Dynamic Characteristics of Soils Estimated Using Microtremors and Seismic Records in Lima Peru

D.L. Calderon, T. Sekiguchi &S. Nakai
Chiba University, Japan

F. Lazares & Z. Aguilar
National University of Engineering, Peru

SUMMARY:
The dynamic characteristics of vibration of the soils in Lima were defined by the estimation of the shear-wave velocity profiles. This estimation was carried out using microtremor and seismometer arrays. Microtremors showed to be a good method to estimate the velocity profiles; however, in some sites, owing to the low signal power in a range of periods, some of the estimated profiles showed high uncertainty, especially in the deep layers. In this context, seismic records, which have a high signal power, were considered to perform the analysis. The dispersion curves of microtremor and seismometer arrays measured at the same site were compared, and a good agreement was observed between both curves. In addition, a verification of the earthquake direction was also performed.

Keywords: Surface Waves, Microtremors, Seismic Records, Arrays, Shear-wave velocity profiles.

1. INTRODUCTION

This study was developed under the framework of the project “Enhancement of Earthquake and Tsunami Disaster Mitigation Technology in Peru” that is sponsored by the Japan International Cooperation Agency (JICA) and Japan Science and Technology Agency (JST).

One of the purposes of this project is the estimation of the dynamic characteristics of vibration of the soils in Lima city. This study becomes necessary in Lima since the city is located in the Pacific Ring of Fire, a seismically active zone that has been experiencing a seismic silence since more than thirty years ago. In addition, during this time of seismic silence, the city has undergone a large urbanization process, and areas that were not populated during the last earthquake are now urbanized. These reasons support the necessity to study the dynamic characteristics of vibration in the whole city.

The first step in order to study the characteristics of vibration is to estimate the soil velocity profile. A well-known method to do this is through the measurement of surface waves in arrays of microtremors. In this study, however, we have not only carried out microtremor array measurements but also a seismometer array measurement. We have compared the results of these two measurements in the Campus of the National University of Engineering in Lima, and verified the convenience of the seismometer array measurement.

2. MEASUREMENTS IN LIMA CITY

The area of study is the city of Lima, capital of Peru, situated in the central coast of the country, and bordered by the Pacific Ocean.

With the purpose to estimate the underground structure, surface waves from microtremors and seismic records were measured around Lima city. The measurement campaigns consisted of single-point microtremor measurements, and microtremor and seismometer array measurements. See Fig. 1 for the location of the microtremor arrays.

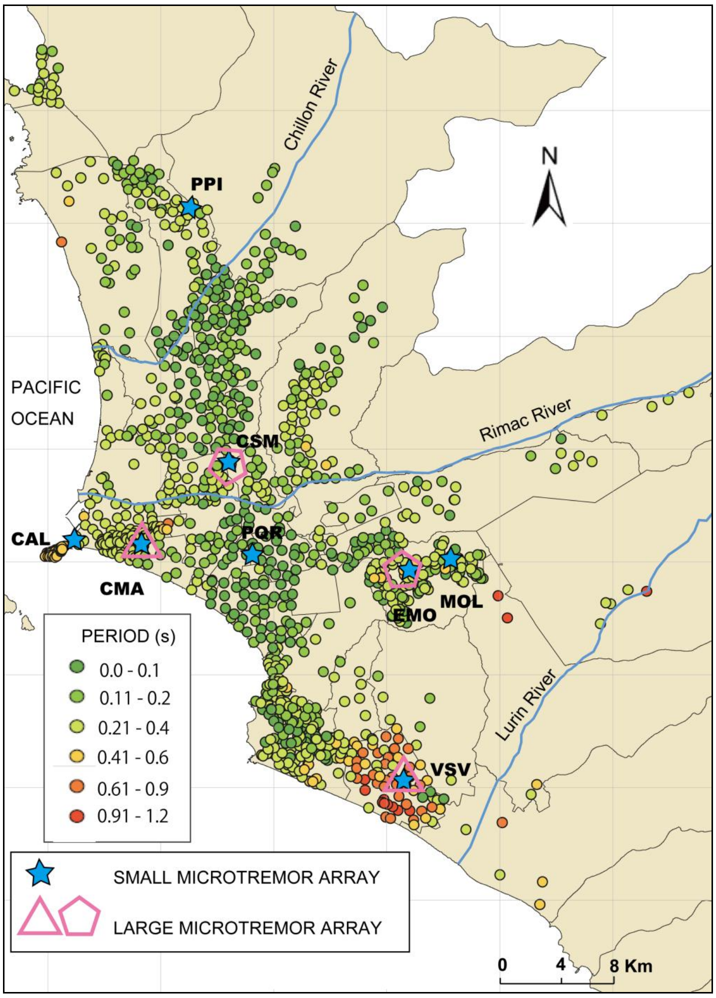

Figure 1. Location of the arrays over the single-point microtremor measurement map of Lima

