SOCIAL AND ECONOMIC ASPECTS OF SEISMIC RISK

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ABSTRACT

An attempt has been made to outline some general procedures for risk management and for the assessment of an acceptable risk level, taking into account scientific, engineering, economic, social and political aspects. The proposed method relies on accepted definitions of seismic hazard, vulnerability and risk. The procedure is first of all meant for the earthquake resistant design of capital engineering structures, like dams and nuclear power plants, but can be adapted also for physical planning and other purposes.

Introduction

Increasing technological complexity of engineering structures incorporated in a sensitive socioeconomic environment calls for rational evaluation of earthquake or seismic risk. The most important and most crucial result of seismic risk analysis is the determination of the acceptable risk for the purpose of earthquake resistant design.

There is no unique procedure for the estimation of seismic risk. In the narrower sense, the object of seismic risk analysis is to describe the nature of possible future ground shaking, that is to assess the seismic hazard. This is actually only the first stage of seismic risk assessment, nevertheless, it is often the only one.

In order to assess the seismic risk, in addition to the information on seismic hazard, data on elements at risk and their vulnerability are required. Once all this information has been prepared, the determination of the acceptable risk is chiefly an economic, social, and political subject. Concerning the economic part of the problem, an appropriate optimization technique would be highly desirable.

Seismic Hazard, Vulnerability and Risk

In engineering seismology and earthquake engineering literature, there is, or at least has been in general, ambiguity regarding the use of some terms. In order to avoid misunderstanding, definitions of terms proposed by UNDRO have been used in this paper. These terms are seismic hazard, seismic risk and specific seismic risk, vulnerability, and elements at risk.

The distribution of the hazard is given by its probability of exceedance $P(X \geq x)$ or the probability density function $p(x) = -(dP/dx)$, where X is a random variable or a set of random variables defining some earthquake parameter or ground motion parameter, and x its value.

Methods for the evaluation of seismic hazard seem to be reasonably adequate in spite of some deficiencies of basic data both in quantity and quality. The general form of $(P(X \geq x)$ for different time periods is given in Figure 1.

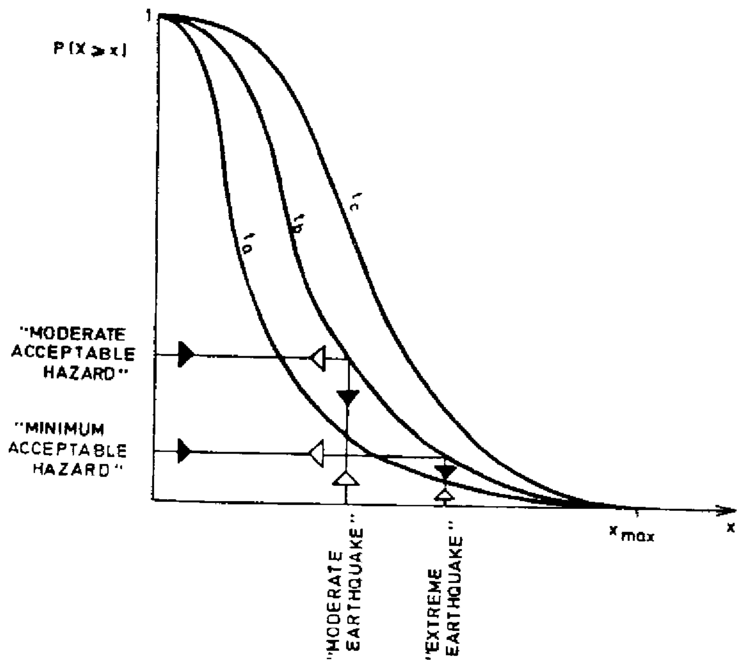

Figure 1

Seismic Hazard Functions

t = Design Period

x_{max} = Maximum Possible Value of X

Direction of Engineering Judgment

Direction of Investor's Policy

As mentioned above, usually seismic risk analysis stops at the assessment of seismic hazard. In this simplified procedure, the problem of the determination of the acceptable seismic risk is transferred to the problem of the determination of the "moderate earthquake" or the "operating basis earthquake" (high probability of occurrence) and the "extreme earthquake" or the "safe shutdown earthquake" (low probability of occurrence). With regard to some more or less (un)justified engineering judgment of "acceptable hazard" in the economic lifetime period the design (ground motion) parameters are determined.

