SOIL PERIODS FOR CENTER OF PUEBLA CITY, MEXICO

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SUMMARY:
Fundamental soil periods were obtained from environmental noise records; 94 points at “Barrio de Santiago” and 268 at Historic Center of Puebla City. It was used an accelerometer Kinemetrics Altus K2. The records were processed by H/V spectral ratios technique, using SAC2000 software. To complete results, additional geotechnical information was used to determinate soil behavior to define an isoperiods map. This information will include in a detailed microzonation map of Puebla City.

Keywords: noise record, H/V spectral ratio, soil periods, seismic microzonation

1. INTRODUCTION

Mexico has been a very important country in the seismic activity. The subduction of the Cocos plate and the North American plate are the principal elements in this topic (*e. g*. 19.09.1985; Mc = 8.1). The principal cities in Mexico have been affected by this kind of activity. The damages have caused death and economic destabilization.

Puebla is located in the center of Mexico, and clasifided in the B Zone of the Seismic Regionalization (CFE, 1993). In spite of the fact that the local seismic activity it is unusual, Puebla has been affected by the seismic activity from North American plate (*e. g.* 1999 Jun 15th, Tehuacán).

In order to find the type of ground of Puebla City, there had made different studies. The studies of Ruiz *et al*., (1992), used the environmental vibration technique to record signs which were processed by spectral ratios H/V. The resulted obtained was an isoperiod map.

Then, Chávez-García *et. al.*, (1994) compiled and applied different techniques; but they have not had recover enough information to make an isoperiod map.

Avilés (1999) by geotechnical information calculed the velocity of the shear waves. As result he defined three ground zones for Puebla City.

Ferrer (2000) recorded noise at forty points distributed in Puebla City by using the environmental vibration technique. The records obtained were preceded with the Nakamura’s Technique. His result was captured in a comparative table with the previous score. The final result demonstrated that any of the studies had a similarity even they were very different each other.

2. METHODOLOGY

2.1 Registration Environmental Noise Sites

Due to the discrepancy of the results described by Ferrer (2000), we decide to obtain numerous noise records in Puebla City, practically at each single corner of the urban trace. However, the size of the city requires an extensive study and much time. For that reason, we decide to concentrate our efforts in the Historical Center and Santiago area of Puebla City (see Figures 1 and 2).

In this study we processed the environmental noise records used by Lermo *et al.*, (2006) and others recorded in a second campaign. In order to establish the fundamental ground periods, we used the H/V spectral ratios method for each site where noise were recorded, 268 records from Historical Center and 94 from Santiago area were used in our study.

We obtained two records of 90 s in each site, using an accelerometer Kinemetrics Altus K2, 1G, with orthogonal triaxial sensors (Longitudinal, L; Transversal, T; Vertical, V), with broad band from 0.01 to 50 Hz. Its longitudinal component (L) was lined up from north to south around the urbanized area.

2.2 Processing Signals

Each record was processed through *Seismic Analysis Code* (SAC2000), which divided two windows to 45 s also calculating for each one the Fast Fourier Transform (FFT). After that, we calculated the spectral ratio H/V (Nakamura, 1989) corresponding the same number of windows which were averaged geometrically. Through the spectral ratios were determined the predominant frequency from each site (Figures 3 and 4, Table 1 and 2).

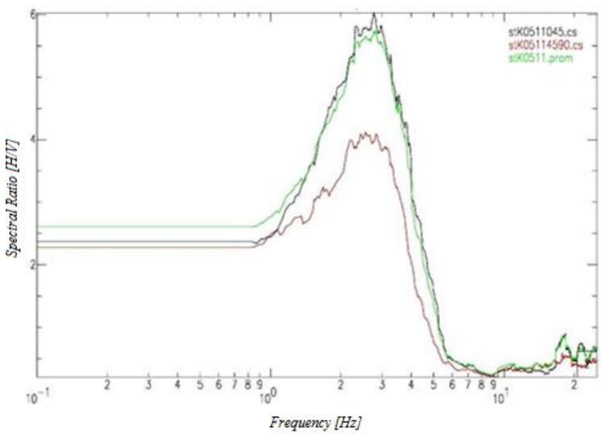

Figure 1. Spectral ratio [H/V], N-S windows of 45 s. 10 Poniente Street and 29 Norte Street