3. ESTIMATED PROFILES

By using arrays of microtremors and seismic records, deep and shallow shear-wave velocity profiles were estimated. A total of eight profiles were found with the arrays of microtremors and one profile was found with the array of seismometers.

3.1. Arrays of Microtremors

In Calderon et al. (2011) the analysis to estimate the soil profiles, that is, the waves correlation process, the dispersion curve development, and the inversion, was extensively explained. Hence, in this study only the estimated profiles will be shown (Fig. 2).

As can be seen from the profiles, some sites in Lima, such as El Callao and Villa El Salvador have a deep profile extending to 600 m approximately; while in Cismid a very shallow profile of about 100 m was estimated.

3.2. Arrays of Seismometers

During the calculation of the dispersion curves from arrays of microtremors (Calderon et al, 2011), a range of periods from 0.5 to 1.5 s where the curve becomes unclear was identified, this problem was related to the low signal-to-noise ratio in Lima. As a way to overcome this limitation, the analysis of surface waves of seismic records which have a power higher than microtremors was attempted.

The methodology to analyze the surface waves of seismic records was the same as the used for the microtremors. However, surface waves have to be identified in the seismic records before to continue with the normal correlation analysis carried out in arrays of microtremors.

The case studied was the array of seismometers located in the campus of the National University of Engineering (UNI) in Lima. Four seismometers were installed there; the seismometers were placed in a shape close as much as possible to a circle, with a radius of 150m approximately (Fig. 3).

