SEISMIC RISK AND SEISMIC ZONING OF THE CARACAS VALLEY

by

José Luis Alonso[I] and Jairo Larotta[II]

SYNOPSIS

The main objetive of this work is to provide appropiate tools to minimize the seismic risk for structures to be designed in the city of Caracas. The seismic hazard was evaluated taking into account: 1)the seismic history based on felt reports (historical) and available instrumental data; 2)known active faults within 100 Km radius; 3)geological hazard (landslides) and 4) the soil conditions. Results of this investigation include: 1)a map of the north-central part of Venezuela showing active faults and the location of main historic and instrumental epicenters; 2)maps of the valley and surrounding areas containing curves of equal peak rock accelerations and velocities expected for return periods of 25 and 75 years; 3)graphs to anticipate the shapes of acceleration response spectra taking into account the fundamental period of soil deposits and the peak ground acceleration for Rock-stiff and deep cohesionless soils deposits (λ=5%); 4)a map of the city showing depth of soil and hazard zones, and 5)normalized acceleration response spectra for a return period of 25 years.

INTRODUCTION

The mountain coastal zone of northen Venezuela constitutes the limits between the tectonic Caribbean Plate and the South American Plate. The observed seismic activity is superficial, and can be related to the system of faults of San Sebastian, La Victoria and Tacagua (see Fig. 1). The earthquake of Cúa in 1878 is attibuted to La Victoria fault, and the earthquakes of 1812, 1900 and 1967 to Sebastian and Tacagua faults. Relative movements of these systems of faults are characterized by strike-slip dextral displacements, showing in some cases relative vertical displacements.

The city of Caracas is located about 10 miles inland from the coast of northen Venezuela in an alluvium-filled valley, about 20 Km long and 5 Km wide, along the Tacagua - El Avila fault system. The valley is crossed in its long dimension by the Rio Guaire.

SEISMIC RISK

Based on available historical and instrumental data, it has been concluded that the magnitude of the earthquakes which have caused considerable damage in the city ranged from 5 to 7.2. The maximum early magnitudes were obtained as a function of the time return periods, using the extreme distribution 1 of Gumbel. This distribution is obtained from the simple model of Poisson and Richter's law magnitudes as follows:

I Head of the Engineering Data Processing Center, Universidad Central de Venezuela, Caracas, Venezuela.

II Consulting Engineer, Fundación Venezolana de Investigaciones Sismológicas - FUNVISIS - Caracas.

$$p(k) = \frac{e^{-\lambda} \cdot \lambda^k}{k!} \quad (1); \qquad F_Y(y) = Pr(Y \leq y) = 1 - e^{-\beta y} \quad (2)$$

The greatest magnitude Y is distributed with cumulative distribution:

$$G(y) = Pr(Y \leq y) \quad (3)$$

The probability of obtaining k earthquakes characterized on anual rate λ is the eq. (1); therefore:

$$G(y) = \sum_{k=0}^{\infty} \frac{e^{-\lambda} \cdot \lambda^k}{k!} (F_Y(y))^k \quad (4)$$

$$G(y) = e^{-\lambda \cdot e^{-\beta y}} \quad , y \geq 0 \quad (5)$$

The last equation is known as Gumbel's number, and indicates the probability of no occurence of events in a period of time. The sampling interval chosen to infere the seismic risk corresponds to the time lapse from 1950 up to the present. Arranging the magnitudes from the smallest to the greatest, the graph in Fig. 2 can be drawn in order to obtain the values of α and β indicated, using the equation:

$$\ln(-\ln G(y)) = \ln\alpha - \ln\beta \quad (6)$$

where $G(y_j) = j/(1+n) \quad , \quad j = 1,..,n \quad (7)$

The straight line in Fig. 2 is representative of the seismicity of the north-central region of Venezuela[1]. The number of earthquakes N_y expected for each magnitude or greater than it is given by:

$$N_y = \alpha \cdot e^{-\beta y} \quad (8)$$

and the return periods for each magnitude are given by:

$$T_y = 1/N_y \quad (9)$$

The results are included in table I. The probability of exceeding the period of return calculated before was also evaluate by:

$$Pr(t < T) = e^{-T/T_y} \quad (10)$$

and the results are drawn in Fig. 3. on the other hand, the seismic risk - for each magnitude (see table II) was evaluated as follows:

$$R_D(y) = 1 - G(y) \quad , \text{D: years} \quad (11)$$

For analysis purposes, it is convenient to evaluate maximun rock accelerations and velocities in terms of return periods. Studies made by Esteva[2] have shown that tremors recorded in ground comparable to compacted conglomerates can be assimilated to the concept of bedrock, and above - parameters can be estimated by the following relations:

$$a = 1230\ e^{0.8\ M}\ (R + 25)^{-2} \quad (12)$$

$$v = 15\ e^{M}(R + 0.17\ e^{0.59\ M})^{-1.7} \qquad (13)$$

where R is the focal distance (Km), M is the magnitude, and a and v are expresed in cm/seg^2 and cm/seg respectively.

