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SEISMIC MICROZONING STUDY IN BARQUISIMETO, VENEZUELA

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ABSTRACT
Between 1998 and 2000, microtremor and seismic refraction surveys were carried out in Barquisimeto for the evaluation of ground shaking parameters. The predominant periods derived from H/V analysis vary between 0.2 to 1.1 s, with the values varying between 0.2 and 0.5 s in the east, where superficial P-wave velocities range between 1.000 and 2.000 m/s, corresponding to outcropping schists. Further to the west, predominant periods increase to average values between 0.5 and 0.8 s, corresponding to an increasing thickness of the sedimentary cover. From analysis of seismic refraction measurements and geotechnical drillings, characteristics were derived down to 15 m in the center of the town, with increasing thickness to the west. The sediments show an intercalation of stiff clay with sand and gravel, and the S- wave velocities range between 400 and 600 m/s.

KEYWORDS
Microtremor, Seismic Refraction, Barquisimeto, Venezuela, Seismic Microzoning

INTRODUCTION
Barquisimeto, one of the most important cities of Venezuela, is located on the transpresive plate boundary between South America and the Caribbean, on which a right-lateral strike-slip of about 1-2 cm/year takes place. At local scale, this large city is sitting next to the Boconó Fault, which is responsible for destructive earthquakes in historic time, like the 1812 earthquake, which caused some 4.000 fatalities in Barquisimeto, Grases [1].

Today Barquisimeto is a fast growing city with over 1 Million inhabitants, expanding mainly over quaternary river terraces. Very few is known on the subsurface conditions, with outcropping schists in the eastern part of the town, where formal construction activity is concentrated, and terraces of unknown thickness in the west, where informal housing areas are fastly spreading.

The study forms part of a project that is being developed since 1998, incorporating the local governmental authorities like the municipality and the Lara state administration. Active participation of public engineers in the evaluation of subsoil data as well as building characteristics for vulnerability assessment is an important part of this seismic microzoning project. The general knowledge on seismic resistant construction shall be introduced to the community at the formal as well as at the informal level. Paleoseismic evaluation shall address the seismic hazard as well as an associated deep seismic reflection/refraction profile, which is planned for the region.

MICROTREMOR MEASUREMENTS

To obtain the values of the predominant periods of soil, the Nakamura method [2] or H/V relationship [3] was used in Barquisimeto. Microtremor measurements were made with spacing of 500 m between each site, the time of recording was 5 minutes, using a portable seismograph Orion – Nanometrics for data adquisition with a Guralp 3 components seismometer sensor. Operating a range of 30s - 50 Hz, the used sampling rate was of 100 samples per second. Window of 30 s with low levels of noise was selected as a first processing step (Figure 1).