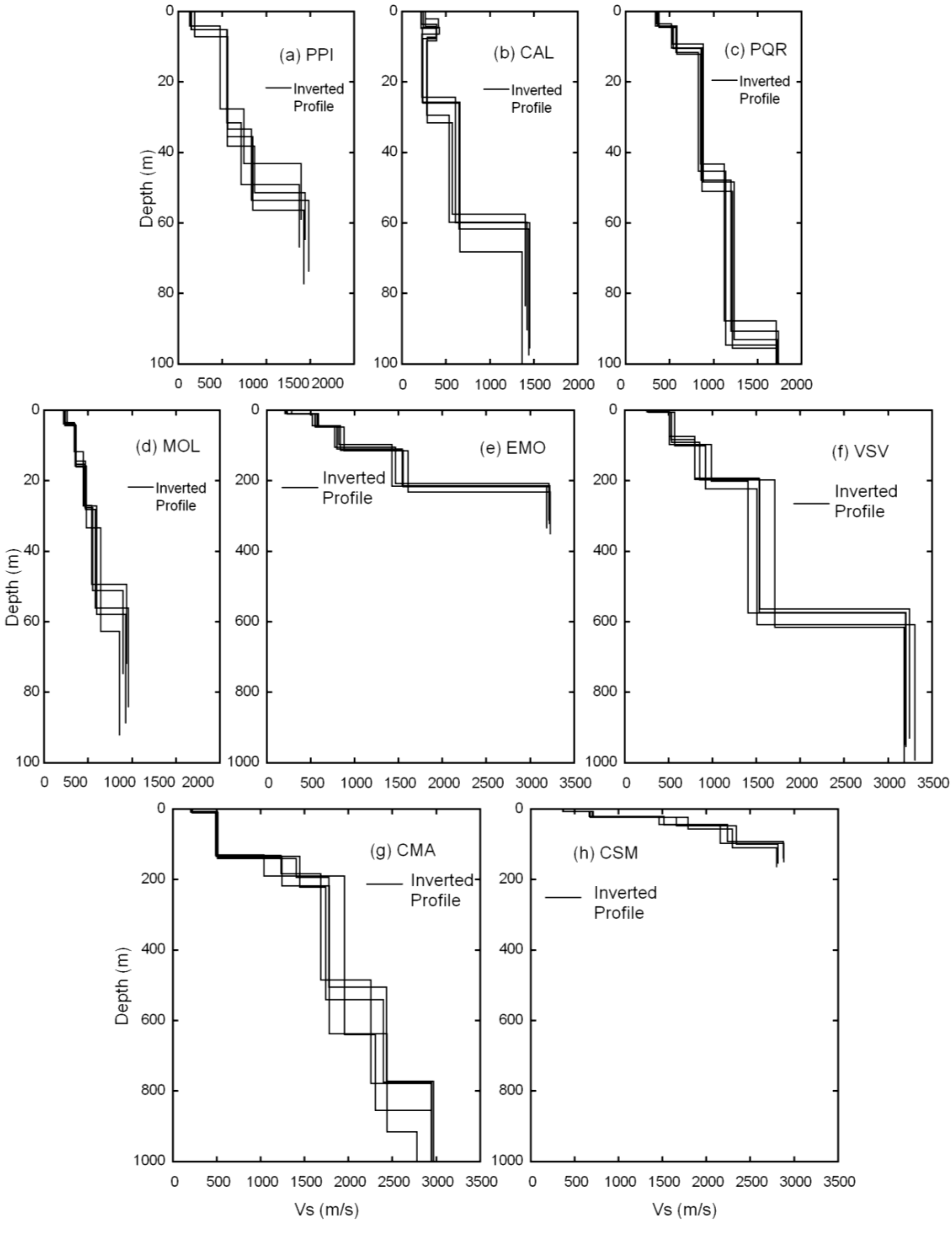

Figure 2. Estimated shear-wave velocity profiles

3.2.1. Seismic Records

Two earthquakes were considered in the analysis; these are the earthquake of August 24, 2011 (M_W 7.0), and the October 28 2011 (M_W 6.8). The location of this earthquake's epicenter is shown in Fig. 4. As it can be seen in Fig. 5, one earthquake was recorded by the four seismometers but the other earthquake was recorded by only three. In this figure, the direction of the earthquake epicenter is also shown.

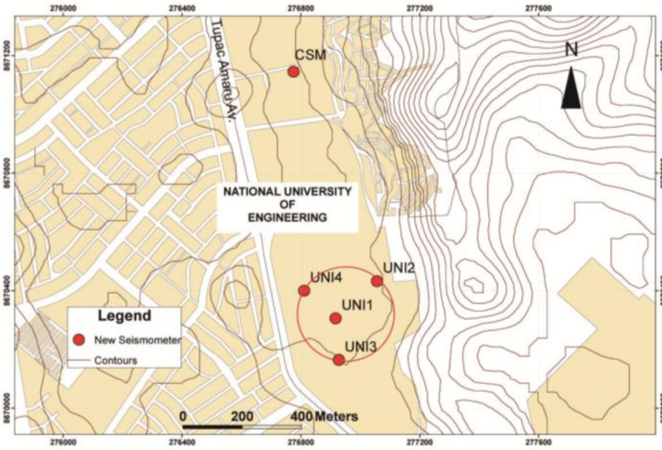

Figure 3. Location of the array of seismometers in the Campus of the University.

