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SEISMIC MICROZONING STUDY IN CHACAO DISTRICT, CARACAS, VENEZUELA

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ABSTRACT

A seismic microzoning study is envisioned in Caracas, the capital of Venezuela, and some important steps ahead have been done in the Chacao district, a busy commercial and residential area in the east of the Caracas valley. The Los Palos Grandes neighbourhood of Chacao suffered most damage during the 1967 Caracas earthquake. Here, sediment thickness reaches more than 300 m and the studies done after the earthquake revealed a close relationship between structural damage and soil conditions. The predominant periods obtained from recent microtremor measurements indicate H/V ratios between 1 and 2 s for this region. Evaluation of available geological and geophysical data as well as gravimetric modelling suggest important changes in the shape of the bedrock topography. This is of special interest for the modelling of the seismic response, which will be done on detailed 2D profiles across the valley. Preliminary results of seismic refraction profiling done in July 2001 will also be presented.

KEYWORDS

Chacao, Caracas, Venezuela, seismic microzoning, predominant periods, seismic refraction, gravity, seismic response.

INTRODUCTION

Caracas, the capital of Venezuela, is located on the plate boundary between the South American Continent and the Caribbean plate, with a main fault system characterized by dextral strike-slip movements of about 1-2 cm/year. The district of Chacao, located within the sedimentary Caracas valley, suffered extensive damage during the July 1967 Caracas earthquake, a magnitude 6.5 earthquake occurred some 25 km northwest of Caracas [1] as a multi-event earthquake located on the San Sebastian fault zone. Four buildings collapsed and 300 people were killed during this event. Damage investigations of buildings were performed in detail, including soil and building dynamical characteristics, and the earthquake engineering characteristics of the deposits, following the earthquake [2]. The main results indicated that the earthquake response is strongly related to the soil conditions, which is seen as the fundamental factor for earthquake damage in the Chacao area [2,3]. Today, Chacao is a dynamic business and residential district with a growing number of high rise buildings, many of them constructed with curting wall facade and with and a high daytime population.

In the Chacao district, previous evaluation of the natural disaster risk has been done in 1994 [4]. The study presented here forms part of a joint research on the seismic risk evaluation in Caracas, an ongoing study since 1997. New geophysical data are interpreted together with existing geological and geophysical data to evaluate the physical characteristics of the valley fill. Vulnerability analysis of buildings and lifelines and the behaviour of the inhabitants will be integrated in a GIS in the future for joint analysis and modelling.

Recently, microtremor and seismic refraction measurements have been done in the Caracas Valley for the evaluation of ground shaking characteristics [5,6,7]. The behaviour of the H/V curves is strongly related to the nature of the soil and it is in accordance with the damages observed after the 1967 earthquake. Predominant periods are as high as 2.1 s in the centre of the basin fill. Rock sites outside the basin show a predominant period of down to 0.2 s. The existing map for the basement depth, which is supposed to be at about 350 m in the Chacao area [8,9], was revised using available borehole data [10] and new gravity data [11]. Seismic refraction measurements have been done in the Chacao district in July 2001, and preliminary analysis reveal a good data quality at least for some of the lines. Seismic response modelling is applied to a north south profile crossing the Caracas valley. Nevertheless, further geophysical and geological data are requested in the future for a more detailed image of the soil-bedrock interface and improvement of the derived models.

MICROTREMOR MEASUREMENTS

Detailed evaluations done after the 1967 Caracas earthquake revealed a close relationship between the building damage (e.g. the height and predominant periods of the buildings), and the soil thickness [2,3]. Amplification factors have been measured using local and teleseisms, but the predominant periods of the soil only have been derived from theoretical considerations based on the sedimentary thickness [2]. Microtremors have been measured in the Caracas valley in the late 90's by Japanese-Venezuelan [5,7] and French-Venezuelan [6] groups for different spacing between stations using the Nakamura [12] method or H/V ratio. Measurements done in a 500 m grid all over the Caracas valley reveal predominant periods over 1s in two distinct regions of the valley, in San Bernardino in the west with few values up to 1.2 s, and in a big area in the east, comprising a parts of the Chacao district, including the Los Palos Grandes area, where building collapse occurred during the 1967 Caracas earthquake, with values up to 2.1 s (Figure 1). Sediment thickness in this area exceeds 300 m [9] and the measured periods coincide well with the theoretically derived predominant periods between 1.3 and 1.7 s [2]. Predominant periods of 1s and more correlate well with sediment thickness of more than 100 m, as observed in the San Bernardino and Los Palos Grandes areas.

