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Earthquake Scenarios in Caracas for Disaster Prevention

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SUMMARY

This study is part of the results obtained by the “Study on Disaster Prevention Basic Plan in the Metropolitan District of Caracas”. Four scenario earthquakes are used for simulations to estimate the seismic intensity, building damages, and human casualties in Caracas, in order to establish a disaster prevention master plan. In this paper we present an overall introduction to the study.

RESUMEN

Este estudio presenta parte de los resultados del “Estudio sobre el Plan Básico de Prevención de Desastres en el Distrito Metropolitano de Caracas”. Se usaron cuatro terremotos de escenario en las simulaciones para estimar las intensidades sísmicas, los daños en edificios y las pérdidas humanas en Caracas con el fin de establecer el plan master de prevención de desastres. En este trabajo presentamos una introducción general al estudio.

INTRODUCCIÓN

Caracas has experienced major earthquakes at least once in a century since its foundation in the early 16th century. Though it is still difficult to predict when and where major earthquake will happen, and it is impossible to prevent the occurrence of an earthquake, however, it is possible to estimate what types of earthquake may occur, and its possible consequences. An effective way to reduce earthquake damage is to make a plan and to take preventive measures with the knowledge of possible damages. This paper presents an attempt toward such actions.

“The Study on Disaster Prevention Basic Plan in the Metropolitan District of Caracas”, executed by the Japan International Cooperation Agency JICA upon the request of the Government of the Bolivarian Republic of Venezuela, was executed in the three municipalities Libertador, Chacao and Sucre. In the earthquake hazard and risk estimation, specific scenario earthquakes are considered, and quantitative estimations are made using current data on buildings and population. The flowchart of the study is illustrated in figure 1.

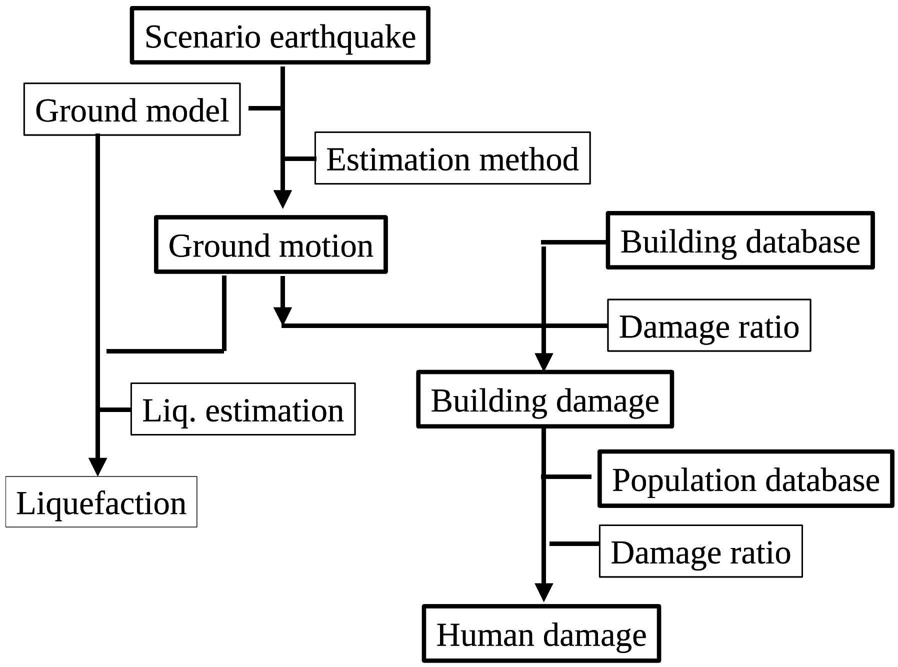

Figure 1. Flowchart of the study.