Figures 4, 5, 6 and 7 contain curves of equal peak rock accelerations and velocities for the valley of Caracas and surrounding areas evaluated - from equations 12 and 13 taking into account the regional tectonic, focal - depths ranging from 7 to 33 Kms, and different values for M and R.

In Fig. 8, the maximun intensities asigned to zones 1, 2 and 3 were derived by the following Rosenblueth's relation:

$$I = 3.84 + 3.32\ \log_{10} v = \log 14v/\log 2 \qquad (14)$$

Although it is recognized that the map shown in Fig. 8 does not satisfy the requirements of a seismic regionalization, it is believed that it - represents a preliminar good approximation to the damage expected in that - area (rock only) without taking into account the local ground effects.

SOIL-RESPONSE ANALYSES

The soils underlying the Caracas Valley are everywhere very similar in dynamic characteristic and the depth of soil is essentially the only significant variable from one site to another. Since there are not recorded - strong earthquake motions in the city, a total of six rock motions accelerograms ($5.5 \leq M \leq 7.3$ at $5 \leq D \leq 100$ Km) having the desired characteristics were generated taking into account the geology, the tectonic, the geodynamic and the seismic activity of the area. The non-linear characteristics of - the various soil strata was considered by using values of shear modulus and damping which were compatible with the strains developed in the strata. - From these analyses, it is clearly shown (Figs. 9 and 10) that the fundamental period of soil deposits increases with depth, and also that the peak - ground acceleration remains practically constant for soil depths larger - than 60 meters.

PROPOSED METHOD FOR DESIGN PURPOSES

The frequency components of the motions at the different sites and the form the response spectra change in a reasonably consistent fashion depending on the softness or hardness of the soil conditions. Based on a statiscal analysis, Seed, Ugas and Lysmer[3] have shown clear differences in normalized spectral shapes for different soil and geologic conditions, pointing out that those shapes considerably depend on the values of peak ground accelerations associated with various site conditions. No reference whatsoever was made with respect to the fundamental period of soil deposits.

In order to take into account both, the peak ground accelerations and the fundamental period of soil deposits, an analytical method has been devised to provide the designer engineer with an easy tool for anticipating - normalized acceleration response spectra for rock-stiff soils and deep cohesionless soils (Figs. 11A and 11B) and for soft to medium clay deposits - (not shown). A detailed explanation of such method can be found elsewhere[4] and escapes from the scope of this investigation. With the aid of graphs - shown in Figs. 11A and 11B, it is a simple matter to evaluate for a given - structure with a known fundamental period the corresponding normalized spectral acceleration, S_a^n, by the following equation:

$$S_a^n = R \cdot F_S \qquad (15)$$

where F_S depends on the value of the fundamental period of the soil deposit on which structure is to be built (Rock-stiff and deep cohesionless soils only). Clearly, similar computations can be made for structures with other fundamental periods. The response acceleration spectrum is then obtained - multiplying the values of S_a^n by the expected peak ground acceleration.

Fig. 12 shows a comparison (wave propagation analysis - vs - proposed method) of acceleration response spectra for a magnitude 7 earthquake at an epicentral distance of 40 Km. Fig. 13 shows the anticipated response spec - tra for a magnitude 7.2 earthquake at 80 Km (see dotted line in Fig. 10) - evaluated for different soil depths. Fig. 14 shows a map indicating the - depth of soil deposits and hazard zones in the Caracas Valley. However, - for design purposes it becomes necessary to express site response in terms of return periods; thus, Figs. 9 and 10 include the variation of the fundamental soil period and peak ground acceleration with depth expected in the Caracas Valley for a return period of 25 years. Clearly, similar distributions can be plotted for different return periods. Fig. 15 shows, as an - ilustrative example, the normalized acceleration response spectra associa - ted to a 25 year return period.