Detailed measurements in a 100 m grid in the Los Palos Grandes area confirm the general trend of the correlation between the predominant periods and the sediment thickness (Figure 2), although some data points over big sedimentary thickness show low predominant periods with respect to the surroundings. The amplification factor seems to show an opposite behaviour with factors between 4 and 8 south of the sedimentary basin and factors mainly between 1 and 6 in the area of highest sedimentary thickness. The same behaviour was observed on dense measurements in the central and western part of the sedimentary basin [6]. In the amplification studies done after the 1967 Caracas earthquake, highest amplification (factor 5-6) was obtained in the region of strong damage south of the mayor sedimentary thickness, whereas surrounding areas, including the center of the basin, showed an amplification factor of 4 [2]. We have to keep in mind that the applicability of the amplification factors using Nakamura´s method [12] is poorly understood theoretically, and that they show a correlation not only with the underground structure but also to other parameters [13]. The results presented here seem to confirm the caution with that the amplification factors derived from microtremor measurements should be treated.

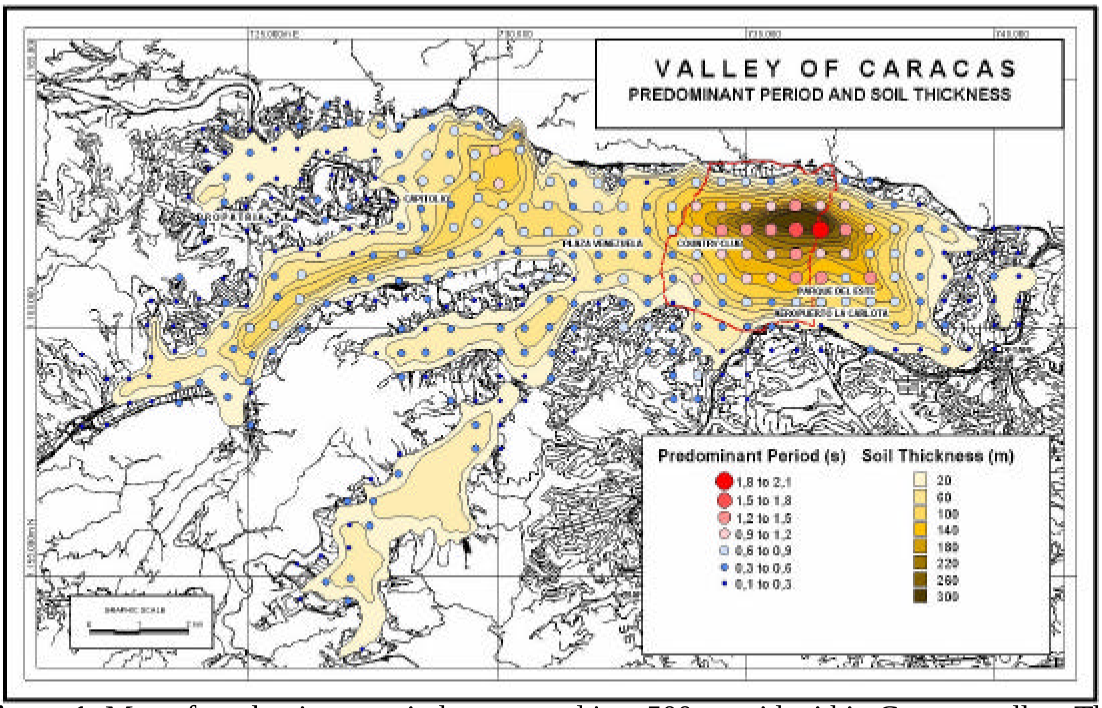

Figure 1: Map of predominant periods measured in a 500 m grid within Caracas valley. The sediment thickness within the Caracas valley, as derived from earlier studies[8,9], is underlain as contour lines; red line = limits of Chacao district.