SCENARIO EARTHQUAKES

Four major earthquakes had occurred along San Sebastian fault system north of Caracas, the most active fault system around Caracas (Audemard et al., 2000) in historical times during the last five centuries (Grases, 1990). Among them, the 1812 earthquake, that caused the worst damage in Venezuela, and the 1967 earthquake are taken as scenarios.

Besides, major earthquakes also occurred in the south of Caracas along the less active Victoria Fault or Tacata Fault. In this study, the 1878 earthquake was taken as a scenario in the South. Moreover, a hypothetical earthquake originated from the even less active Avila fault is also taken as a reference, because of its closeness to the study area, even though it has no historical record in last five centuries. The locations of the faults for scenario earthquakes are shown in figure 2.

Regarding the parameters for scenario earthquakes, right-lateral mechanism is assumed for all scenarios based on neotectonic data (Audemard et al., 2000) and according to seismological observations in the area (Romero et al., 2002). Magnitudes are taken from existing studies (Suárez and Nabelek, 1990; Grases and Rodríguez, 2001). The fault length is estimated from magnitudes, using an empirical formula. The fault length for the 1967 earthquake is defined as a distance between the two major events (Suárez and Nabelek, 1990). For the hypothetical Avila earthquake, a minimum magnitude is assumed. The assigned parameters are shown in table 1.

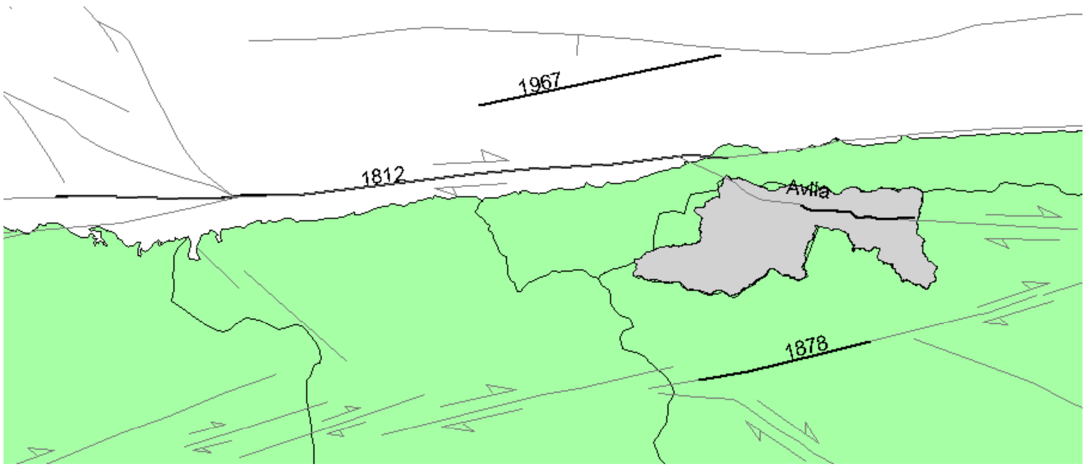

Figure 2. Location of faults for scenario earthquakes used in this study.

Table 1. Parameters of Scenario Earthquakes.

Scenario	Mw	Fault Length (km)	Fault system
1967	6.6	42	San Sebastian
1812	7.1	115	San Sebastian
1878	6.3	30	La Victoria
Avila	6	20	Tacagua-El Avila

GROUND MOTION ESTIMATION

There are many studies and information in various institutions regarding the ground condition in Caracas. A ground model is developed to evaluate amplification effect of subsoil integrating existing geological (Matsuda, 2001), geotechnical (Feliziani, 2003) and geophysical (Enomoto et al., 2001; Rocabado et al, 2001) information, using a 500 m sized grid (figure 3).
Each ground model is calibrated by comparing its theoretical amplification curve with the spectral ratio between horizontal and vertical component of microtremor measured within the same mesh (figure 4).
An empirical attenuation formula (equation 1, figure 5) that involves near field source mechanism and different ground conditions, and which is applicable to earthquakes with large magnitudes, is used to estimate the ground motion on bedrock (Campbell, 1997).

$$Ln (A_H) = -3.512+0.904*Mw-1.328*Ln(R_{SEIS}^2+(0.149*Exp(0.647*Mw))\char`^2)^{(1/2)} +(0.405-0.222*Ln(R_{SEIS})) \quad (1)$$

Where A_H is peak acceleration on the bedrock in units of g (g=981cm/second^2), Mw is the moment magnitude, R_{SEIS} is the shortest distance between the center of each mesh and the seismogenic rupture zone on the fault in km.

