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Subsurface Investigation Analysis Using Combined MASW Survey

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Abstract. This paper deals with the investigation and characterization of soil at one critical location in Yupia Arunachal Pradesh using the combined MASW method. Limitations in the use of active and passive methods for characterization of the soil at shallow and greater depth led to the use of a combine MASW survey. The *Vs* determined from the combined MASW has more accurate Vs in shallow and deeper depth. The most important parameter for the accuracy of the *Vs* profiles is the resolution of the dispersion image obtained from the raw data. This research work reflects the importance of combining the active and passive MASW dispersion image. In this paper efficacy of combined MASW survey to determine Vs is shown along with a case study.

Keywords: Multichannel analysis of surface waves, Shear wave velocity, passive roadside, passive remote

1 Introduction

MASW survey method is effectively being used and researched in the field of geotechnical engineering projects [Park et al., 1999]. The popularity gained by MASW method over conventional method is that it is cost effective, non-destructive, time efficient and user friendly [Baglari et al., 2018]. The method is the modified or advanced version of earlier used surface waves techniques like GPR, NMR and seismic refraction survey [Johnson et al., 1985, Griffin et al., 2002 and Haeni et al., 1986] in the field of geophysics for microzonation and bed rock mapping[Gosnieewski.,2011]. The principle behind the MASW method is the dispersion of surface waves mainly in the form of Rayleigh wave which propagates through the layered soil beneath the earth surface. Data acquisition, dispersion and inversion analysis is the three steps that are being applied in the MASW method. Time domain raw signal or data generated from the source (active or passive) is filtered and muted in the required frequency range of 3-50 Hz to obtain the dispersion curve [Taipodia et al., 2018]. The theoretical dispersion curve is then inverted to obtain the shear wave velocity *Vs* profile after applying various inversion parameters and undergoing several iterations to bring theoretical DC close to experimental DC [Xia., 2014]. The Shear wave velocity *Vs* so obtained is an important critical engineering property of soil which carries required information and directly related to shear modulus. The method is extensively being used in geotechnical and earthquake engineering projects to determine the dynamic property and soil profiling. There are three basic approaches of MASW on which extensive research is being carried out by many researchers around the world. Those approaches are Active MASW, Passive MASW and the Combine MASW survey Method [Park et al., 2005]. To overcome the limitation of Active MASW method and growing curiosity of researchers to explore deeper depth into the soil, Passive MASW approach (Park et al., 2007 and 2008] came into existence where source of wave field is natural (tidal), or cultural (traffic) which travels in low frequency range of (3- 30 Hz) and generates longer wavelength Rayleigh wave that penetrates deeper into the soil and bring much more information to a depth up to 100 m. The use of 24 or more channels helps in fully exploiting the advantages of MASW survey method in both recording and processing. There are two types of approaches in passive MASW survey method i.e. passive roadside and passive remote [Park et al., 2004 and 2005]. Due to limitation of spacious survey area, the passive roadside MASW survey method is being used over the passive remote though passive remote generates Vs in 2D. The Rayleigh waves generated from traffic source is being used for the analysis while considering all the parameters including filtering and muting to obtain most analyzable dispersion image [Park et al 2002, Zhang et al 2004 and Taipodia et al 2018]. Further high-resolution dispersion image is inverted incorporating all the inversion parameters to obtain *Vs* profile with least RMSE and greater depth say about100 m [Dorman et al., 1962, Leipski et al., 1991and Taipodia et al., 2018].It was realized that the greater depth of investigation (i.e.> 20 m) is required for which the passive MASW was used. But due to absence of high frequency wave during passive MASW survey, the information of shallow subsurface strata is not clear. To overcome the problems faced during active and passive MASW, combined MASW survey was carried out. Combined MASW survey combines the dispersion images obtained from the active and passive MASW survey. Anbazhagan and Ketan, 2018; Ketan and Anbazhagan, 2019 has conducted a seismic site classification for deep soil sites in Indo-Gangetic basin. It is stated that the shear wave velocity at 30 m depth (VS30) is an essential parameter for site characterization and site amplification estimation and hence the site classification in the present study is carried out by determining Vs30 as in Ketan and Anbazhagan, 2019.

