SEISMIC INTERFEROMETRY ANALYSIS OF THE MANTARO-TABLACHACA SEISMIC NETWORK (PERU)

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ABSTRACT

Seismic interferometry is a technique to estimate the Green's function between two receivers by the use of the cross-correlation method with the aim of retrieving information about the subsurface. This study is aimed at appling ambient noise cross-correlations to data that have emerged continuously from vertical components of the Mantaro-Tablachaca seismic network in the central area of Peru between January and June 2010.

Cross-correlation was calculated in a period range from 1 to 10 seconds from data for 21 station pairs using 7 stations in this area. Dispersive waves in the cross-correlations were identified as surface waves. The group velocity for Rayleigh waves were estimated from multiple filtering analysis of the cross-correlations. The observed group velocities of Rayleigh waves were compared with the theoretical ones calculated from 1D P-wave models of an existing model in this area.

The observed group velocity dispersion curves show special variations of Rayleigh wave velocity; in NE directions CPA-TBL and QCH-TBL have low velocities than in other directions. This result indicates the advantage of the seismic interferometry processing of long term microtremors data, to obtain superficial wave dispersion measurement in this area.

Keywords: Seismic interferometry, cross-correlation, seismic noise.

1. INTRODUCTION

In recent years, new techniques have been developed by conducting theoretical and experimental demonstrations through which the Green's function for an elastic medium can be recovered by the cross-correlation of seismic noise recorded at two seismographs. The seismic noise that travels through the Earth (caused by wind, ocean waves, rock fracturing and human anthropogenic activities) are useful data for this purpose. These artificial energy sources contain the information about the Earth's subsurface structures and properties. Emergent signal can be extracted of the ambient noise cross-correlation function between two receivers. These coherent signals are related to the time domain Green's function between these two receivers. Large networks of broadband and short period seismic sensors are commonly used for earthquake monitoring worldwide and they measure ambient noise continuously. These ambient noise recordings can be readily processed to provide an estimate of the time domain Green's function based on the noise cross-correlation function between all station pairs of the network (Sabra et al., 2005).

In this study we apply cross-correlation of ambient noise continuously Bensen et al. (2007) to the observations in the Mantaro - Tablachaca seismic network (period: January - June, 2010) to estimate superficial wave dispersion characteristics of the region. Standard processing procedures are applied to the cross-correlation, and the one-bit sampling method to equalize power in signals from

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different times. Multiple-filter analysis is used to extract the group velocities from the estimated Green’s functions, which are then used to image the spatially varying dispersion at periods between 1 and 10 seconds.

2. DATA

Mantaro Seismic Network is located in the department of Huancavelica (central area of Peru), 100 km from the city of Huancayo and 450 km from the city of Lima, and its aim is monitoring local seismicity of this area because the Mantaro hydroelectric power plant that is supplying power to 48% of the country including Lima city, is situated in this area. The topography and morphology of the area is rugged with elevations ranging from 2,850 and 4,415 meters above sea level.

A variety of geology is widespread in this area (Figure 1) and a great part belongs to the Paleozoic sedimentary series between the Precambrian basement schist and the Pucara Group carbonate series (Triassic-Jurassic) which consists of marine and continental facies of the Excelsior and Mitu groups mostly known in the Eastern Cordillera of central and southern Peru (Dalmayrac, 1978). In the area, there are intrusive rocks (rhyolite and dacite) that are assumed to be of the Paleozoic and the Jurassic. From a tectonic point of view, the target area is located near of Pampas fault, Arhuayaco fault (inverse fault) and Jabonillos inverse fault.

In this study the Seismic Interferometry technique was applied to seismic recordings collected on the vertical component of 7 stations of the Mantaro-Tablachaca Seismic Network (operated by the Geophysical Institute of Peru - IGP) for a continuous recording for the 6-month period from January 2010 through June 2010.