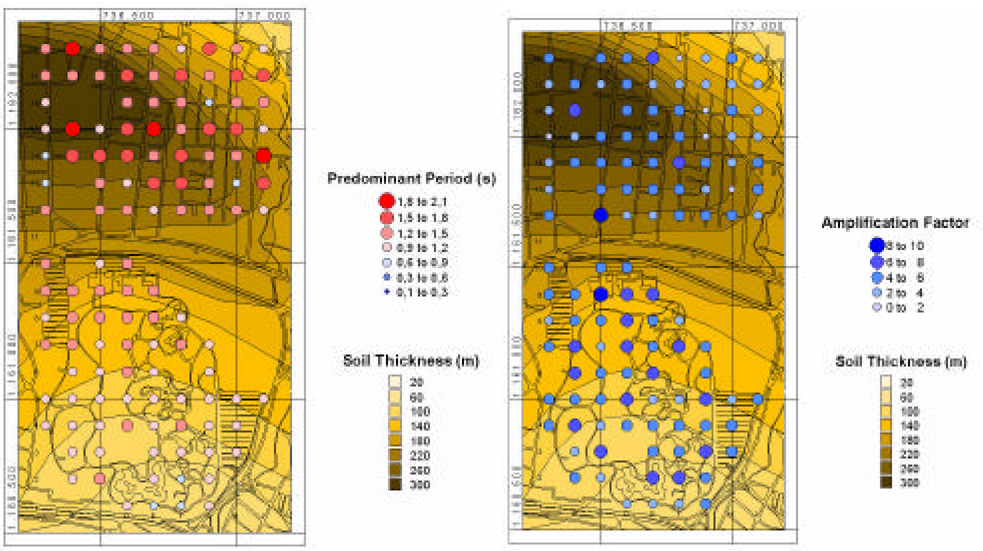

Figure 2: Map of predominant periods (left) and amplification factors (right) measured in a 100 m grid in the eastern part of the Los Palos Grandes sedimentary basin; sediment thickness as Figure 1.

MODELLING OF THE SEDIMENT THICKNESS

The main sources of information on the sedimentary thickness in Caracas valley constitute the results of the geophysical and drilling programs done for groundwater exploration [8] and the seismic refraction studies to investigate the effects of the 1967 Caracas earthquake [9]. Unfortunately, in both studies the original data have never been reported or plotted on the maps. This makes it difficult to differ the regions with a dense and reliable database from regions mainly based on interpolations. Therefore, a total of 166 drillholes and the reported seismic refraction results were analysed [10] and plotted using a Geographical Information System (Mapinfo) in order to reference the database (Figure 3). Big parts of the map are unchanged with respect to the map of the sediment thickness as shown in Figure 1. Mayor modifications are made only in the Los Palos Grandes area, where data sources and areas of interpolation can be clearly differentiated now. The predominant west-east direction of the deep sedimentary basin in the east seems to be controlled more in a north-south direction, but data density is sparse. The deepest drill hole in the area has 340 m without reaching bedrock, but the exact location is questioned [10]. The results of the seismic refraction measurements done after the 1967 Caracas earthquake, indicate a maximum sediment thickness of about 300 m for the Los Palos Grandes area [2,9], as referred in Figure 3. Bedrock velocities are given with 4000 m/s and an intermediate layer, located at 150 to 200 m depth in Los Palos Grandes, shows a P-wave velocity of 2400 m/s, interpreted as sedimentary rocks or compacted soil. The missing original data make it difficult to judge the reliability of this study, in which a deep drill hole is suggested for confirmation of the geophysical results.