Often some subjective reasons (investment policy, unfavourable financial situation, investors' goals, local motives) create policy formulation of "acceptable costs" and "acceptable design parameters." The usual final decision lies somewhere between the above mentioned engineering judgment and investors' policy.

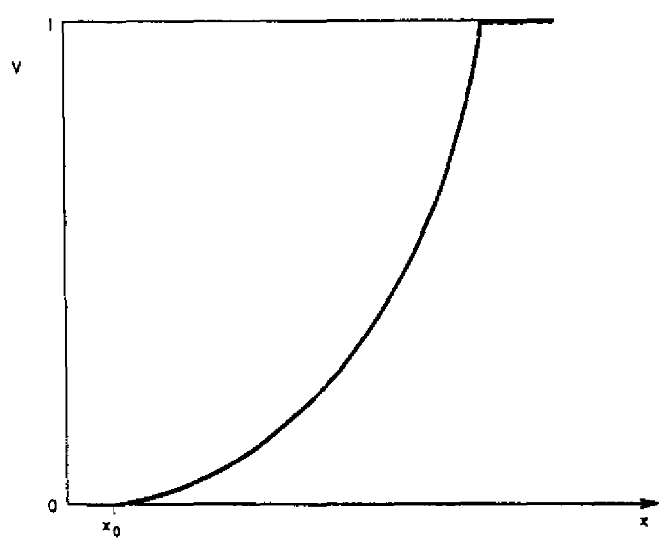

Figure 2

Vulnerability Function

To assess the possible degree of loss (that is the specific risk) and its absolute value (the risk) of an element at risk, the vulnerability of this element has to be taken into account. Neglecting the randomness of the properties of elements at risk and vagueness in vulnerability estimation, a simplified profile of a vulnerability function V(x) is rather similar to the one represented in Figure 2.

Specific risk R/E is determined by convolution of hazard and vulnerability:

$$(1) \qquad \frac{R}{E} = \int_{x_0}^{x_{max}} V(x)p(x)dx$$

where E represents element at risk (some property of that element, e.g. its monetary equivalent or number) and R means corresponding risk. Expected losses are given by the risk:

$$(2) \qquad R = E\int_{x_0}^{x_{max}} V(x)p(x)dx$$

Taking into account all important elements at risk, the first approximation of the total expected losses will be:

$$(3) \qquad \sum_{i=1}^{n} R_i = \sum_{i=1}^{n} E_i\int_{x_0}^{x_{max}} V_i(x)p(x)dx$$

A more complete solution should involve mutual dependence of individual elements at risk. Total risk of a group of interrelated elements at risk will be generally higher than a simple sum of partial risks:

$$(4) \qquad R\left(\sum_{i=1}^{n} E_i\right) \geq \sum_{i=1}^{n} R(E_i)$$

Elements at risk are, in the case of an adverse seismic event, interconnected by some positive feedback loops.

Acceptable Seismic Risk

Let us define economically acceptable seismic risk of an engineering structure (dam, nuclear power plant, etc.) on the basis of the minimum of a sum of earthquake resistant construction costs and expected losses during earthquakes.

Expected losses include direct structural damage and production losses (standstill losses) on the one hand and indirect damage and losses in the natural, economic, social, cultural, and political environment (local, regional, interregional, . . .) on the other, caused by the above direct damage and losses.

