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Analysis of Soil Periods through Strong Motion Records by the Horizontal-To-Vertical Spectral Ratio Method in the District Of Chorrillos, Lima, Peru

Carlos Huamán-Binda[1], Juan Paulino-Solano[2], Carmen Ortiz-Salas[3]
Universidad Peruana de Ciencias Aplicadas
Av. Primavera 2390, Lima, Perú
[1]U201513191@upc.edu.pe; [2]U201912346@upc.edu.pe; [3]pccicort@upc.edu.pe

***Abstract* -** This article presents the results of the analysis of predominant soil periods using the spectral ratio (HVSR) methodology, based on strong motion records at seismic stations in the Chorrillos district, Lima, Peru, a high seismicity area at the western edge of South America. The district contains fine soil deposits, different to the coarse alluvial conglomerate of Lima downtown. The seismic stations are located on sandy soils interspersed with clay strata, moderately compact to dense aeolian sands of variable thickness, and silty-clay soils followed by peat with intercalations of silty sand, according to the existing seismic microzonation. The results indicate that the HVSR method can be very useful to determine the predominant soil periods, which represent the soil profile on which the strong motion record has been recorded. These soil periods, which are in the range of 0.21 s to 0.49 s, are compared with those determined from previous microtremor measurements and inferred from geophysical tests of shear wave velocity, obtaining a good correlation. Also, site classification of the soil profile at these stations is verified according to the Peruvian Seismic Code.

***Keywords*:** soil period, HVSR, Vs_{30}, soil profile, seismic amplification

1. Introduction

In the western edge of South America, the Nazca tectonic plate moves beneath the South American plate, causing seismicity and affecting geodynamics and geomorphology of the Peruvian territory. This tectonic activity, called plate subduction, is the main cause of the destructive earthquakes that have occurred near the coast of Peru [1]. The earthquakes that have affected the city of Lima have revealed that there is a site effect in the ground seismic response, that is, seismic amplification occurs in specific areas of the city, due to the presence of soft soils with long periods [2]. The seismic microzonation of Lima city has advanced significantly through geophysical and geotechnical tests to characterize soil profiles and its seismic response [3]. However, relatively recent strong motion networks, and microtremor tests to measure environmental noise, provide new information on the predominant soil period and the seismic amplification, calculated by the method of horizontal-to-vertical spectral ratios (HVSR) [4,5], which will improve knowledge of the seismic response of soils in the city of Lima.

Several researchers have applied the HVSR method to strong motion and microtremor records, to calculate the predominant site period and the amplification ratio; furthermore, these soil periods along with measurements of Vs30, have been used to classify the site according to seismic codes, and to propose microzonation maps. Thus, HVSR method was used in [6] to obtain a simple model of site amplification, and the fundamental frequency, in the strong motion stations of the extensive seismic network of Iran. In [7] the degree of nonlinear response (DNL), a parameter calculated by integrating the logarithm of the ratio of strong and weak motion HVSRs, with respect to frequency, was proposed. In [8] the HVSR method in a region of Turkey was applied to estimate shear wave velocity and soil stiffness. Finally, other authors such as [9] in Uzbekistan, [10] in Colombia, or [11] in Mexico, applied the HVSR method to strong motion records and microtremors for seismic microzoning of cities or territories.

This article proposes to use the HVSR technique to process strong motion records at seismic stations located in the district of Chorrillos, Lima, Peru, to calculate the predominant soil period, comparing these periods with those previously determined using microtremors tests, and also to confirm the site soil profile according to Seismic Standard

E.030 of the Peruvian National Building Code, by reviewing shear wave velocity measurement tests carried out near the seismic stations.

As a result of the research, the predominant soil periods were analysed in three strong motion stations of the Chorrillos district, finding differences between these soil periods, which indicates different soil profiles in each station. These periods were compared with those previously obtained through microtremor tests carried out near the stations, obtaining a good correlation, and with the soil periods inferred from the available Vs_{30} values. Soil profile at each station is defined in accordance with the Peruvian seismic code.

2. Methodology and Tools

2.1 Strong Motion Records

The strong motion records for this research were collected from the CISMID (REDACIS) website [12], which is freely available. The strong motion records are from the seismic stations in the Chorrillos district, which belong to the SENCICO (SC), CISMID (CM), and Postgrado FIC-UNI (PG) station networks. The information about these stations is presented in Table 1, and their location is shown in Fig. 1.

Table 1: Strong motion stations at Chorrillos district.