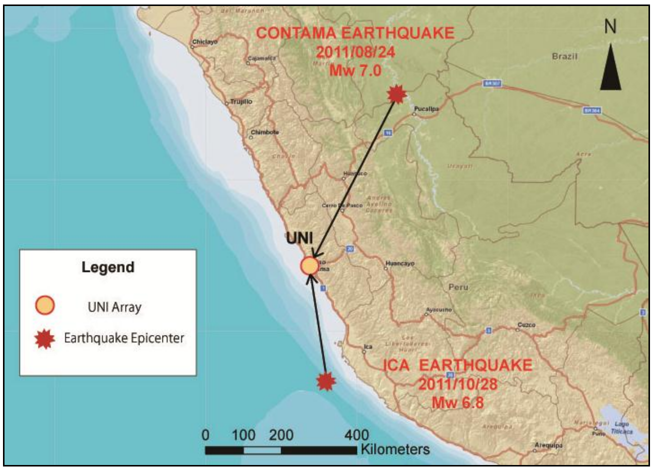

Figure 4. Location of the earthquake's epicenters used in this study

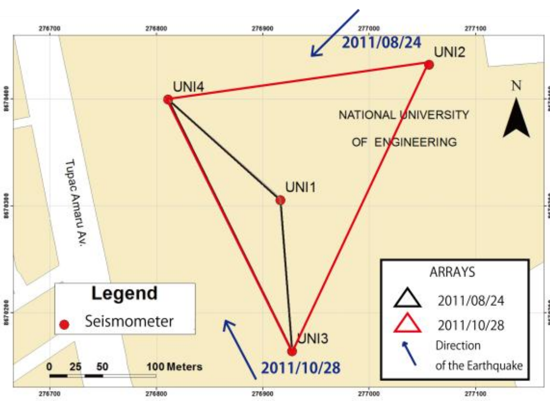

Figure 5. Arrays configuration with seismometers located at the National University of Engineering.

3.2.2. Selection of the Data

As an example of the data selection procedure followed for the arrays of seismometers at UNI, the time histories and non-stationary spectrum (Dziewonski et al, 1969) for the two earthquakes are plot and shown in Figs. 6 and 7.

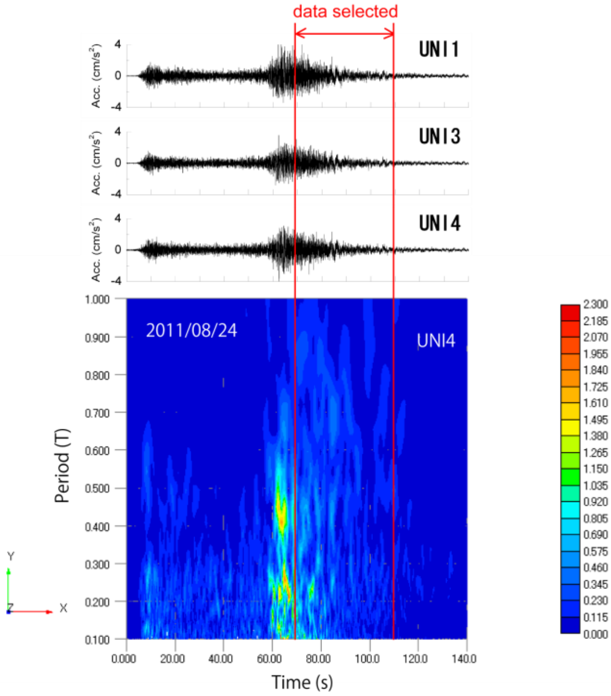

Figure 6. Time histories and non-stationary spectrum for the earthquake of August 24, 2011, at station UNI4.

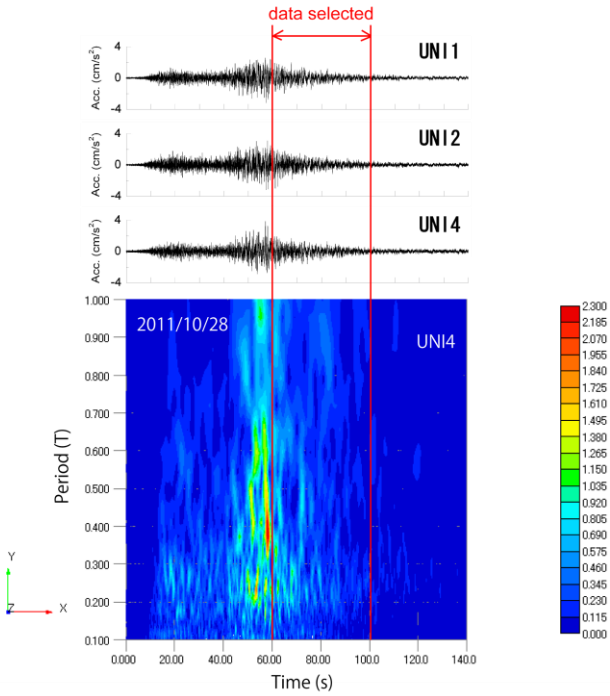

Figure 7. Time histories and non-stationary spectrum for the earthquake of October 28, 2011, at station UNI4.

By observation of the time-histories the arrival of the P and S waves can be observed and from the non-stationary spectrum the range of influence of the surface waves can be identified. In the case of the earthquake of August 24 (Fig. 6), the range of surface waves considered for calculation was from 70 to 110 seconds, and in the case of the earthquake of October 28, the range was from 60 to 100 seconds.