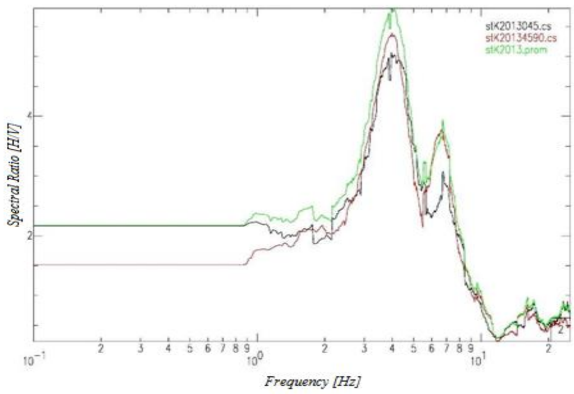

Figure 2. Spectral ratio[H/V], E-W direction, windows of 45 s. Reforma Avenue and 23 Sur Street

Table 2.1. Periods obtained for Santiago area

POINT	LOCATION	N-S (s)	E-W (s)
1	ARGENTINA - 14 PTE	0.23	0.22
2	10 PTE - 29 NTE	0.36	0.36
3	29 NTE - 6 PTE	0.35	0.33
4	DIAGONAL DEFENSORES DE LA REPUBLICA - REFORMA	0.21	0.24
5	DIAGONAL DEFESORES DE LA REPUBLICA - 10 PTE	0.49	0.36
6	REFORMA- 23 SUR	0.24	0.24
7	21 SUR- 13 PTE	0.11	0.11
8	23 SUR- 21 PTE	0.15	0.15
9	19 SUR- 17 PTE	1	1
10	17 NTE- 12 PTE	0.19	0.2
11	15 NTE- 10 PTE	0.22	0.22
12	15 NTE- 6 PTE	0.17	0.18
13	15 SUR - 15 PTE	1	1
14	15 SUR- 19 PTE	1	1
15	SN MARTIN TEXMELUCAN-PROLONGACION REFORMA	0.21	0.21
16	TEZIUTLAN SUR- TULANCINGO	0.11	0.12
17	2 PTE- BLVD NORTE	0.32	0.32
18	DIAGONAL 19 PTE- 21 PTE	0.11	0.11
19	DIAGONAL 19 PTE- 19 PTE	0.13	0.13
20	25 SUR- AV 9 PTE	0.12	0.11
21	23 SUR- 5 PTE	0.11	0.11

Table 2.2. Periods obtained for the Historical Center

POINT	LOCATION	N-S (s)	E-W (s)
1	16 NTE Y 6 OTE	0.23	0.35
2	16 NTE Y 7 OTE	0.33	0.3
3	14 SUR Y 13 OTE	0.28	0.32
4	10 SUR Y 13 OTE	0.36	0.29
5	10 SUR Y 15 OTE	0.24	0.23
6	10 SUR Y 17 OTE	0.33	0.3
7	6 SUR Y 25 OTE	0.42	0.48
8	12 NTE Y 14 OTE	0.39	0.21
9	26 OTE Y 16 NTE	0.15	0.18
10	13 SUR Y 13 PTE	0.4	0.26
11	13 SUR Y 11 PTE	0.46	0.49
12	PASEO BRAVO 13 SUR ENTRE 7 Y 9 PTE	0.44	0.36
13	13 SUR Y 3 PTE	0.21	0.21
14	13 NTE Y 8 PTE	0.23	0.19
15	13 NTE Y 10 PTE	0.29	0.38
16	11 NTE Y 12 PTE	0.15	0.17
17	11 SUR Y 5 PTE	0.38	0.36
18	9 SUR Y 13 PTE	0.56	0.58
19	9 SUR Y 11 PTE	0.26	0.25
20	9 SUR Y 9 PTE	0.29	0.26
21	9 SUR Y 7 PTE	0.29	0.2
22	7 SUR Y 5 PTE	0.33	0.38
23	7 NTE Y 2 PTE	0.81	0.87
24	7 NTE Y 4 PTE	0.29	0.31
25	7 NTE Y 8 PTE	0.34	0.3
26	9 NTE Y 16 PTE	0.32	0.36
27	14 PTE Y 13 SUR	0.19	0.23
28	AV. REFORMA Y 5 NTE	0.5	0.45
29	3 SUR Y 3 PTE	0.51	0.47
30	3 SUR Y 5 PTE	0.38	0.42