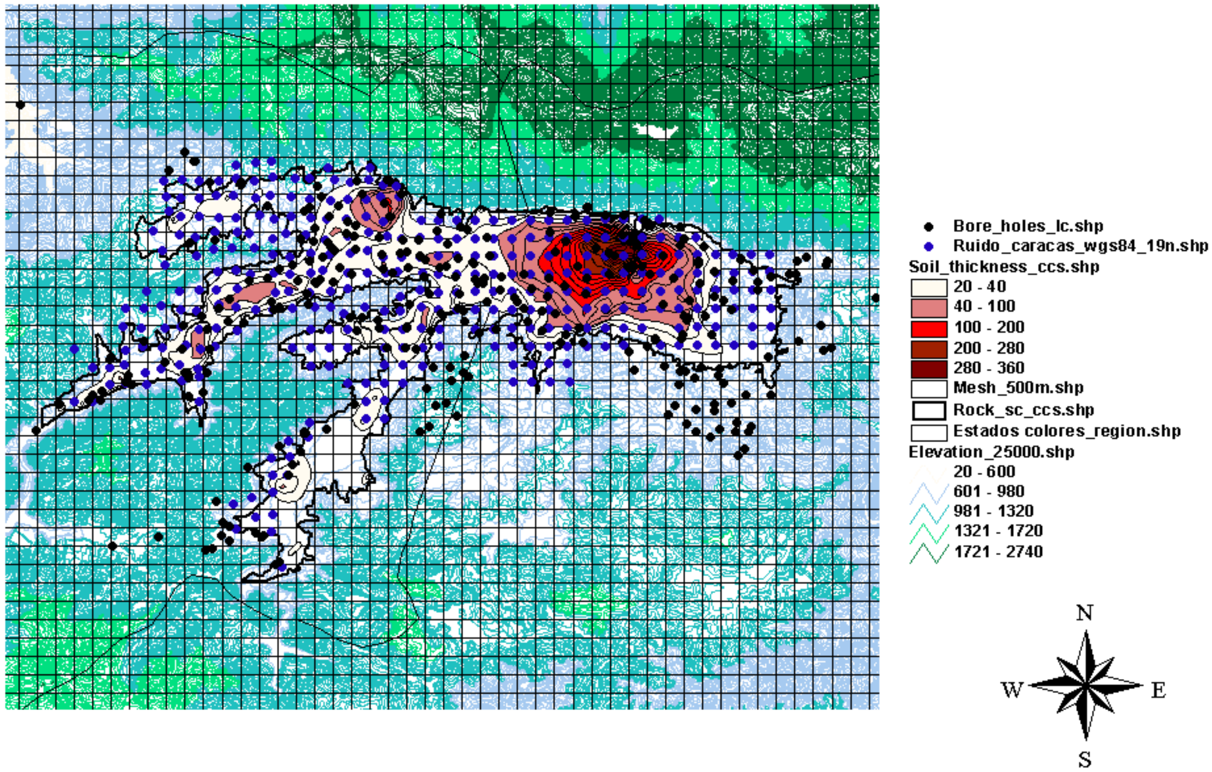

Figure 3. Distribution of borehole data (black dots), microtremor measurement points (blue dots), and sediment thickness (red contour lines). The best available borehole data is selected in each mesh to develop a ground model (source: Feliziani, 2003; Enomoto et al, 2001; Rocabado, et al., 2001; Kantak et al., 2004).

