PROBLEMS OF EARTHQUAKE HAZARD ASSESSMENT AND VULNERABILITY ANALYSIS

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Introduction

According to recently adopted definitions, "seismic hazard" means the probability that a certain ground motion parameter will not be exceeded at a site within a specific period of time. "Vulnerability" is the degree of loss to a given element at risk, resulting from the occurence of a natural phenomenon, and is expressed on a scale from 0 to 1. The word "risk" is then used to denote the expected, probable loss in terms of number of lives lost, damage to property or disruption of economic activity. Thus, risk depends on hazard, vulnerability and elements at risk. The definitions were formulated by a group of experts convened in Geneva by UNDRO in July 1979 [UNDRO , 1980].

The knowledge of seismic risk is a determining factor in preventing or mitigating the disastrous effects of earthquakes. Equally determining is the awareness of risk, that is the perception by the public and the authorities of its social and economic implications. Such awareness will ease the problem of defining locally acceptable levels of risk, which are in themselves determining factors for the successful application of detailed land-use measures and site planning as well as the formulation and implementation of appropriate building codes. Hazard and vulnerability analyses comprise the key inputs to risk assessment. The purpose of the present paper is therefore to review the methodology of hazard and vulnerability assessments and the accuracy of the information provided.

Methods of Seismic Hazard Assessment

The present methods of seismic hazard assessment are based on the following operations:

1. Definition of potential earthquake source regions in terms of their boundaries and of the average earthquake activity which is defined by the magnitude (or intensity)-frequency relationship

$$N\ (M) = \alpha e^{-\beta M}$$

and by the upper threshold magnitude (or intensity) M_{max} truncating the N (M) distribution.

2. Determination of the attenuation function for the selected ground motion parameter X, that is

$$f\ (X) = X_0 a D^n e^{-bD}$$

where D is epicentral distance and a, n and b are coefficients.
3. Formulation of a statistical model defining the probability of occurrence of a certain ground motion parameter at a site during a period of interest. The calculation of the probability function is based on the cumulative distribution of ground motion parameters resulting from the earthquake activity in all surrounding source regions.

The mathematical formulae describing different statistical approaches can be found in the literature. Most methods consider earthquake occurrence as a random Poisson process with a constant annual rate. A detailed scheme of individual steps is reproduced in Figure 1. The described procedure has several weak points. It is first of all very difficult to estimate the earthquake potential of a certain volume of the Earth's crust or upper mantle.

The source regions are delineated by using mainly evidence from past earthquakes and assuming simple correlations between tectonic features and the origin of earthquakes. The N (M) distribution always represents an averaged observation without taking into account fluctuations in seismicity.

Most estimates of M_{max} are still based more on personal judgment than on a defined algorithm. The assumption of a random character of earthquake occurrence greatly simplifies the whole earthquake-generating process; however, it seems to be valid, at least for large events.

The attenuation functions are again taken in an averaged form, disregarding the azimuthal or regional variations observed in the change of the parameter with distance and magnitude of the event.

All these simplifications, reflecting the level of knowledge, result in substantial inaccuracy of the calculated probabilities or other parameters. There are ways to improve accuracy, e.g. by installing temporary networks of stations monitoring various geodynamic phenomena, by detailed geological mapping, by field and laboratory experiments, etc.; however, such detailed investigations are made only when seismic hazard is being estimated for critical structures or installations (large dams, power plants). Standard seismic hazard maps on the scale 1:1 million or 1:500,000 are always based on simplified models of earthquake occurrence and earthquake effects and provide average data which may be modified by corrections for local conditions. These corrections can be quite significant, e.g. in terms of macroseismic intensity, the range may be ± 2 degrees of the scale, or factor four for accelerations, etc. Such variations must be taken into account when review hazard maps are used for economic considerations.