Each station is equipped with short period sensors, Kinemetric SS-1 and ADQ digitizers connected to a 16-bit analog-to digital converter. The data are sampled at rates of 100 Hz.

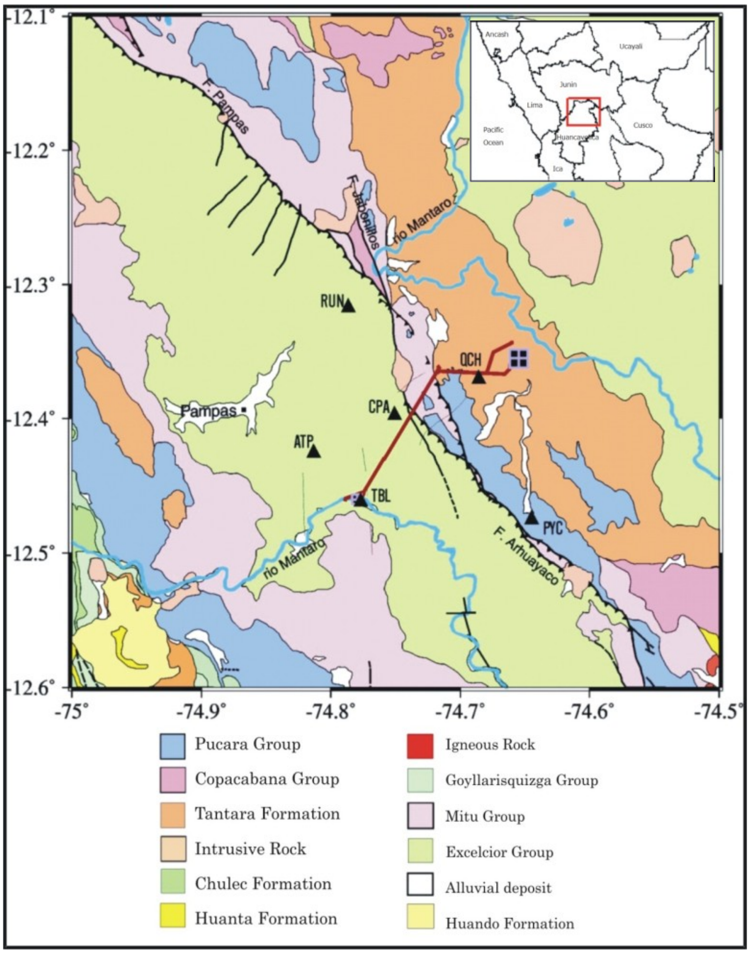

Figure 1. Geologic Map of the study area showing the locations of the stations (black triangle)

3. THEORY AND METHODOLOGY

Seismic interferometry is a technique that allows us to characterize the wave propagation between receivers, and by using this technique, it is possible to extract the Green’s function from seismic events recorded in two or more receivers.

We follow the method described by Bensen et al. (2007) for data processing from observations of ambient seismic noise to the production of group velocity measurements. Figure 2 shows this scheme which is summarized by the fundamental steps for applying Seismic Interferometry.

3.1. Data preparation

The noise cross-correlation functions were computed for 21 station pairs separated by a 7–70 km distance, and was computed considering windows with a length of 24 hours. Corrections for instrument response were unnecessary because we cross-correlated waveforms with the matched instrumental responses. Cross correlation then removes the common instrumental phase response.

Originally the data were recorded every 20 minutes. The first step was to merge records in signal with a length of 24 hours. To assess data quality and pick up the dominant frequency, we used the spectrally decomposed noise seismic data into the frequency domain via the fast Fourier transform (FFT). Frequency band for computing the noise cross-correlation function was 0.1–1 Hz, which contained most of the coherent ambient noise between these stations pairs. The next step involves applying time domain normalization in order to remove the influence of large amplitude events such as earthquakes and other non-stationary noise sources (instrumental irregularities, noise sources near to stations, etc.) from the subsequent cross-correlation. We decided to apply one bit normalization that was explained before.