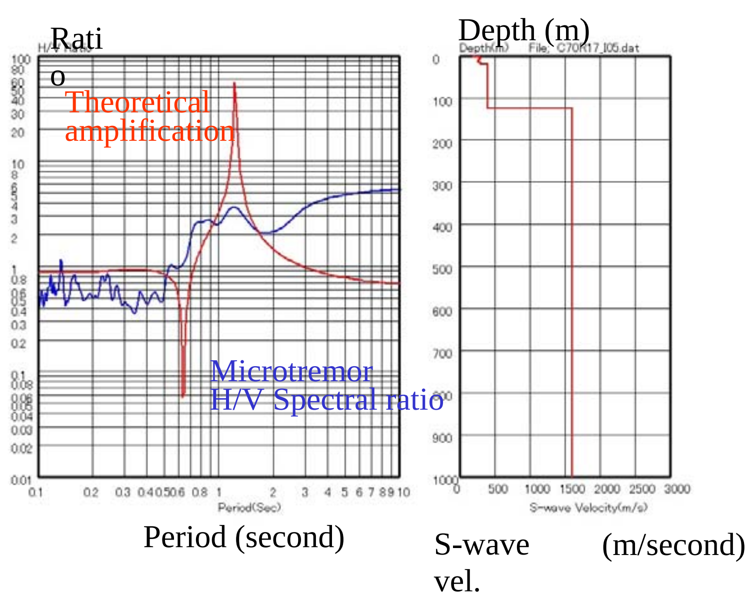

Figure 4. An example of ground model calibration using the theoretical amplification (left, red line), based on the ground model (right) and H/V spectral ratio from microtremors (left, blue line).

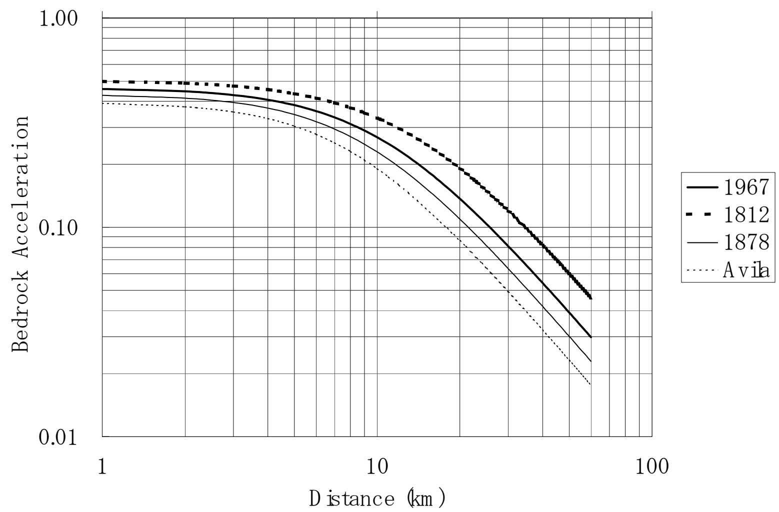

Figure 5. Attenuation curve employed in this study (Campbell, 1997).

The real strong motion records used as input waves for the seismic response of the subsoil (table 2 and figure 6), were generated from earthquakes with the same mechanism and a compatible magnitude, recorded on bedrock at a distance compatible to the distance between the respective fault and the study area (PEER, COSMOS).

Table 2. List of strong motion records used as input waves.