2 Location

The location of the experimental field site is at Yupia opposite to Thursday Market, the coordinates of which are 27.136420, 98.705444. Figure 1 shows the Google image of the experimental site.

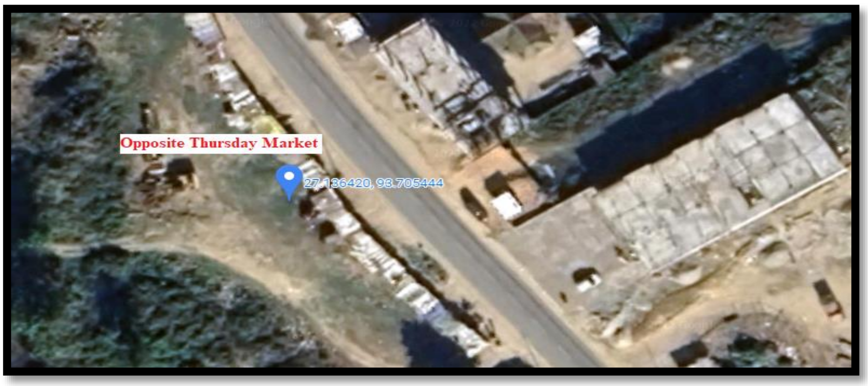


Fig. 1. Image captured from Google map indicating the experimental site.

3 Experimentation Program

Passive MASW survey was conducted at one site at Yupia i.e. Thursday Market. Figure 2 shows the layout experimental setup of a Passive roadside MASW survey conducted in the field. Seismic waves are generated through traffic, which after propagating through soil substrata and recorded by a set of geophone receivers placed in a linear array. The receivers are connected to a Data Acquisition System (DAQ) comprising of a seismograph. In the present study, 24 channels of 4.5 Hz geophones were placed in a linear array with geophone spacing varying from 1-5 m. The offline distance of 19 m was maintained as per the feasibility and availability of the space. Acquisition time and sampling frequency is varied to check the effect of data acquisition parameters on raw field image and resolution of dispersion image. It was found that for particular site condition the acquisition time of 2000 ms and sampling frequency of 1 ms-1000 Hz was optimum which gave fairly good and large range analyzable dispersion image.

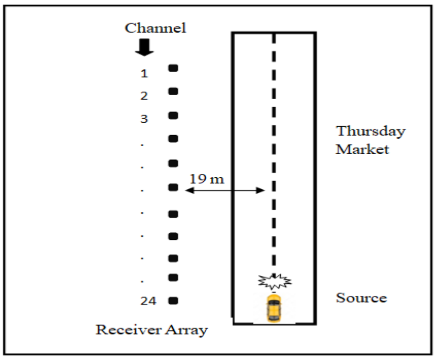


Fig. 2. Layout of passive roadside MASW

4 Results and Discussion

The raw data were acquired from the field using 4.5 Hz geophones, the acquisition duration was fixed at 2000 ms with 2 s interval, a sampling frequency of 1000 Hz is adopted based on resolution of image. 3-4 vertical stacking was carried out to obtain the best resolution dispersion image.

4.1 Comparative analysis of raw image

Traces of raw image in figure 3a are obtained from the active MASW survey. The raw images shown here is filtered with band-pass filter. The image shows proper wave propagation till 24th channel. The propagation time is 300 ms.