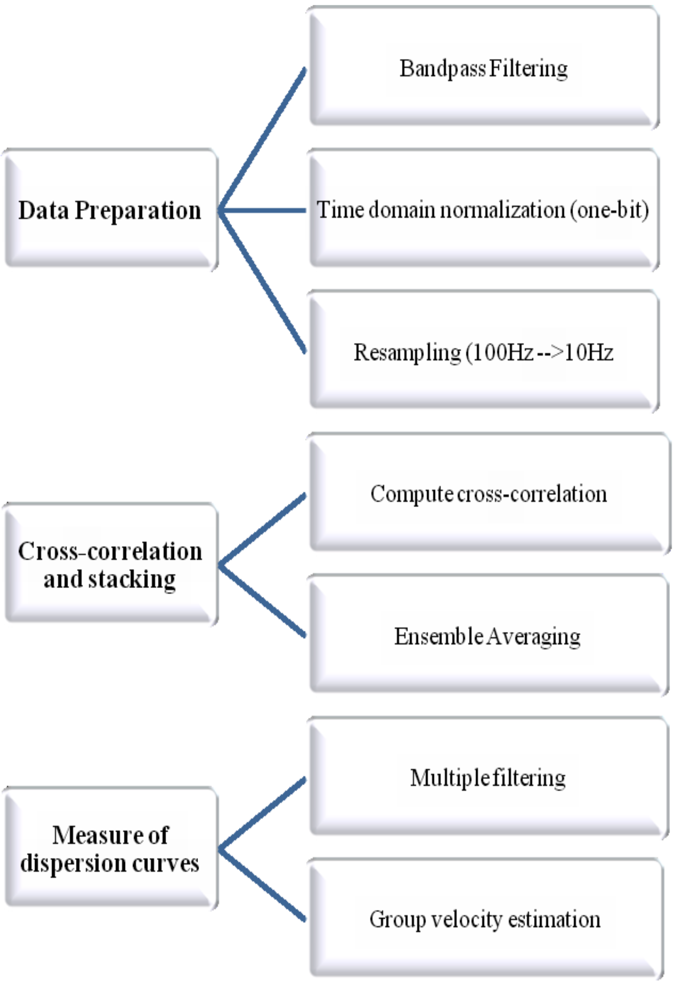

Figure 2. Example of the results of moment tensor inversion

3.2. Cross-correlation and stacking

After data preparation we perform cross-correlations between all possible station pairs. In our case, 21 station pairs. The resulting cross-correlations are two sided time functions with both positive and negative time coordinates.

We performed the cross-correlation in the frequency domain. After the daily cross-correlations are returned to the time domain, they are added to one another, or stacked, to correspond to longer time-series. In our case we stacked for 143 days. The daily cross-correlation have been computed and stacked the resulting waveform is an estimated Green's function using them the group velocity as a function of period can be measured. Figure 3. shows the final stacking cross-correlation (6 months). The correlation is stored from -40 to 40 s. This range always depends on the inter-station distance and the group velocity speeds. From the signals emerge we can see a tendency of the group velocity dispersion.

3.3 Measure of dispersion curve

One particularly useful property of surface waves is that they are dispersive, and the longer period waves usually travel faster than those of shorter period. Hence surface wave dispersion can be represented as a dispersion curve, which is a plot of the travel speed of a surface wave versus period.

In order to get group velocity dispersion curves, first we must obtain measurement of single waveform which involves significant analyst interaction. We applied frequency-time analysis (Levshin, 1989) to 10 period bands between 1 to 10s to calculate their envelopes, the procedure conducted for each station pairs is shown in Figure 4. We calculated multiple filtering analysis of seismic noise cross-correlation for 6 month. The data from ATP-TBL, CPA-TBL, PYC-TBL and RUN-TBL station pairs shows clear signals.

