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Estimation of the seismic intensity in Caracas during 1812 earthquake using seismic microzonation methodology

Estimación de la intensidad sísmica en Caracas durante el terremoto de 1812 utilizando metodología de microzonificación

Yoshitaka Yamazaki[1], Frank Audemard[2], Rogelio Altez[3], Julio Hernández[4], Nuris Orihuela[5], Salvador Safina[6], Michael Schmitz[7], Ichiro Tanaka[8] y H. Kagawa[9]

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Resumen

Este trabajo es parte del resultado del estudio conducido por la Agencia Japonesa de Cooperación Internacional (JICA), titulado "Estudio Básico sobre Prevención de Desastres en el Distrito Metropolitano de Caracas". Se utiliza el terremoto del 26 de marzo de 1812, que causó graves daños en Caracas, como uno de los escenarios posibles de ocurrencia de terremotos, estimando su posible impacto en la actualidad, para así establecer un plan de prevención de desastres. A pesar de que pudo desarrollarse una metodología de microzonificación sísmica necesaria para la simulación, persiste una gran incertidumbre en la localización de la ruptura de la falla. Del mismo modo, las fuentes primarias, que hasta ahora no habían sido lo suficientemente claras como para validar una simulación, fueron revisadas críticamente en esta investigación, revelando que un 60% de las edificaciones de la época fueron severamente dañadas en Caracas por el terremoto de 1812. Los datos sobre las edificaciones de la ciudad para ese momento fueron sistematizados, con el objeto de establecer un mejor modelo para la simulación. Los planos en grados de daños de edificios, elaborados de acuerdo a lo que reveló la revisión documental, muestran que la parte norte

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Study Team -Earthquake Disaster Group of the Japan International Cooperation Agency (JICA)

1 OYO International Corporation, Japón, e-mail: yamazaki@oyointer.com

2 Fundación Venezolana de Investigaciones Sismológicas (FUNVISIS), Departamento de Ciencias de la Tierra, e-mail: faudemard@funvisis.org.ve

3 Universidad Central de Venezuela, Facultad de Ciencias Económicas y Sociales, Escuela de Antropología, e-mail: ryaltez@cantv.net

4 Fundación Venezolana de Investigaciones Sismológicas (FUNVISIS), Departamento de Ingeniería Sísmica, e-mail: jhernandez@funvisis.org.ve

5 Fundación Venezolana de Investigaciones Sismológicas (FUNVISIS), Presidencia, e-mail: norihuela@funvisis.org.ve

6 SismoMetric, Caracas-Venezuela, e-mail: safinasal@cantv.net

7 Fundación Venezolana de Investigaciones Sismológicas (FUNVISIS), Departamento de Sismología, e-mail: mschmitz@funvisis.org.ve

8 OYO International Corporation, Japón, e-mail: ichiro@oyointer.com

9 OYO International Corporation, Japón, e-mail: kagawa@oyointer.com

de la ciudad sufrió la mayor cantidad de daños, evidenciando la proximidad de la ruptura de la falla, así como también los efectos de sitio, lo que corresponde a los resultados de la simulación.

***Palabras clave*:** intensidad sísmica; Caracas; terremoto de 1812; microzonificación sísmica.

Abstract

This work is part of the results of the study conducted by the Japanese International Cooperation Agency (JICA), called "The Basic Study on Disaster Prevention in the Metropolitan District of Caracas". The earthquake from March 26, 1812, which caused the worst damage in the history of Caracas, is used as one of the scenario earthquake to estimate its impact to today's Caracas, in order to establish the base for a disaster prevention plan. Although a seismic microzonation methodology for the simulation was developed, there remains a great uncertainty with respect to the location of the fault rupture. Besides, numerous available historical documents were not clear enough to validate the simulation. Therefore, historical documents were critically reviewed, which revealed that about 60% of the buildings were heavily damaged in Caracas by the 1812 earthquake. A building database in Caracas is used to find a best fit model by the simulations. Mapping the damage degree of buildings from documents' review revealed that the northern part of 1812 Caracas suffered higher damage degree, which is in agreement with the results of the simulation, and which can be explained by the proximity to the fault rupture and by site effects.

***Key words*:** **s**eismic intensity; Caracas; 1812 earthquake; seismic microzonation.

Introduction

Caracas, the capital of Venezuela, has experienced major earthquakes at least once in a century since its foundation in the early 16th century (Figure 1). The 1812 earthquake, which caused the worst damage in the history of Caracas, thus can be considered a worst case scenario for Caracas in terms of disaster prevention. Though it is still difficult to predict earthquakes, it is possible to reduce its damages with proper knowledge and effective actions. The study of historical earthquakes with today's scientific knowledge can provide important lessons. This study demonstrates such an attempt.

This contribution is a part of the results from *The Basic Study on Disaster Prevention in the Metropolitan District of Caracas*, executed by the Japan International Cooperation Agency (JICA) upon the request from the government of the Bolivarian Republic of Venezuela for the study area (Figure 2), as a base for a disaster prevention plan. Numerous discussions between Venezuelan institutions and the JICA study team were made under the coordination of FUNVISIS in order to develop a suitable methodology.

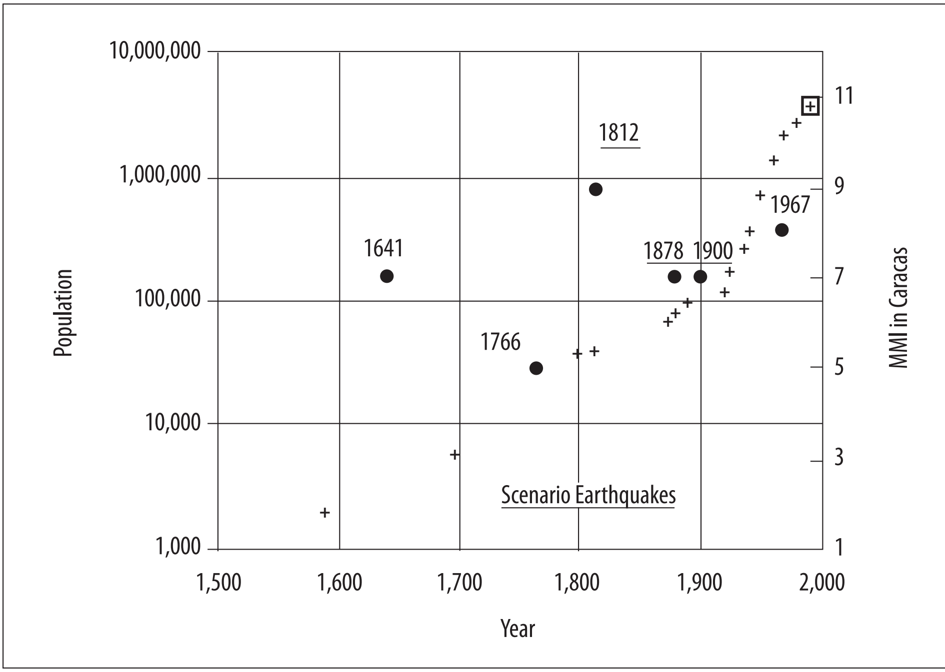

Figure 1. Population growth and earthquake history in Caracas (Fundación Polar, 2000; National census data; Grases, 1990)