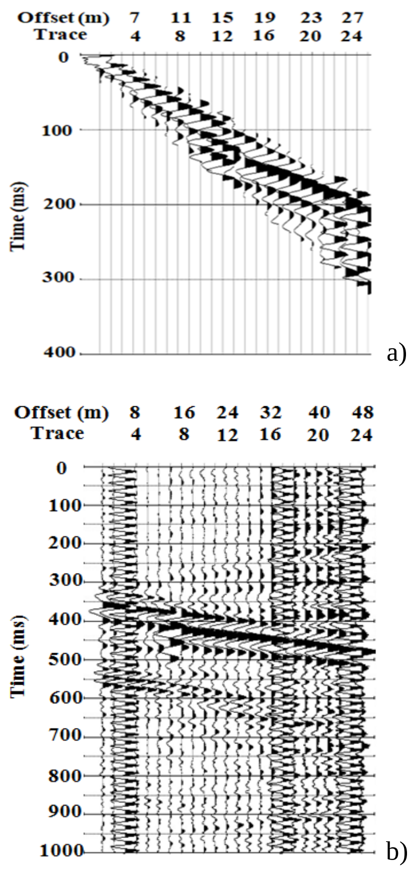
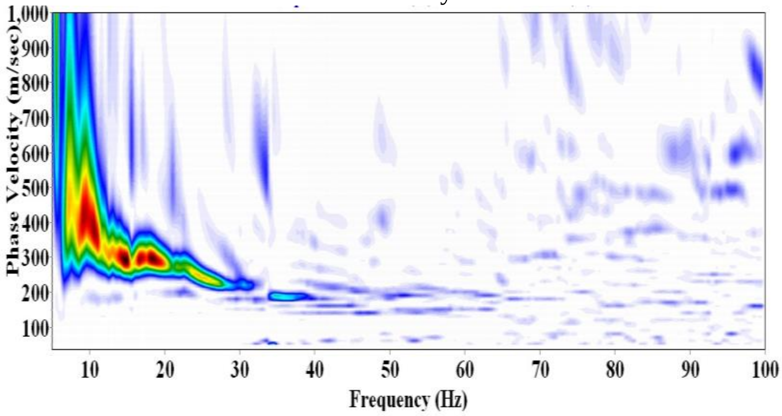


Fig. 3. A) Raw image of active Survey b) Raw image of passive survey

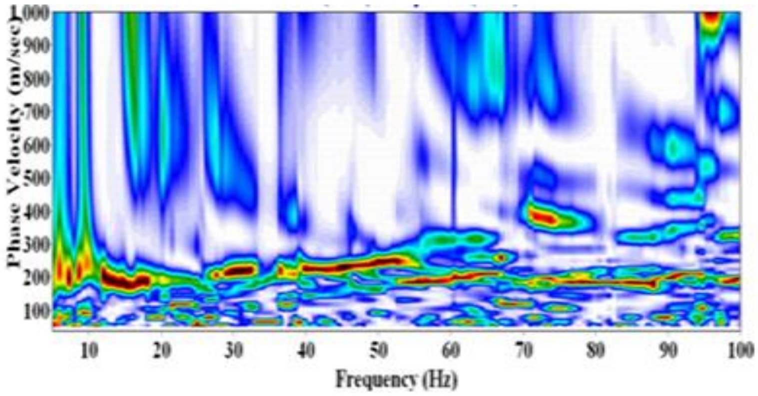
The unwanted noise was muted. Top and bottom muting were carried out which makes the raw image clearer for further analysis of dispersion image. Figure 3b shows the raw image obtained from Passive MASW. This image is also obtained after band pass filtering. There is still some hazy and unwanted noise even after filtering. Total time of propagation is 400 ms. The phase is incomplete till 24th channel. The time of acquisition is 400 ms in the present case.