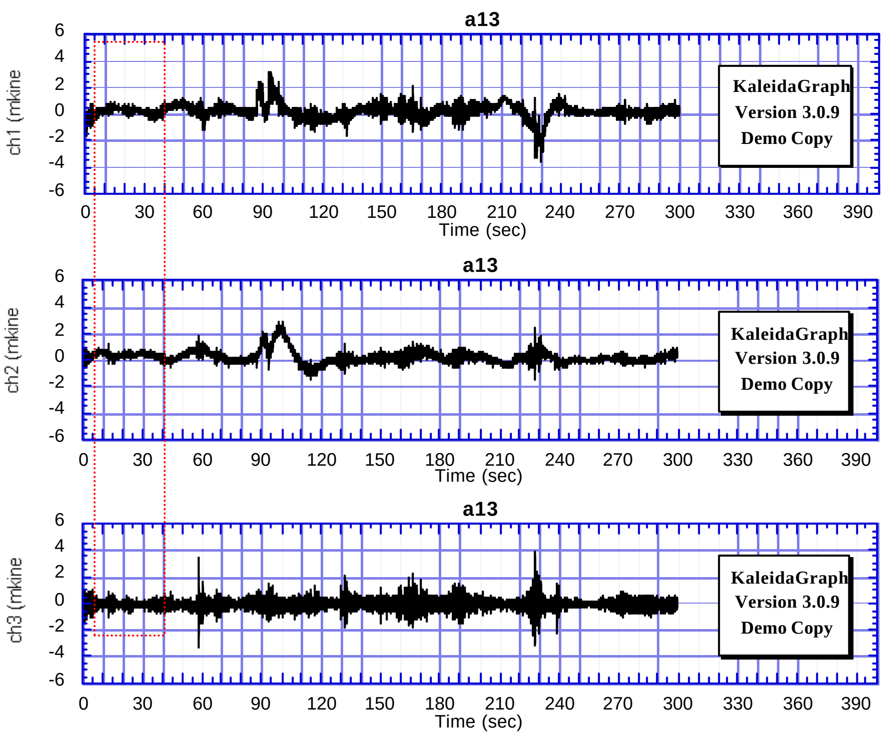
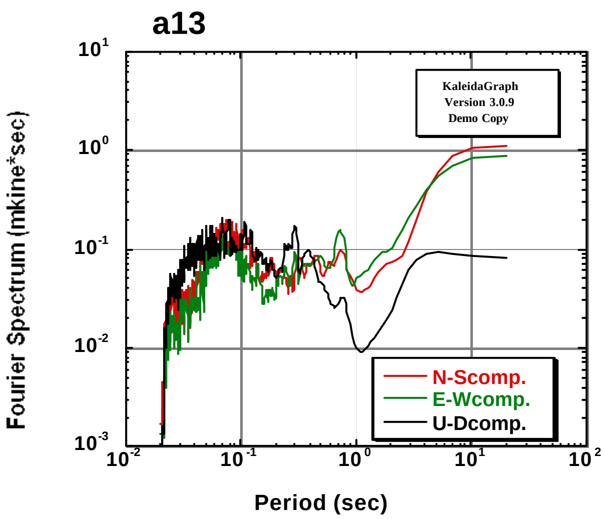


Figure 1: Original data record, indicating processing window of 30 s (dashed line)

For the selected windows, the Fourier spectrum was calculated for each component, (north-south, east-west and up-down) and the H/V relationship was calculated using the mean of two horizontal components versus the vertical component. The Fourier spectrum for each component, as well as the derived H/V ratio, indicating the characteristic peak selected for obtaining the predominant period, are shown in Figure 2.



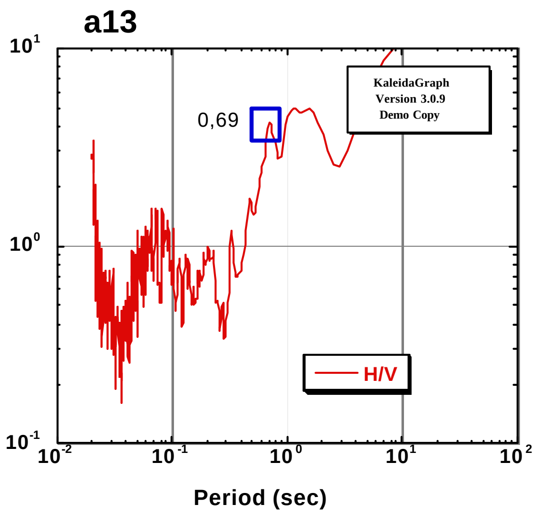


Figure 2: Fourier spectrum of the three components (above) and H/V ratio (below) for data shown in figure 1.

The values of the predominant periods of soil vary between 0.2 s and 1.1 s, see figure 3, with a mean value of 0.5 s. The maximum values are distributed in western and eastern zone with values between 0.8 s and 1.1 s, the minimal values vary between 0.2 s and 0.5 s and are spread over the central and eastern zone. In figure 4 it is possible observe the relationship between predominant periods and depth: the thickness the quaternary alluvial sequence is the higher the fundamental period is.