Network	Station	Latitude	Longitude
SC	SCCHO (Centro de Formación SENCICO)	-12°10’45.48”	-77°0’30.24”
CM	UPCVI (Universidad Peruana de Ciencias Aplicadas – Campus Villa)	-12°11’52.08”	-77°0’25.92”
PG	BRISA (Urbanización Las Brisas de Villa)	-12°13’0.84”	-76°59’35.16”

Fig. 1: Location of seismic stations in Chorrillos district. Reference: Google Earth©

The seismic records were selected from the database considering those with magnitude equal to or greater than M 4.0. These records are presented in the following tables, with information on the date of the event, geographical coordinates, magnitude M and epicentral depth.

Table 2: Strong motion records at SENCICO station.

Date	Latitude (°)	Longitude (°)	Magnitude M	Depth (km)
7/01/2022	-11.96	-76.88	5.6	116
16/07/2022	-11.09	-77.68	4.0	68
19/07/2022	-12.84	-76.16	4.8	79
29/07/2022	-11.81	-77.45	4.1	60
11/08/2022	-13.4	-74.99	4.8	106
14/08/2022	-12.36	-76.98	4.3	67
8/09/2022	-16.26	-73.51	5.6	29
13/09/2022	-11.09	-76.69	4.1	113
19/06/2023	-13.09	-76.78	4.5	49
8/08/2023	-11.88	-77.42	4.0	56
4/10/2023	-12.26	-76.11	4.6	102
24/10/2023	-13.25	-76.99	5.0	31

Table 3: Strong motion records at UPC Campus Villa station.

Date	Latitude (°)	Longitude (°)	Magnitude M	Depth (km)
15/12/2022	-11.43	-76.32	4.8	20
16/12/2022	-11.42	-76.34	4.8	18
24/12/2022	-12.65	-77.1	4.0	38
19/06/2023	-13.09	-76.78	4.5	49
2/07/2023	-12.64	-76.3	4.9	125
8/08/2023	-13.05	-76.95	4.2	40
4/10/2023	-12.26	-76.11	4.6	102
24/10/2023	-13.25	-76.99	5.0	31

Table 4: Strong motion records at Brisas de Villa station.

Date	Latitude (°)	Longitude (°)	Magnitude M	Depth (km)
30/12/2022	-15.14	-76.0	5.8	31
15/04/2023	-13.51	-77.15	4.3	34
19/06/2023	-13.09	-76.78	4.5	49
8/08/2023	-13.05	-76.95	4.2	40
24/10/2023	-12.26	-76.11	4.6	102

2.2 Tools

The free software SeismoProcessor [13] was used to process the seismic records. This program allows viewing, modifying and processing seismic and microtremor records, performing baseline correction and signal filtering, and obtaining the time-history of accelerations, velocities and displacements, Fourier amplitude spectrum, elastic and inelastic response spectrum, and the transfer function.

2.3 Strong motion data processing

The records corrected by baseline and bandpass filter (0.1-25 Hz) of accelerations, velocities and displacements were obtained in the E-W, N-S and Vertical components of the selected earthquake records. In addition, the Fourier spectra of each component and the transfer function, or spectral ratio, were obtained by dividing the ordinates of the geometric average of the horizontal components and the ordinates of the vertical component, to determine the predominant soil period according to the HVSR method.

3. Results

The following figures present the results of the corrected records, from one of the earthquakes processed at the SENCICO station on 07/01/2022.

