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VULNERABILITY AND THE MSK SCALE

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ABSTRACT

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Vulnerability is defined as the degree of damage (or loss) due to shaking of a given intensity. The text of the MSK macroseismic scale describing individual intensity grades determines vulnerability functions for three main categories of structures. The resulting curves are compared with the few existing examples of vulnerability curves derived for specific categories of buildings in the Caucasus and in California.

INTRODUCTION

According to definitions recently adopted by a group of experts (Expert Group Meeting, 1980), seismic hazard means the probability of occurrence of a certain ground motion parameter at a site within a specific period of time. In our understanding we can also speak about earthquake hazard if we have in mind the probability of earthquake occurrence within a defined area (or volume) during a selected time interval. This definition is also valid, in principle, for other natural phenomena, such as floods, volcanic eruptions, etc. Vulnerability is another basic term, defined as the degree of loss to a given element at risk resulting from the occurrence of a natural phenomenon, and is expressed on a scale from 0 to 1 or from 0 to 100%. The third term "risk" denotes the expected probable loss in a specified period in terms of the numbers of lives lost, of damage to property, or of disruption of economic activity. Thus, risk depends on hazard and vulnerability of elements at risk, therefore hazard and vulnerability analyses comprise the key inputs to risk assessment. The knowledge of seismic risk is decisive in introducing measures for prevention or mitigation of disastrous earthquake effects. The purpose of the present paper is to use the description of the MSK scale for defining simple vulnerability functions.

DETERMINATION OF VULNERABILITY

As a result of strong ground motion generated by an earthquake, different elements at risk, such as buildings, population, public utilities, industry, etc.

are damaged to various degrees; people are injured or killed, the ground is deformed, etc. Every element is vulnerable to a different extent according to its sensitivity to vibrations or to secondary effects. The vulnerability of an element can be expressed by the percentage of its functional deterioration due to a certain level of seismic hazard. In this way vulnerability functions for individual elements can be compiled.

Experimental information on vulnerability is relatively rare and less clearly defined than information on seismic hazard, although the situation is improving steadily. Under the circumstances, we have assumed that the description of damage in the MSK-64 macroseismic scale can be used also in defining simple vulnerability functions valid for three basic types of structure introduced by the scale (Willmore and Kárnik, 1970).

Type A: buildings of fieldstone, rural structure, adobe (clay) houses.

Type B: brick buildings, large block constructions, half-timbered structures, structures of hewn blocks of stone.

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

The damage is classified by six grades as follows:

Grade 0: no damage.

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

Grade 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).

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

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

Grade 5: total collapse of buildings.

Table I gives the authors' rough estimate of loss in value, i.e. the damage ratio due to various degrees of damage: Fig.1 is a graphical demonstration of Table I. Values above 30% might be considered as too high for economical repair, and can therefore be classified as a 100% loss of function in certain cases. The relationship between the degree of damage to the basic types of structures and the intensity degree is shown in Table II, which corresponds to the description of the scale, defining the number of houses damaged in terms: few — 5%, many — 50%, or most — 75%; the figures in brackets are estimated and complete the missing description, so that the total of 100% is reached, for each degree and structural type.

There have been proposals for a further subdivision of structural types to accommodate, e.g. tall buildings now very common in new settlements,

TABLE I

Damage ratio

Damage category DC, MSK-64 scale	1	2	3	4	5
Damage ratio DR (%)	2	10	30	80?	100

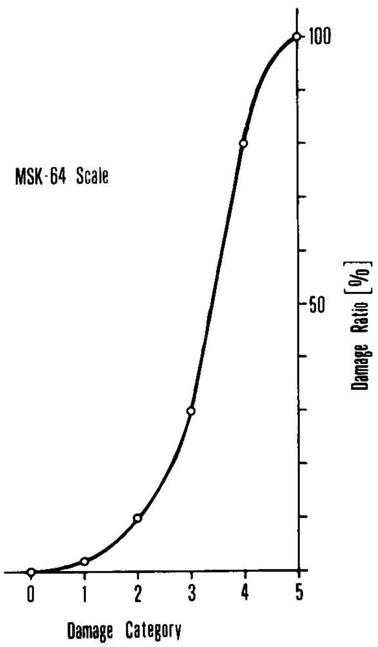

Fig.1. Damage ratio for damage categories introduced by MSK-64 scale.

pipe-lines, earthquake-resistant constructions, etc. (Ad-hoc Panel Meeting of Experts, 1981). Other proposals have been made to introduce five classes of damaged structures instead of the present three. So far, these proposals have not been accepted.