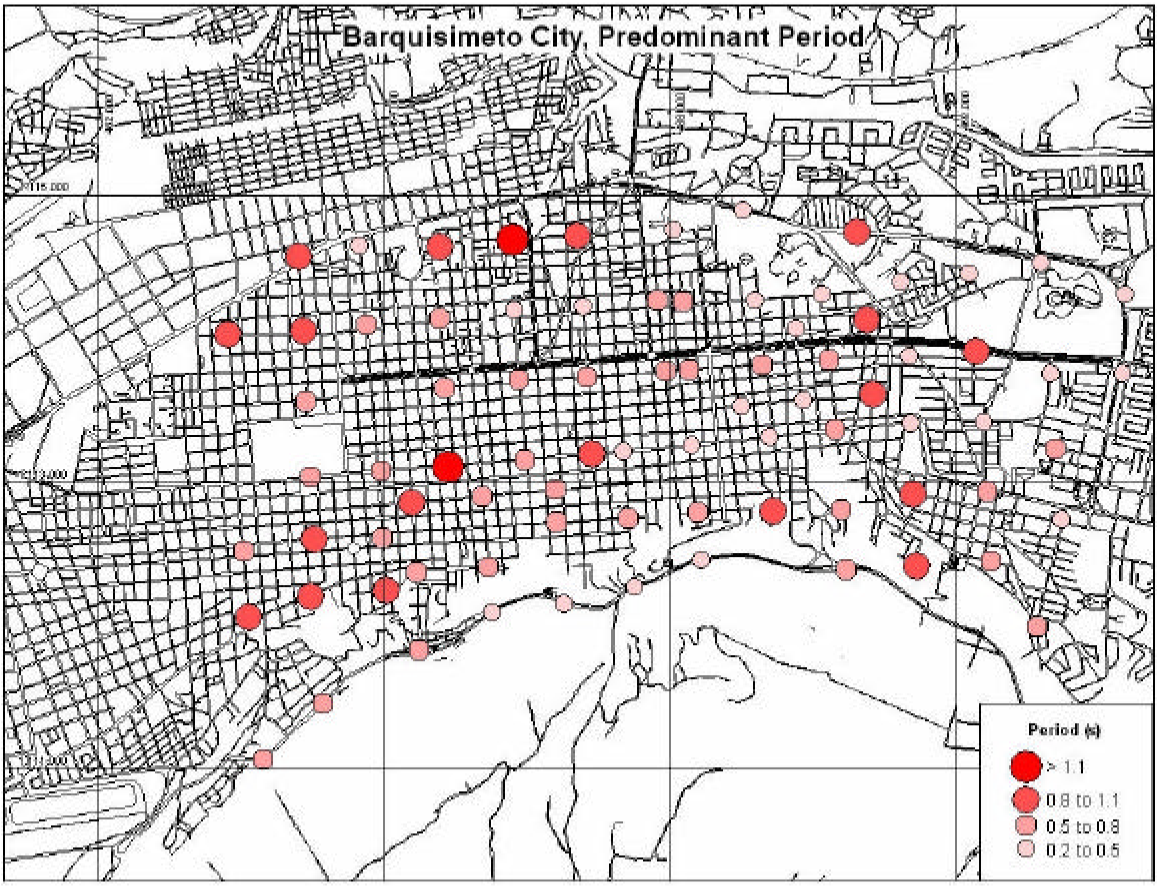


Figure 3: Location map of microtremor measurements and the derived periods.

GEOTECHNICAL EVALUATION AND SEISMIC REFRACTION MEASUREMENTS

A total of 77 geotechnical drillings were analyzed as to their geotechnical parameters and depth of bedrock [4], aiming at defining the rock depth (mica-schists) where possible. Only 32 out of 77 drillings reached the mica-schists. Additionally, 11 near surface seismic refraction lines were carried out in order to obtain P and S wave velocities.

For the seismic refraction studies a sledge hammer was used as energy source: vertical blows for the P wave study and lateral blows for S wave study. The recording device was a Geometrics Strata View seismograph of 48 channels, with horizontal and vertical 28 Hz geophones. The top of the mica-schists in Barquisimeto was derived from the analysis of geotechnical drillings and seismic refraction measurements (figure 4).

