THE QUANTIFICATION OF SEISMIC HAZARD FOR THE PURPOSES OF RISK ASSESSMENT

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SUMMARY

For the planning of reconstruction and development, for earthquake preparedness, for insurance as well as for decision-making in design, quantitative assessments are needed of the seismic risk to various types of buildings in various locations. In this paper, we discuss some of the problems that arise in attempting to quantify seismic hazard for this purpose. It appears that the concept of seismic intensity needs careful re-examination.

INTRODUCTION

It is generally agreed that the specific seismic risk to any building or structure is determined by two mutually independent factors: (a) the vulnerability of the structure to seismic ground motion of various intensities, and (b) the seismic hazard at the site, this being expressed as the probabilities of occurrence of ground motion of various intensities.

In the definitions of seismic hazard and vulnerability as generally adopted (eg. UNDRO, 1979), it is tacitly assumed that the "intensity" of seismic ground motion can be measured and expressed by a single numerical parameter. This is, in fact, the general practice, whether intensity is expressed on a macroseismic scale or as a value of some physical parameter such as peak ground acceleration.

However, attempts to correlate the actual degree of damage to buildings in recent earthquakes, such as those in Romania (1977) and in Montenegro (1979), have revealed such a wide scatter in damage degree at each intensity level (Figure 1), or such a lack of correlation between damage degree and intensity (Figure 2), that no useful predictive relationship between intensity and damage degree can be derived from them. This may be due either to lack of precision in defining structural type, or to insufficiently precise quantification of damage, or to uncertainties in the measure of ground motion intensity, or to a combination of two or more of these factors. We shall focus attention in this paper on the definition and quantification of seismic intensity.

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THE CONCEPT OF SEISMIC INTENSITY

The "intensity" of seismic ground motion is generally taken to mean the strength of such motion, or its severity. As such, it is in principle susceptible to quantification in terms of some physical parameter, such as acceleration, which can be measured by suitable instruments. This definition implies that the intensity of ground motion at a given site during a given earthquake is uniquely determined by the magnitude, focal depth and focal mechanism of the earthquake, by the physical properties of the materials through which the seismic waves travel from the earthquake focus to the site, and by the physical properties of the ground at the site, all of which are "natural" factors.

However, seismic intensity has also, for historical reasons, the meaning of "damaging power". Until the invention and widespread use of the modern strong-motion accelerograph, the only way in which seismologists could estimate the "intensity" of ground motion was by observing the degree of damage suffered by typical buildings or structures and by expressing the results of their observations as degrees on a "macroseismic" intensity scale. For the purposes of assessing seismic risk (the probability of loss through earthquake action), this concept of intensity is of considerable interest, since the damaging power of ground motion is precisely what will determine such loss. However, there are some very severe limitations to the use of such macroseismic intensity scales in practice.

The assessment of ground motion intensity from observations of the damage to buildings of various types is equivalent, in physical terms, to the employment of large numbers of recording instruments, each of which has a different sensitivity and different dynamic response, and to taking as a measure of intensity the average value of some parameter extracted from the records of these instruments. This being so, it is not surprising to find that the actual performance of buildings, when subjected to ground motion of apparently uniform macroseismic intensity, varies widely from type to type and even from one building to another within a given structural type.

In fact, since the damaging power of ground motion clearly depends not only on the characteristics of such motion but on the dynamic properties of the structure subjected to it, it is logically impossible to assign a unique value of intensity, in the sense of damaging power, to any given ground motion event: there will be as many different effective values of intensity as there are different types of building at the site.

It follows from the above reasoning that estimates of seismic hazard, if they are to be of use in risk assessment, cannot be expressed in terms of any single measure of intensity. They must contain information which will render it possible to make separate assessments of seismic risk for at least a few main types of building. There appear to be two possible approaches to a solution of this problem:

(a) to abandon altogether the concept of intensity and to relate damage directly to seismic source parameters and focal distance;

(b) to introduce the concept of effective intensity, which for a given time-history of ground motion will be different for different types of structure.

THE ONTOLOGICAL APPROACH

The principal direct cause of damage in earthquakes is ground shaking whose intensity, or damaging power, is determined by the magnitude and focal depth of the earthquake, the distance of the site from the source or epicentre, the attenuation between source and site and, finally, on local soil conditions.