Figure 2. Study area (Libertador, Chacao and Sucre counties), 1812 Caracas, and Quaternary faults (from Audemard *et al.*, 2000)

Seismic microzonation

Seismic ground motion and damage degree of structures generally varies even in a small area where epicentral distances are almost the same. It is understood that this phenomena is due to the differences in ground conditions, as well as spatial distribution of structures. An assessment called *seismic microzonation* is made to evaluate the spatial distribution of the seismic motions and the associated damages, usually dividing the study area into an appropriate sized mesh. Numerous seismic microzonation studies have been made for earthquake disaster prevention in Japan (Kagami, 1993).

In this study, an analytical deterministic approach is employed to simulate hazard and risk by several specific earthquakes, here called *scenario earthquakes* (Figure 3). The hazard analysis is based on the estimation of ground motions, as well as associated geological hazard such as liquefaction. The risk analysis involves estimation of building damage based on the hazard analysis and the human casualties. The results are visualized on maps and tables, and they shall be used to make a prevention plan by the responsible administration, as well as to raise awareness among the public.

As a scenario earthquake, one usually uses typical past events, because the prediction of a future earthquake is di-

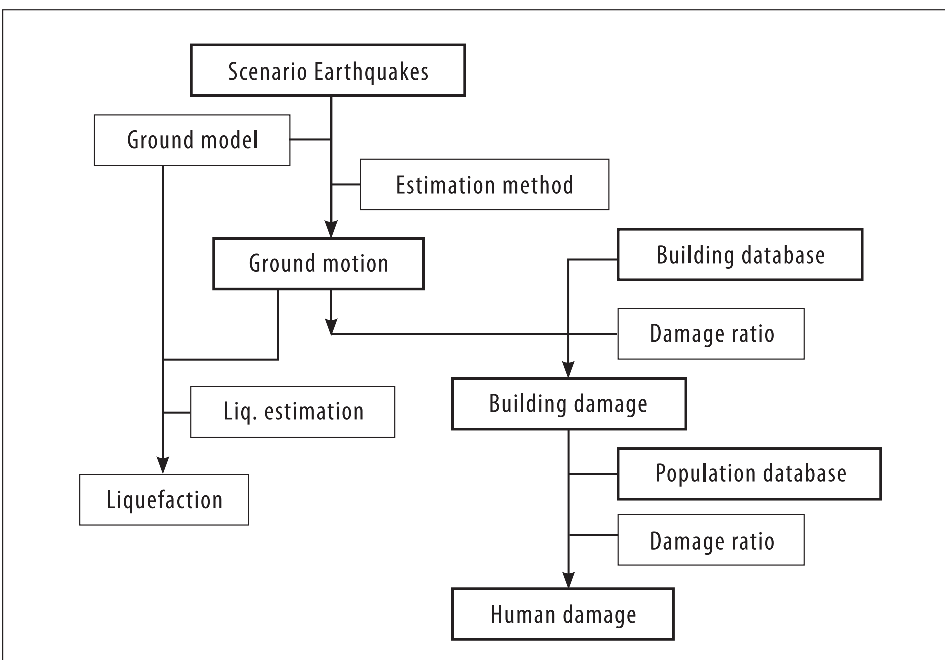

Figure 3. Flowchart of "The Basic Study on Disaster Prevention in the Metropolitan District of Caracas"

fficult. Here, the results of the simulations are calibrated with past records in order to validate them. For their nature, the result should not be interpreted as a prediction of a future earthquake, nor should they be used for seismic design of structures, nor for calculation of insurance premium. For such purposes, a probabilistic approach should be used.

As the characteristics of a disaster are strongly influenced by the natural and social conditions, a suitable methodology for the simulation needs to be developed making best use of available data, as demonstrated in the following sections.

Source characteristics of the 1812 earthquake

The estimation of ground motion depends on three factors: Source characteristics, wave propagation, and site effects. In this study, the 1812 earthquake was selected as one of the four scenario earthquakes, through review of the catalog of historic earthquakes, instrumental seismic activity, and active fault studies. Studies and interpretations on this earthquake are numerous (Table 1) and additionally, there are many historical documents available. However, their quantitative information is not clear, because the time the earthquake occurred was also a period of social disorder during the struggle for national independence.

In this study, the event that occurred in 1812 near Caracas is considered as scenario earthquake, and it is represented as a line source allocated somewhere along the San Sebastian fault, with a mechanism of right lateral type as derived from tectonic and seismological observations

Table 1. Existing studies on the parameters of the 1812 earthquake

	Fiedler, 1961			Fiedler, 1968	Grases, 1990			FUNVISIS 997	Altez, 2000	Grases and Rodríguez, 2001		Altez, 2004
M	7.0	6.2	6.3	7.1	7.0	7.2	6.3			6..5-6.7	6.9-7.2	
Lat.	8.5	10.2	10.6	10.8	8.5	10.2	10.6					
Lon	71.3	69.1	66.9	66.9	71.3	69.1	66.9					
Depth	19.0	7.0	6.0	10-20	19.0	7.0	6.0					
MMI				IX+	IX	IX	VIII	X	IX		IX	
MMI in CCS				8-8.5								
Area				Near Caracas	Mérida	Barquisi-meto-SanFelipe	Caracas		Mérida	Mérida	San Felipe	Caracas
Time				16:07	16:07	16:07	16:07		17:00			16:07
Death				10.000	5.000	8.000	10.000					2.000

(Audemard *et al.*, 2000). The magnitude is defined as Mw=7.1 (Grases & Rodríguez, 2001), and the fault length is taken as 115 km from Audemard (2002). The absolute position of the ruptured segment along the fault trace is determined by the results of the simulation presented in this study.