Once the data for calculation is identified, the cross-spectrum of each pair of seismometers is evaluated. In Fig. 8 (a) and (b) the correlations between two stations decrease from 360 to 0 degrees from about a period of 0.2 to 0.3 seconds. This is an indication of the possible range of periods of the dispersion curve, in which the phase velocity values are considered to be valid.

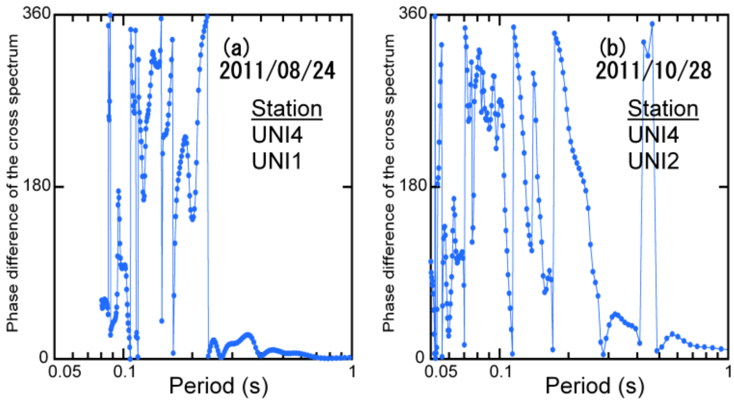

Figure 8. Cross-spectra between (a) stations UNI4 and UNI1, and (b) stations UNI4 and UNI2 for the earthquake of August 24, 2011.

The next procedure is to calculate the F-k power spectra (Capon, 1969). In Fig. 9 some F-k spectra for the array of August 24, and October 28, 2011 are presented. By comparison of the direction of the earthquake with the direction of the main peak in the F-k spectra, it is possible to verify the validity of the points that will form the dispersion curve.

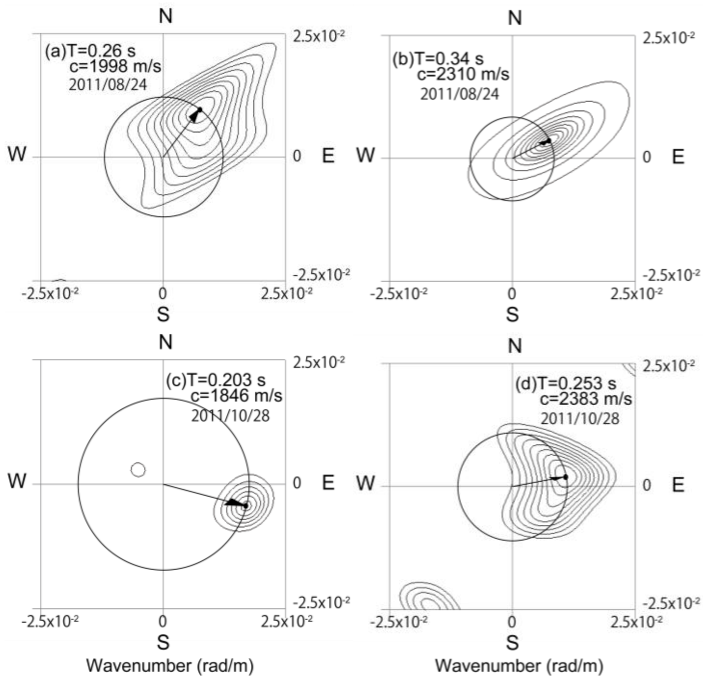

Figure 9. F-k spectra (a) and (b) for the earthquake of August 24, 2011, and (c) and (d) for the earthquake of October 28, 2011.

3.2.3. Calculation of the Dispersion Curve

Finally, the dispersion curve is calculated and shown in Fig. 10. In this figure not only the dispersion curve found from the arrays of seismometers is shown, but also the dispersion curve calculated from arrays of microtremors.

The continuity of the dispersion curves calculated by microtremor arrays and seismometer arrays is observed. This fact supports the use of seismometer arrays for dispersion curves calculation.