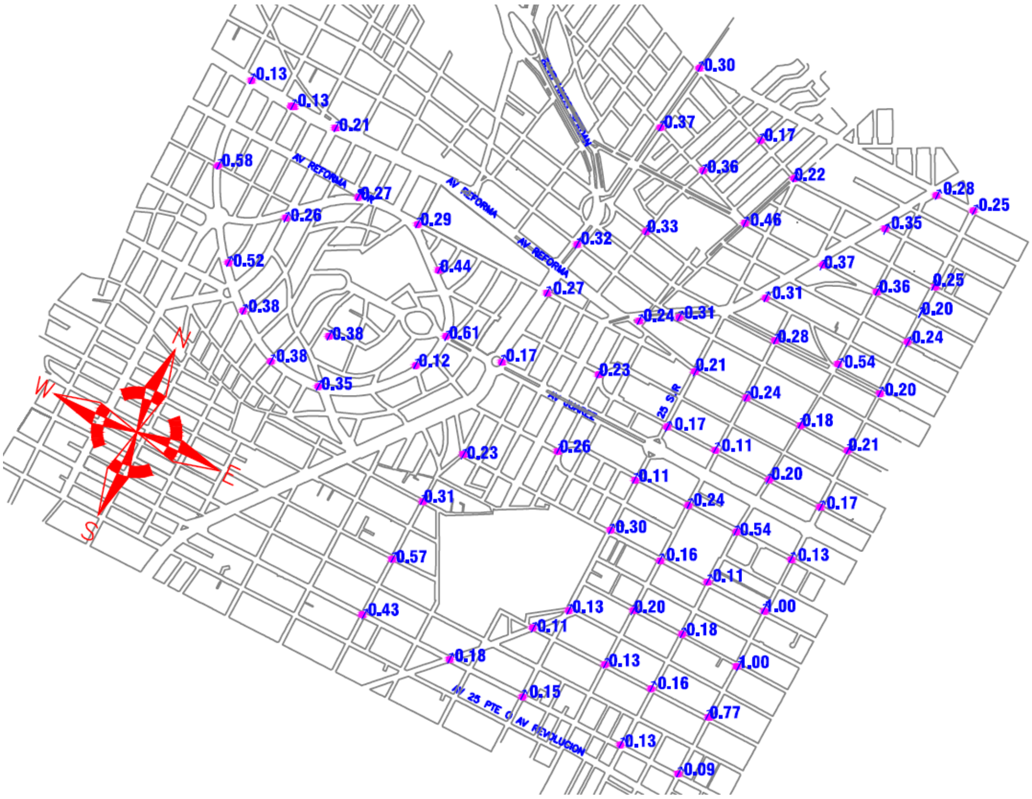

Figure 3. Periods (s) for Santiago area

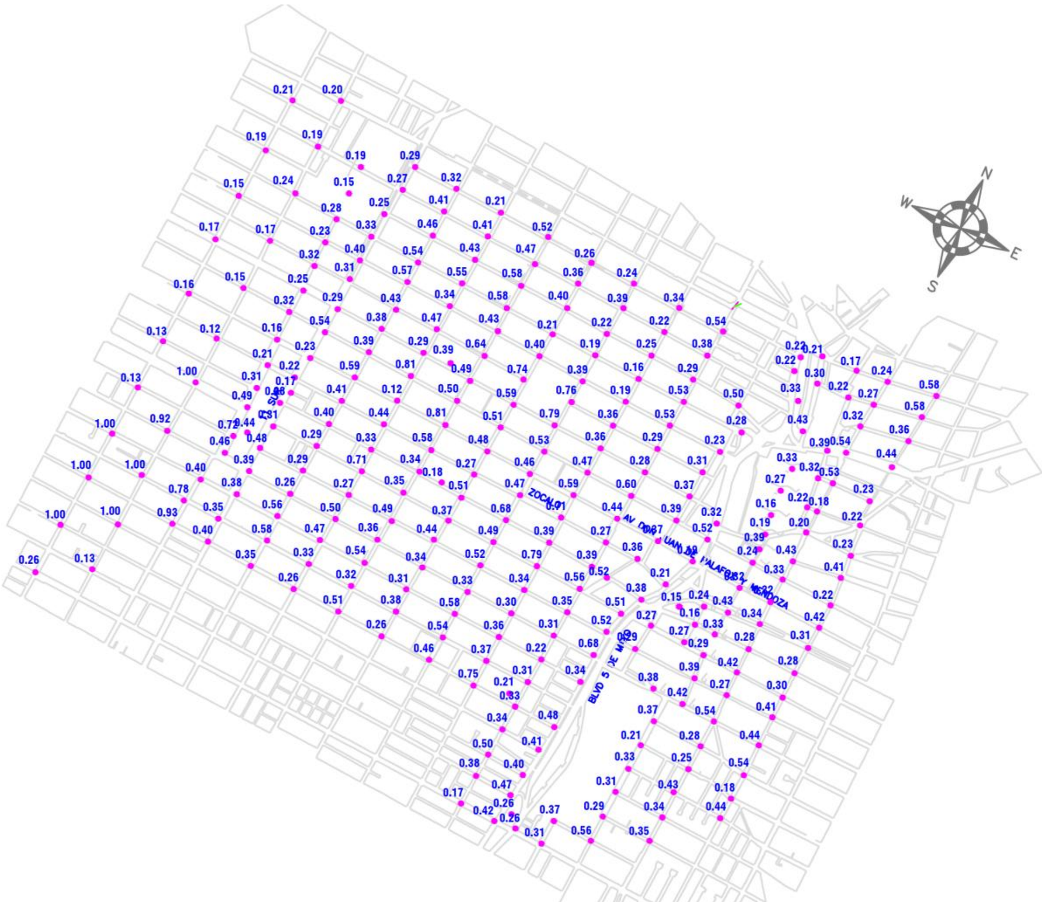

Figure 4. Periods (s) for the Historical Center of Puebla City

3. ANALYSIS AND INTERPRETATION OF RESULTS

In order to compare our results with those obtained in previous studies; we have prepared a table showing the corresponding values. Unfortunately, there is not enough detailed information from the previous studies to compare all the results.

Table 3.1. Comparison of result obtained in different investigations

Location	*Ferrer T(s)*	*Ruiz T(s)*	*Chávez T(s)*	*TS* T(s)*	*Percentage difference TS*-Ferrer*	*TS*-Ruiz*	*TS*-Chávez*
1103, 21 Sur St. (U.P.A.E.P.)	*1.94*	*0.72*	*-*	*0.18*	*91%*	*75%*	*-*
6 Poniente and 27 Norte St. (Atrás Hospital San Alejandro)	*2.19*	*0.73*	*0.3*	*0.33*	*85%*	*55%*	*10%*
13 Sur and 5 PonienteSt. (P. Bravo)	*1.47*	*0.72*	*2.2*	*0.31*	*79%*	*57%*	*86%*
3 Oriente St.., between 16 de Septiembre y 2 Sur St. (Main plaza)	*1.55*	*0.72*	*-*	*0.71*	*54%*	*1%*	*-*
Col. La Paz (Teziutlán Sur St. and Chignahuapan Av.)	*0.93*	*0.3*	*0.7*	*0.29*	*69%*	*3%*	*59%*

**TS: This Study*

Table 3.1 shows the comparison between different studies. At 21 Sur St. and 11 Poniente St. site, obtained periods are completely different for each study. At 6 Poniente St. and 27 Norte St., is different between Ferrer (2000) and Ruiz (1992); however with Chávez *et al.*, (1994) the period is very similar. Paseo Bravo periods are different from each other. In addition, period at the main plaza for Ruíz (1992) and the present study is the same period, but different with Chávez-García *et al.*, (1994). Finally, at Teziutlán Sur Av. and Chignahuapan Av., there are differences between obtained periods despite there is no difference with Ruiz (1992).

Analyzing the map with the dominant period obtained for the Historical Center (see Fig. 4), there is some homogeneity between the results which are not variable in the adjacent points (Corner to corner). For this reason it is possible to classify the zone for different periods which are similar from each other (see Fig. 5).

