(11) MACRO ZONING OF ECUADOR - A CASE STUDY -

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INTRODUCTION: The total loss caused by an earthquake can be divided into primary and secondary losses. Primary loss is that which occurs immediately or shortly after the disaster and is caused by its direct effects. It mainly comprises property damage and human casualties and is usually geographically localized. Secondary loss includes the loss of economic activity of the country due to the loss of production in the economic sectors linked to those that suffer from direct losses. Based on the study of the effects of previous earthquakes on the national-level economy, it is concluded that the parameters that best define the seismic vulnerability of a region are: the expected seismic activity and its effect to the structures, the population density and the contribution of the region to the national economy. As an example, this paper describes the macro zoning of Ecuador. The administrative division, i.e. "province", is adopted in order to give adequate weight to population concentration and to the actual contribution of each area to the national economy.

SEISMICITY AND EXPECTED STRUCTURAL DAMAGE LEVEL: Data from 1723 earthquakes of $M \geq 4.0$ compiled by the US Geological Survey since 1904 have been used to define the seismic hazard. The ERISA Program developed by Tomatsu and Katayama is applied to perform the statistical analysis on the seismic risk for the Ecuadorian conditions and the expected peak ground acceleration for a return period of 100 years is determined. In general, it can be said that the values of expected accelerations are less than 150 gals for about 80% of the territory with an expectancy of greater activity along the Pacific Coast.

From the 1982 National Census (1), a total of 1,576,441 dwellings were identified. Out of the total number, 62.97% of the dwellings correspond to unreinforced masonry structures. Therefore, it is considered that the use of a damage model adopted to masonry structures by the authors elsewhere (2) will provide a good representation of the level of damage to be induced by the expected seismic activity of a region.

The damage index is expressed as

$$D = L(Ra,\ td,\ Tg)/R(T,\ Uu) \qquad (1)$$

where L= Seismic load function, R= Structure's resistance function, Ra= rms acceleration, td= Duration of the strong motion phase, Tg= Predominant period of the strong motion, Uu= Ultimate displacement of the structure, T= Fundamental period of the structure. The damage to the structure is given in terms of the damage ratio which is defined as the ratio of the earthquake damage cost to the replacement value. In addition to the damage caused by the strong ground shaking, damage induced by ground failure, fault rupture, liquefaction, etc. is also considered. The impact of the main collateral hazards is incorporated in the following form:

$$D' = D*(1+\Sigma fi), \quad i=1,2,3,4 \qquad (2)$$

where D' is the damage index with consideration of the collateral hazards and the structural characteristics. The modifying factors are given in Table I.

The damage scale including D' is presented in Table II. By using this scale together with the expected peak acceleration, the distribution of the expected level of structural damage is obtained and presented in Fig. 1.

TABLE I		
i	Criterion	fi
1	Substandard construction quality	0.2
2	Medium liquefaction hazard	0.1
3	High liquefaction hazard	0.2
4	Unfavorable structural features (projected elements, excessive eccentricities, bad distribution, etc.)	0.1

TABLE II. Damage Scale

i	Damage Level	D.R. Range (%)	Mean D.R.	D' Range	Mean D'	Coeff. of Contribut.
1	Collapse	80 - 100	86.565	> 0.30	0.431	1.0
2	Severe	40 - 80	59.881	.20 - .29	0.249	0.8
3	Moderate	15 - 35	25.462	.12 - .20	0.163	0.6
4	Minor	5 - 15	13.519	.07 - .12	0.114	0.4
5	Slight	0 - 3	1.632	.03 - .07	0.042	0.2

STUDIES OF THE DISTRIBUTION OF THE POPULATION: The population of Ecuador as of 1987 was 9,923,000 for a total area of 270,667 Km^2, resulting in an average population density of 36.7 per Km^2. However, there is a very wide variation in the density corresponding to each area, ranging from 1 per Km^2 to 131.6 per Km^2. A scale of population density is defined by taking the highest and lowest densities as the maximum and minimum values of the scale. The intermediate values are interpolated adopting a linear proportionality to the damage scale. This process is shown schematically in Fig 2. The scale of population density is presented in Table III. By using this scale, the distribution of the population is obtained and presented in Fig. 3.