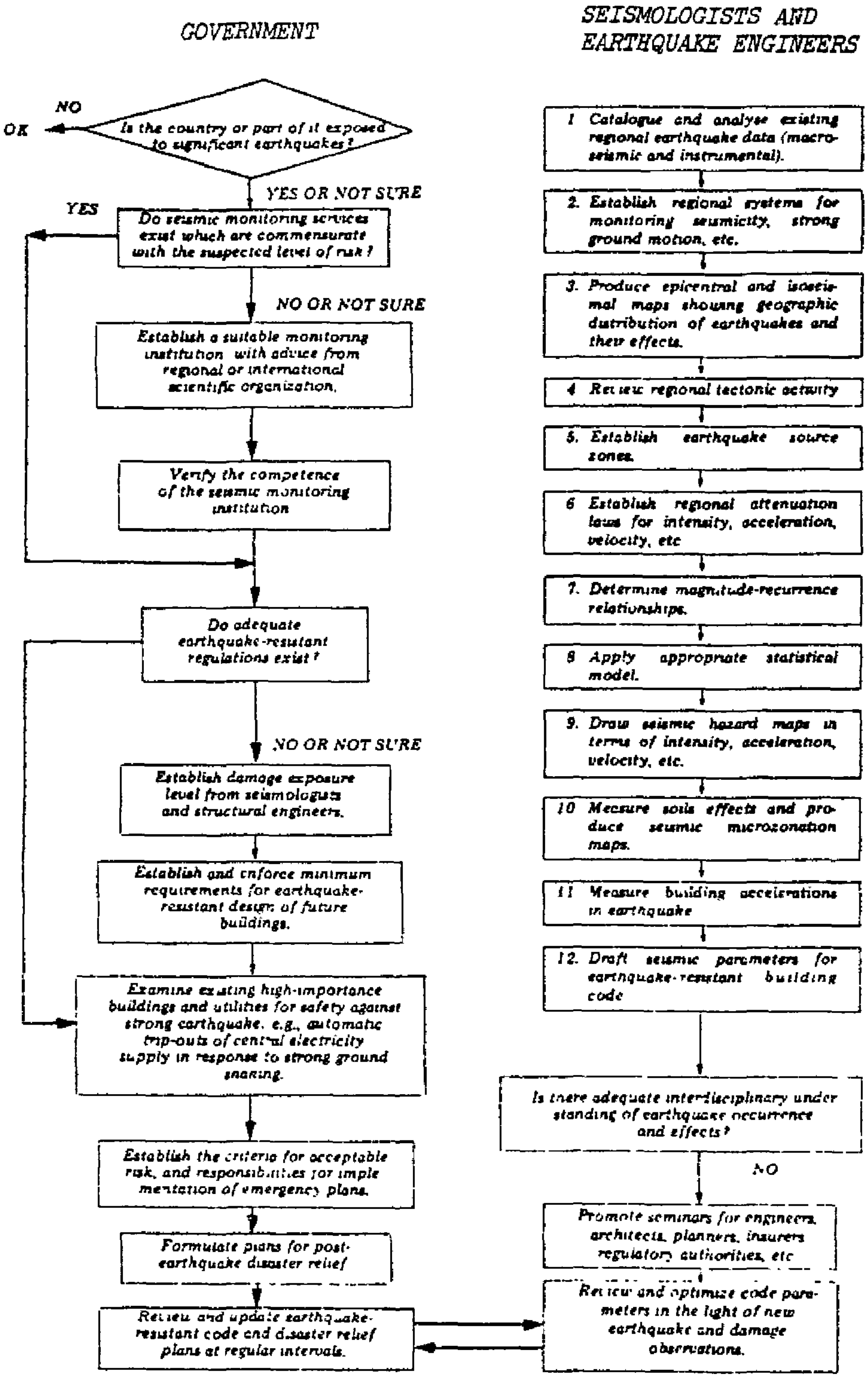

Figure 1

Detailed Steps in Seismic Hazard Assessment

Vulnerability

As mentioned above, vulnerability means the degree of loss to a given element at risk, such as buildings, population, public utilities, industry, etc. As a result of strong ground motion generated by an earthquake, buildings are damaged to various extents, people are injured or killed, bridges may collapse, pipelines may be interrupted, etc. Every element is vulnerable to a different extent according to its sensitivity to vibrations or secondary effects. The vulnerability of an element can be expressed by the percentage by which its function would decrease due to a certain level of hazard.