Contrasting, there are an important number of records where the periods are not similar with the adjacent points, probably 2D effects. However, there is no geotechnical evidence of this affirmation. Other possibility of this difference could be caused by poor location of the accelerometer. In order to understand the differences in continuous sites, the geotechnical area was reviewed.

Table 3.2 Comparison of results in the Historical Center

Location	**Period (s) N-S**	**Period (s) E-W**
3 ote and 2 sur	*0.57*	*0.71*
5 ote and 2 sur	*0.22*	*0.35*
7 ote and 2 sur	*0.77*	*0.79*
9 pte and 7 sur	*0.27*	*0.20*
7 pte and 7 sur	*0.73*	*0.71*
5 pte and 7 sur	*0.38*	*0.33*
4 pte and 11 norte	*0.29*	*0.31*
2 pte and 11 norte	*0.54*	*0.52*
Reforma and 11 norte	*0.23*	*0.40*

Figure 5. Grouped periods for the Historical Center of Puebla City

4. LOCAL GEOTECHNICAL CONDITIONS

There is well known that the characteristic of the ground motion caused by seismic events depends on the geotechnical local conditions. Then, it is important to include in this analysis the geotechnical data which will allow us to understand all the factors that can affect the ground motion, like topography and their effects like amplification and duration and finally to determine the damages in the structures. We have used information from 45 geotechnical studies which we have used to propose stratigraphic profiles and to compare with the periods obtained from noise records. From the distribution of these sites were draw six stratigraphic sections (see Figure 6).

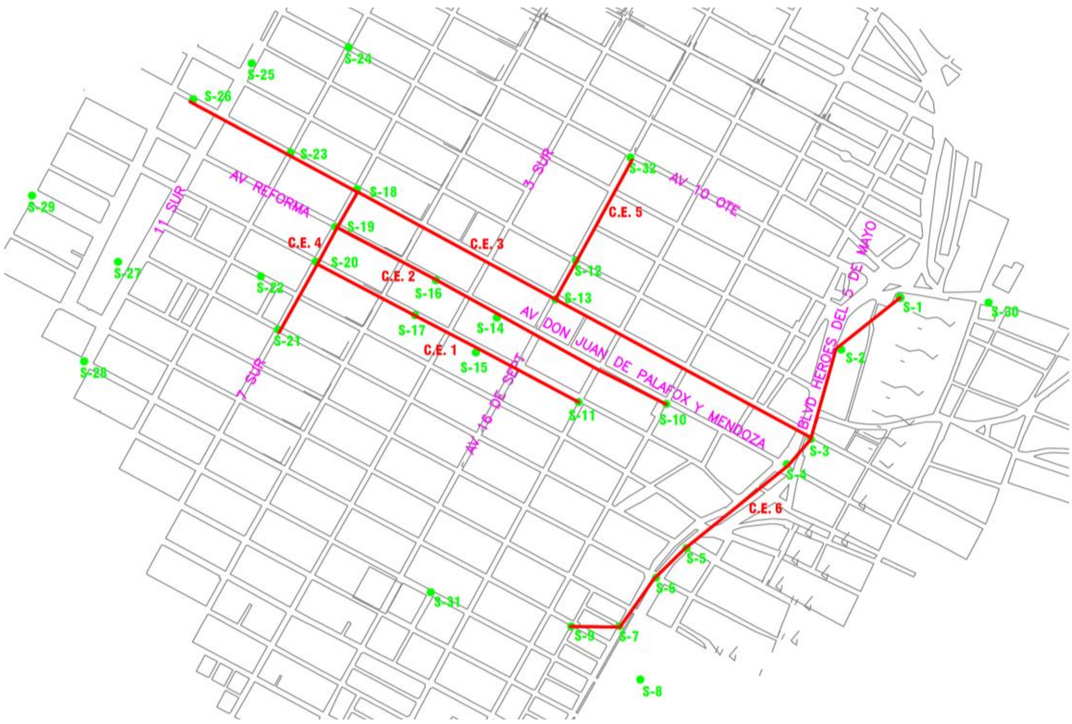

Figure 6. Localization of the geotechnical studies and stratigraphic profile

Stratigraphic layer 1. We observed a heterogeneous fill layer which has a maximum of 6 m, underlie a stratum of sandy loam and silty with a variable thickness (from 2 to 6 m). A third layer is conformed from travertine rock from good to bad quality. Finally, there are silty sand and sandy with small travertine.