Attenuation of seismic waves

The second step for defining the model for simulation is the evaluation of the seismic wave propagation along the bedrock. For this study, an attenuation law is selected considering the data set used for its development, and the conditions required for this scenario. As a result, an attenuation law that can distinguish source mechanism, which is applicable to an earthquake with a large magnitude in the near field, and which can treat different ground conditions is used with the mean value for strike-slip faulting recorded on hard rock (Campbell, 1997; Figure 4), as described in equation (1).

$$\ln(A_H) = -3.512 + 0.914M - 1.328\ln\sqrt{R_{SEIS}^2 + [0.149\exp(0.647M)]^2} + [0.405 - 0.222\ln(R_{SEIS})] \qquad (1)$$

A_H is the peak acceleration on the bedrock in units of g (g=981cm/s^2), M is the moment magnitude; R_{SEIS} is the shortest distance in km between the bedrock site and the seismogenic rupture zone along the fault. The depth to the upper limit of ruptured segment is set here to 5 km, derived from seismological observation in the study area (Sobiesiak, 2003).

Development of the ground model

The third step is the evaluation of the site effects. The study area is divided into a 500 m sized mesh. A ground model for each mesh is developed by integrating geomorphological (Matsuda, 2001), geological and geotechnical (Feliziani, 2003), and geophysical (Enomoto *et al.*, 2001, Rocabado *et al.*, 2001, Sánchez *et al.*, 2005) data. The depth to bedrock for the model is defined from the sediment thickness estimated from compilations of drillholes and geophysical studies (Weston, 1969; Kantak *et al.*, 2005; Sánchez *et al.*, 2005).

The shear wave velocity of the subsoil above the bedrock is defined from

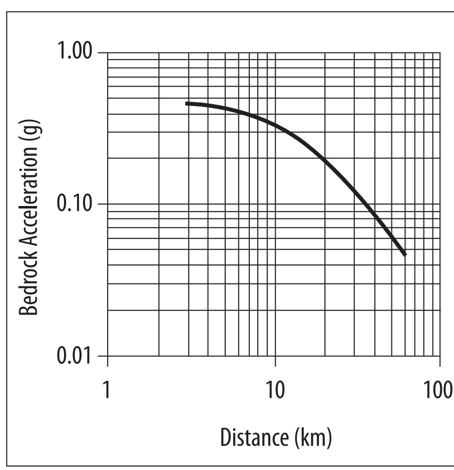

Figure 4. Attenuation curve used in this study (Campbell, 1997)

the average shear wave velocity estimated from micro tremor measurements (Schmitz *et al.*, 2003). Existing borehole data were selected considering the deepest drilling with results from standard penetration tests in each mesh from a borehole database (Feliziani, 2003). Then, the borehole data and the results from microtremor measurements in the same or nearest mesh are selected to develop a ground model (Figure 5). The shear wave velocity for each soil layer in the borehole data is estimated from standard penetration test values using an empirical formula (Imai *et al.*, 1977). The density is defined according to the geology of each layer and the gravimetric models in the valley (Sánchez *et al.*, 2001). The ground model for each mesh is calibrated comparing the theoretical response with the observed H/V spectral ratio at each point (Figure 6).

Input waves

To calculate the seismic response of the subsoil, it is necessary to select the input waves, generated by an earthquake with the same source mechanism as the scenario earthquake, and which is recorded on a rock site at a distance from the fault comparable to the one in the study area. Several candidate records were searched

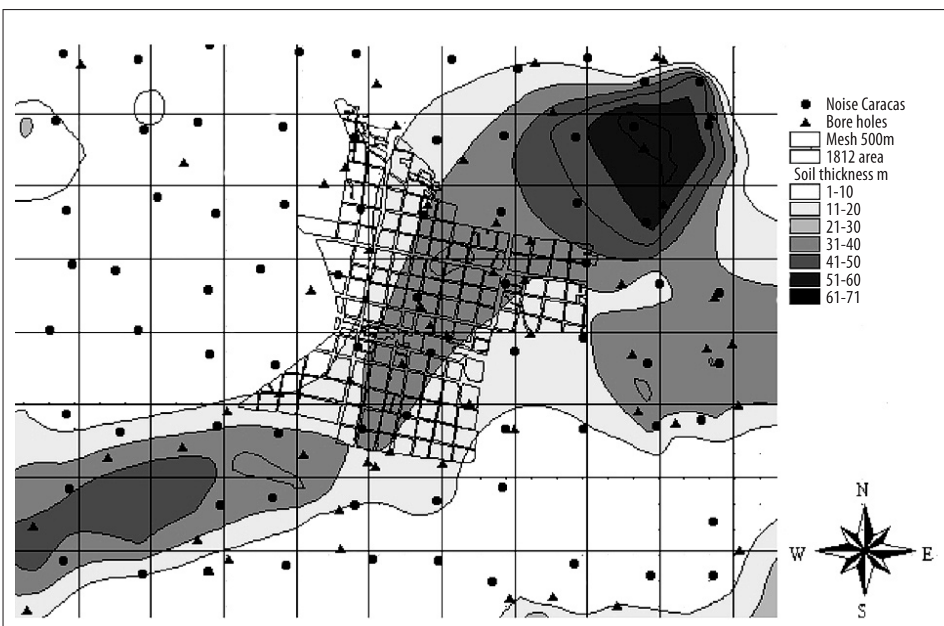

Figure 5. Distribution of microtremor measurement points (circles), borehole data (triangles), and sediment thickness (contour lines) around old Caracas (Sources: Enomoto *et al.*, 2001; Rocabado *et al.*, 2001; Feliziani, 2003; Kantak *et al.*, 2005)