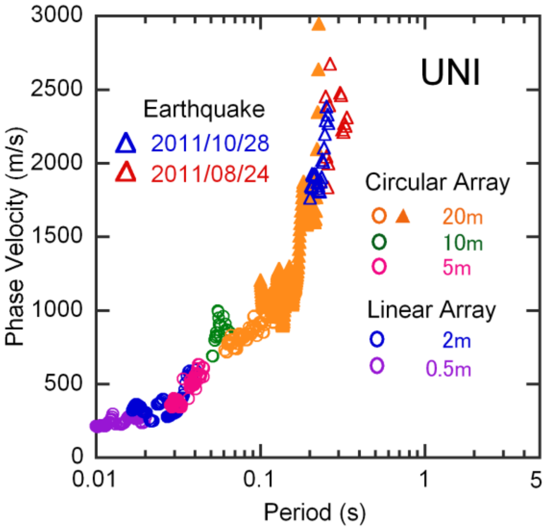

Figure 10. Dispersion curves from Arrays of microtremors and Seismometers (the circles refer to the F-k method, the filled triangle to the nc-CCA method in microtremors and the unfilled triangle to the F-k method in seismic records).

3.2.4. Inversion of the Dispersion Curve

The dispersion curve calculated from microtremor and seismometer arrays in UNI (Fig. 10) is inverted in order to estimate the shear-wave velocity profile. This process is carried out using the methodology of Genetic Algorithms (GA).

The search space is defined in Table 1, this model was determined taking as reference the profile estimated in Cismid (CSM) (Fig. 2 (h)) due to his short distance to UNI.

Table 1. Boundary Matrix for the Inversion Process

UNI		
Layer	Vs (m/s)	Thickness(m/s)
1	[200-500]	[1-10]
2	[500-750]	[15-30]
3	[800-1250]	[30-80]
4	[1500-2000]	[30-80]
Half-space	[2500-3000]	-

The inversion was carried out five times, and the number of generations and number of populations was twenty. In addition, the effect of higher modes was considered in the inversion process (Tokimatsu, 1995).

Fig. 11(a) compares the five computed dispersion curves with the target one (red circles).The computed ones approaches well to the target one, and an inversion trend is identify at about one second.

The estimated profiles are shown in Fig. 11 (b); it is observed that the variance in that first layers is small, but large for the last layer, even though, as an average the maximum depth can be considered to be 120 meters. Finally Fig. 11 (c) shows a good agreement between the observed and the computed H/V spectra.