Stratigraphic layer 2. The stratigraphic sequence of the heterogeneous fillers is from 1 to 3 m of thickness. Underlying there is Sandy silt and Sandy clay with thickness about 5 m which finish near to the 5 de Mayo Boulevard. Then, there is travertine from good to excellent quality with a thickness almost to 8 m. Finally, there are sandy silt and fine sand (see Figure 8)

Stratigraphic layer 3. It has been filled by remains of brick and ceramic, sandy loam, sandy clay, silty and a little bit of travertine rock.

Stratigraphic layer 4. The sequence of fillers made by building materials like silt clay, clay loam, sandy clay, gravel, sandy clay laminated with travertine rock. Finally there is a deep layer of travertine.

Stratigraphic layer 5. The stratigraphic sequence of the heterogeneous fillers has a deep from 2.50 m, there is also sandy loam soil from medium to hard consistence which is losing gradually. There is also travertine rock from 5.40 to 14.00 m, with bad or good quality.

Stratigraphic layer 6. Erratic sequence of fillings heterogeneous pluvial deposits (Silt and silty sand with clay). There is a moderate loss of compactness, depending on the fine granular soils. This material overlies to the tufa deposits (see Figure 8).

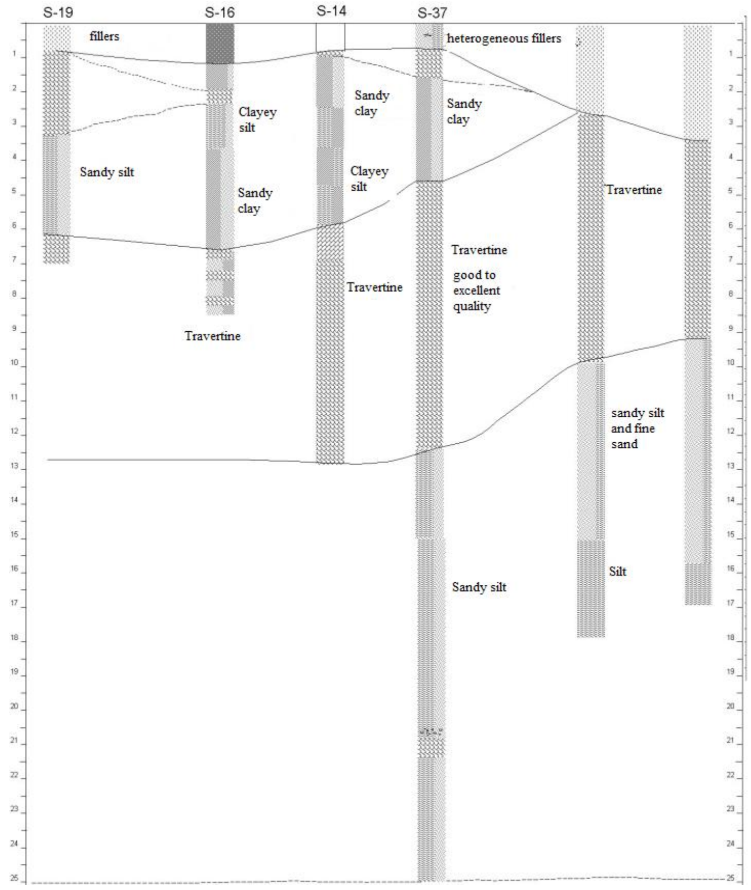

Figure 7. Stratigraphic layer 2. Reforma Avenue, between 7 and 4 Norte Street

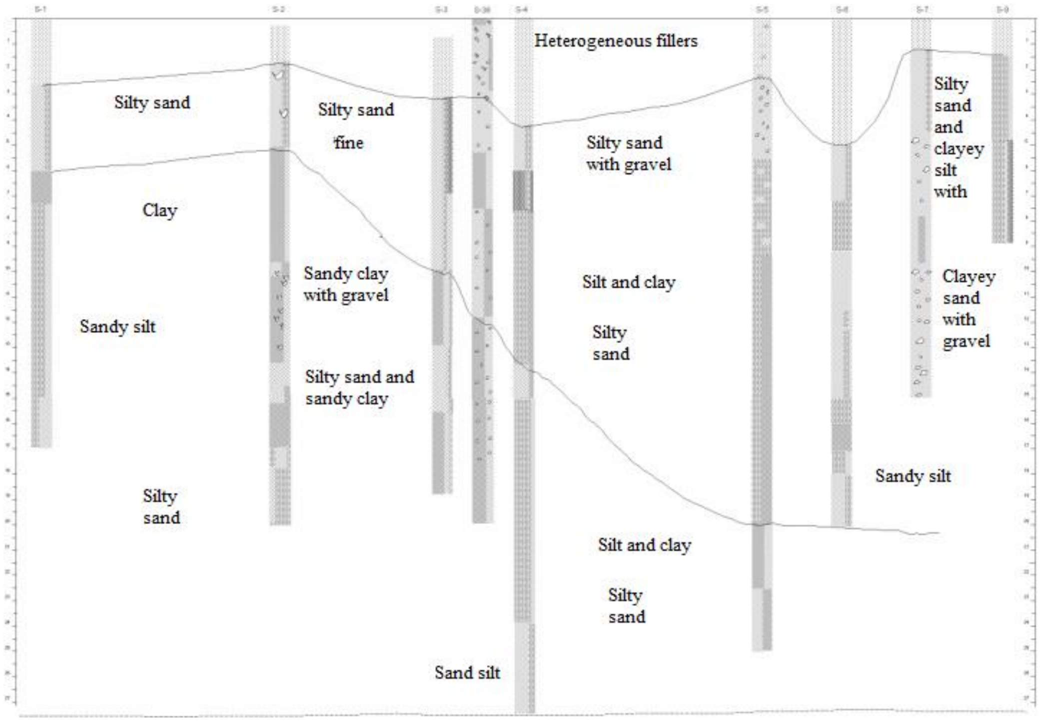

Figure 8. Stratigraphic layer 6. Héroes del 5 de Mayo boulevard, between 14 and 15 oriente street

