Application of passive surface-wave method for Quzika hydropower damsite exploration

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***Abstract*—The passive surface wave method can detect the shear wave velocity structure of subsurface mediums, by recording the vertical component of weak vibration on the earth's surface, and then extracting Rayleigh wave dispersion curve. This paper documents the first application of the passive surface wave method in a large-scale water resources and hydropower project. Using the passive surface wave method, we made a thorough investigation of the shear wave velocity structure over the depth of 100m underground in damsite area to achieve the mission requirements. In addition to deploying the triangular array in valley terrace area, we tried to arrange the linear array in steep slope area in the exploration. Favorable results were obtained by using the spatial autocorrelation method to extract dispersion curves. The above research shows that, due to its characteristics of strong anti-interference ability, high resolution, and less effect by site conditions, the passive surface wave method has some technical advantages compared with other geophysical methods, and has good application prospect in exploration of large-scale water resources and hydropower projects.**

Keywords—passive surface-wave; quzika hydropower; damsite exploration

I. INTRODUCTION

Quzika hydropower damsite locates in the upper reaches of Lancang River, belonging to Mangkang county, Tibet Autonomous Region. The project scale is big(2) , and the engineering rating is II. The damsite area is between the cliffy mountains with snow-covered summit, and is characterized by complicated geological condition, such as obvious bedding crushing, strongly rumpled structure, fractured rock mass, etc..

Some exploration means, such as drilling, logging, shallow seismic method, resistivity method, and magnetotelluric method, have been applied to determine the underlying subsoil structure in damsite aera. This paper documents the application of the passive surface wave method in Quzika hydropower damsite exploration. In the attempt to use the passive surface wave method for large-scale water resources and hydropower project in high altitude area with complex geological condition, evaluating the effectiveness and issues of this method will have some practical significance for similar engineering projects.

II. PASSIVE SURFACE WAVE METHOD

Compared with the active Rayleigh wave method using the artificial seismic source, the passive surface wave method records the vertical component of weak vibration on the earth's surface to extract Rayleigh wave dispersion curve and detect the shear wave velocity structure of subsurface mediums. There are two general techniques for extracting Rayleigh wave information, one is the SPAC (spatial autocorrelation) method based on coherent analysis, the other is F-K (frequency-wavenumber) method based on two-dimension wave field transformation [1]. This paper uses the SPAC method.

Given a group of passive surface wave receiving stations, one locates at the center of a circle, the others at circumference with equal spacing. It is assumed that the signal consists of a series of plane wave with incident angle ϕ, angle frequency ω, and wavenumber k, and is stationary in both time and space. The spatial autocorrelation coefficients are defined as the average SPAC function at all the observation sites on the array, that is,

$$\rho(\omega,r)=\frac{1}{2\pi\phi(\omega,0,0)}\int_0^{2\pi}\phi(\omega,r,\theta)\mathrm{d}\theta=J_0\left(\frac{\omega r}{c(\omega)}\right) \quad (1)$$

The SPAC coefficients, $\rho(\omega,r)$ can be directly calculated from the observed data using equation (2)

$$\rho(\omega,r)=\frac{1}{2\pi}\int_0^{2\pi}\frac{\mathrm{real}\{[S_{CX}(\omega,r,\theta)]\}}{\sqrt{[S_C(\omega,0,0)]\cdot[S_X(\omega,r,\theta)]}}\mathrm{d}\theta \quad (2)$$

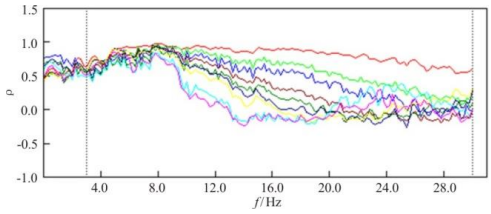
where $\mathrm{real}(\cdot)$ stands for the real part of a complex value, $S_C(\omega,0,0)$ and $S_X(\omega,r,\theta)$ are the power spectra of signal at two sites C and X, respectively, and $S_{CX}(\omega,r,\theta)$ is the cross spectrum between the two sites, [ ] denotes the block average over time. In the case of linear arrays, based on the assumption that waves travel in various directions, the SPAC coefficients were calculated by using the equation (1), but without averaging of the cross correlation coefficients azimuthally [2].