Considering in (4) only those elements at risk, which could be inflicted by the damage of the structure under consideration and taking into account only those interrelated effects which are caused by mentioned structural damage and production losses, the total economic risk could be written as:

(5) $$R_{TE} = R_{SD} + R_{PL} + \left[R(\Sigma_j \; E_j) - \Sigma_j \; R(E_j) \right]$$

Writing the term in the square brackets as ΔR_E, we obtain:

(6) $$R_{TE} = R_{SD} + R_{PL} + \Delta R_E$$

where

R_{TE} means total expected economic losses = total economic risk,

R_{SD} means expected structural damage = structural risk,

R_{PL} means expected production losses = production risk,

ΔR_E means expected damage and losses related to R_{SD} and R_{PL} = indirect environmental risk.

It is useful to separate some subgroups of ΔR_E. A reasonable procedure is to distinguish expected damage and losses at the local scale from the expected losses at the regional (interregional, national) scale. In this sense we can write the expression (6) as:

(7) $$R_{TE} = R_{SD} + R_{PL} + \Delta R_{EL} + \Delta R_{ER}$$

where:

ΔR_{EL} means expected damage and losses in the local environment = indirect local environmental risk,

ΔR_{ER} means expected damage and losses in the regional (interregional, national) environment = indirect regional environmental risk.

In (5), (6) and (7) only those elements at risk have to be taken into account which are economically evaluable. The vulnerability of any element at risk in (5), (6) or (7) depends on the vulnerability of the abovementioned structure. From (2) and (3) we can see that the risk is a function of x_o, the maximum value of parameter X at which an element at risk is still completely safe. For our structure this value is practically equal to the corresponding earthquake resistant design parameter. It is evident that:

(8) $$x_{oj} \geq x_{oS}$$

where:

x_{oj} means x_o of an arbitrary element at risk,

x_{oS} means design parameter or x_o of the structure.

Let the design parameter take all values of the variable X. Next suppose we know risk functions $R_{SD}(x)$, $R_{PL}(x)$, $\Delta R_{EL}(x)$, and $\Delta R_{ER}(x)$, x meaning all possible values of the design parameter. The general profiles of $R_1(x) = R_{SD}(x)$, $R_2(x) = R_{SD}(x) + R_{PL}(x)$, $R_3(x) = R_{SD}(x) + R_{PL}(x) + \Delta R_{EL}(x)$, and $R_4 = R_{SD}(x) + R_{PL}(x) + \Delta R_{EL}(x) + \Delta R_{ER}(x)$ are represented by curves in Figure 3.

Let the earthquake resistant construction costs be represented as a function of design parameter values x in a general and simplified form in Figure 4. An eventual change in type of construction at some x would very likely alter the course of the curve in Figure 4 abruptly. For the sake of simplicity a smoothed curve is presented.

Summing risk and cost functions from Figure 3 and Figure 4, we get cost-risk functions or cost-loss functions represented graphically in Figure 5.

Economically acceptable seismic risk can be defined as:

$$R_{AE} = R(x_{\min(C+R)}) \qquad (9)$$

Taking into account more elements at risk, min(C+R) moves to the right. An economically acceptable risk depends upon the decision maker. An investor's acceptable risk might be related to $\min(C+R_1)$ or to $\min(C+R_2)$. Local society might accept $\min(C+R_3)$, while regional or national policy should be based on $\min(C+R_4)$.

In the above procedure only the economic component at risk has been treated. How can one deal with elements at risk which are not economically assessable or have an economically questionable equivalent, the most important and most typical among them being population?

Expected life losses and injuries can be assessed using equations (1) and (2), with E expressing the number of inhabitants in a potentially affected area. In the same manner as for other elements at risk a population function can be found. Since the risk level is given in number of expected victims and not in a monetary equivalent, population risk function cannot be directly used in calculation of cost-loss function. It would be ethically unacceptable to make a transformation of a population risk function to some monetary equivalent risk function for the sake of simplicity of acceptable risk level assessment.