CONCLUSION

The primary objective of the present paper was to suggest based on the information given in Figs. 1 to 10, a simple technique for assessing normalized shapes of acceleration spectra for rock-stiff and deep cohesionless soils similar to those commonly found in cities like Caracas. The only parameters needed in the computations are the fundamental period of soil deposits and the peak ground acceleration values referred to any given return period. Since there are not recorded strong earthquake motions available for the city - of Caracas, it may be concluded that consideration of these results in a local seismic code is clearly desirable.

ACKNOWLEDGEMENT

The support given by the Fundación Venezolana de Investigaciones Sismológicas and the Engineering Data Processing Center of the Universidad Central de Venezuela which sponsored the study described in the preceding pages, is gratefully acknowledged.

REFERENCES

1.- Larotta, J., "Riesgo Sísmico del Area Norte-Central de Venezuela", I° - Congreso Venezolano de Sismología e Ingeniería Sísmica, Caracas 1974.

2.- Esteva, L., "Seismic Risk and Seismic Design Decitions", Dept. of Civil Engineering MIT 1971.

3.- Seed, H. B., Ugas, C. and Lysmer, J., "Site-Dependent Spectra for Earthquake-Resistant Design", Report No. EERC 74-12, U.C. Berkeley, 1974.

4.- Alonso, J.L., "Simulación de Espectros Normalizados de Respuesta Sísmica", Trabajo de Ascenso, Universidad Central de Venezuela, Octubre 1976.

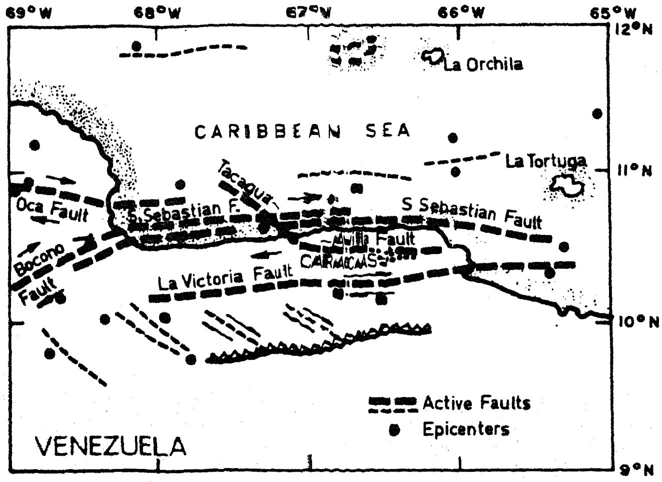

FIG.: 1 TECTONIC OF NORTHEN VENEZUELA.

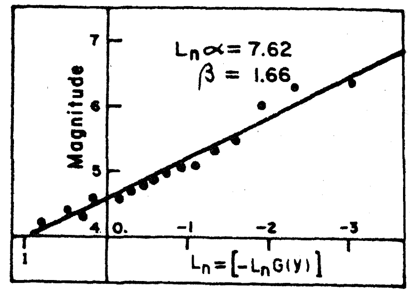

FIG.: 2 SEISMICITY OF THE REGION.

TABLE I

MAGNITUDE	Ny	Ty
5.0	0.506	2 Years
6.0	0.096	10.4 Years
6.5	0.042	24 Years
7.0	0.018	54 Years
7.2	0.013	76 Years

TABLE II

MAGNITUDE (y)	$R_{33}(y)$	$R_{50}(y)$	$R_{80}(y)$	$R_{100}(y)$
4.0	1.0	1.0	1.0	1.0
5.0	0.999	1.0	1.0	1.0
6.0	0.958	0.991	0.999	1.0
6.5	0.749	0.877	0.965	0.985
7.0	0.453	0.599	0.768	0.839
7.2	0.351	0.481	0.650	0.731

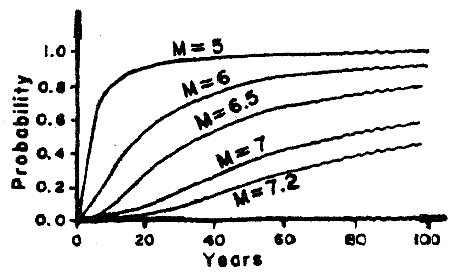

FIG.: 3 PROBABILITY OF EXCEEDANCE OF RETURN PERIODS.

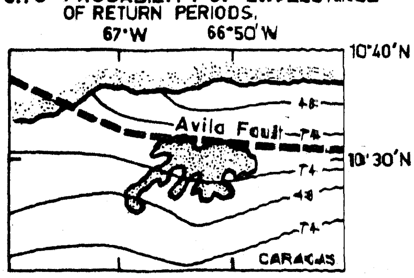

FIG.:4 EXPECTED MAX. VELOCITIES IN ROCK (cm/seg) IN 25 YEARS.