Scenario	**Earthquake**	**Date**	**Site name**
1967	Imperial Valley, USA	1979/10/15	6604 Cerro Prieto
1812	Duzce, Turkey	1999/11/12	Mudurnu
1878	Big Bear Lake、USA	1992/06/28	Snow Creek
Avila	Morgan Hill、USA	1984/04/24	47379 Gilroy Array #1

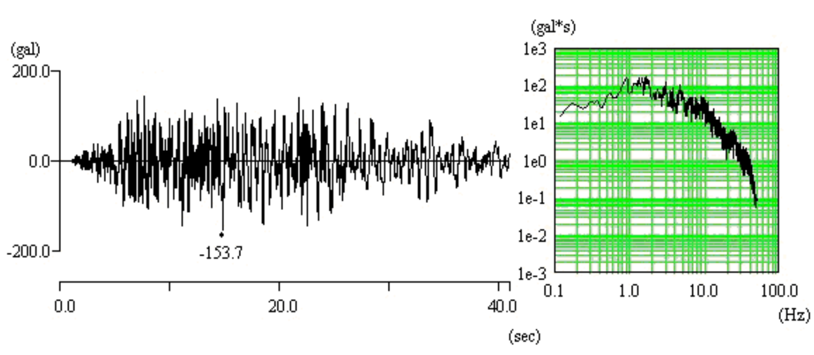

Figure 6. Input accelerogram and its spectrum used for the 1967 Scenario Earthquake.

The peak value of input waves at the bedrock is adjusted by an attenuation formula. The seismic response of the subsurface is then evaluated using a one-dimensional subsoil model. The peak ground acceleration and peak ground velocity are calculated in every mesh.
To link the ground motion with the damage estimation of buildings, taking into account the period of the ground motion, the seismic intensity is calculated in each mesh (figure 7), using an empirical relation between spectrum intensity (SI) and seismic intensity (MMI) as shown in eq. (2) and eq. (3). The Spectrum Intensity is defined by Housner (1952) as integrating velocity response spectrum at 20 % damping over period range between 0.1 to 2.5 seconds.

$$MMI=\log 14(V)/\log 2 \quad (2)$$
$$V=SI/2.4 \quad (3)$$

Figure 7. Estimated seismic intensity distribution for the 1967 scenario earthquake.

For the evaluation of liquefaction susceptibility, borehole data obtained from the metro construction works were used. First, the study area for liquefaction susceptibility was limited based on geomorphological considerations, and then the liquefaction susceptibility was evaluated as shown in figure 8, using a method employed at highway standard specification in Japan (Japan Road Association, 1996).

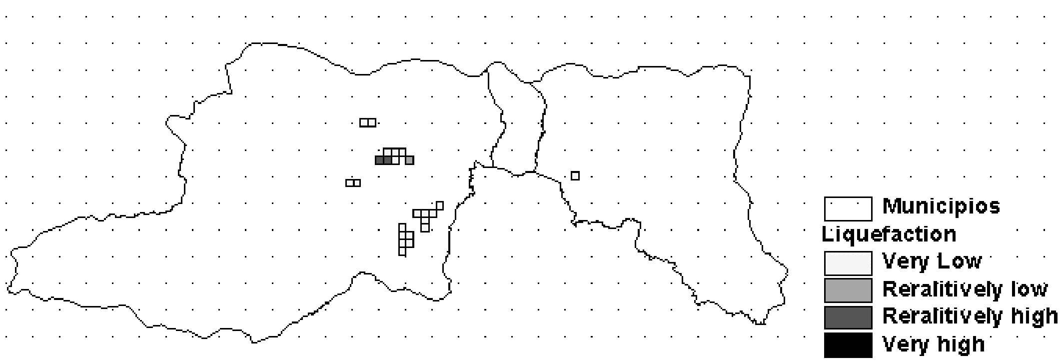

Figure 8. Estimated liquefaction susceptibility for the 1967 scenario earthquake.

BUILDING DAMAGE ESTIMATION

In damage estimation, the buildings are categorized to evaluate all the buildings in the study area statistically. To develop a building database, the study area was divided into urban, rural, and barrio areas.