4.1 Comparative Analysis of Dispersion Image

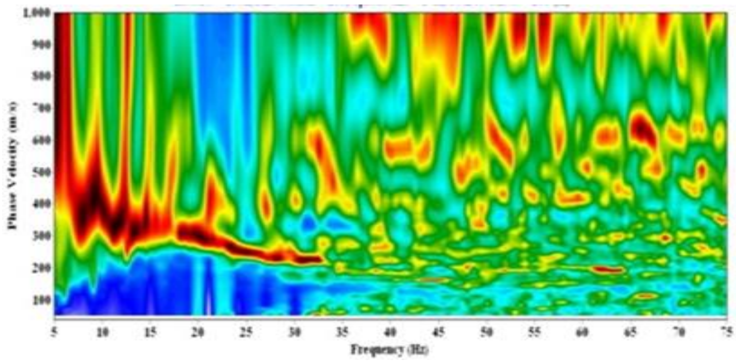
Figure 4a shows the dispersion image obtained after filtering and muting the raw image. A good continuous energy trend is visible ranging from around 8 Hz to 30 Hz. The image shows good energy content. Fundamental mode is generated in active survey in higher frequency range which is evident that shallow depth profiling is more distinct and can be characterized more accurately.



a)



b)



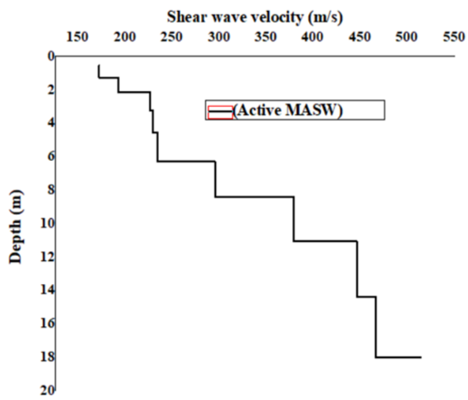
c)

Fig. 4. a) Dispersion image from Active Survey b) Dispersion image from Passive Survey c) Dispersion image from combined MASW

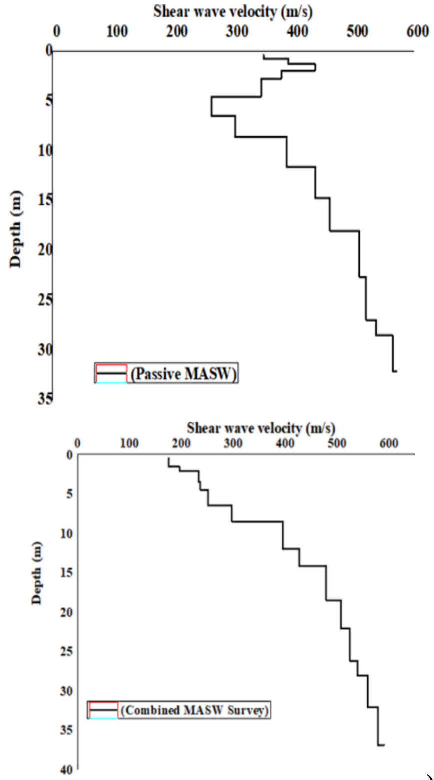
From figure 4b it is clear that passive survey energy concentration reaches up to 0-100 Hz which means that the analyzable frequency range increased. There is discontinuity in the image trend in higher frequency side. Figure 4c shows the dispersion image obtained by combining the active and passive dispersion images. This image shows a good continuous energy trend from the lower to the high frequency range. Higher mode waves are also present indicating new area of research.

4.2 Comparative analysis of shear wave velocity profile

Before inverting the dispersion curve, various inversion parameters such as number of points picked, frequency picking, density picking and number of layers is incorporated to get the most accurate shear wave velocity profile with least RMSE which was below 3. All the effect of inversion parameters were checked and optimum parameter is incorporated to obtain the shear wave velocity profile for subsurface profiling and characterization.



a)



b)

c)

Fig. 5. a) Shear wave velocity Vs profile obtained from Active survey b) Shear wave velocity Vs profile obtained from Passive Survey c) Shear wave velocity Vs profile obtained from combine MASW Survey