In assessing seismic hazard, seismologists start by identifying nearby seismic source zones and by deriving, from data on past earthquakes, a magnitude-frequency relationship for earthquakes in each zone. Then, using empirical or semi-empirical relationships between magnitude, depth of focus, epicentral distance and some index of ground motion intensity, they assess the probabilities of occurrence of events of various intensities at the given site. So far, so good; but, as we have seen above, it is impossible to express the damaging power of ground motion by any single parameter of "intensity".

It appears from recent studies (eg. Milutinovic and Kameda, 1983) that the principle factors governing the damaging power of ground motion are the peak ground acceleration, the duration of ground shaking and the relation between the power spectrum of the motion and the natural period of the structure. Damage to individual structures will depend both on these characteristics and on those of the structure itself (eg. its ductility, damping, structural capacity, etc.).

The significant ground motion parameters (peak acceleration, duration, spectral content) are determined, apart from local soil effects, by the earthquake magnitude, focal depth, epicentral distance and source-to-site attenuation, that is to say be the same basic factors on which conventional seismic hazard assessments are made. If, instead of expressing attenuation in terms of a relation between intensity and distance, it were possible to express it by a relation between epicentral distance and degree of damage, some of the difficulties that arise from the use of the concept of intensity might be avoided. It may therefore be worthwhile to re-examine the data on damage caused by recent earthquakes (eg. Romania, 1977; Montenegro, 1979) in order to discover what was the relationship between epicentral distance and the degree of damage to buildings of several closely-defined structural types under various given soil conditions. With the adoption of standard procedures for damage assessment, it is possible to envisage the gradual building-up of an empirical data base of this kind, with evidence from earthquakes of various magnitudes and focal depths.

Progress in establishing such a data base will inevitably be slow but would have the advantage of making it possible to base estimates of probable damage, and therefore of specific risk, directly to the basic seismological data (magnitude, focal depth, epicentral distance) on which all seismic hazard assessments are based.

If this approach were to be adopted, seismologists would be called upon to provide, on a site-by-site basis, hazard assessments in the form of magnitude-frequency-distance relationships for earthquakes in the source zones affecting each site, and to do this separately for normal-depth earthquakes on the one hand, and for intermediate and deep-focus earthquakes on the other. This should not present them with any particular difficulty.

THE HEURISTIC APPROACH

Empirical magnitude-frequency relationships are of necessity based on the instrumental data that have been acquired only since the beginning of the present century. These data are incomplete for some parts of the world and in any case give only a picture of recent seismic activity. In hazard assessment, seismologists are therefore accustomed to supplement these data with information on historical (pre-1900) earthquakes, derived from reports of damage and expressed in terms of local ground-motion intensities.

It is indeed possible to base hazard assessments on intensity data alone, provided these are sufficiently abundant and homogeneous, leaving aside deliberately any attempt to study the causes of seismic ground motion. Maps of maximum observed intensity illustrate the spatial variations in the average damaging power of long-term seismic activity; if sufficient data are available, probability distribution curves of intensity can be derived for particular sites. However, such hazard assessments cannot be used directly to deduce the specific risk to any particular structure or type of structure.

In the absence of a substantial number of records of ground motion in the 1977 Romanian earthquake, the observed damage to buildings of various types in Bucharest was related (Sandi & Vasilescu, 1982) to values of MSK intensity based on the average degree of damage to all buildings in different areas of the city. Vulnerability functions, such as that shown in Figure 1, were obtained for several types of building. Data of this kind make it possible to derive, for each structural type, "effective intensities" corresponding to each level of MSK intensity but differing from one structural type to another.

The collection and analysis of similar data after future earthquakes will make it possible to establish locally-valid relationships between MSK or another standard intensity and "effective intensities" for various types of structure, and thus to base assessments of specific risk on the relatively large volume of macroseismic data that may be available in areas for which instrumental data are scarce. Such assessments may be less reliable than those based on the "ontological" approach, but would have the advantage that they automatically take into account the influence of local soil conditions.