It is natural to treat the population at risk (and maybe some other elements at risk with an inestimable value, e.g. cultural and historical monuments) apart from economically evaluable elements. As with the risks associated with other activities of every-day life, people have to live with certain seismic risk. Therefore, the decision about the acceptable public or social seismic risk level is the right and obligation of the population at risk. Some minimum requirements on social seismic risk level should be at least regulated at the national level and given in earthquake resistant design and safety codes.

No matter how the population at risk is included in the procedure, the care for public safety will very likely push min(C+R) and the corresponding design parameter to higher values. Taking into account the requirements for public safety and care for some other unevaluable elements at risk, the total acceptable seismic risk will be:

$$R_A \leq R_{AE} \qquad (10)$$

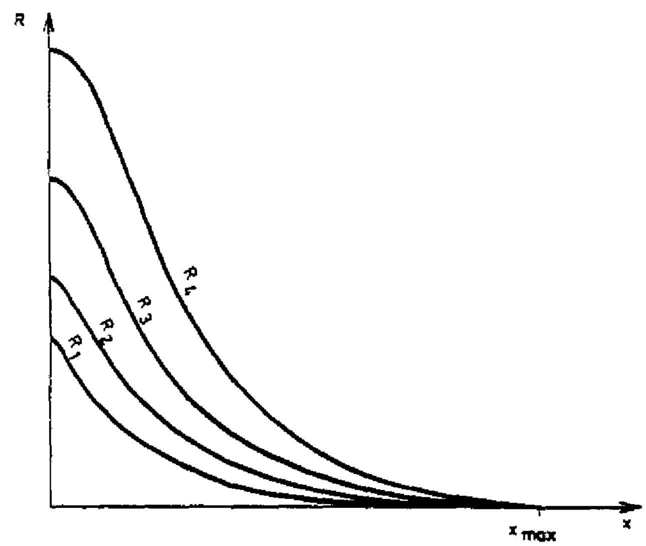

Figure 3

Risk Functions for a Given Design Period

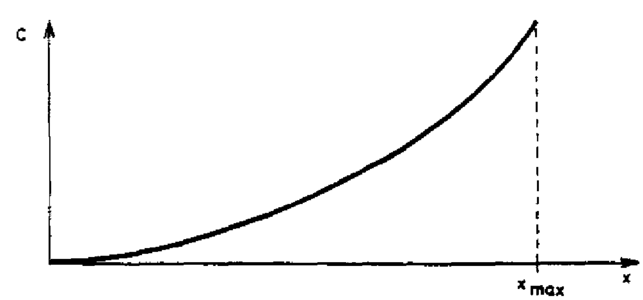

Figure 4

Cost Function

Figure 6 represents general outlines of the proposed risk management procedure. Only from the assessed acceptable risk can we get an idea about what an acceptable hazard might be, and not *a priori*, as it is often done.

Up to now, the structure has been taken as a whole. Since a capital engineering structure is a system of substructures, different earthquake resistant design criteria can be used for different components. In this sense the concepts of "moderate" and "extreme" earthquakes could be applied. However, a design parameter level approach might be preferable. It has to be emphasized that various design parameter levels do not necessarily result in different risk levels (but there are of course different hazard levels), and eventual dissimilar risk levels do not generally have the same succession of values as the corresponding design parameters (as it is in the case of hazard).