5. ACCELEROMETRIC INFORMATION

The Universidad Popular Autónoma del Estado de Puebla (UPAEP) operates three accelerographs stations (Table 5) which were located depending on the ground type proposed by Ruiz *et al.* (1992). There is one in San Baltazar (south of the City). The second one in the central building of the UPAEP and the last one in the Civil Engineers Association of Puebla (CEAP), where there are not records yet.

Each station has a Kinemetrics SSA-2 accelerometer which three orthogonal sensors, full scale ±1g, response frequency of DC -50 Hz –3 dB, natural frequency of 50 Hz, and 0.7 damping. These accelerometers could record 200 samples per second, 12 bits resolution (Ferrer, 1994). Each SSA-2 was installed inside a metallic stand which protects from external agents which is anchored in a special foundation (Velázquez R., 1995).

Table 5.1 Location of the station operated by UPAEP

Station	***Nomenclature***	***Latitude (N)***	***Longitude (W)***	***Soil***
San Baltazar	*PB*	*19° 02´ 50.756"*	*98° 13´ 01.360"*	*Hard*
UPAEP	*PC*	*19° 00´ 33.261"*	*98° 12´ 38.180"*	*Transition*
CEAP	*PL*	*19° 02’ 23.85”*	*98° 12’ 00.38”*	*Transition*

Accelerometric records from the stations shown in Table 5.1 were processed and it was obtained the maximum acceleration per each direction. Also, we used H/V spectral ratios in order to determinate the fundamental period of soil (Ts). Twenty records were taken on the analysis where 11 were from PB station and 9 from PC station.