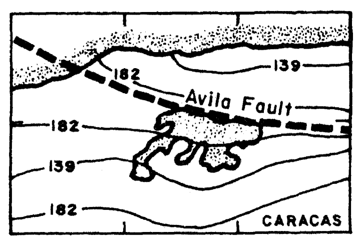

FIG.:5 EXPECTED MAX. ACCELERATIONS IN ROCK (cm/seg²) IN 25 YEARS

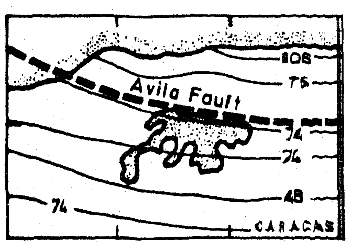

FIG.:6 EXPECTED MAX. VELOCITIES IN ROCK (cm/seg) IN 75 YEARS.

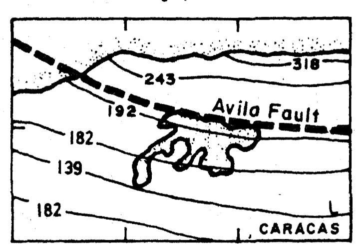

FIG.:7 EXPECTED MAX. ACCELERATIONS IN ROCK (cm/seg²) IN 75 YEARS.

SEISMIC REGIONALIZATION

ZONE	MMCS	V (cm/seg)
3	XI - IX	105 - to 35
2	VIII - VII	34 - to 9.2
1	VI - V	9.1 - to 6.6

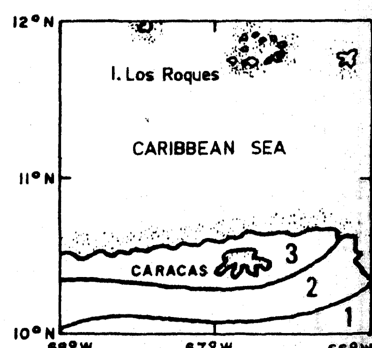

FIG.: 8 MERCALLI MODIFIED INTENSITY EVALUATED IN ROCK FOR 75 YEARS.