By combining the above information of damage and quantity, we calculated simple vulnerability functions for the three categories of buildings (Fig.2) in the following way. The probable loss in value (in %) of a structure is defined by the damage category, e.g. category 3 means an approximate 30% loss in value of the building, category 5 means a total destruction (i.e., 100%), etc. Each degree of intensity on the macroseismic scale represents the number of buildings of a certain category to be damaged, to the extent corresponding to damage categories 1, 2, 3. In the description of the scale, percentages corresponding to the expressions "few", "many", and "most" are also specified. By combining the loss in value (damage ratios) DR (Table I) with the above percentages N (Table II) using the formula:

$$V = \frac{\sum_{i=0}^{5} N_i (\mathrm{DR})_i}{100}$$

we calculated vulnerability values for buildings in categories A, B and C and the individual degrees of macroseismic intensity (Table III, Fig.2).

TABLE II

Damage categories and corresponding damage ratios for individual degrees of the MSK scale

MSK-64 Macroseismic intensity	Type of structure					
	A		B		C	
	N(%)	DC	N(%)	DC	N(%)	DC
V	(95	0)	100	0	100	0
VI	(45	0)	(95	0)	100	0
	50	1	5	1		
	5	2				
VII	(10	1)	(15	0)	(50	0)
	(35	2)	(35	1)	50	1
	50	3	50	2		
	5	4				
VIII	(10	2)	(10	1)	(10	0)
	(35	3)	(35	2)	(35	1)
	50	4	50	3	50	2
	5	5	5	4	5	3
IX	(15	3)	(10	2)	(10	1)
	(35	4)	(35	3)	(35	2)
	50	5	50	4	50	3
			5	5	5	4
X	(25	4)	(15	3)	(10	2)
	75	5	(35	4)	(35	3)
			50	5	50	4
					5	5
XI	(100	5)	(25	4)	(50	4)
			75	5	(50	5)

Note: Values in brackets are complementary estimates.

If we considered a 100% loss in value (damage ratio) already achieved for damage category 4, which may be justified, the figures in Table III would be higher for $I \geqslant$ VIII.

This exercise can be repeated under different classifications of damage and type of buildings. The resulting vulnerability functions can be used in some preliminary risk analysis, particularly if the hazard assessment has been made in terms of macroseismic intensity.

In the literature there are only a few examples of vulnerability functions (e.g. Koridze and Zazashvili, 1981; Algermissen et al., 1978; Ward and Taylor, 1980; Schulze et al., 1981). We plotted two of them (from Koridze and Zazashvili, 1981, and Algermissen et al., 1978) in Fig.3 together with our results; these relate to the situation in Georgia (U.S.S.R.) and in the San Francisco area (U.S.A.).

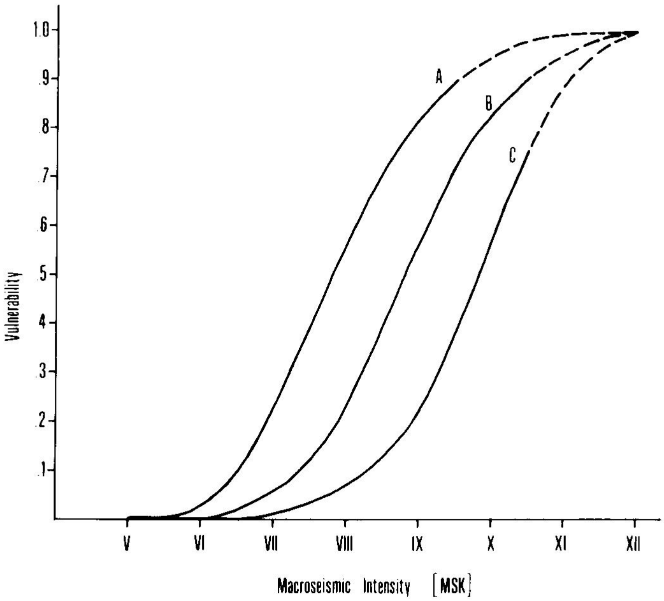

Fig.2. Vulnerability functions for three categories of buildings of the MSK scale.

TABLE III

Vulnerability corresponding to three categories of buildings of the MSK scale

Category of buildings	Macroseismic intensity, MSK-64 scale:						
	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

From individual dwellings constructed on the territory of the Georgian S.S.R., three of the most widespread types considered by Koridze and Zazashvili (1981) were: type A′ — stone masonry dwellings; type B′ — brick masonry and concrete block dwellings; type C′ — wooden dwellings.