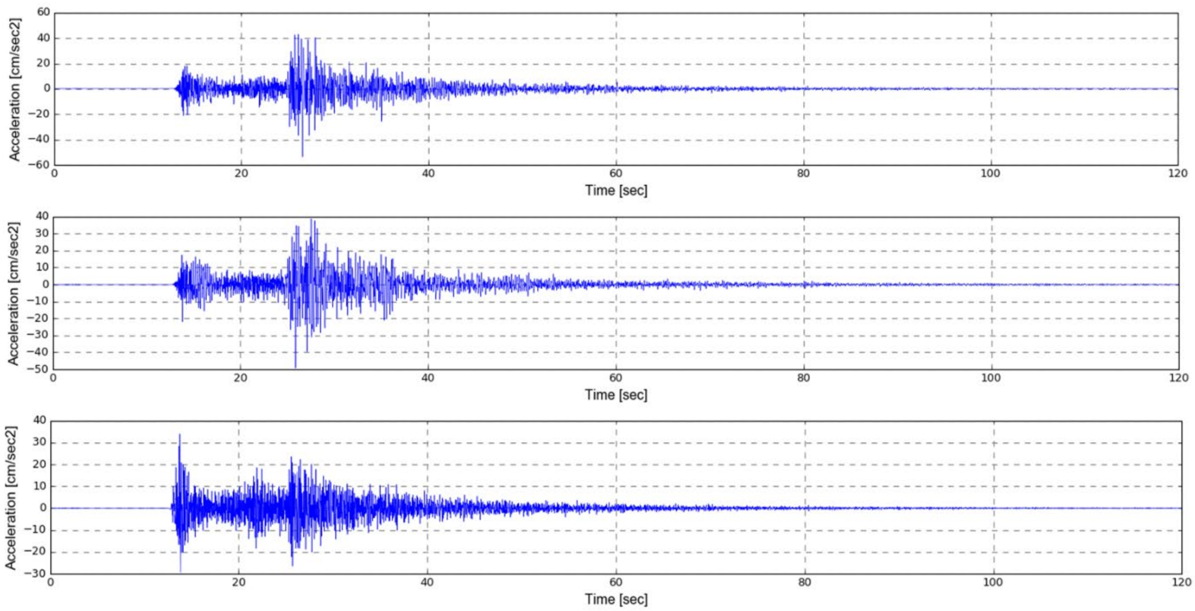

Fig. 2: Corrected E-W, N-S and Vertical acceleration records from 07/01/2022 earthquake at SENCICO station.

Processing of all the records from the SENCICO by the HVSR spectral ratio methodology station allowed us to obtain an average curve of the HVSR spectral ratio, which is shown below.

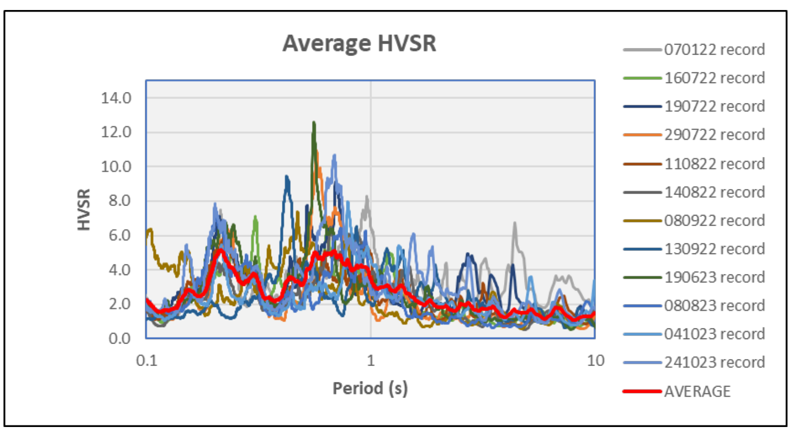

Fig. 3: Average spectral ratio of the SENCICO Station strong motion records

From Fig. 3, the predominant soil period at the SENCICO Station is 0.21 s; however, another characteristic period is observed at 0.69 s. Similar amplification ratios are observed for these periods.

Similarly, the earthquakes recorded at the UPC Campus Villa Station were processed, and the average spectral ratio of all the records, HVSR, was obtained, as seen in the following figure.

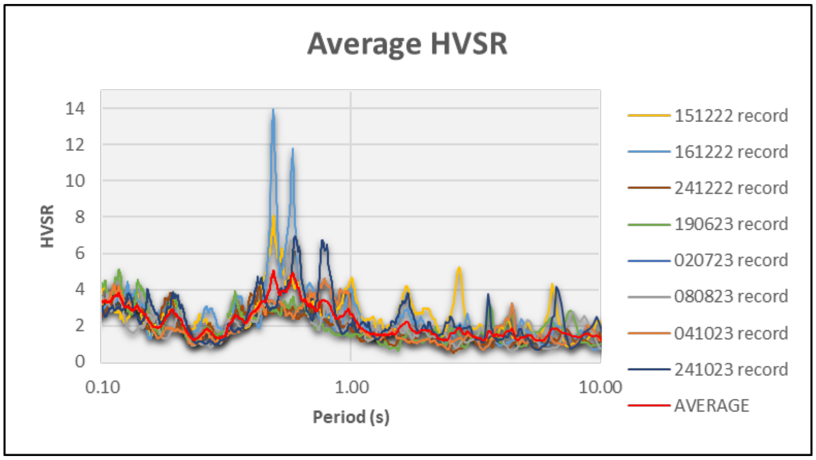

Fig. 4: Average spectral ratio of the UPC Campus Villa Station strong motion records

From Fig. 4, the predominant soil period at the UPC Campus Villa Station was obtained as 0.49 s; however, another soil period of 0.58 s is also observed. Similar amplification ratios are observed for these periods.

Finally, the earthquakes recorded at the Brisas de Villa Station were processed, and the average spectral ratio of all records, HVSR, was calculated, as seen in the following figure.