III. DATA ACQUISITION

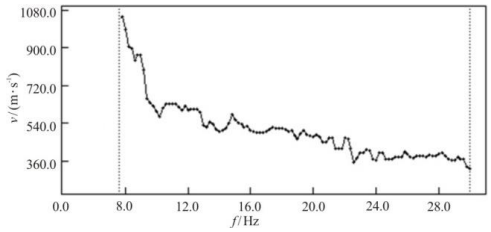
To determine the underlying subsoil structure over the depth of 100m underground in damsite aera, we laid out 10 survey lines and totally 196 points, with 4 lines along the axis of damsite and 6 lines paralleling to the river. We carried out the observation using the triangular array recording geometry in valley terrace, and linear array in steep bank. According to the mission requirements and field experiments, and with consideration of work efficiency, the selected triangular array layout has 10 channels with the maximal side of 20m; the linear array has 12 channels with an interval of 5m and the total length of 55m. We used DAQLink III seismograph and CDJ-Z2A geophones, with a sample interval of 2ms and record length of 600ms.

IV. DATA PROCESSING

The data processing in the passive surface wave method generally includes preprocessing, dispersion curve extracting, dispersion curve inversion, and result plotting. In pre-processing, the main work is to check and test the observed data, and remove the block with strong noises. In Quzika damsite exploration, the major preprocessing is to remove the seismic wave events originating from the explosion in seismic refraction method.



(a)

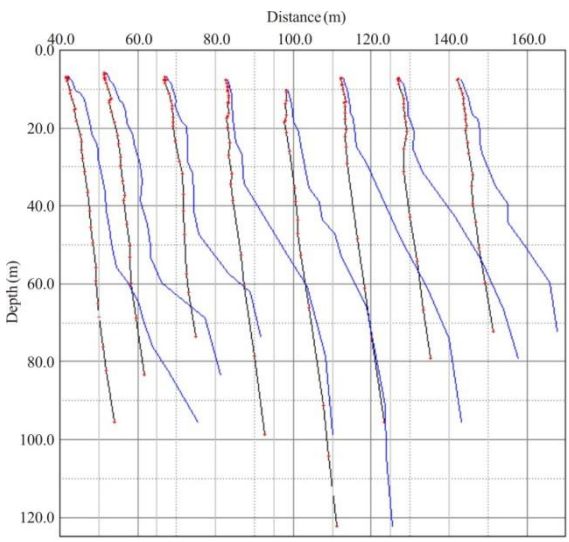


(b)

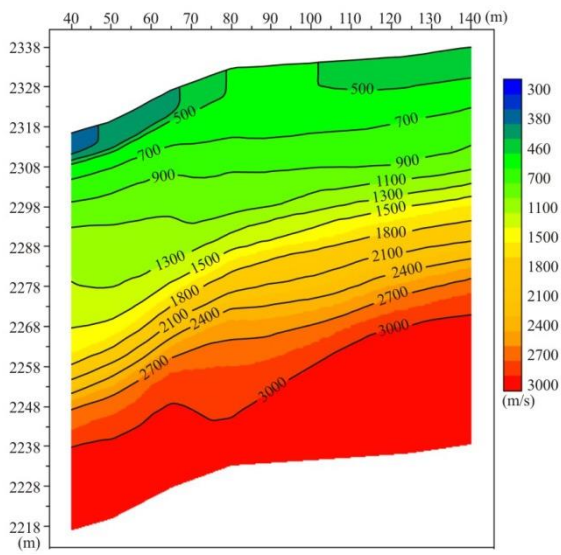
Fig. 1. Deriving dispersion curve form spatial autocorrelation coefficient. (a) autocorrelation curve; (b) dispersion curve.