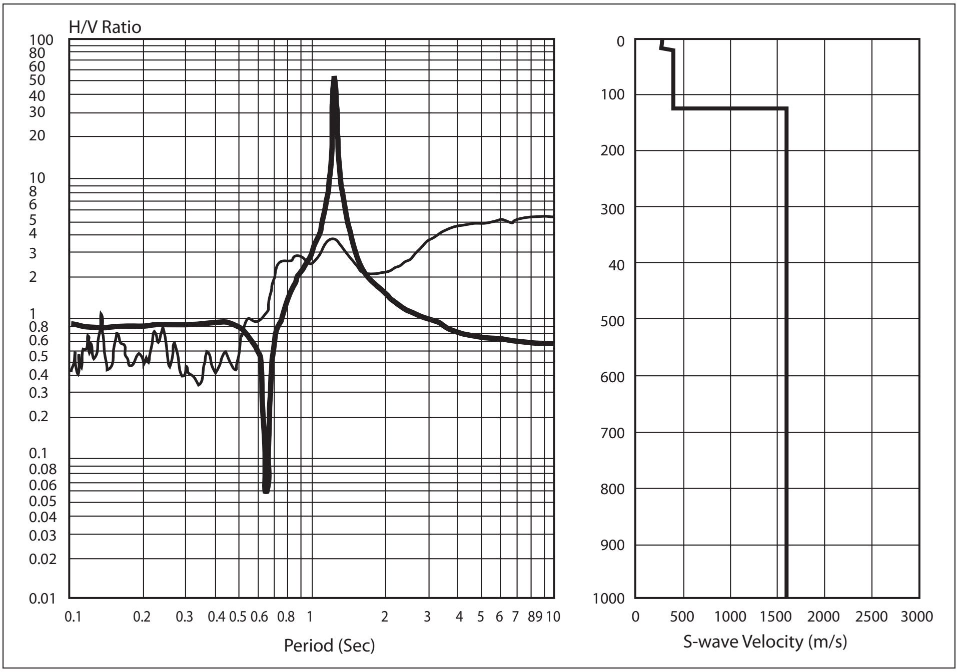

Figure 6. An example of ground model calibration using the theoretical amplification values (left, ▬▬), based on the developed ground model (right) and H/V spectral ratio from microtremors (left, ———) (H/V spectrum from Enomoto *et al.*, 2001)

from worldwide strong motion record databases. A suitable record, obtained during the November 12, 1999 Duzce earthquake in Turkey (M=7.1) and recorded at Mudurnu station on a rock site located 33.6 km from the fault (PEER), was selected considering the spectral component and its duration (Figure 7).

Soil response calculation

Though it would be desirable to use two or three-dimensional methods to include topographic effects and the detailed bedrock topography in the Caracas valley as input for the modeling, such a ground model was not readily available. Therefore, a one-dimensional approach is employed for soil response calculation. For the calculation, the maximum amplitude of the input wave is adjusted according to the value calculated by applying the attenuation law (Campbell, 1977) for each mesh. Then, the ground motion at the surface is calculated using the SHAKE program. In order to be able to correlate the ground motion with the building damage, the seismic intensity is calculated. For the calculation of the seismic intensity, the pseudo velocity spectrum at 20% damping is integrated

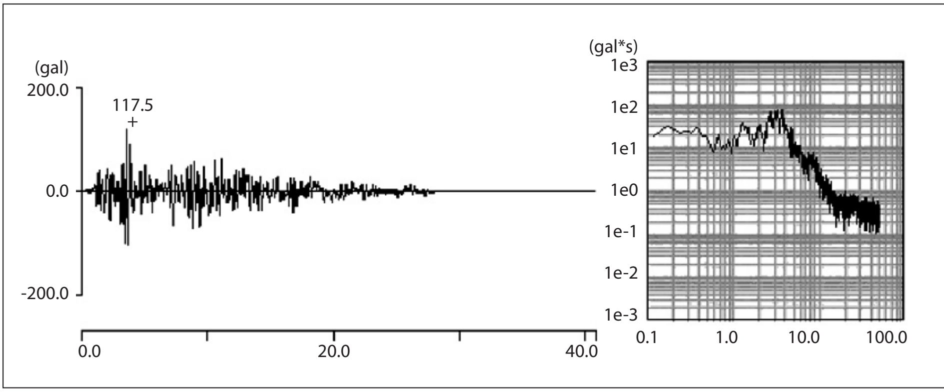

Figure 7. Strong motion record at Mudurnu station during the Duzce earthquake in Turkey on November 12, 1999 (M=7.1), used as input wave for the simulation (from PEER strong motion database)

over a period range from 0.1 s to 2.5 s, obtaining the Housner Spectrum Intensity (SI) (Housner, 1952). Then, the average pseudo velocity (V in cm/s) is calculated as shown in equation (2). The Modified Mercalli Intensity (MMI) is estimated by an empirical relation between V and MMI as shown in equation (3) (Esteva and Rosenblueth, 1964).

$$V=SI/2.4 \quad (2)$$

$$MMI=\log(14V)/\log 2 \quad (3)$$

This approach allows considering the potential damage for all the range of structures with any vibration period. On the contrary, a simple relationship between peak acceleration and intensity overlooks that range and does not adequately represent the soil response features.

Problems and approaches

Although a methodology for the seismic hazard analysis was developed, the exact fault location is still uncertain, because there is no unique solution given in the exiting studies. Besides, interpretations of the seismic intensities of the 1812 earthquake in Caracas are numerous, as shown in table 1. On the other hand, historical documents on the damage occurred in Caracas are not clear enough. As such, it was not possible to validate the simulation.

The damage extent and distribution in 1812 Caracas is considered the key information for the simulation. Thus, an approach as shown in figure 8 is employed. First, historical documents are carefully reviewed considering their credibility. Then, the basic information available for 1812 Caracas is examined, and the characteristics of the buildings are reviewed in order to evaluate their strength against earthquakes.

Based on the vulnerability of buildings and spatial expansion of Caracas, a building database for 1812 Caracas is developed. Using this database, a vulnerability curve, the seismic intensities, and damage ratios for the buildings are estimated. Finally, the resulting damage ratio is compared with the damages ratio derived from the historical documents, in order to determine the most likely fault rupture location.