Sufficient statistical data recording actual earthquake loss values was available mainly for stone dwellings (type A′). For other types the loss was arranged in the form of damage probability matrices, containing the distribution of the number of dwellings according to the degree of damage corresponding to different earthquake intensities. The vulnerability was expressed as the ratio of the estimated repair cost to total dwelling cost for three structural types of dwellings (Table IV, Fig.3). For brick masonry and concrete block dwellings (type B′) the vulnerability is half as much as for type A′.

Algermissen et al. (1978) have provided a taxonomy useful for estimating expected losses to classes of construction at given earthquake intensities

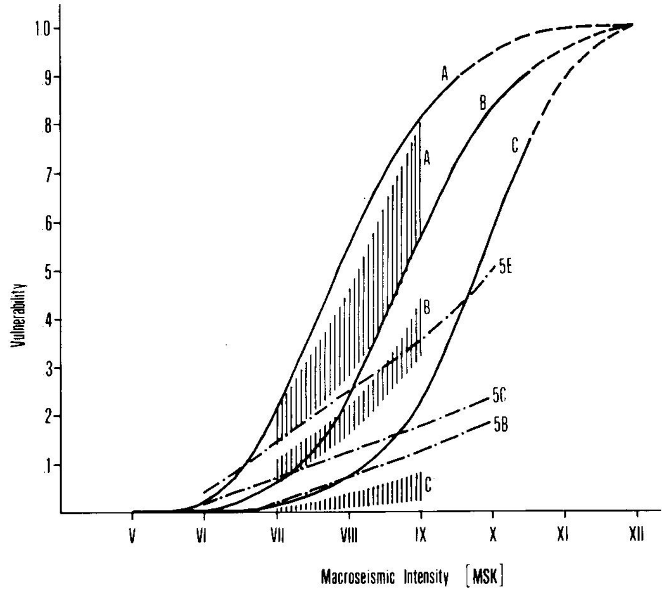

Fig.3. Comparison between vulnerability functions for three categories of buildings corresponding to the MSK scale. (A, B, C) with the vulnerability functions published by Koridze and Zazashvili (1981) for the Caucasus region (A', B', C') and by Algermissen et al. (1978) for California 5B, 5C, 5E).

TABLE IV

Vulnerability of three categories of buildings in the Caucasus region (Koridze and Zazashvili, 1981)

Category of buildings caucasus	Macroseismic intensity, MSK-64 scale: VII	VIII	IX
A'	0.14—0.22	0.28—0.46	0.56—0.80
B'	0.06—0.11	0.16—0.22	0.32—0.44
C'	0.005—0.01	0.01—0.04	0.02—0.08

(MM scale). Five broad classes of buildings have been considered: 1 — wood frame; 2 — all-metal buildings; 3 — steel frame buildings; 4 — reinforced concrete, combined reinforced concrete and structural steel frame; 5 — mixed construction.

The building classes studied cover most of the building types in the San Francisco Bay area with the exception of one to four family dwellings, lifeline facilities, and special types of structure, such as oil refineries and storage facilities, military installations, and bridges. In Table V and Fig.3 the values of loss for the following three selected types of buildings are given: 5E — unreinforced, mixed construction; 5C — mixed construction, ordinary seismic

TABLE V

Vulnerability of three selected categories of buildings in California (Algermissen et al., 1978)

Category of buildings California	Macroseismic intensity, MM scale:				
	VI	VII	VIII	IX	X
5E	0.04	0.145	0.25	0.35	0.50
5C	0.02	0.07	0.125	0.175	0.23
5B	0	0.02	0.075	0.13	0.16

damage control features; 5B — mixed construction, superior seismic damage control features.

The main conclusion following from Fig.3 is that the shape of the vulnerability curves for the Caucasus is identical to empirical curves resulting from the description of the MSK scale; the curves for the San Francisco Bay Area exhibit, however, a smaller slope. Naturally, we cannot expect a close similarity because of a large variety in the dynamic response of structures typical for different areas. The detailed classification of structural types presented for California enables, however, an increased accuracy of risk calculations.

CONCLUSIONS

Hazard and vulnerability values are needed for social and economic analyses within development programmes. The present state of the art permits only preliminary estimates of the social and economic impact of earthquake disasters because of lack of vulnerability functions which would cover all elements that should be considered in risk endorsements. 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.

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