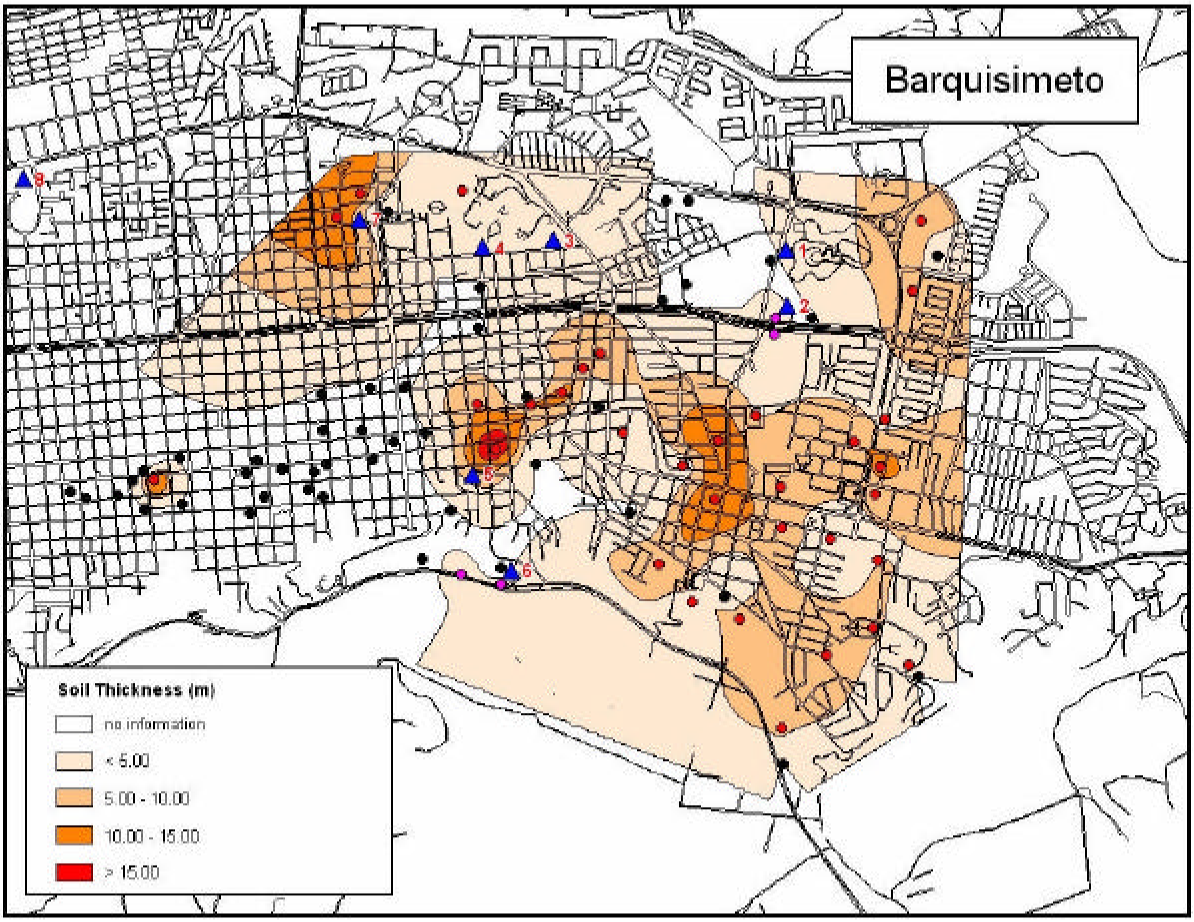


Figure 4: Drilling location (dots), soil thickness (Top of mica-schists) and location of Seismic refraction studies (triangles)

First arrivals picking for 1D models was performed for each seismic line, using REFLEX™ program. The 2D models were calculated using the RAYAMP™ program. An example of first arrivals and 1D models is shown in figure 5.

The seismic velocity analyses identify a first layer with p wave velocities between 450 m/s and 800 m/s, corresponding to quaternary sediments of the Barquisimeto terrace. A second layer can be easily interpreted and corresponds to metamorphic rocks (mica-schists), whose p wave velocities vary between 1800 m/s and 3000 m/s. The S wave velocities vary between 400 m/s and 650 m/s for the first layer, while it ranges between 700 m/s and 1200 m/s in second layer (mica-schists).

The estimated bedrock depth varies between 5 m and 15 m, being the maximum depth localized in the central zone where it reaches depths over 15 m. The minimal values are distributed across the rest of the city, and varies between 5 m and 10 m. Table 1 summarizes the results of the 2D model interpretation for seismic refraction lines shown in figure 4.