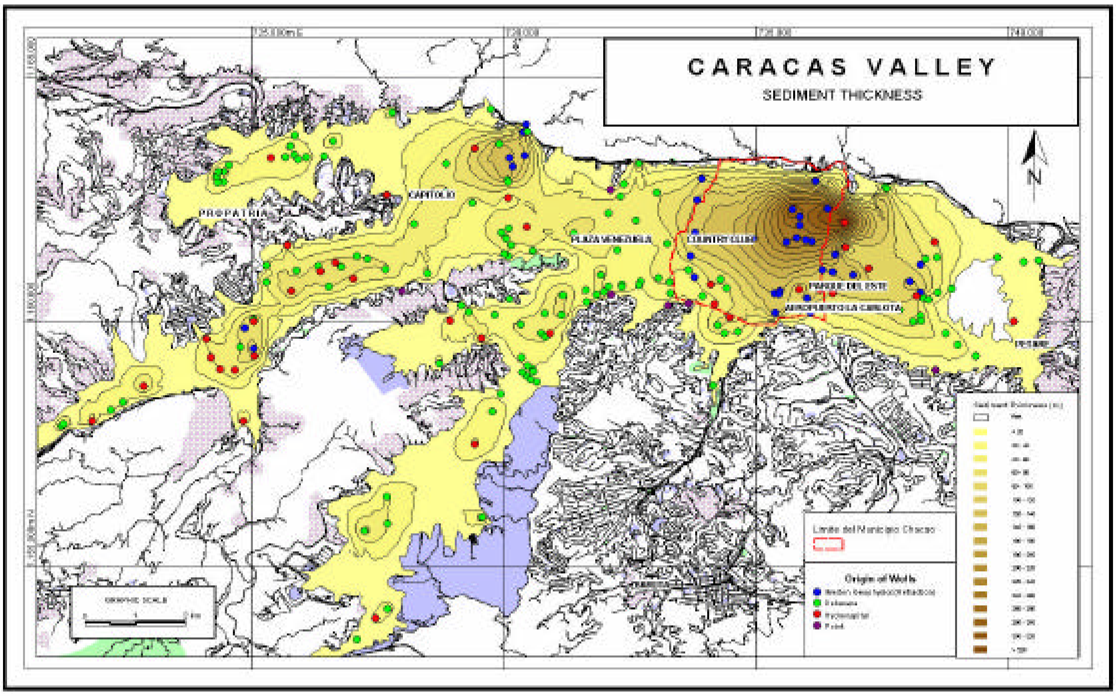

Figure 3: Map of sediment thickness in the Caracas valley [10] based on drill holes and geophysical data [8,9]; the limits of Chacao district are indicated by the red line.

More than 200 gravimetric measurements were done in the Los Palos Grandes area in order to model the Bouguer anomaly in the area, which was referenced to 850 m above sea level [11].

North-south and east-west striking 2-D models were calculated for the region, considering the bedrock geometry displayed in Figure 3. The densities used for the bedrock vary between 2.6 and 2.7 g/cm^3 and for the alluvial sediments between 1.8 and 2.4 g/cm^3, decreasing from north to south and increasing with depth. The resulting bedrock geometry is displayed in Figure 4. The general west-east trend of the basin seems to be overlain by a N45^{o}E striking feature in the center of the basin.