CONCLUDING REMARKS

This paper raises more questions than it answers, but this is perhaps inevitable at the present stage of seismic risk studies. It cannot be too strongly emphasised that, whatever approach is adopted, progress in this field will depend largely on the rate of acquisition of reliable and homogeneous data on the damage suffered by buildings of closely-defined structural types as a result of seismic ground motion. The adoption of standard methods and procedures for damage assessment after destructive earthquakes, such as those proposed by Balkan working groups, is an important step forward, and the collection of the maximum possible volume of damage data in any future earthquake will certainly justify the considerable effort involved in doing so.

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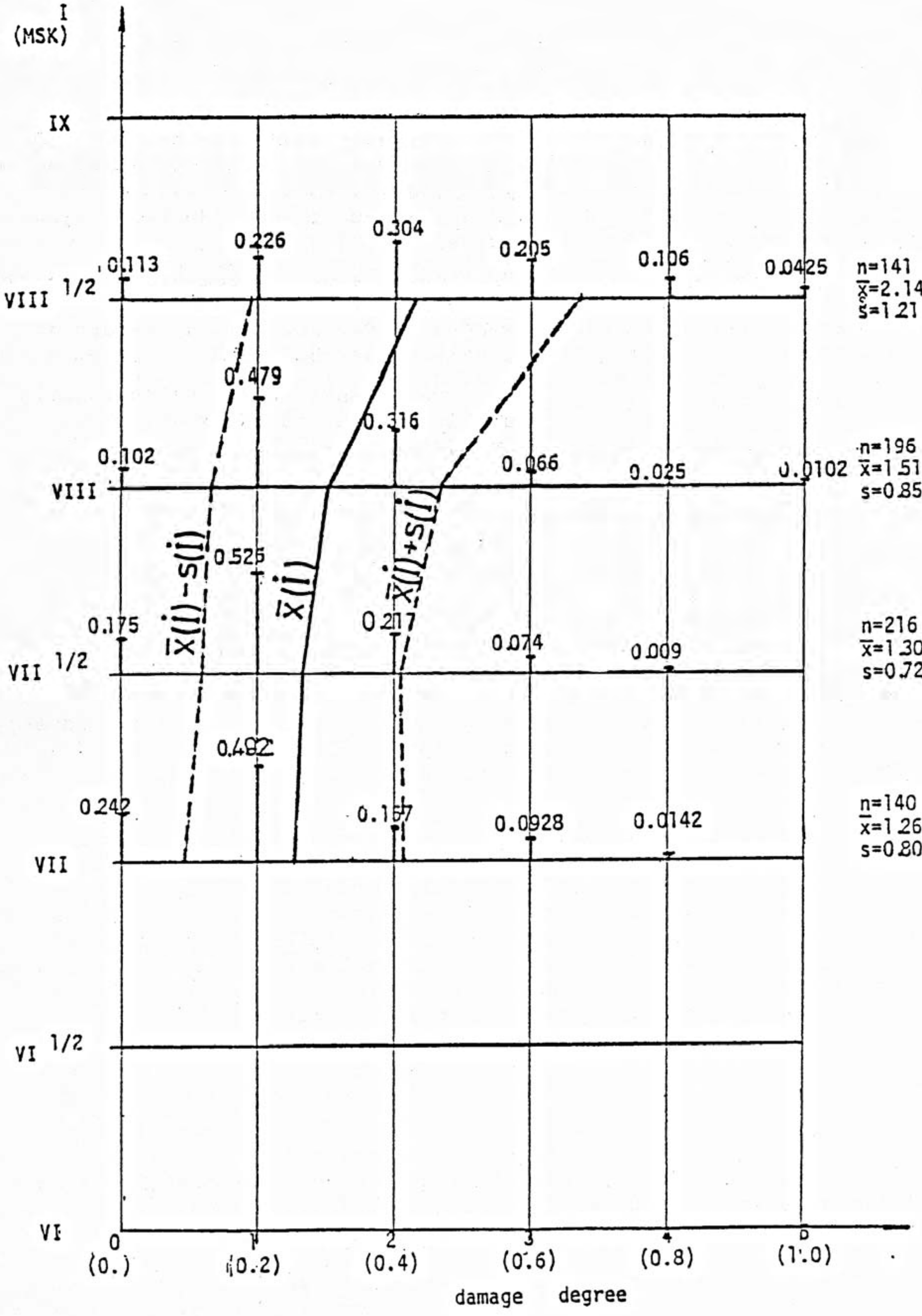

Fig.1 Observed vulnerability of reinforced concrete frame structures, Bucharest, 1977.