For the urban area, the buildings are categorized by structural type, number of stories, and year of construction. Structural types are categorized into reinforced concrete, steel structure, and adobe structure buildings. Buildings are divided in lower and higher than four stories, according to the necessity of obtaining construction permit in the building code. The year for construction is divided into "before" or "after" the year 1982, when the required strength in the seismic building code was increased significantly, based on the review on history of building code development. The number of buildings in the urban area for each building type was estimated by field sampling, using the building database developed during Avila Project (Delgado and Jimenez, 2002) as a reference.

Buildings in barrio and rural areas are divided by the slope angle (higher than 20 degrees or not), using a digital terrain model. The number of buildings in barrio area is estimated using an empirical relationship found between the area and the number of buildings (Sucre Municipality Engineering Office, 2003). The number of buildings in rural area is counted on aerial photographs.

For the damage estimation, a relationship between seismic intensity and damage ratio for different types of buildings is made using damage statistics obtained by earthquakes in Italy and Spain based on the European Macroseismic Scale (EMS). Then, corresponding vulnerability curves are developed for the building types in Caracas by a weighted combination of the buildings types in the European Macroseismic Scale (EMS) (figure 9; Safina, 2003). The vulnerability curve for middle to high-rise RC buildings is calibrated with the damage data from the 1967 Caracas earthquake (FUNVISIS, 1978).

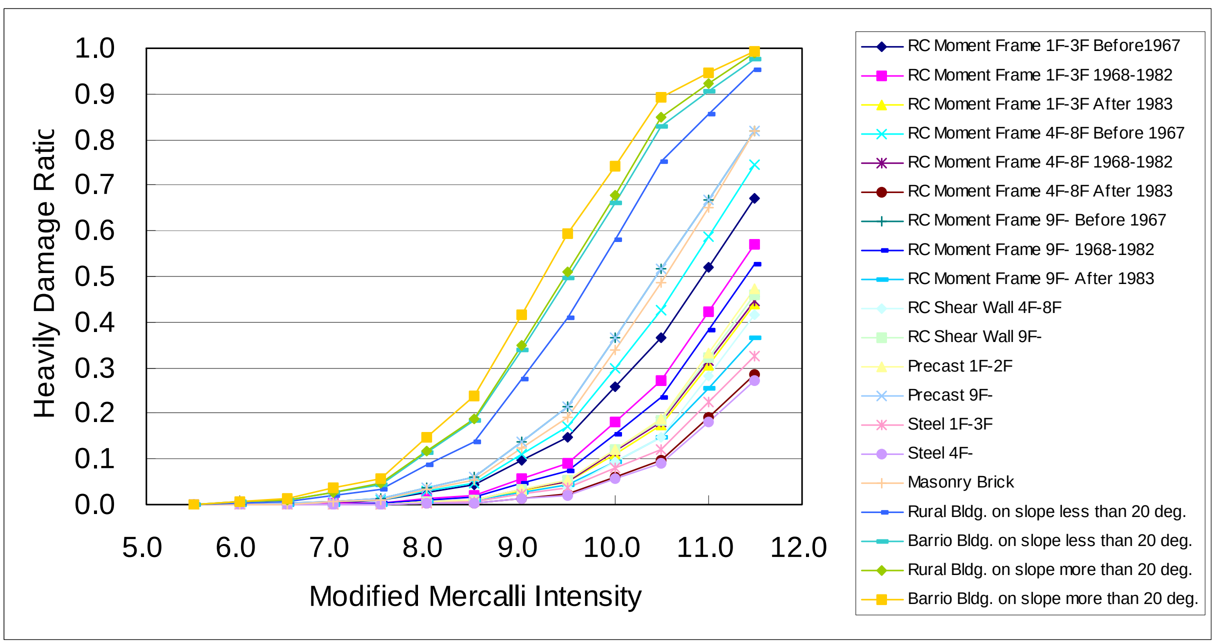

Figure 9. Vulnerability curves of buildings in Caracas (Safina, 2003).