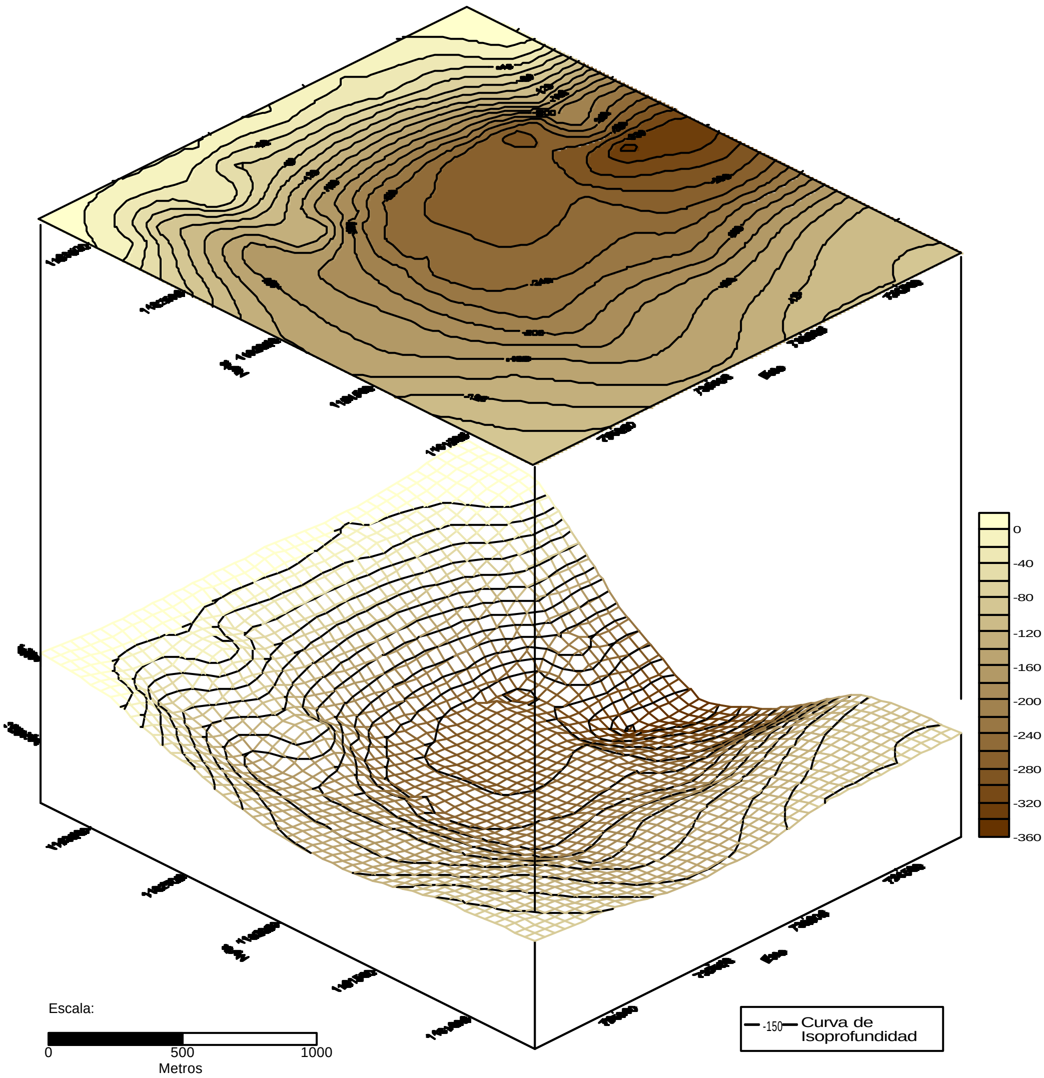

Figure 4: Contour map and isometry of sediment thickness in the Caracas valley derived from gravimetric modelling [11].

SEISMIC REFRACTION MEASUREMENTS

In order to provide more data on the sedimentary thickness and seismic velocities, seismic refraction measurements (Estudio Cortical de Caracas – ECCAR) were done in the study region in July 2001 (Figure 5). A total of 190 independent recording instruments (REFTEK 24-bit recorders –Texans- with vertical component geophones) were deployed along the profiles shown in figure 5 with a station spacing between 50 and 150 m. Explosive charges between 10 and 20 kg, fired in boreholes of 10-15 m depth, were used as energy sources.

