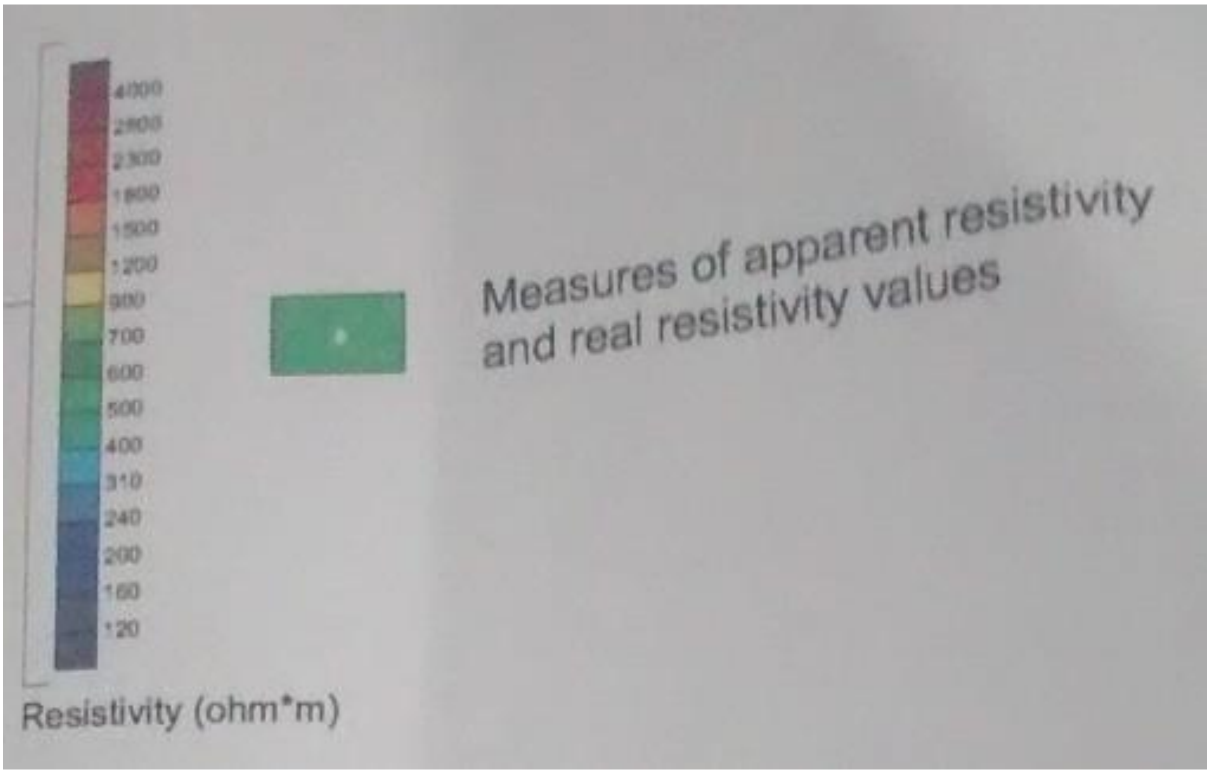

Figure 20: Legend for the above resistivity profile. (*ref: RVNL report for resistivity survey)*

As seen in the provided resistivity profile, the uppermost part is mostly unconsolidated grains mostly sands as the resistivities are low but still a bit higher than the lower saturated water table where the resistivity face its minima, which was also inferred in the seismic profile that the upper parts are mostly unconsolidated and after water table lies the fractured bed rock. Thus the results for the experiment are thus correct with a minimum of error. After inversion also the model that was arrived at was with 0.1% error.

Comparison of results with refraction interpreted data.

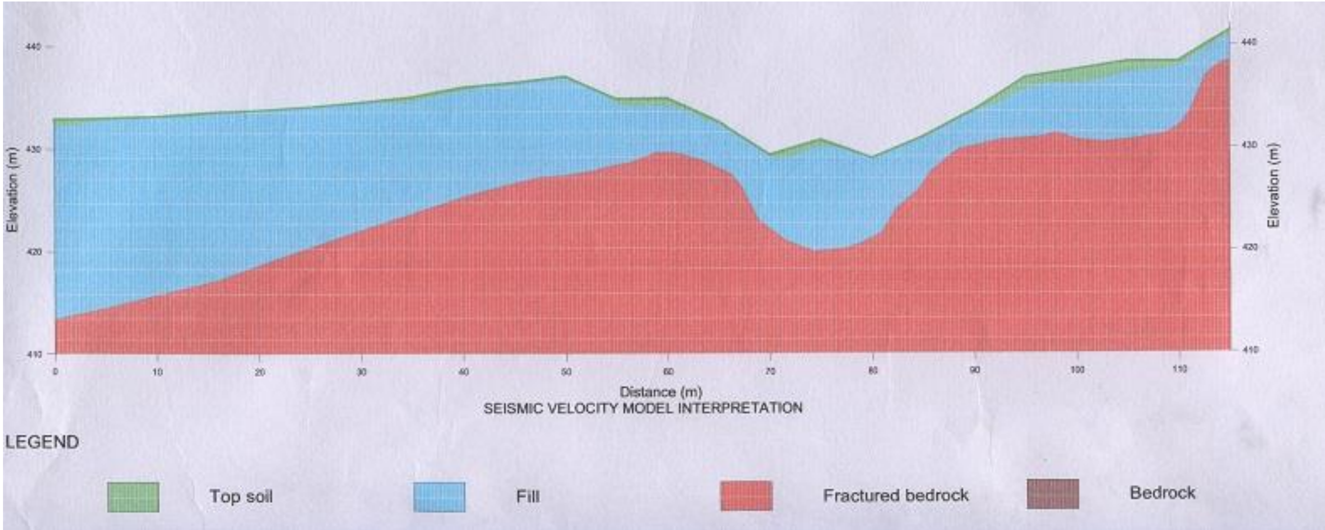

Figure 21: Seismic refraction interpreted model. (*ref: RVNL report for seismic survey)*

As seen in the provided refraction velocity profile, the uppermost part is mostly unconsolidated grains (Top soil) mostly sands as the velocity is low but still a bit higher than the lower unconsolidated layer whose thickness is increasing downslope where the velocity faces its minima, which was also inferred in the seismic profile that the upper parts are mostly unconsolidated and after water table lies the fractured bed rock. Thus the results for the experiment are thus correct when compared to refraction model also with a minimum of error. After inversion also the model that was arrived at was with 0.1% error. At the 0 point the thickness of unconsolidated layer is much lesser and thickness gradually increases as we move down dip. Thus proving our velocity model correct.

References:

1. Data acquisition and analysis system for surface-wave method, OYO Corporation, http://www.oyo.co.jp/english/instru_e/soft/seisimager/
2. Gabriels, P., Snieder, R., and Nolet, G., 1987, In situ measurements of shear-wave velocity in sediments with higher-mode Rayleigh waves: Geophysical Prospecting, 35, 187-196.
3. Choon B. Park, Richard Miller and Jianghai Xia, Imaging dispersion curves of surface waves on multi-channel record, 1997
4. Choon B. Park, Richard Miller and Jianghai Xia, Multichannel analysis of surface waves, Society of Exploration Geophysics, 1999.
5. Daniele Boiero, Surface wave analysis for building shear wave velocity models, 2009.
6. http://www.masw.com/