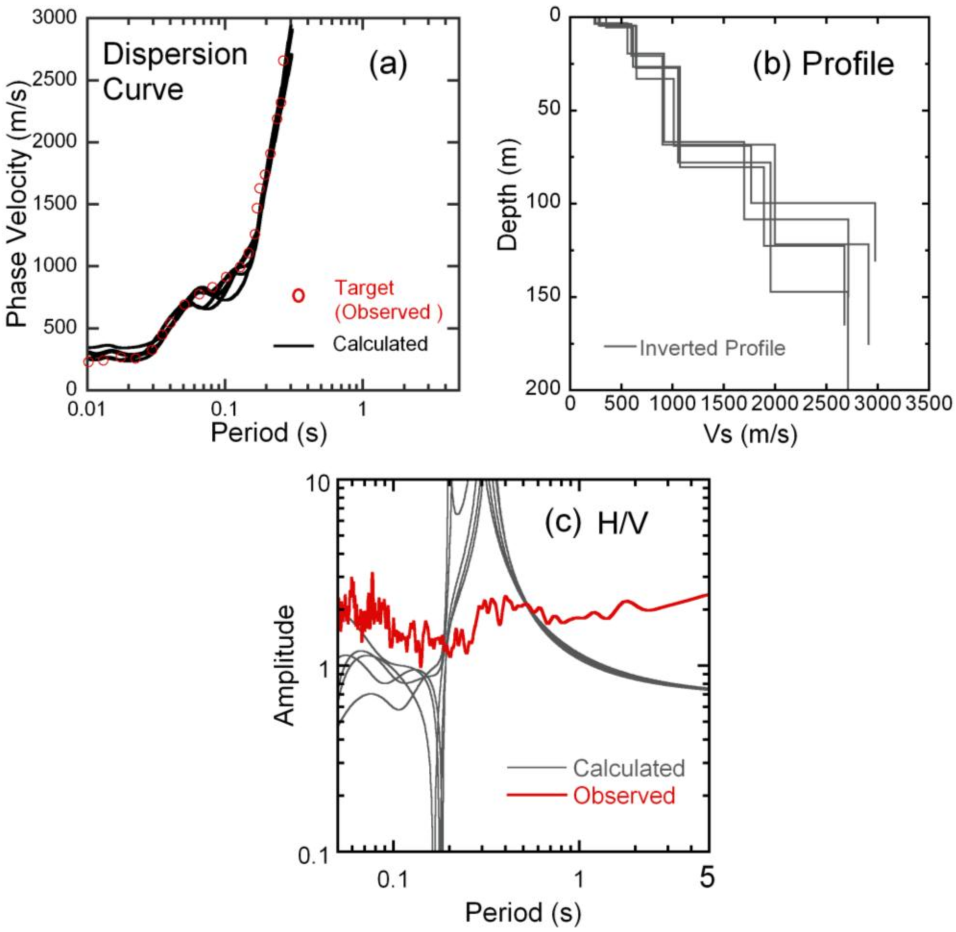

Figure 11. Target and calculated dispersion curves, (b) Inverted profiles, and (c) Observed and calculated H/V spectra, estimated at UNI near the array of seismometers.

4. DISCUSSION

The estimation of the shear-wave velocity profiles is necessary to estimate the amplification and other dynamic characteristics of vibration of the soils in Lima. Eight shear-wave velocity profiles with depths to hundreds of meters and sometimes to the seismic bedrock were estimated by performing microtremor arrays measurements.

In general, microtremors were good enough to estimate the deep soil velocity profiles in Lima, however, for the range of periods from 0.5 to 1.5 s, a low signal power was observed. As a result, some dispersion curves were not well-defined introducing uncertainty in the estimated profiles.

Due to the low signal-to-noise ratio found during the analysis of microtremors, the use of seismic records was proposed as an alternative because of the high power associated to seismic records.

An array of four seismometers was located in the Campus of the National University of Engineering. Two seismic events were analysed; these events were chosen because the location of their epicentres is far enough and the magnitude is large enough as to create surface waves in the University.

The dispersion curve of the seismometer array showed a continuous curve for the period range from 0.2 to 0.4 s. In the same place a microtremor array measurement was carried out in order to compare the results. A good agreement between the dispersion curves of microtremors and seismometer arrays was found.

Furthermore, through the F-k spectra showed in Fig. 9 the verification of the earthquake direction was carried out. In the case of the August 24th earthquake a slight variation in the direction of the earthquake was observed; the reason of this small change could be influenced by the Andes Cordillera. In the case of the earthquake of October 28th, the variation was more noticeable; the reason could be the propagation characteristics of the waves in this direction, however, more seismic events coming from that direction should be analysed in order to support this hypothesis.

5. CONCLUSIONS

Deep shear-wave velocity profiles that define the dynamic characteristics of vibration of the soils in Lima were estimated. The following conclusions were found from the microtremor and seismometer arrays measurements.

1. Microtremors were good enough to estimate the velocity profiles; however in some areas of deep profiles the low signal power generated uncertainty in the estimated profiles, such as in El Callao and Villa El Salvador profiles.
2. Seismic records were a good alternative to the low signal power of microtremors. The resulting dispersion curve was compared with the dispersion curve of microtremor arrays, and a good agreement was observed.
3. The earthquake epicentre direction was verified in the F-k spectra. While for the earthquake of August 24th 2011 the variation is small, it is more important for the earthquake of October 28th 2011. In order to understand this change of the direction more events coming from that direction should be analysed.

AKCNOWLEDGEMENT

We would like to express our gratitude to the Japanese Agencies JICA and JST for supporting the activities of this research and for providing new equipment such as new seismometers and sensors for microtremor measurements.

REFERENCES

Calderon, D., Lazares, F., Aguilar, Z., Sekiguchi, T., Nakai, S. (2011). Estimation of Deep Soil Profiles in Lima Peru. *Journal of Civil Engineering and Architecture* **5:7**, 618-627.

Capon, J. (1969). High-resolution frequency-wavenumber spectrum analysis. Proc. IEEE, **57:8**, 1408-1418.

Cho, I., Tada, T. and Shinozaki, Y. (2004). A new method to determine phase velocities of Rayleigh waves from microseisms. *Geophysics* **69**, 1535-1551.

Dziewonski, A. et al (1969). A technique for the analysis of transient seismic signals. *Bulletin of Seismological Society of America*. **59:1**, 427-444.

Tokimatsu, K. (1995). Geotechnical site characterization using surface waves. *The first international conference on earthquake geotechnical engineering IS-Tokyo*, 1333-1368.