STUDIES OF THE DISTRIBUTION OF THE ECONOMY: From the consideration of the main economical sectors, the participation of each area in the national economy is determined. The considered economical sectors are: Agriculture, Forestry, Animal Husbandry, Manufacturing Industry, Fishery, Oil, Electrical Power, and Tourism, which account for up to 81% of the total Gross National Product. The rates of economical participation vary also largely, ranging from 0.37% to 20.37%. A scale of economical participation is defined following the same process used in the definition of the scale of population (Fig. 2). The scale of economical participation is presented in Table IV. Using this scale, the distribution of the economical participation is obtained and presented in Fig. 4.

TABLE III. Population Scale

Level	Density Range	Mean Density	Coeff. of Contribut.
1	120 - 150	131.6	1.0
2	60 - 120	90.567	0.8
3	25 - 60	37.462	0.6
4	5 - 25	19.279	0.4
5	0 - 5	1.00	0.2

TABLE IV. Economic Participation Scale

Level	Particip. Range %	Mean Particip.	Coeff. of Contribut.
1	18.5-23.5	20.317	1.0
2	8.5-18.5	14.05	0.8
3	3.5-8.50	5.967	0.6
4	1.0-3.50	3.162	0.4
5	0.0-1.00	0.37	0.2

MACRO ZONING OF ECUADOR: The seismic vulnerability of a region is determined from the three considered parameters: expected level of structural damage, population density, and economical participation. To do so, coefficients of contribution are given to the three scales assigning a value of 1.0 to the highest level of each scale and a value of to 0.2 to the lowest level of each scale. The coefficients corresponding to levels 2, 3, and 4 are 0.8, 0.6, and 0.4, respectively. These coefficients are also presented in Tables II, III, and IV. The scales are applied to each considered area and a seismic priority score is evaluated by

$$S_{pj} = \Sigma\, w_i * C_{ij} \ , \qquad i = 1,2,3 \qquad (3)$$

S_{pj} = Seismic priority score for the Area j.
w_i = Weighting coefficient.
C_{ij} = Coefficients of contribution considering expected damage (i=1), *population density (i=2), and economical participation (i=3),for* the Area j.

At this stage, w_i is taken equal to 1.0 for i=1,2,3. Further studies and considerations are to be done in order to determine more appropriate values of w_i. Similar studies may also be done with regard to the adopted values of the coefficients of contribution, C_{ij}.
Areas having similar values of S_p are grouped into larger zones. Five zones are determined from Zone I, the one with the highest vulnerability, to Zone V, the zone with the lowest vulnerability (Fig. 5).

CONCLUSIONS: A seismic risk analysis has been performed for Ecuador taking into account not only the expected seismic activity and the potential level of damage to structures but also the population and economical aspects. The approach adopted is intended to express the potential damageability in a macroscopic fashion and is hoped to be useful for economical decision making by governmental officials. It should be noticed that the contribution and weighting coefficients for each considered parameter may be improved after considering the economy's structure, development stage of a country, etc. Further studies are to be done in that direction.

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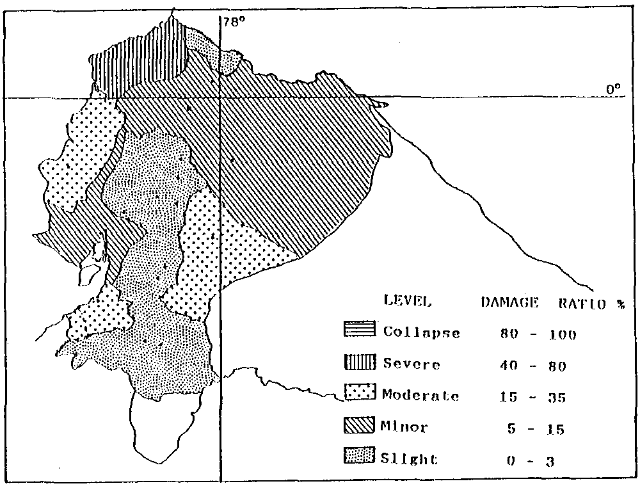

FIGURE 1
Distribution of the expected stuctural damage.