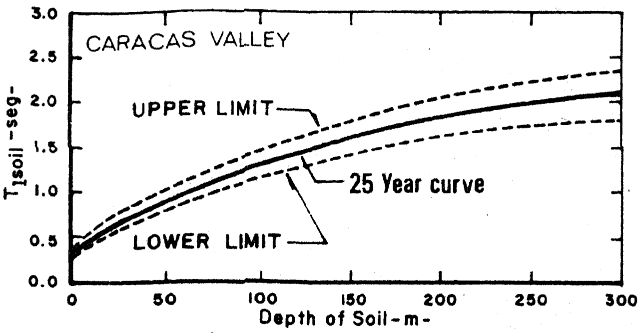

FIG.: 9 COMPUTED VARIATION OF FUND. SOIL PERIOD

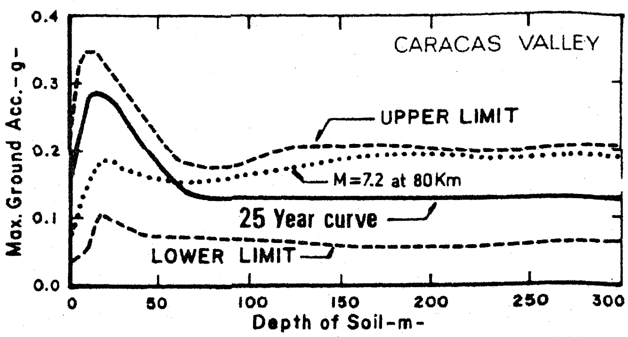

FIG.: 10 COMPUTED MAX. GROUND ACCELERATION

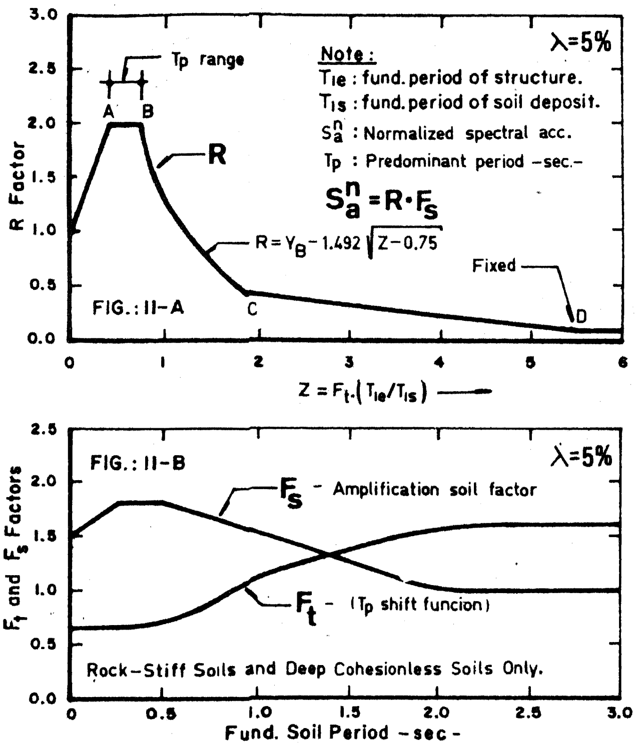

FIG.: II PROPOSED METHOD FOR EVALUATING NORMALIZED RESPONSE SPECTRA. (Alonso J.L., 1976)

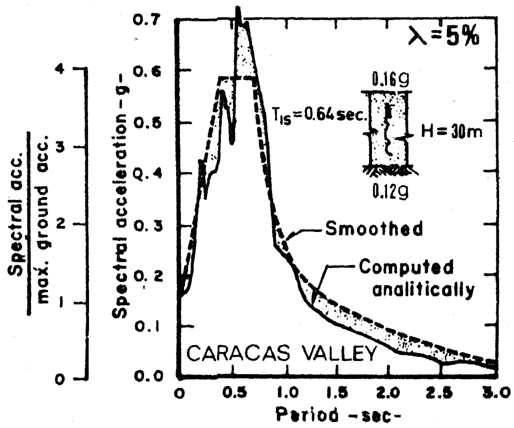

FIG.: 12 SMOOTHED ACCELERATION SPECTRUM FOR A MAGNITUDE 7 EQ. AT 40 KM.

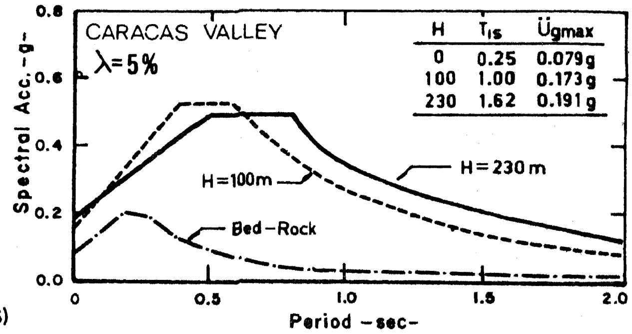

FIG.: 13 ANTICIPATED ACCELERATION SPECTRA FOR A MAGNITUDE 7.2 EQ. AT 80 KM.

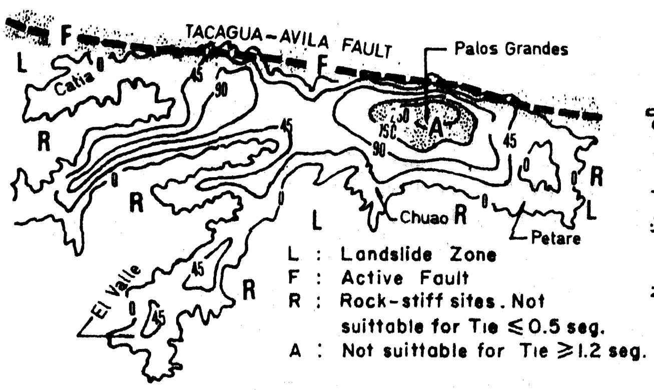

FIG.: 14 MAP SHOWING DEPTH OF SOIL DEPOSITS AND HAZARD ZONES - CARACAS VALLEY

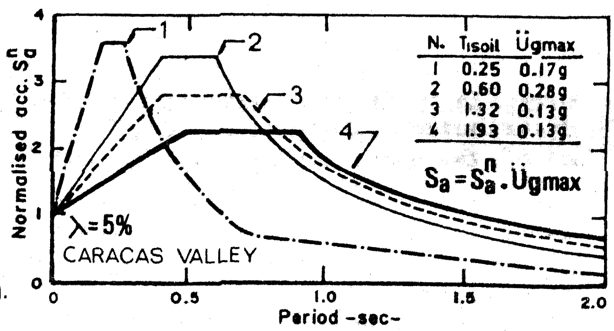

FIG.: 15 NORMALIZED ACCELERATION SPECTRA FOR A RETURN PERIOD OF 25 YEARS