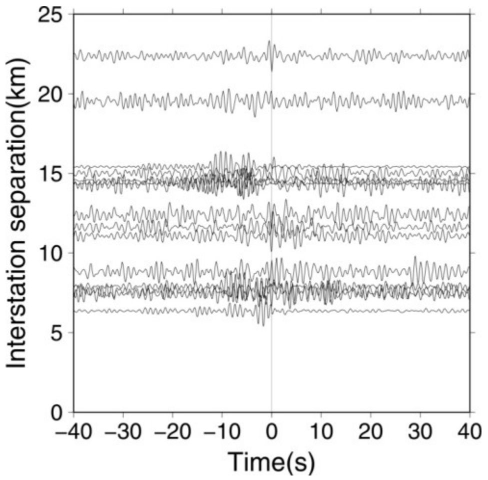

Figure 3. Six months of cross-correlation of 21 pair of stations. Stacked correlograms as a function of distance between station pairs.

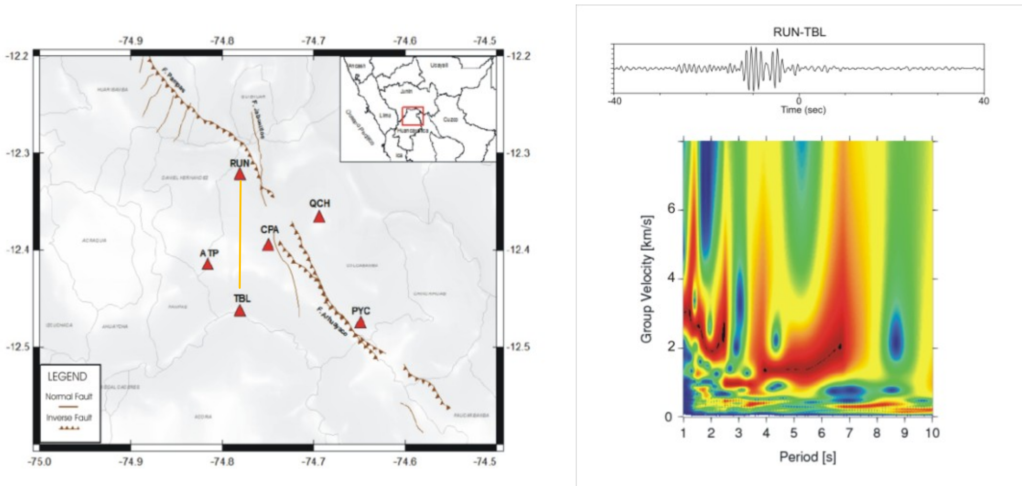

Figure 4. Results of pair station RUN-TBL. (Left) The locations of the station pairs. (Right) The upper frame shows the six months cross-correlation (period: 1-10s). The lower frame shows the group velocity diagram with a dispersion curve (black line)

4. RESULTS AND DISCUSSION

To define values of the optimal filter parameter as a function of distance and the range of filter center frequencies, that can be trusted; Theoretical Groups velocity dispersion curve was constructed for central area of Peru from 1D model velocity - P wave by Villegas (2009) using seismic record data obtained through the Mantaro seismic network. Figure 5 shows theoretical dispersion curves, the blue dotted curve was generated using the model before mention (6 layers). The red and grey dotted curve was generated by placing a layer of low velocity (1km/s) over the previous model, the first 500m thick and the second 400km thick respectively.

Figures 5 and 6 shows the results obtained in this study. Figure 5 we compare the dispersion curves theoretical and observed. We can distinguish two velocity groups, first formed by the CPA-TBL and QCH-TBL station pairs that have a velocity of about 1km/s, which coincides with the first theoretical curve calculated from layer thickness 500m. The second group then displays a speed of about 1.5km/s for station pairs RUN-TBL and PYC-TBL which coincide with the theoretical curve 400m thickness.