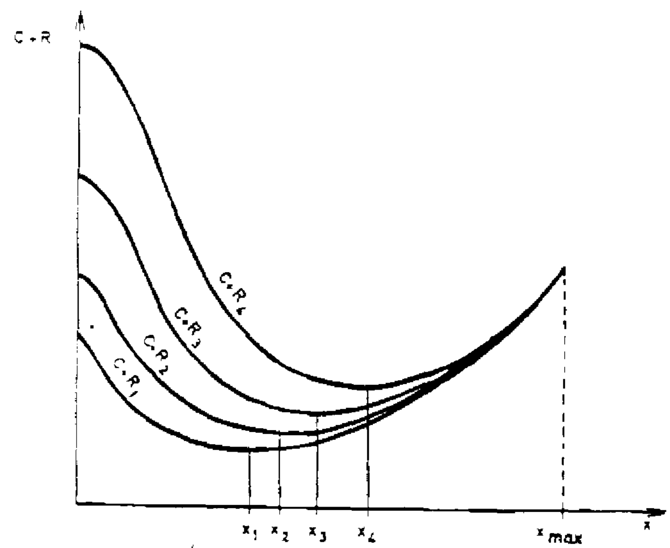

Figure 5

Cost-Loss Functions for a Given Design Period

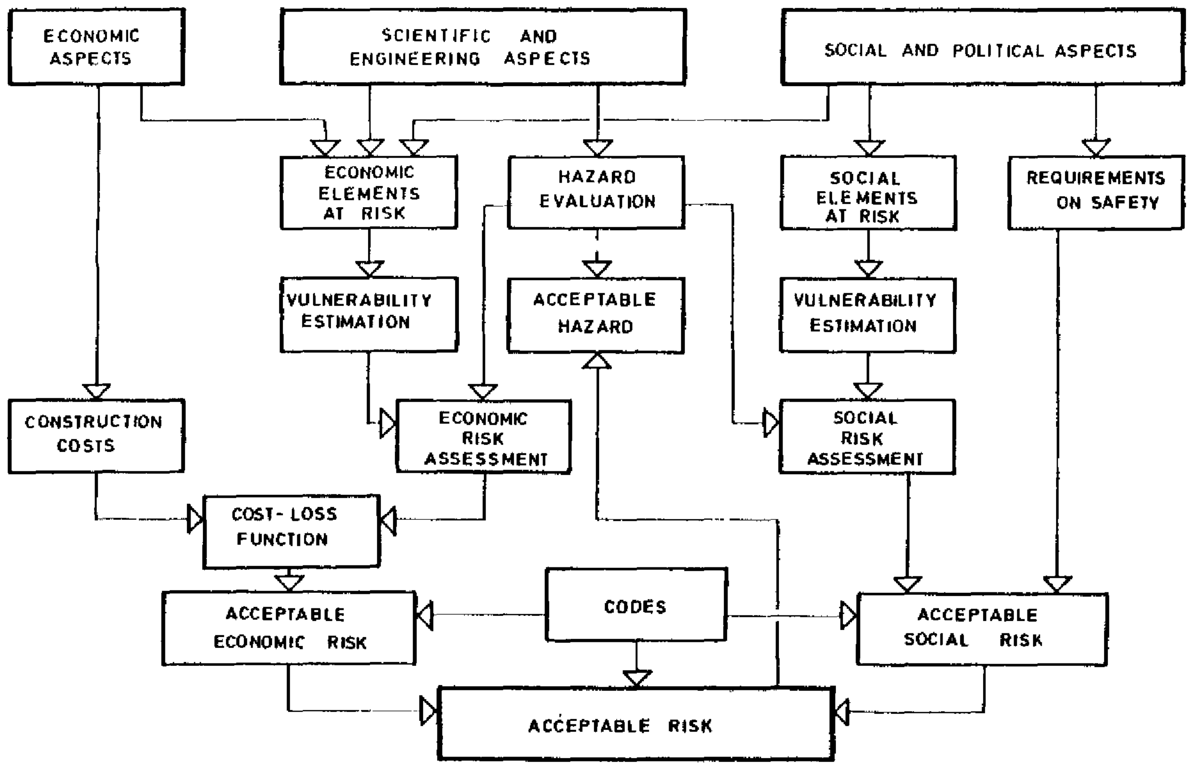

Figure 6

General Scheme for Managing Seismic Risk

Conclusions

In the procedure for the assessment of acceptable seismic risk just described, some questionable suppositions, approximations and simplifications have been made, some of them are already present in the accepted concepts of hazard, vulnerability and risk.

It has not been mentioned that the basic information on vulnerability, on mutual dependence of individual elements at risk, and on cost functions is rather poor and unreliable. Even the definitions of those quantities are not entirely clear. Also the concept of expected losses over a given lifetime period may not be entirely satisfactory.