According to the equation (1), SPAC coefficient is the function with respect to phase velocity and frequency. By fitting the SPAC coefficients to a first order Bessel function, we can obtain the phase velocities. Fig. 1a shows the SPAC coefficient curves, where a different curve denotes the result corresponding to a different station pair. Fig.1b shows the dispersion curve obtained by fitting the SPAC coefficient to a first order Bessel function.

Using all dispersion curves in a survey line, we can obtain the S-wave velocity structure under the line. Fig.2a shows a series of dispersion curve groups, where the blue polygonal line stands for apparent S-wave velocity curve; Fig.2b shows the contour map of apparent S-wave velocity corresponding to the dispersion curves in Fig.2a.



(a)

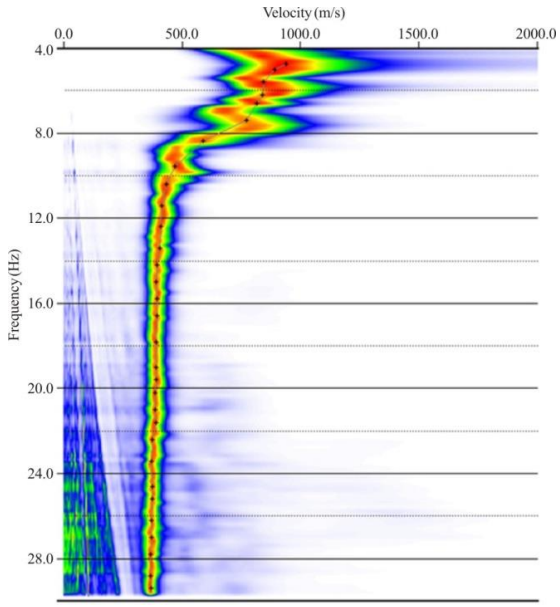


(b)

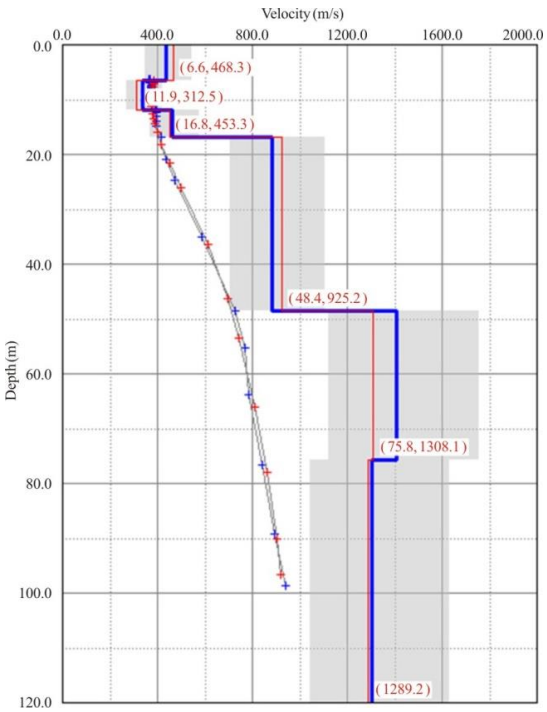
Fig. 2. Results from the passive surface wave method. (a) dispersion curve set; (b) contour map of apparent shear wave velocity.

V. DISCUSSION

So far there are no publications about linear array exploration using the passive surface wave method in domestic journals. In Quzika damsite exploration, we use the linear array substituting the triangular array in cliffy area. Fig.3 shows the typical results obtained with the SPAC method, where 3a indicates the dispersion spectrum and 3b is the inversion result. Compared with those obtained from Remi method[3], the results from the SPAC method have higher resolution and less uncertainty.