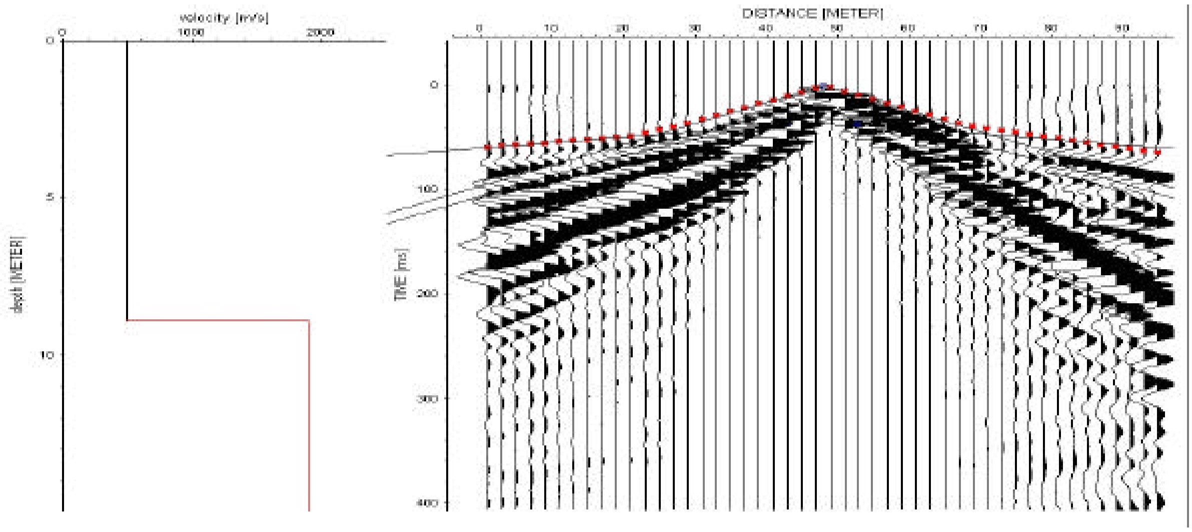


Figure 5: First arrival and calculated 1D model for line 8

Line	Depth	P wave velocity (m/s)	S wave velocity (m/s)
1	9 - 11	833 - 839	436 - 496
		2525	1018
2	4 - 6	647 - 652	410 - 633
		1291	2159
3	10 - 16	700 - 1200	460 - 580
		2860 - 4800	700 - 1180
4	1	260 - 530	
	7 - 16	780 - 2215	
		2000 - 2950	
5	14 - 16	540 - 1400	
		3774	
6	7 - 14	580 - 640	
		1580 - 1665	
7	6 - 9	485 - 665	
		3470 – 3800	
8	9 - 10	460	
		1900 - 2000	

Table 1: Depth and velocity of seismic refraction lines
(For location see figure 4)

CONCLUSIONS

The western and eastern areas of Barquisimeto display maximum period values between 0.8 and 1.1 s, while the minimum values, varying between 0.2 and 0.5 s, are in the central and eastern zones.

Analyzing the obtained soil predominant periods and comparing then with geotechnical drilling and seismic refraction line data, it is possible to establish a relationship between soil thickness and predominant periods. Zones with high periods are associated to large sediment thickness.

The seismic refraction study determine that P wave velocities for the first layer vary between 550 m/s and 800 m/s, corresponding to quaternary alluvial sediments of the Barquisimeto terrace. The metamorphic rock has values of P wave velocities between 1800 m/s and 3000 m/s. The S wave velocities vary between 400 m/s and 650 m for the first layer, where as the S wave velocities in metamorphic rocks varies between 700 m/s and 1200 m/s.

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REFERENCES

1. Grases J, Terremotos destructores del Caribe 1502 – 1990. 1ª Ed. ORCYT – UNESCO, Montevideo, Uruguay, 132 pp, 1990

2. Nakamura Y. A Method for Dynamic Characteristics Estimation of Subsurface using Microtremor on the Ground Surface. QR of RTRI, Vol 30, No 1, Feb 1989.

3. Konno K, Ohmachi T. Ground-Motion Characteristics estimated from Spectral Ratio between Horizontal and Vertical Components of Microtremor. Bulletin of the Seismological Society of America, Vol. 88, pp 228-241, February 1998.

4. Pacheco G, Terán R. Caracterización Microsísmica de suelos. Caso de estudio. Tesis de grado. Universidad Centro Occidental Lisandro Alvarado, Barquisimeto, 300 pp, 1999.