HUMAN CASUALTY ESTIMATION

Regarding the human casualty estimation, two empirical equations between number of heavily damaged buildings and human death are developed. The one for low rise buildings is made using the damage statistics during 1999 Quindio earthquake in Colombia (DANE, 1999), and the one for mid to high-rise buildings is made by data mainly for the damage of collective RC structures in the world (Coburn and Spence, 1992).
The number of injured people is estimated using the empirical equation between number of human death and number of injured, developed from statistical data during Quindio earthquake (DANE, 1999).

VERIFICATION OF THE INTENSITY ESTIMATION

The possibility of verification of the intensity estimation varies for each scenario due to the availability of existing information. For the 1812 scenario, historical documents are critically reviewed to verify the most likely damage amount and its special distribution in Old Caracas (Altez, 2004). Then, the ground motion that can generate such seismic intensity and damage distribution is adopted by adjusting the exact earthquake location until a satisfactory fit is obtained (figure 10).

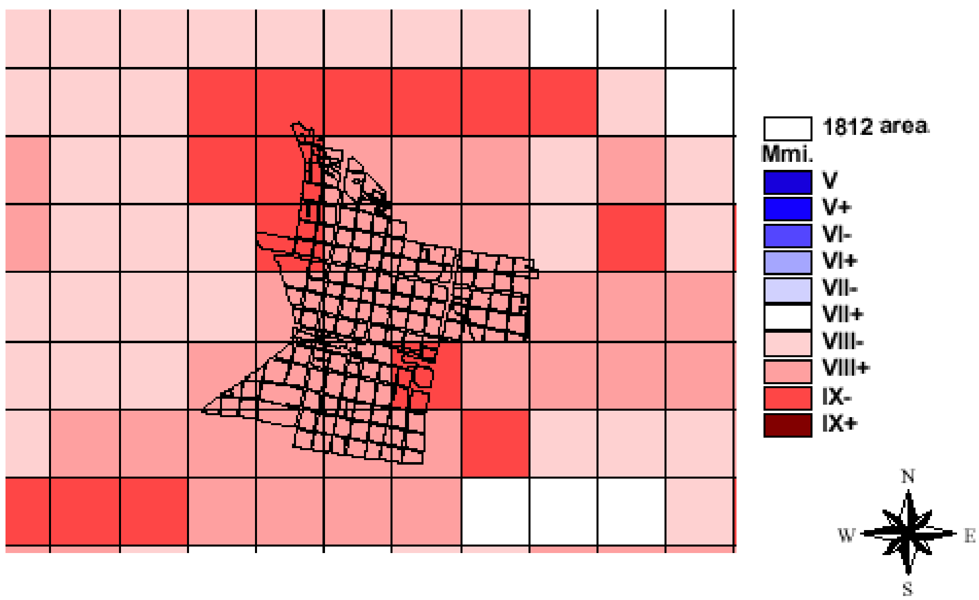

Figure 10. Estimated seismic intensity distribution for the 1812 earthquake in Old Caracas.

For the 1878 scenario, the estimated result is compared with seismic intensity and damage observations at a macro scale (Grases, 1990). Neither heavily damaged buildings nor human casualties are recorded within Caracas for that event, which coincides with the estimated damage, which is also limited in number.
For the 1967 scenario, a detailed seismic intensity distribution within Caracas (figure 11; Fiedler, 1968), and the number of heavily damaged buildings and human death is recorded (FUNVISIS, 1978), so that the seismic intensity and the building damage can be calibrated using the building database projected for that time.