The building database for 1812 Caracas

The spatial expansion of Caracas in the early 19th century is limited compared to that of today (Figure 9). Approximately 5.000 houses existed in 1812 in Caracas, including public houses and buildings. There were three large groups of constructions, whereas the majority of the houses were made of stones. They can

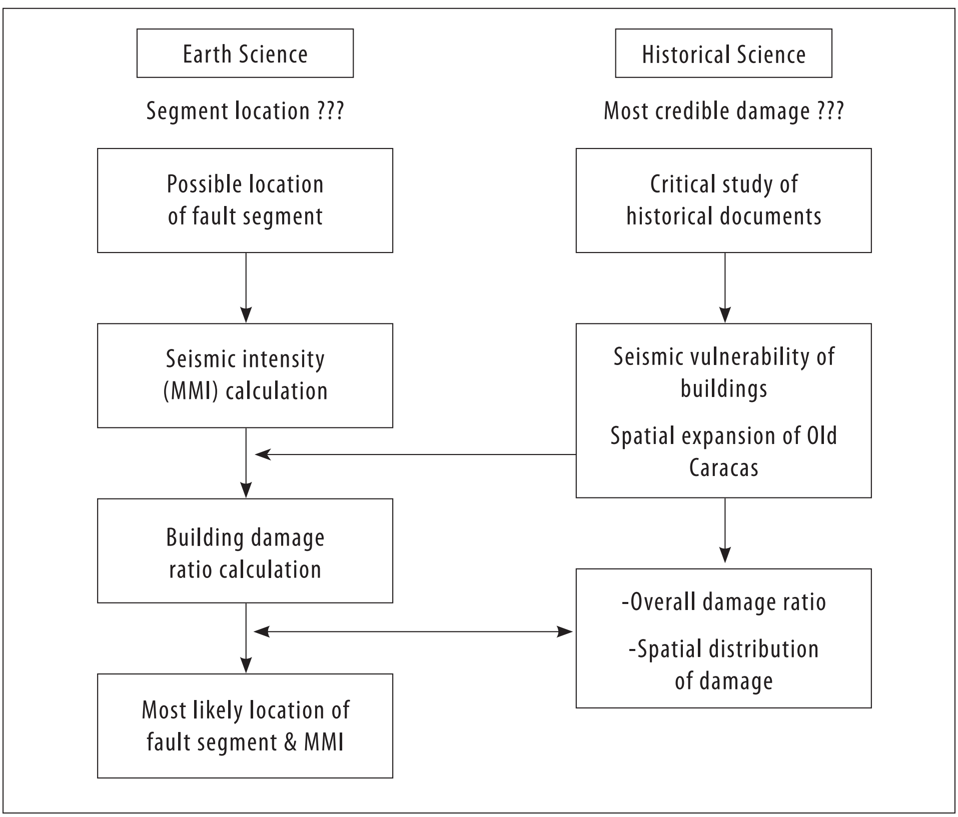

Figure 8. Flowchart of interaction between earth sciences and historical sciences to solve the problems in this study

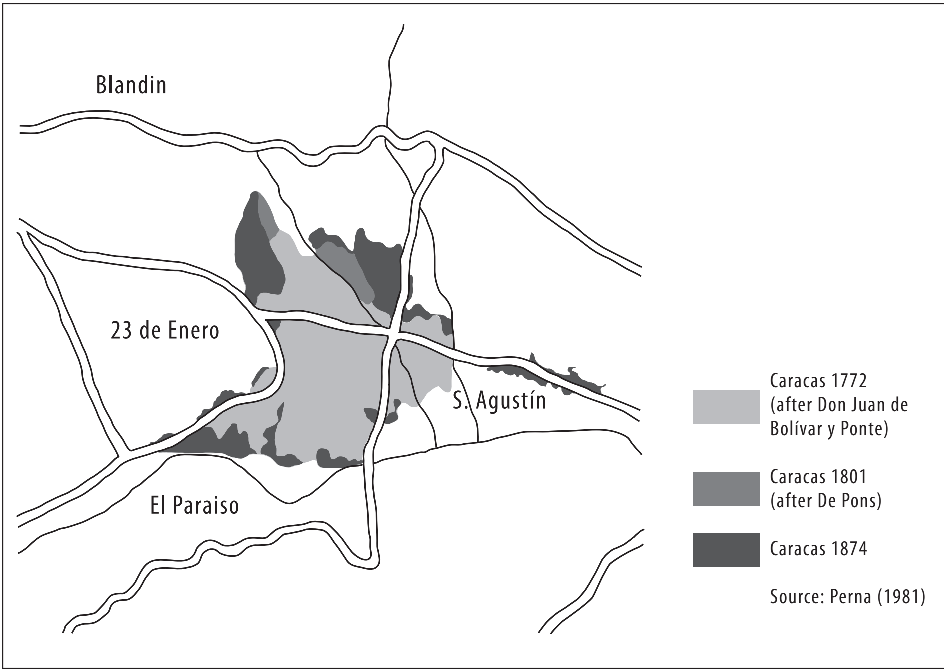

Figure 9. Spatial expansion of Old Caracas around 1812

be further subdivided into three groups, according to the socio economic classes (Table 2; Altez, 2004).

To develop a building database for 1812 Caracas, the definitions of the vulnerability against earthquakes, according to the European Macroseismic Scale 1998 (EMS-98) are used. In the EMS-98, different vulnerability classes are assigned for masonry buildings (Figure 10). It is assumed, that the average type of houses that existed uniformly distributed within Caracas, corresponded to a vulnerability class which is composed 75% of class A and 25% of class B, resulting in the vulnerability curve shown in figure 11, according to the review of historical documents and discussion with the experts in FUNVISIS.

Damage degree of buildings in 1812 caracas

In the EMS-98, the damage level of buildings due to earthquakes is classified into categories ranging from I (negligible to slight damage) through V (destruction) (illustration for masonry buildings see figure 12). Since human casualties are closely connected to the building damage, the damage levels IV and V are considered here, and they are called as "heavily damage" hereafter. The seismic intensities are estimated from the damage levels of building and their vulnerability class (Table 3), according to EMS-98. The numerical equivalent of the qualitative descriptions for the contribution

Table 2. Types of buildings in Caracas in 1812 as revealed from the review of historical documents (Altez, 2004)

Type of building	Type of construction
Churches	Stone, whitewashed walls, brick arches and wood frames with roofs of tile and wood.
Public administration buildings	Walls of adobe and stone, brick fronts, wood window bars and tile hip roofs.
Home houses	• High class: adobe and stone walls, brick fronts, windows with wood bars and tile hip roofs. Those with two stories had balconies. • Middle class: Adobe walls and roofs of straw or tiles strengthened with thin trunks. • Poor class: walls of bahareque and reeds, and roofs of straw or palm leaves.