Table 5.2. Accelerations and Ts for each accelerometric station from different seismic events

RECORD	*ACCELERATION (cm/s2)*		*Ts N-S (s)*	*Ts E-W (s)*
	N - S	*E - W*		
RIPB0008.091	*-3.17*	*-4.14*	*0.38*	*0.24*
RIPB0301.221	*6.64*	*-5.58*	*0.9*	*0.29*
RIPB9402.231	*6.23*	*6.33*	*1.67*	*1.49*
RIPB9403.141	*-4.28*	*-3.05*	*2.21*	*1.46*
RIPB9405.231	*4.04*	*2.87*	*0.16*	*0.16*
RIPB9412.101	*7.82*	*-5.87*	*1.82*	*1.92*
RIPB9509.141	*-25.8*	*26.41*	*1.68*	*1.67*
RIPB9510.211	*-4.16*	*2.72*	*1.88*	*1.88*
RIPB9607.151	*-5.56*	*4.24*	*1.41*	*1.18*
RIPB9701.111	*-11.39*	*7.86*	*1.72*	*1.7*
RIPB9510.301	*-2.73*	*2.76*	*0.39*	*0.17*
RIPC0206.071	*-1.98*	*-1.6*	*0.35*	*0.74*
RIPC0301.221	*4.51*	*4.09*	*0.22*	*0.25*
RIPC0406.141	*-2.86*	*2.84*	*0.24*	*0.24*
RIPC9402.231	*-11.5*	*-9*	*0.32*	*0.32*
RIPC9412.101	*-3.39*	*3.82*	*0.28*	*0.25*
RIPC9509.141	*11.2*	*-16.9*	*0.32*	*0.31*
RIPC9510.211	*2.77*	*-3.45*	*0.22*	*0.31*
RIPC9607.151	*-3.42*	*-3.73*	*2.18*	*2.21*
RIPC9701.111	*-5.22*	*-5.12*	*0.32*	*0.31*

From the table 6, the first column shows the name of the seismic record. First four letters represents the station name, and the next 6 digits represent the date. The last one number is assigned for the number of the seismic event of the date, according with the Mexican Strong Motion Database convention (Alcántara *et al.*, 2000). Second and third columns show the maximum corrected acceleration in orthogonal directions. Finally, the fourth and fifth columns shows the period in the corresponding direction.

With the data obtained from table 6, we show the behavior of the period as a function of acceleration. It is well known that ground period must be the same for any acceleration. However, in the Figure 9 it can be observed that the period fluctuates. This may be due to the resolution of the accelerometers or that the energy supplied by the seismic events is low and therefore the ground can not to develop its fundamental period.

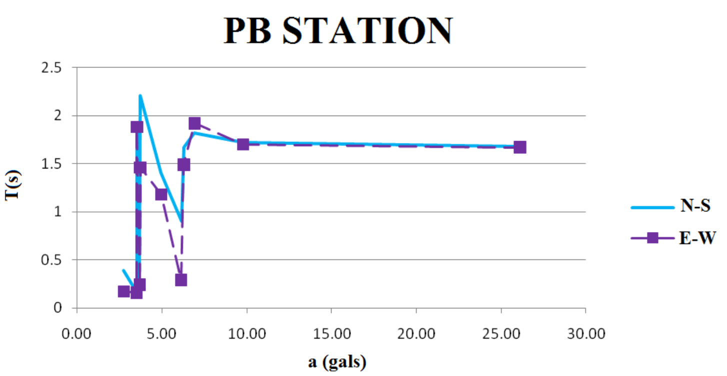

Figure 9. Graphic acceleration – period for PB Station

6. CONCLUSIONS

In this study periods for Santiago area and the historical center were obtained from environmental noise records. There were processed by mean H/V spectral ratios (Nakamura, 1989). Periods were grouped when they have the same value (see Figure 5). This information need to be supplemented with geotechnical model which describes the ground motion. We obtained the periods of 362 sites on the historical center and Santiago area at Puebla City. Although the records are very close together, we observed differences in some periods.

Analyzing the results, a map has been proposed for the historical center and Santiago area. However, the variability in periods from one to other close site (Table 3.1), it can be caused for 2D effects or errors in recording. We need to supplement the present study with more information from the zone.

The accelerometric information analysis has showed that there are differences for the period obtained in different seismic events. The period in PB station is more than 10 gals, between 1.5 and 2 s (Figure 9). In other hand the PC station is from 0.2 to 0.4 s.

From the seismic records the period in PC station is around 0.3 s (Table 5.2), but from environmental noise records the period is 0.18 s (Table 2.1). Again it is considered necessary to review the results of calculation of Ts on this site.

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