(a)

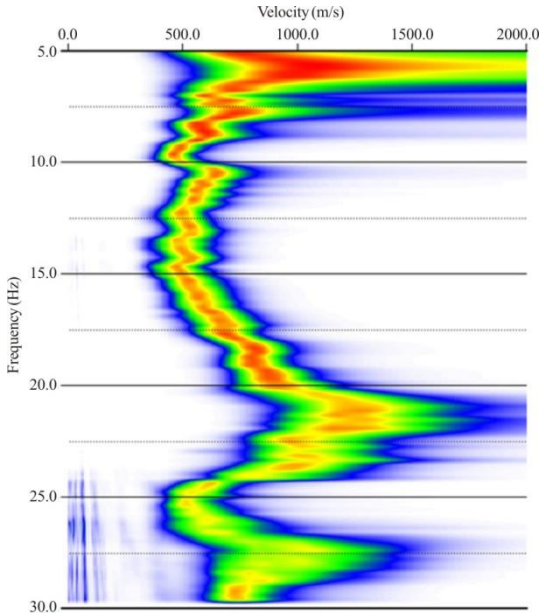


(b)

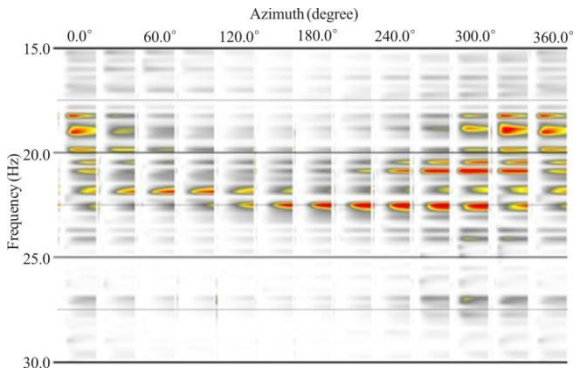
Fig.3. Results from the passive surface wave method using a linear array. (a) dispersion spectrum; (b) inversion results.

For passive surface wave exploration, water flow of the river is a continuous source, especially in the upper reaches of Lancang River with the condition of rich water yield and swift current. By comparing all 196 dispersion spectra, we found that there are some disturbances from the moving water when the array is near the bank.

Fig.4a shows the typical dispersion spectrum suffering the effect of the river. We can see that the velocity increases obviously over 15Hz because of the disturbance originated from the river. The azimuth scan results as shown in Fig.4b reveal that that the high frequency waves are traveling in 240°～30° and the traveling direction is in agreement with the moving water.



(a)



(b)

Fig.4. The result affected by a river. (a) The dispersion image; (b) The azimuthal scan results.

VI. CONCLUSION

In Quzika hydropower damsite exploration, using the passive surface wave method to carry out data acquisition and analysis, we made a thorough investigation of the shear wave velocity structure over the depth of 100m underground to achieve the mission requirements. This is the first application of the passive surface wave method in large-scale water resources and hydropower project, and the first one in high altitude area with complex geological condition. This is also the first attempt to arrange linear arrays in exploration with favorable results obtained.

The passive surface wave method does not require artificial seismic sources, using the weak vibration on the earth's surface to detect the underlying subsoil structure. Due to its characteristics of strong anti-interference ability, high resolution, and less effect by site conditions, the passive surface wave method has some technical advantages compared with other geophysical methods, and has good application prospect in exploration of large-scale water resources and hydropower projects.

On the basis of the practical application in Quzika damsite, there are some advices about using the passive surface wave method in similar engineering projects as follows.

- The passive surface wave method is based upon the phase analysis of wave propagation, requiring high consistency of field data. The data quality will be seriously affected by the coupling condition between geophone and earth surface, so geophones must be strictly checked and firmly placed.
- A linear array can be arranged in the limited field where a two-dimensional array is unavailable, using the SPAC method to extract surface wave dispersion curves.
- In the circumstance that the measuring array is near the river, because of the effect of moving water, joint inversion with the active surface wave method is recommended to improve the shallow data quality.

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