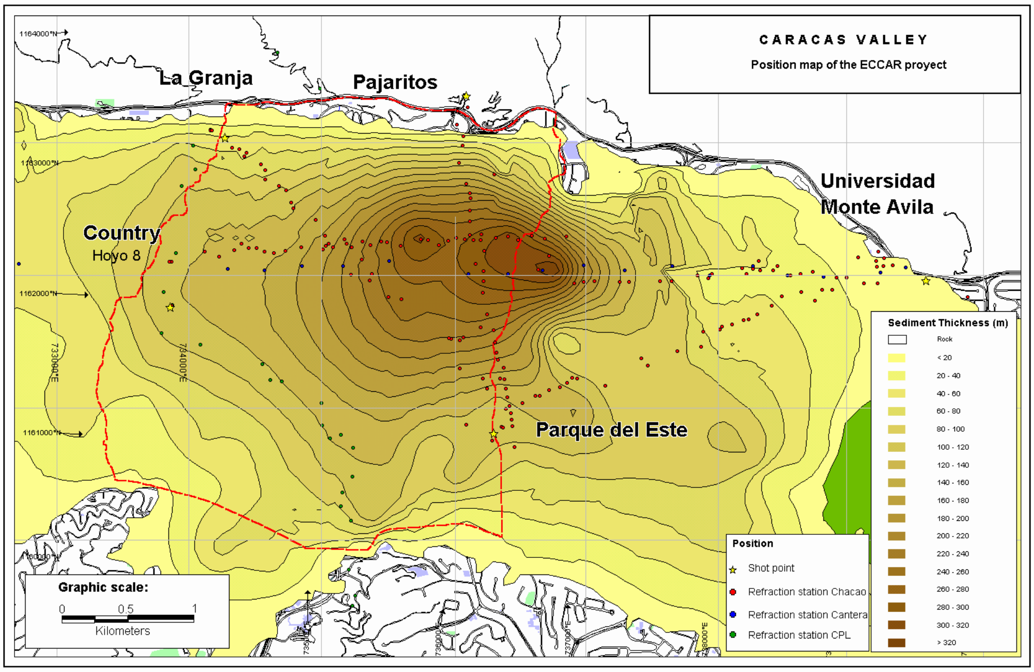

Figure 5: Map of sediment thickness [10] with the location of the seismic refraction profiles measured in July 2001 in the eastern part of the Caracas valley; for orientation see Figure 3.

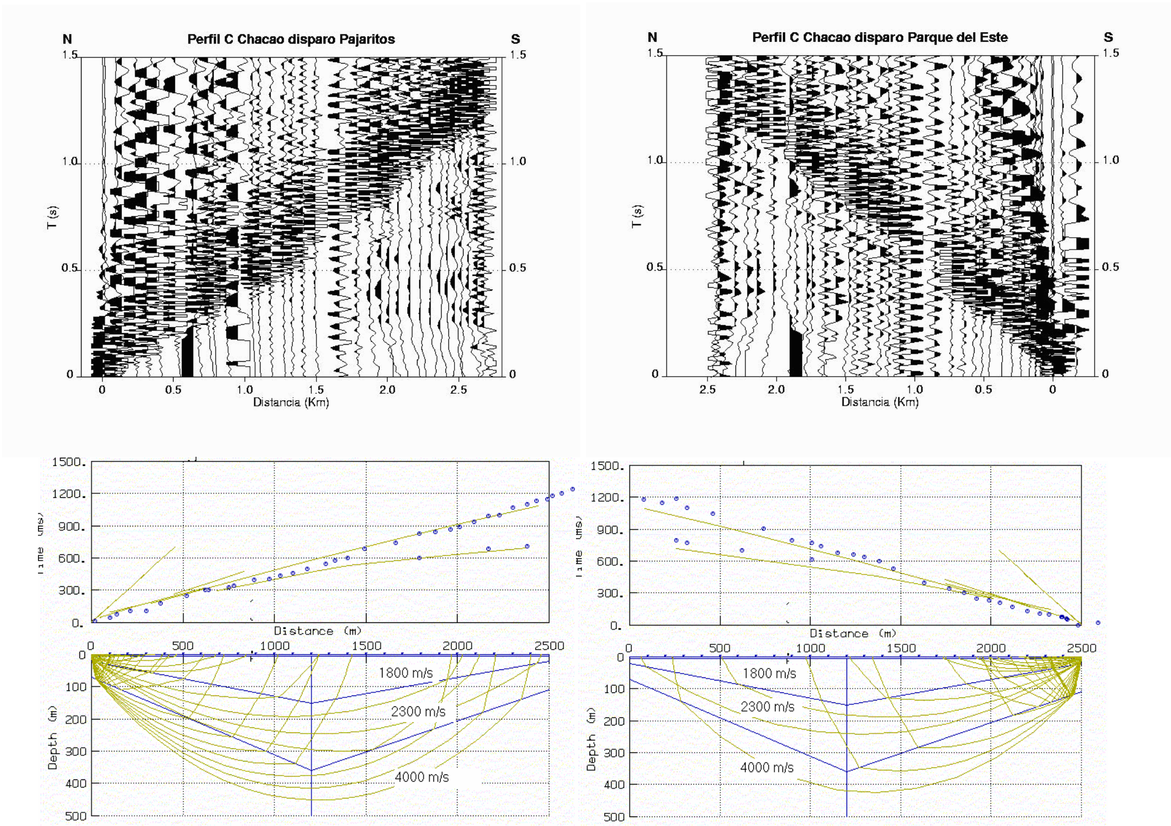

Figure 6: Seismic sections from the north-south profile crossing the Los Palos Grandes deep sedimentary basin (above) and preliminary 2D raytracing modelling (below) with observed (blue circles) and calculated (yellow lines) traveltimes.