Nevertheless, once the concepts and definitions of basic quantities and their interrelationships have been clarified and more reliable and more plentiful information has been accumulated, the proposed method might find a practical use in seismic risk management.

REFERENCE

United Nations. Office of the U.N. Disaster Relief Coordinator. Natural Disasters and Vulnerability Analysis: Report of Expert Group Meeting (9-12 July 1979). Geneva: UNDRO, 1980.

THE PROBLEM OF ASSESSING SEISMIC RISK TO EXISTING BUILDINGS

E.M. Fournier d'Albe

The new UNDP/UNESCO project entitled "Earthquake Risk Reduction in the Balkan Region," in which Bulgaria, Greece, Romania, Turkey and Yugoslavia are taking part, has first of all to develop methods for evaluating the risk to buildings and structures. This is not easy to do for existing buildings, particularly the older ones.

The proportion of its value lost by any building on the occurrence of earthquake ground motion of intensity I is, by definition, equal to its vulnerability V_I to ground motion of that intensity (using here the definitions adopted by UNDRO and UNESCO). The risk to the building over a given period of time is given by the equation

$$R = E \times \int_{o}^{I_{max}} V_I . p_I . dI$$

where p_I is the probability of earthquake ground motion of intensity I occurring at the site of the building during the given period of time, and E is the value of the building. The specific risk to the building is simply the value of the integral.

The use of the above equation to assess risk presents very different problems, depending on whether one is concerned with new buildings or with old ones.

By new buildings, I mean those for which one has detailed structural plans and for which it is possible to calculate the vulnerability, using the results of laboratory tests and the accumulated knowledge of the relations between the dynamical properties of structures and their vulnerability to ground motion. Then, if information is available on the seismic hazard in terms of the relevant parameters of ground motion (i.e., peak acceleration, peak particle velocity, power spectrum, etc.), one may use the above equation to calculate the specific risk and, if desired, the absolute risk in terms of value.

On the other hand, it is impossible to apply this equation to the many old buildings whose dynamical properties can neither be measured nor inferred with accuracy and whose vulnerability therefore remains unknown. Furthermore, unless an earthquake has occurred in the area very recently, no information is likely to be available on seismic hazard expressed in terms of the physical parameters of ground motion.

The situation is, however, not quite so desperate as it may appear at first sight. Records of earthquake damage have been kept for many centuries throughout the Balkan region, and the information contained in these records has been compiled, analysed and published in the form of catalogues and isoseismal maps. In the latter, the degree of damage has been transposed into an "intensity" on one or the other of the commonly-used macroseismic scales (i.e., Mercalli-Cancani-Sieberg (MCS), Modified Mercalli (MM), Medvedev-Sponheuer-Karnik (MSK)). A sufficient amount of information exists in this form for it to be treated statistically. However, this information is not, properly speaking, information on seismic hazard. It may be taken as such only insofar as it is borne in mind that "intensity" on any macroseismic scale subsumes a standard vulnerability for all buildings in each of a small numer (not more than three) of general building types.

In fact, maps in which seismic hazard is expressed as expected intensity on a macroseismic scale are actually maps of specific risk rather than of hazard.

But specific risk is precisely what we would like to assess. Economists and planners need not, therefore, despair if the seismologists to whom they turn for advice lack precise data on seismic hazard and vulnerability. In order to obtain an approximate evaluation of the risk to existing buildings, it is not absolutely necessary to know whether earthquakes are caused by convection in the upper mantle of the earth or by ancient heroes turning in their graves. Data on the "intensity" of past earthquakes are almost certain to be available wherever a significant seismic hazard exists, and such data may be used directly to derive an approximate assessment of risk.

A word of caution must nevertheless be added. The analysis of macroseismic data on intensity will not make possible the evaluation of the risk to any individual building but only that of the average risk to buildings in the broad categories specified in whichever scale has been used to express intensity.