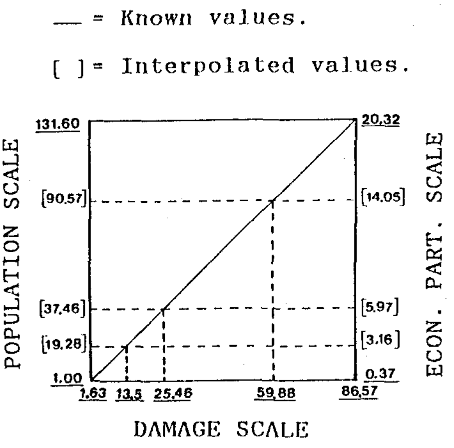

FIGURE 2
Determination of the population and economic particip. scales

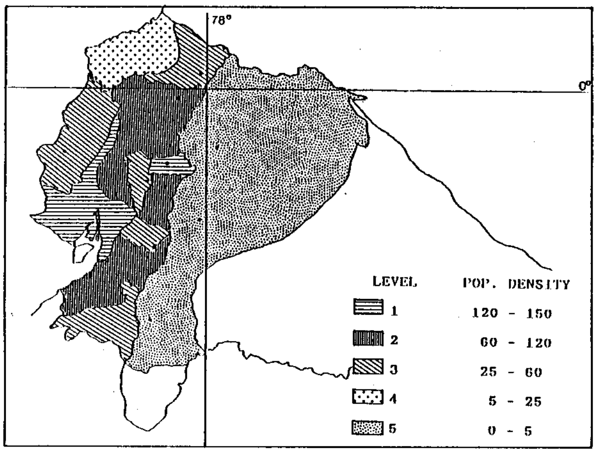

FIGURE 3
Distribution of the Population.

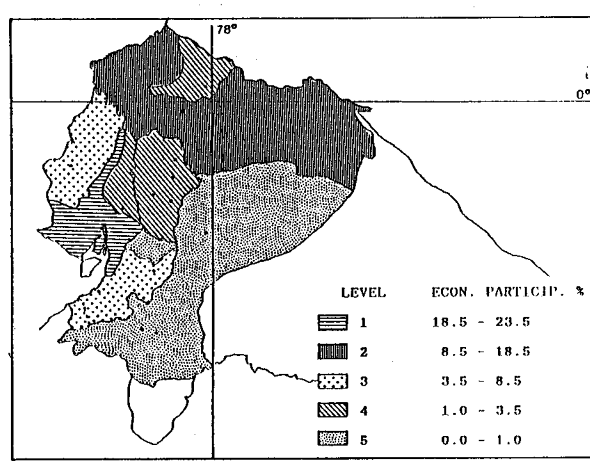

FIGURE 4
Distribution of the Economic Participation.

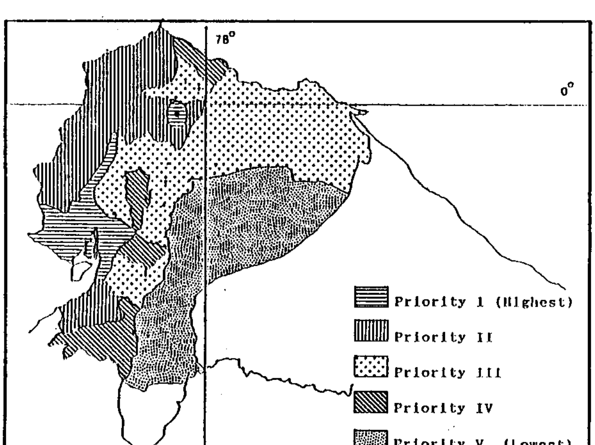

FIGURE 5
Macro Zoning of Ecuador.