From figure 5a it can be seen that from active survey depth achieved is less than 30 m due to shorter wavelength waves generated through active sources like sledge hammer whereas depth achieved for passive MASWsurvey (fig 5b) is 35 m which can further increase depending on site condition and procedure adopted. It can be seen that Vs obtained from active MASW is around 160 m/s to 250 m/s whereas at shallow depth less than 6 m for passive MASW the Vs obtained is around 350 m/s to 450 m/s. The Vs obtained from combined MASW shows a value of around160 m/s to 270 m/s. The depth of investigation is 20 m in case of Active MASW survey whereas it is 35 m in passive MASW survey. The combined MASW depth is 40 m. Thus, it can be said that combined MASW provides more clarity both at shallow and deeper depth.

4.3 Validation with borehole data

Since Bore hole or cross hole field test has not been conducted on the proposed site therefore validation process using SPT-N value couldn't be established using the correlation proposed by Anbazhagan and ketan 2018. However, as per the research conducted and correlation established keeping in mind the various testing parameters and site conition, conclusion can be drawn that for Vs > 250 m/s the coefficient derived using orthogonal analysis for proposed site will be well predicting. In present case the shear wave velocity Vs lies between 500 to 600 m/s. Considering all site and testing paramteres the orthogonal regression analysis method can be used for calculating the Vs and SPT-N for the purpose of validation.

The site characterization and classification can be carried out for Vs_{30} which is shear velocity at 30 m depth as mentioned in Ketan and Anbazhagam 2019. Though it has limitation but it is essential parameter for site characterization and site amplification estimation.

5 Case Study at Indira Gandhi Park, Itanagar

Indira Gandhi Park is a lone recreational park of the state capital situated at the heart of the city which comes under reserve forest. The place is quite popular with both tourists and locals, and it is a nice family place for city dwellers where lots of recreational activities take place on an everyday basis. The Place is covered with greenery all around and happens to be a very important place in the state capital of Arunachal Pradesh.

5.1 Study Area

One suitable location in IG Park was selected for conducting the MASW survey to assess the risk of landslide, erosion and other geotechnical hazards that might occur in near future due to adverse climatic condition of the area and future development due to rapid growth of population. The site is situated at 27.098774, 93.620021

Fig. 6. Google image of IG park indicating location of experiment

5.2 Methods Used

The survey method used in the case study was Active MASW survey and Passive Roadside MASW survey to obtain the raw data depth ranging from 0 to 100 m. In this case study MASW survey aspect is focused on getting the site characteristics.

5.3 Survey Procedure

The line location for conduct of MASW survey was roughly decided as per the requirements and 24 geophone of 4.5 Hz was laid along the roadside with offline distance of 7.2 m from the centre of the road. The receiver spacing chosen was 1m with offset distance of 5m. All the cables were well connected to the seismograph which then connected to data acquisition box to save the raw data for further analysis to obtain the *Vs* profile. For Active MASW trigger geophone is used and connected to seismograph. To generate active source sledge hammer of 10Kg and metal plate is used. For passive source the normal flow traffic from moving vehicle is considered. While gathering the raw data various data acquisition and geometrical parameters were considered to get the best resolution dispersion image. For active MASW survey 0 ms pre-trigger, acquisition time of 2000ms, sample number 16000 with three stacking was set. The sampling frequency was varied to 250 us-4000 Hz, 500 us-2000 Hz, 1ms-1000Hz, 125 us-8000Hz. For passive roadside MASW survey, acquisition time of 2000ms, sample number 16000, interval of 2 s with three repetitions was set. The sampling frequency was varied to 250 us-4000 Hz, 500 us-2000 Hz, 1ms-1000Hz.