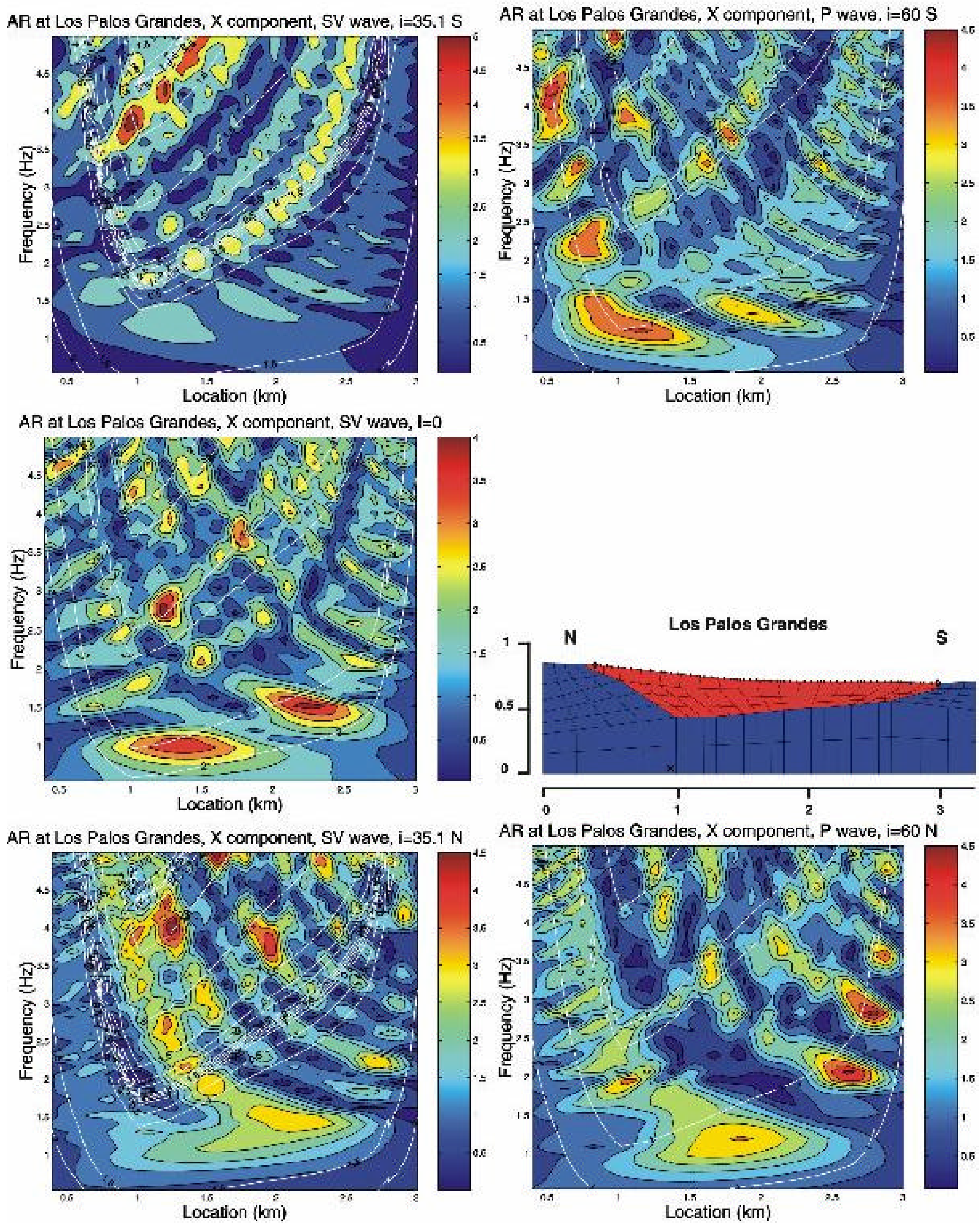

Figure 7: Amplification spectra along a N-S profile along Los Palos Grandes using a 2D P-SV spectral element method, as excited by a plane P or S wave for various angles of incidence. Contours of 1D modelling (white lines) are also displayed for comparison; I=35.1 is the critical angle. The 2D models reveal a strong dependence of the frequency of the maximum amplification (1-4.5 Hz), and their location along the profile, on the angle of incidence. The maximum amplification in the 2D case (red = 4-4.5) is about twice the values of the 1D models (max. 2).