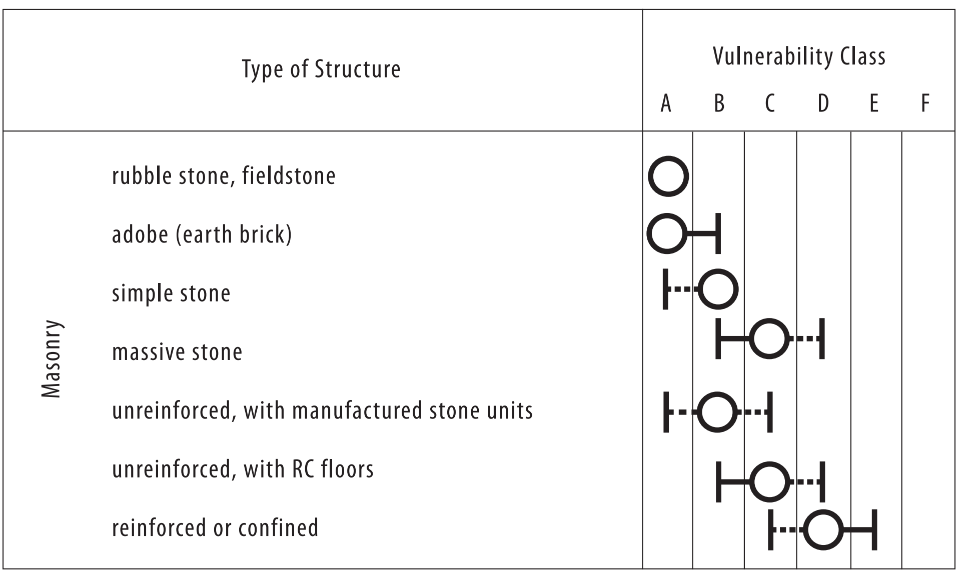

Figure 10. Vulnerability classes for different structural types of masonry buildings according to EMS-98

of houses of different damage grade to the respective vulnerability classes (as shown in table 3) are given in figure 13. The damage degree of buildings in Caracas, evaluated by historical documents using the EMS-98, scale is shown in table 4 (Altez, 2004). It is estimated that about 3.000 out of 5.000 houses, or 60 %, suffered damaged degree of V.

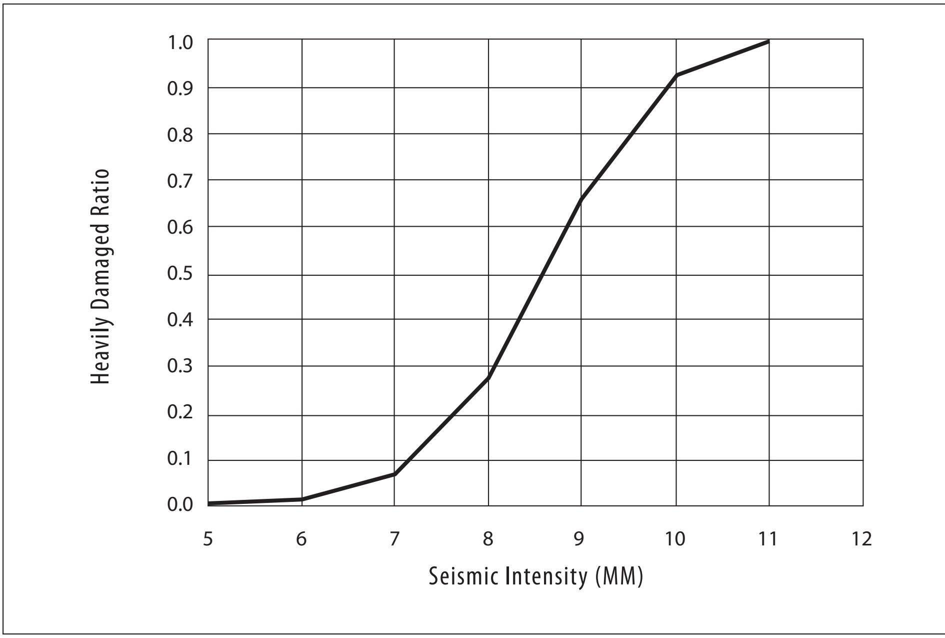

Figure 11. Proposed vulnerability curve of buildings in Caracas in 1812 (Safina, 2003)

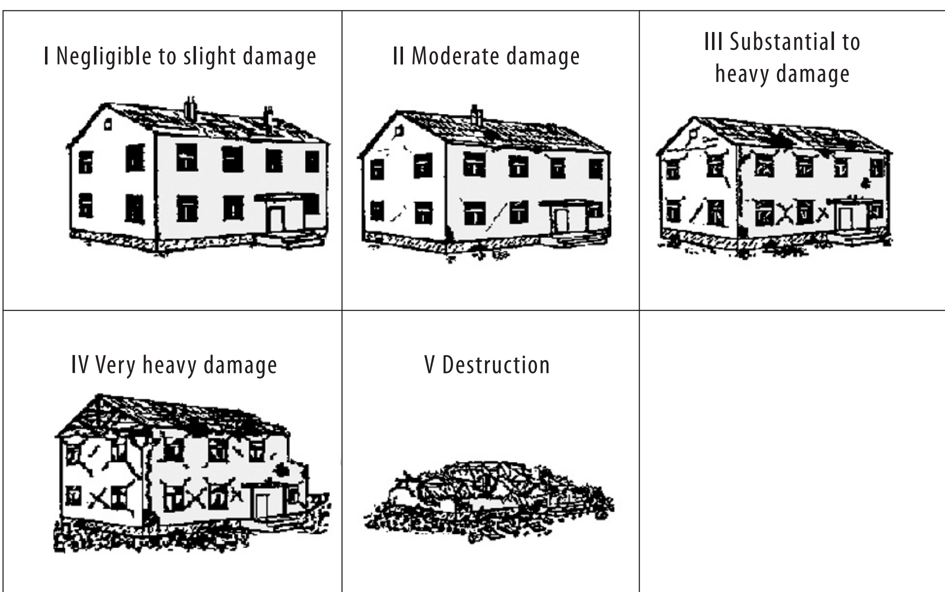

Figure 12. Illustration of damage degrees of masonry buildings according to EMS-98

Table 3. Seismic intensities as evaluated by vulnerability class damage grade of different vulnerability classes of buildings according to EMS-98

Seismic Intensity	Damage grade for vulnerability class A	Damage grade for vulnerability class B
VII Damaging	Many of grade III A few of grade IV	Many of grade II A few of grade III
VIII Heavily damaging	Many of grade IV A few of grade V	Many of grade III A few of grade IV
IX Destructive	Many of grade V	Many of grade IV A few of grade V