5.4 Data processing and analysis

The raw data was acquired from both the active and passive MASW survey methods. The data was analyzed in various stages, considering various factors to get the *Vs* profile like filtering, muting, extraction of dispersion curve, and inversion. In the first stage of data processing, the raw data obtained was filtered using a band pass filter to remove the unwanted noise and allow the higher energy frequency after applying proper field geometry. The filtered image is then muted to some extent both at the top and bottom, using strong tapering to remove the distorted wave signal. The filtered and muted image is pre-processed to get a higher energy dispersion image of the optimum resolution for the extraction of the dispersion curve. The picking of points to extract the dispersion curves plays an important and crucial role in the final Vs result. Here in this data processing manual, picking was considered to be numbers varying from 15-20. Frequency picking was done based on the significant energy concentration of the dispersion image. The optimum number of layers was kept as it gave the least RMSE value. The iteration varies from 10-15, which seems to be the optimum for the above raw data. Combined MASW analysis is carried out by stacking both active and passive data to get enlarged analyzable frequency range and to better identify the modal nature of dispersion trend generated from active and passive source. The combined MASW dispersion image is shown in figure 7a. The image shows a dispersion trend in wide frequency range. The higher modes are easily identifiable from the dispersion images. The corresponding Vs is shown in figure 7b. The maximum depth of investigation is up to 40 m. According to NEHRP site classification stiff soil at shallower depth to dense soil to soft rock at around depth of 40 m.

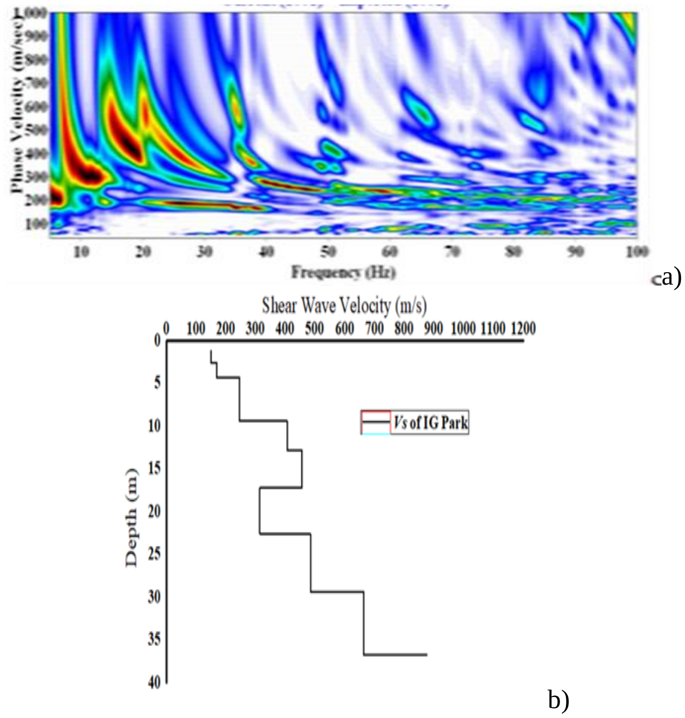


Fig. 7. Shows the dispersion image, dispersion curve and *Vs* profile of the active data obtained from the study area.

6 Conclusions

From the study of the critical site and case study, it is concluded that incorporating optimum data acquisition and inversion parameters are the most vital pre requisite necessity of any approach of MASW survey. These parameters decide a lot in the accuracy of final shear wave velocity profile. Experimental and comparative analysis of graphical representation of shear wave velocity shows that the deeper depth is achievable in passive roadside which is double the depth achieved by active survey that signifies that greater depth of investigation and soil profiling can be achieved with the help of Passive survey. From the present study it can be concluded that combined MASW provides more clarity both at shallow and deeper depth. Modal study can also be carried out in combined MASW survey.

The Vs_{30} for IG park ranges between 450 m/s to 650 m/s. it signifies that the soil profile type is A which depicts that the site is of very dense soil/soft rock as per NEHRP, USA where as per the Eurocode 8 the site is of class B which describes that deposits of very dense sand, gravel or very stiff clay is present at least several tens of m in thickness, characterized by a gradual increase of mechanical properties with depth.

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