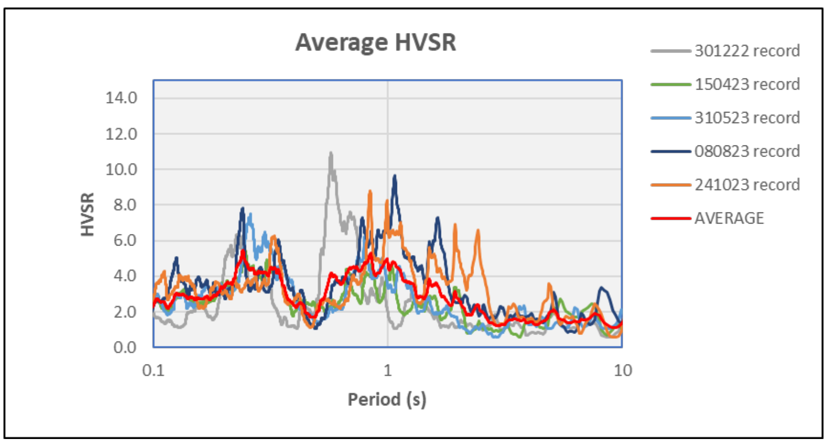

Fig. 5: Average spectral ratio of the Brisas de Villa station strong motion records

From Fig. 5, a value of predominant soil period at the Brisas de Villa station of 0.24 s was obtained; however, another soil period of 0.85 s is also observed. Similar amplification ratios are observed for these periods.

4. Analysis of results

The results of soil periods obtained by processing earthquakes at the SENCICO, UPC Campus Villa and Brisas de Villa stations in Chorrillos, using the HVSR spectral ratio method, indicate that the predominant soil period at the SENCICO station is 0.21 s, at the UPC Campus Villa station is 0.49 s, and at the Brisas de Villa station is 0.24 s. However, in each of these stations other similar peak amplification values at longer periods also occur.

According to the location of these stations referred to the seismic microzonation of the Chorrillos district [3], the SENCICO station site corresponds to sandy soils interspersed with clay strata, with a thickness of less than 10 m. The UPC Campus Villa station site corresponds to medium dense to dense aeolian sands of variable thickness. The Brisas de Villa station site is superficially made up of silty-clay soils of medium compactness, followed by peat with intercalations of silty sand.

On the other hand, the MASW and microtremor geophysical tests, carried out by [3], indicate that the weighted average shear wave velocity in the first 30 m from the surface (Vs_{30}), is 415 m/s at a site close to the SENCICO station, and the predominant period measured by microtremors is 0.17 s. In the vicinity of the UPC Villa station, Vs_{30} is 304 m/s, and the predominant period for microtremors is 0.36 s to 0.49 s. For the Brisas de Villa station, Vs_{30} is 330 m/s and microtremor tests give a predominant period of 0.26 s to 0.33 in nearby sites.

Table 5 presents a comparison between the previous parameters and summarizes the predominant soil periods obtained by the spectral ratio after processing the recorded earthquakes, the predominant soil periods obtained by microtremors, and the predominant soil periods obtained by the expression T = 4H/Vs, where T is the period of the soil, H is the thickness of the soil profile, 30 m for this case, and Vs is the velocity Vs_{30} measured at near sites to the station.

Table 5: Comparison of predominant soil periods at seismic stations of Chorrillos district

Station	Vs_{30} (m/s)	Predominant period (s)		
		T (seismic records)	T (microtremors)	T = 4H/Vs
SCCHO	415	0.21	0.17	0.29
UPCVI	304	0.49	0.36 / 0.49	0.39
BRISA	330	0.24	0.26 / 0.33	0.36

5. Conclusions

The HVSR analysis for the seismic records of earthquakes recorded at strong motion stations in Chorrillos district present predominant soil periods of 0.21 s, 0.49 s, and 0.24 s, for the SENCICO, UPC Campus Villa and Brisas de Villa stations, respectively. However, in all cases a second amplification peak occurs, similar to the first, at longer periods.

These multiple peaks would indicate that the soil profile is not only made up of one stratum, but instead could contain other soil strata of greater or lesser stiffness.

The comparison of predominant soil periods obtained by processing strong motion records and microtremor records at nearby sites, shows a good correlation between these periods, as presented in Table 5. The differences between soil periods obtained from seismic records and microtremors would be caused by the nonlinear behaviour of the soil under greater deformations during earthquakes.

With respect to the soil profile according to Seismic Standard E.030 of the Peruvian Building Code (RNE), the soil profile at the SENCICO station corresponds to a type S2 profile, based on its shear wave velocity Vs_{30}, with a predominant period of 0.21 s, while for the UPC Villa station, the soil profile would also be S2, based on the Vs_{30} value, although the soil period obtained by the spectral ratio method is 0.49 s. For the Brisas de Villa station, the soil profile would be also S2 type, based on the Vs_{30} at near location.

The processing of strong motion records at seismic stations in the district of Chorrillos, Lima, by the HVSR spectral ratio method, demonstrates consistent results for the same station, the average of which defines the predominant soil period at the site.

It is recommended to continue processing the data from strong motion records and comparing them with data from microtremors and geophysical tests, performed at the same site, to characterize the predominant period of the soil and confirm the soil type according to seismic codes.

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