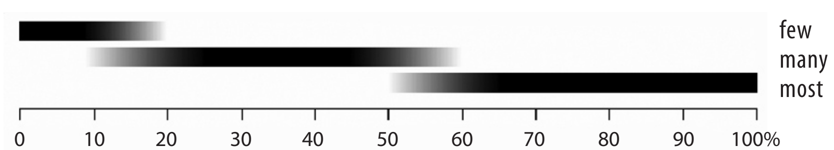

Figure 13. Numerical interpretation of expressions used in EMS-98

Table 4. Type of building and damage degrees according to EMS-98 in Old Caracas as revealed from review of historical documents (Altez, 2004)

Type of construction	Total No. in the city (approx.)	III	IV	V
Buildings	25	2/8%	10/40%	13/52%
Public administration houses	13	1/?	2/?	3/?
Homes	5.000	?	?	3.000/60%

Estimation of the seismic intensities and the fault location

Based on the reviewed situation, the possible fault segment location was evaluated by a trial and error procedure using different models for the location of the fault rupture (Figure 14), in order to reproduce a simulation where heavily damage of buildings in 1812 Caracas is around 60% (Table 5). Model F, in which the east end of the fault is located between model C and model N, produces a heavily damage ratio of 56.9 %, which is found to be the most likely one.

The location of the public buildings and churches with their damage degree, as revealed from historical documents, is mapped together with the estimated seismic intensity map using model F (Figure 15).

Conclusions

The results of this study indicate that the northern part of 1812 Caracas suffered higher ground motion, and respectively a higher damage degree than the southern one. This good coincidence of areas with high damage degrees and high seismic intensities may be attri-

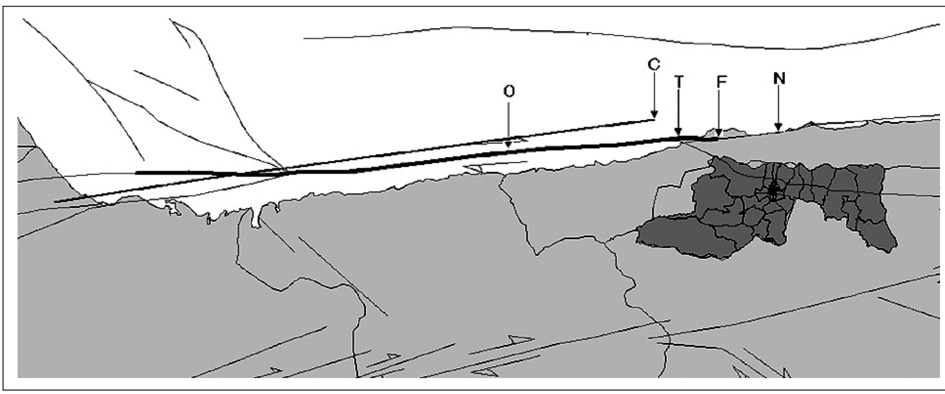

Figure 14. Possible locations of fault segment which ruptured during the 1812 earthquake. The arrows indicate the east end of the segment, corresponding to the models in table 5

Table 5. Comparison of simulation results by various models

Model	Base	MMI			Heavily damage
		Ave.	Max.	Min.	
O	End of 1967 segment	6.6	7.3	5.7	
C	Audemard (2002)	7.8	8.5	7.0	27.6%
T	End of Tacagua fault	8.3	9.0	7.5	41.9%
F	In between C & N	8.6	9.4	7.9	56.9%
N	Grases (1990)	9.0	9.8	8.3	70.8%

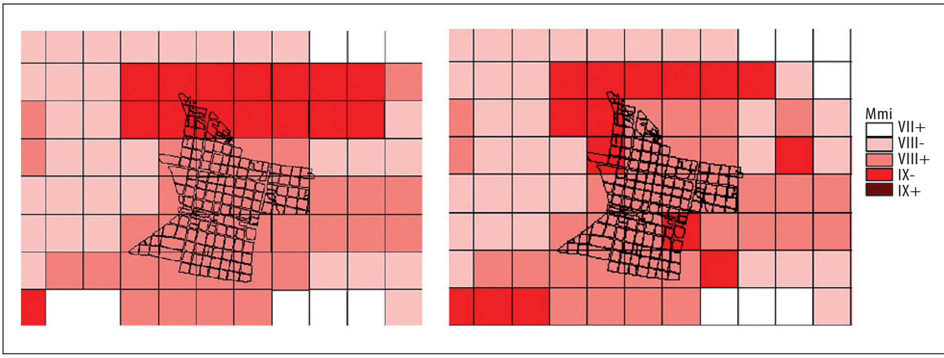

Figure 15. Damage degree of buildings in Caracas during the 1812 earthquake estimated by historical documents' review (Altez, 2004) in the left. Seismic intensity in 1812 Caracas during the 1812 earthquake, estimated by Model F in the right

buted to the fact that the northern part of 1812 Caracas is located closer of the fault trace, and also to site effects. A quantitative evaluation of the historical disaster was realized by the integration of existing, newly revised data, and in a close collaboration between earth and historical science using precious historical documentations. Thus, contradictions in the information regarding the seismic intensity and their implication for the seismological parameters of the event could be resolved. This allows for a more accurate simulation of the effects of the 1812 scenario earthquake in "The Basic Study on Disaster Prevention in the Metropolitan District of Caracas".

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References quoted

ALTEZ, R. 2004. *Detailed Damage Evaluation of the 1812 Caracas Earthquake*. Report submitted to JICA. (Inedited).

ALTEZ, R. 2000. *Terremotos confundidos: los sismos del 26 de marzo de 1812 en Caracas y Mérida*. **Bolivarium**. Caracas. VIII (9):1-32.

AUDEMARD, F. 2002. Ruptura de los grandes sismos venezolanos de los siglos XIX y XX relevados por la sismicidad instrumental contemporánea. *XI Congreso Venezolano de Geofísica*, (17 al 20 de Noviembre). Caracas, Venezuela.

AUDEMARD, F. A.; MACHETTE, M.; COX, J.; HART, R. and HALLER, K. 2000. *Map* *and database of Quaternary faults in Venezuela and its offshore regions*. U.S. Geological Survey Open-File-Report 00-18, 79 pp + map.