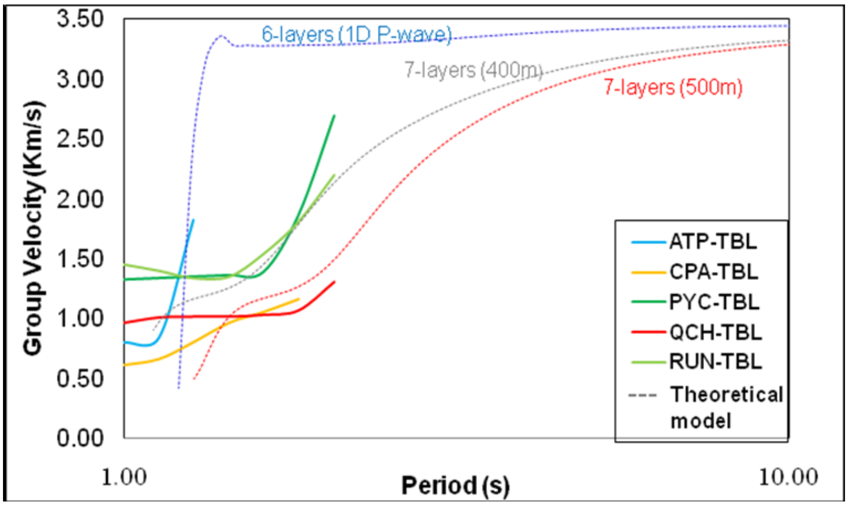

Figure 5. Temporal variability of dispersion measurement. Solid lines are from 6 month stacks observation for the station pairs ATP-TBL, CPA-TBL, PYC-TBL, QCH-TBL and RUN-TBL. The dot lines are theoretical group velocity dispersion constructed for the central area of Peru from 1D model velocity - P wave (Villegas, 2009).

Geological distribution of the station pairs way path shown in Figure 6. This result indicates that the thickness of the sedimentary layer in this area varies over short distances and direction of way path and this result is consistent because the Mantaro seismic network is located in a mountain area.

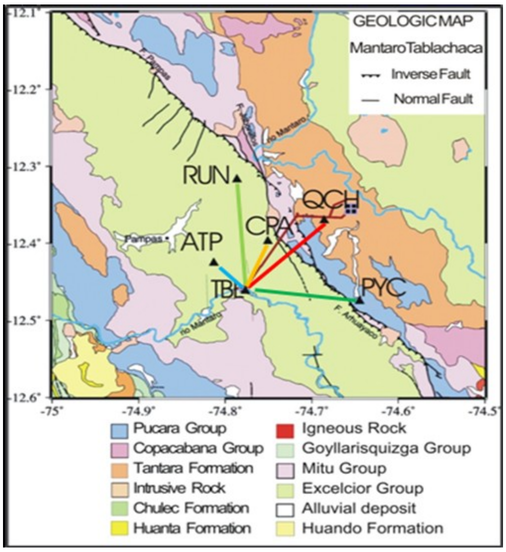

Figure 5. Station locations used in this study, color coded by the inter-station paths for the measurements shown in Figures 4 are indicated.

5. CONCLUSIONS

The time domain Green's function was estimated by the cross-correlation of continuous ambient seismic noise recordings at 7 short-period stations of the Mantaro seismic network in the central area of Peru, in the frequency band 0.1-1 Hz. for 21 station pairs (from January to June, 2010). We can extract Rayleigh wave component of seismic interferometry.

We obtained special variations of Rayleigh wave velocities in NE direction shows low velocities that in other directions.

Comparison between the group velocity dispersion curves obtained in this study and theoretical curves obtained for area, we can see this result suggests the existence of a sedimentary layer with approximated thickness of 500m in the way path the CPA-TBL and QCH-TBL station pairs and different thickness in others direction. This is coherent because this area is located in mountain area and the sedimentary layers are not distribution homogeneous..

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