A preliminary analysis of the seismic refraction data indicates a good data quality along the central north-south profile (Figure 6), whereas the records on the east-west profiles are more noisy. Clear P-wave arrivals are observed for a layer with a seismic velocity of 2300 m/s in the depth range 150 to 350 m. Above, water saturated sediments with a velocity of 1800 m/s prevail. There are also indications for earlier arrivals derived from a layer with 4000 m/s, possibly the top of the basement, located at about 350 m depth in the center of the basin. This would confirm the general feature of the results obtained after the 1967 Caracas earthquake [2,9]. The upper limit of the layer with a velocity of 2300 m/s, indicated as sedimentary rocks or compacted soil [2,9], seems to be located closer to the surface than indicated by the previous studies.

MODELLING OF THE SEISMIC RESPONSE

In order to assess the influence of the soil conditions and the geometry of the sedimentary basin on the seismic response, modelling using the spectral element method [14] has been done. In our preliminary modelling, a 2D (P-SV) propagation code has been used. As shown by Papageorgiou and Kim [15], and confirmed in our modelling, the amplification spectra are richer than expected from 1D modelling. The modelling of the seismic response along a north-south profile in Los Palos Grandes results in amplification effects close to the mayor damage zone of the 1967 Caracas earthquake (Figure 7). We conclude, that the depth of the sedimentary layers is not the crucial parameter for high amplification factors, but a combination of the sedimentary thickness and the shape of the bedrock. To the date, the bedrock geometry as derived after the 1967 Caracas earthquake [9] (see also Figure 1) was used for the modelling, in order to reproduce the modelling results from Papageorgiou and Kim [15], who used a discrete wavenumber boundary element method. Refined 2D modelling will be done along various profiles crossing the Caracas valley in north-south and east-west direction, using the new data on seismic velocities and geometry of the sedimentary basin. 3D modelling at different scales is also envisaged using the same numerical tool.

SEISMIC VULNERABILITY

The seismic vulnerability is defined as the degree of damage that suffers a structure at the occurrence of an earthquake of a given magnitude. It is an intrinsic characteristics of the structure that depends on the design criteria, the building quality and the maintenance of the structure. It also depends on the site where it is located; indeed it will be more vulnerable if it is located on a soil with high licuation potential or on a soil with a predominant period similar to that of the structure. In fact, it is a complex task trying to predict the probable behaviour of a construction during a given earthquake, due to the quantity of variables that intervene.

In general, the methodologies for evaluation of the seismic vulnerability can be divided in two methods, as there are the analytic and subjective methods. During this project the determination of the vulnerability index will be done by means of the subjective method [16]. The following expression (Eq 1) indicates the equation for it's calculation:

$$Iv = \sum_{i=1}^{n} k_{vi} w_i \qquad (1)$$

Where: n is the number of parameters to evaluate, kvi is the valuation of the parameter and w is the importance that is given to the parameter.

The analytic methods rely on the calculation of the Damage Index and they are based on the non-lineal step to step dynamic analysis. This implies to have all the structural plans of the building available. This method will be applied on some essential buildings, only. The joint interpretation of both methods will help to define appropriate vulnerability functions for each site within the seismic microzoning project of Chacao district.

CONCLUSIONS

The Los Palos Grandes area, most heavily damaged during the 1967 Caracas earthquake, is characterized by the biggest sedimentary thickness within the Caracas valley (see Figure 3). A close relationship between the damage occurred and the underground conditions already had been derived from the studies conducted after the earthquake [2,3,9]. The existing information on bedrock geometry and geophysical parameters of the sedimentary basin should be improved in order to get a realistic model of the seismic response to be expected in a future event.

Within the scope of a seismic microzoning project envisioned for the Chacao district, geophysical measurements have been done in recent time. The application of microtremor measurements using Nakamura's technique [12] seems a viable tool for the analysis of the predominant period in the study region. The amplification factors derived from the same analysis are not completely understood theoretically and should be interpreted with caution. The modelling of the seismic response in the valley using an improved geophysical model of the basin could help to understand the occurrence of the damage of the 1967 Caracas earthquake, as well the expected damage of possible future earthquakes. Seismic refraction and gravimetric measurements have been done recently to improve the knowledge on the geophysical parameters within the sedimentary basin. Further geophysical measurements and some deep drillholes will be necessary to get a detailed image on the underground structure.

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