Information on vulnerability is relatively rare and less clearly defined than information on seismic hazard. We can use some observations on vulnerability contained in the description of macroseismic scales. First of all, each scale introduces several basic types of structures, and degrees of intensity are assessed according to the extent of damage on individual structural types. For instance, the MSK-64 scale [Willmore and Karnik, 1970] uses three categories of structures:

A. Buildings of fieldstone, rural structures, adobe (clay) houses

B. Brick buildings, large block constructions, half-timbered structures, structures of hewn blocks of stone

C. Precast concrete skeleton constructions, precast large panel constructions, well-built wooden structures

The classification of damage in the scale is as follows:

Classification of Damage

0: no damage

1: slight damage (fine cracks in plaster, fall of small pieces of plaster)

2: moderate damage (small cracks in walls, fall of fairly large pieces of plaster, particles slip off, cracks in chimneys, parts of chimneys fall down)

3: heavy damage (large and deep cracks in walls, fall of chimneys)

4: destruction (gaps in walls, parts of buildings may collapse, separate parts of buildings become disconnected, inner walls and filled-in walls collapse)

5: total collapse of buildings

Table 1 gives a rough estimate of loss in value due to various degrees of damage. Values above 30% can be considered as too high for economic repair and can therefore be classified as a 100% loss. The relationship between the degree of damage to a basic type of structure and the grade of intensity is shown in Table 2, which completes the information in the scale.

Table 1

Loss of Value Due to Degree of Damage

Damage category, MSK-64 scale	1	2	3	4	5
% Loss in value of buildings	2	10	30	80	100

Table 2

Grade of Intensity, Type of Structure, and Degree of Damage

MSK-64 Intensity	Type of Structure		
	A	B	C
V	95-0 5-1	100-0	100-0
VI	45-0 50-1 5-2	95-0 5-1	100-0
VII	10-1 35-2 50-3 5-4	15-0 35-1 50-2	50-0 50-1
VIII	10-2 35-3 50-4 5-5	10-1 35-2 50-3 5-4	10-0 35-1 50-2 5-3
IX	15-3 35-4 50-5	10-2 35-3 50-4 5-5	10-1 35-2 50-3 5-4
X	25-4 75-5	15-3 35-4 50-5	10-2 35-3 50-4 5-5
XI	100-5	25-4 75-5	50-4 50-5

There have been proposals for further subdivision of structural types to accommodate, e.g., the tall buildings now very common in new settlements, pipelines, earthquake-resistant constructions, etc. Other proposals have been made to introduce five classes of quantity of damaged structures instead of the three now in use (few = 5%, many = 50%, most = 75%). So far, these proposals have not been accepted.

By combining the above information, we can draw simple vulnerability functions for the three categories of buildings. They may be used in risk estimates when the rough subdivision of buildings is sufficient. For more detailed studies, vulnerability functions for individual elements must still be elaborated.

Simple vulnerability functions can be calculated by using the description of a category of damage if we estimate the probable loss in value (in %) of a structure, e.g. damage category 3 means an approximate 30% loss in value of the building and category 5 means total destruction (i.e. 100%). Each intensity grade on the macroseismic scale is defined by describing how many buildings of, say, category A were damaged to the extent corresponding to damage category 1, 2, 3.... In the description of the scale, percentages corresponding to the expressions "few," "many," and "most" are specified; however, it is necessary to complete the figures for each intensity grade and type of structure to get a 100% total. Such an attempt is presented in Table 2. Now, by combining the loss in value (Table 1) with the above percentages, one can obtain the estimated degree of loss (damage) inflicted on buildings in categories A, B and C (Table 3). If we consider a 100% loss in value already for damage category 4, which is quite justified, the figures in Table 3 will be higher for I $\geq$ VIII.

Table 3

Loss in Value by Buiding Category for Various Intensities

Category of Building	Macroseismic Intensity V	VI	VII	VIII	IX	X	XI
A	0.001	0.015	0.227	0.565	0.825	(0.950)	(1.000)
B	0	0.001	0.057	0.227	0.565	(0.825)	(0.950)
C	0	0	0.010	0.072	0.227	(0.565)	(0.900)

This exercise can be repeated under different criteria of damage, loss in value and type of building. However, the resulting vulnerability values could be used in some preliminary economic analyses, particularly if the hazard assessment has been made in terms of macroseismic intensity.

Conclusions

Hazard and vulnerability values are needed for social and economic analyses within development programs. The present state of the art permits only preliminary estimates of the social and economic impact of earthquake disasters. An improvement could be made by expanding data on the vulnerability of different elements at risk and by developing standard methodologies of hazard, vulnerability and risk assessment.

REFERENCES

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