CAMPBELL, K.W. 1997. *Empirical Near-Source Attenuation Relationships for Horizontal and Vertical Components of Peak Ground Acceleration, Peak Ground Velocity, and Pseudo-Absolute Acceleration Response Spectra*. **Seismological Research Letters**, 68 (1):154-179.

EMS-98: European Seismological Commission, Subcommission on Engineering Seismology, Working Group Macroseismic Scales. European Macroseismic Scale 1998 (EMS-98). Luxembourg, 1998. [On line] http://www.gfz-potsdam.de/pb1/pg2/ems_new/index.htm.

ENOMOTO, T.; SCHMITZ, M.; MATSUDA, I.; ABEKI, N.; MASAKI, K.; NAVARRO, M.; ROCABADO, V. and SANCHEZ, A. 2001. Fundamental study on seismic risk assessment using soil dynamic characteristics in Caracas. *Venezuela International Workshop "Study on Countermeasures for Earthquake Disaster in Caracas (1999-2001)"*. Caracas, Venezuela (August 24 - August 25, 2000), Série Técnica FUNVISIS No.1-2001:40-45.

ESTEVA, L. and ROSENBLUETH, E. 1964. *Espectros de temblores a distancias moderadas y grandes*. **Bol. Soc. Mex. Ing. Sísm**. 2(1):1-18.

FELIZIANI, P. 2003. *A Project for Boring Database Development*. (Funded by FONACIT. Fondo Nacional de Ciencia y Tecnología), unpublished.

FIEDLER, G. 1961. Áreas afectadas por terremotos en Venezuela. *Tercer Congreso Geológico Venezolano*, Tomo 4, Boletín de Geología, Publicación Especial Nº 3. Caracas, Venezuela.

FIEDLER, G. 1968. *Estudio Sismológico de la Región de Caracas con Relación al Terremoto del 29 de Julio de 1967. (Terremoto del Cuatricentenario). Reporte y Evaluaciones*. **Boletín Técnico IMME**. Caracas, Venezuela, 23-24:127-222.

FUNDACIÓN POLAR. 2000. **Diccionario Multimedia de Historia de Venezuela**.

FUNVISIS. 1997. *Estudio neotectónico y geología de fallas activas en el Piedemonte surandino de los Andes venezolanos*. Proyecto INTEVEP 95-061, Abril. (Inedited).

GRASES, J. 1990. **Terremotos destructores del Caribe. 1502-1990**. 1º ed., Orcyt-Unesco. Montevideo, Uruguay. 132 pp.

GRASES, J. and RODRÍGUEZ, J. A. 2001. Estimaciones de Magnitud de Sismos Venezolanos a partir de mapas de isosistas. *Memorias del 2do Seminario Iberoamericano de Ingeniería Sísmica*. Madrid.

HOUSNER, G. W. 1952. Spectrum Intensities of Strong Motion Earthquakes, *Proceedings of the symposium on Earthquakes and Blast Effects on Structures*. Earthquake Engineering Research Institute.

IMAI, T. and TONOUCHI, K. 1977. P- and S-wave Velocities of the Ground in Japan. **Proc. 9th ICSMFE**, 2:257-260.

KAGAMI, H., 1993. *Seismic microzonation map, Earthquake motion and ground conditions, in commemoration of the 20th anniversary of the research subcommittee on earthquake ground motion*. **The Architectural Institute of Japan**: 443-454.

KANTAK, P.; SCHMITZ, M. and AUDEMARD, F. 2005. *Sediment thickness and a west-east geologic cross section in the Caracas Valley*. **Boletín de la Sociedad Venezolana de Geólogos**. (In print).

MATSUDA, I. 2001. Landforms and soil conditions in Caracas basin and surroundings. Fundamental study on seismic risk assessment using soil dynamic characteristics in Caracas. *Venezuela International Workshop "Study on Countermeasures for Earthquake Disaster in Caracas (1999-2001)"*. Caracas, Venezuela (August 24 - August 25, 2000), Série Técnica FUNVISIS, Nº1-2001:112-121.

PEER (Pacific Earthquake Engineering Research Center). PEER Strong Motion Database. [On line] http://peer.berkeley.edu/smcat/index.html.

PERNA, C. 1981. **Evolución de la geografía urbana de Caracas**. Ediciones de la Facultad de Humanidades y Educación, Universidad Central de Venezuela. Caracas, p.120.

ROCABADO, V.; SCHMITZ, M.; MALAVÉ, G. and ENOMOTO, T. 2001. Períodos fundamentales y amplificación del suelo de la ciudad de Caracas utilizando la técnica de Nakamura. Fundamental study on seismic risk assessment using soil dynamic characteristics in Caracas. *Venezuela International Workshop "Study on Countermeasures for Earthquake Disaster in Caracas (1999 – 2001)"*. Caracas, Venezuela (August 24 - August 25, 2000), Série Técnica FUNVISIS No.1-2001:129-135.

SAFINA, S. 2003. *Propuesta preliminar de funciones de daño para las principales categorías de edificaciones de la ciudad de Caracas*. Unpublished report.

SÁNCHEZ J.; ORIHUELA, N.; MEZA, R. and AMBROSIO, R. 2001. Modelaje gravimétrico de la cuenca de Los Palos Grandes. *Venezuela International Workshop "Study on Countermeasures for Earthquake Disaster in Caracas (1999 – 2001)",* Caracas, Venezuela (August 24 - August 25, 2000), Série Técnica FUNVISIS No.1-2001:158-165.

SÁNCHEZ, J.; SCHMITZ, M.; CANO, M. and V. 2005. *Mediciones sísmicas profundas en Caracas para la determinación del espesor de sedimentos y velocidades sísmicas*. **Boletín de la Sociedad Venezolana de Geólogos**. (In print).

SCHMITZ, M.; SÁNCHEZ, J.; ROCABADO, V. and ENOMOTO, T. 2003. Geophysical investigations as the base for a seismic microzoning study in Caracas. *Venezuela International Workshop "Study on Countermeasures for Earthquake Disaster in Caracas (1999-2001)"*. Caracas, Venezuela (August 24 - August 25, 2000), Série Técnica FUNVISIS No.1-2001:123-131.

SOBIESIAK, M. 2003. Personal communication.

WESTON GEOPHYSICAL ENGINEERS INTERNATIONAL INC. 1969. Investigaciones Sísmicas en el Valle de Caracas y en el Litoral Central (bajo la planificación y supervisión de la Comisión Presidencial para el Estudio del Sismo), 1-22.