(From: Sandi & Vasilescu, 1982)

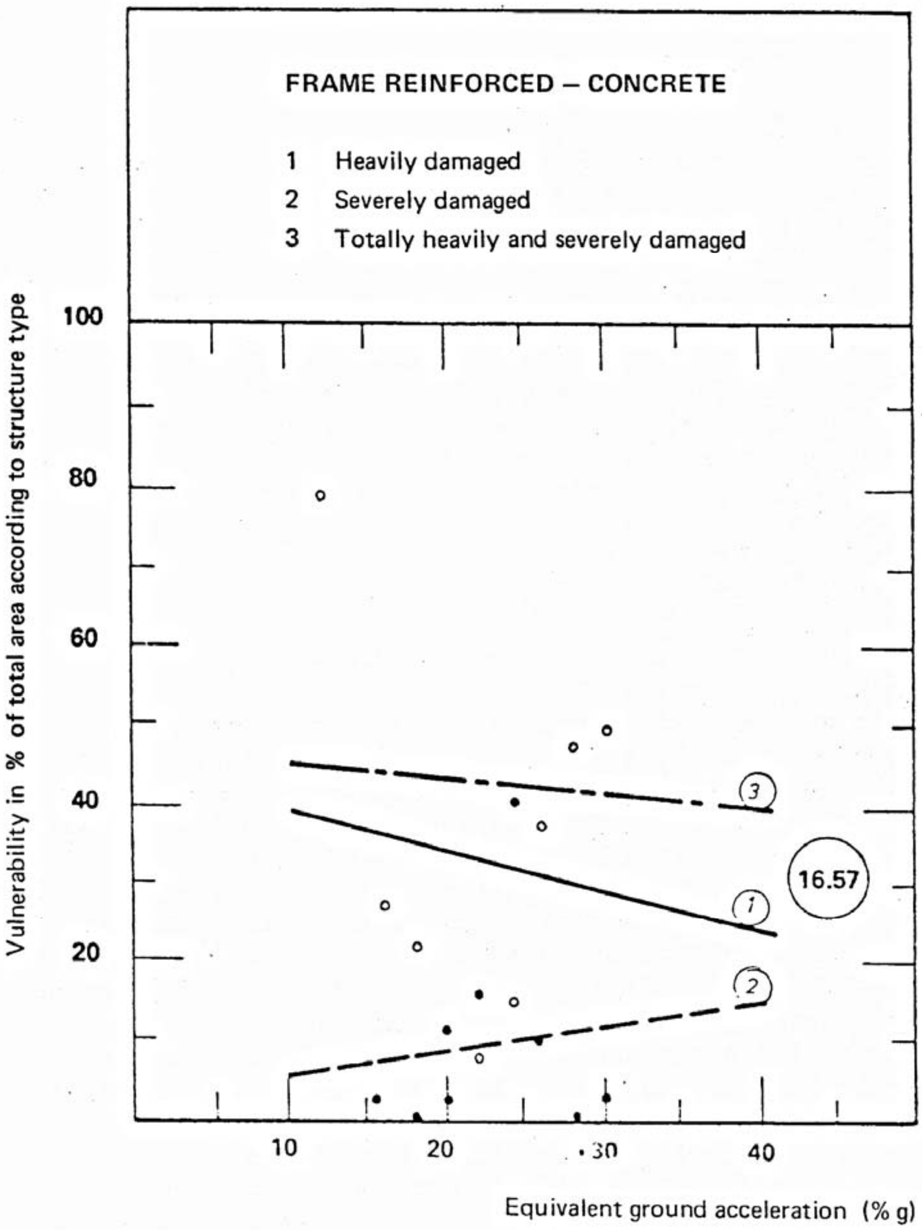

Fig. 2 Empirical vulnerability functions for reinforced - concrete frame buildings

(From Petrovski et al. IZIIS Report 84-084, Skopje, May 1984)