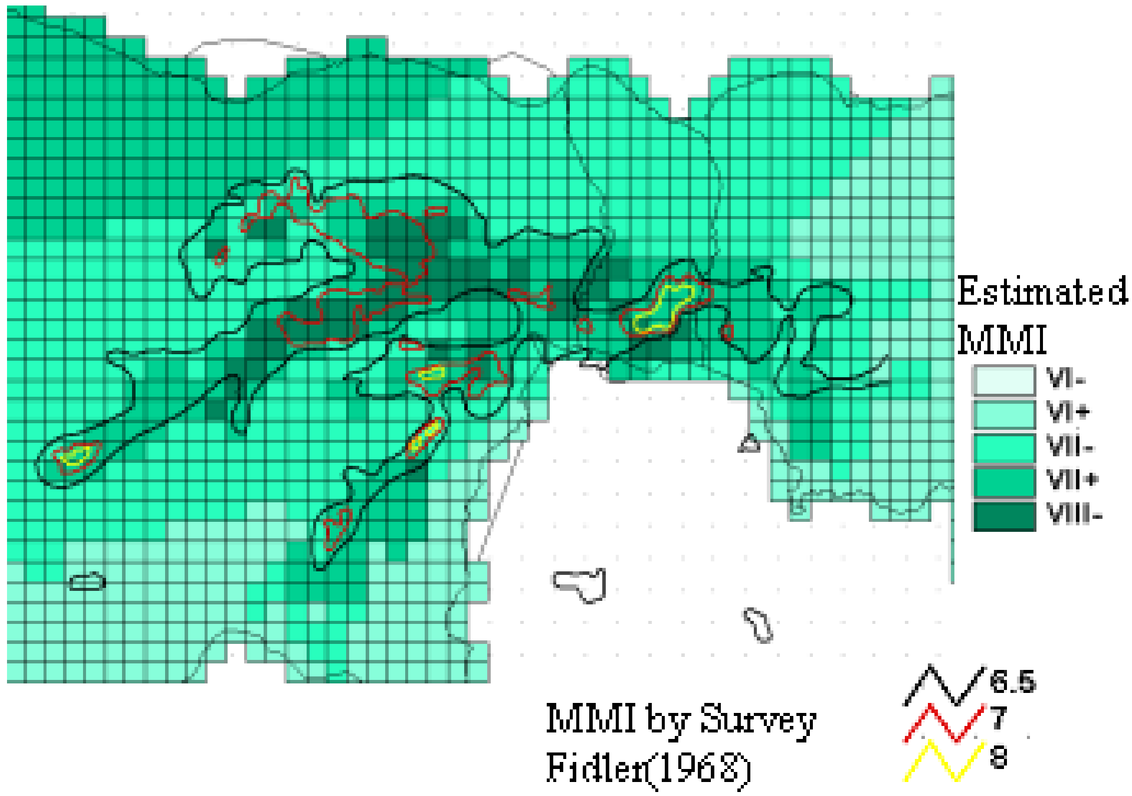

Figure 11. Comparison between the estimated seismic intensity for the 1967 scenario earthquake and the surveyed seismic intensity during the 1967 earthquake (Fiedler, 1968).

CONCLUSIONS

During the development of the Disaster Prevention Basic Plan in the Metropolitan District of Caracas, considerations regarding the earthquake disaster were discussed between the members of the JICA study group and local institutions, coordinated by FUNVISIS. The detailed methodology applied within the study was afined during numerous discussions of the study group. Local information was used for the calibration of the results of the different scenario earthquakes, for which the intensity distribution and damage distribution were calculated. The results will be used for the design of the Disaster Prevention Plan in the Metropolitan district of Caracas.

For example, it is estimated that a strong ground motion similar to the 1967 earthquake could produce larger building damage and human casualty than at the time of 1967 as shown in table 3, if it occurs in today's Caracas, where the dwelled area is expanded and the number of vulnerable buildings is increased.

Table 3. Population and building status and damage for the 1967 earthquake.

	Status in 1967*	**Status in 2003 for 3 municipalities**
Population	1.8 million	2.7 million
Buildings	180,000	314,000
	Real Damage in 1967*	**Estimated number for the 1967 Scenario**
Heavily Damaged Buildings	224**	About 10,000
Number of Death	274	About 600
Number of Injury	About 2,000	About 4,500

(*: FUNVISIS, 1978, **:Buildings higher than 4F)

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