PUBLIC POLICY IN EARTHQUAKE EFFECTS MITIGATION: EARTHQUAKE PREDICTION AND EARTHQUAKE ENGINEERING

by

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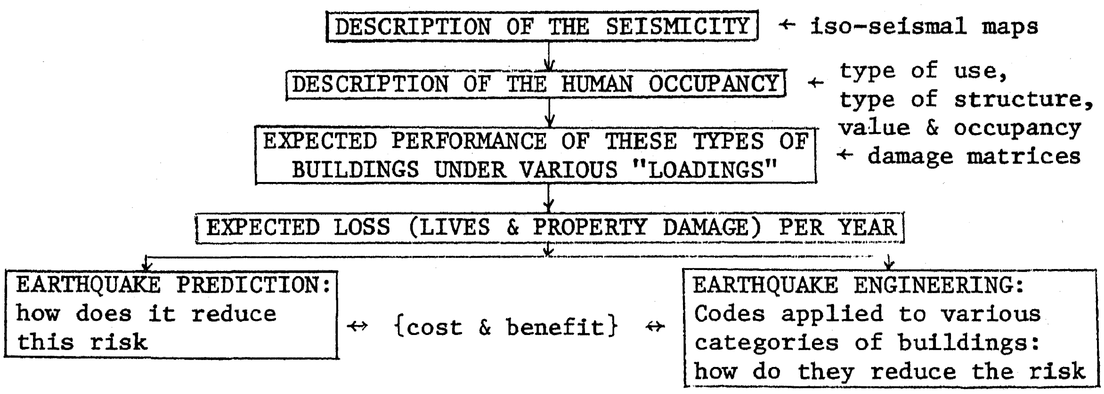
When a global investment is intended in a country for the purpose of mitigating the earthquake effects, several solutions are available. One of these solutions is the enforcement of building code regulations. This may involve the development of new codes to incorporate a better understanding of the earthquake phenomenon and its effects on man-made facilities. A newer perspective in this field is that of earthquake prediction. This also involves an investment in research, development and warning system. Both these solutions are costly. An often asked question is regarding their efficiency in a given state of technology, how they can reduce the risk and at what cost.

The model presented in this paper is developed to answer the above questions. However, before an evaluation of the costs and benefits of these policies can be developed, one needs to make a detailed assessment of the seismic losses - life loss and property damage.

The general model is developed in several steps and follows the following flow chart. (Valid only for a given region and a given length of time - say one year.) All the measures are assessed probabilistically in this paper.



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1. Risk and the Question of the Value of Life

The measure of risk in this work is the expected loss per year for a given region. This measure has two components: expected life loss and expected property damage. Let $C_1, C_2, \ldots C_n$ be the global set of seismic circumstances with probabilities p_i; ℓ_i and d_i being the corresponding losses. Then

$$\text{Risk } R = \sum_i p_i \ell_i = \bar{\ell}$$

$$= \sum_i p_i d_i = \bar{d}$$

These two components will be carefully kept separated

The choice of the expected value of loss implies that the public policy will be based upon a linear utility function. This is justified first by the fact that the life of the 10th victim has the same value as the life of the 1,000th victim in an egalitarian society. Secondly, there is no group utility function except in a large population with individual exponential utilities and a normal distribution of risk aversion and risk preference. In this case, the global utility function of the loss is linear.

The allocation of the intended investment can be made in such a way that the expected expenditure to be supported by a community for each additional life saved, has a decreasing marginal return. This allows one to meaningfully compare the additional investment versus life situation. As an example, the comparison of the cost of saving an additional life for seismic risk mitigation versus other public sector endeavor such as an investment in hospitals, can be carried out. Again, as mentioned before, one basically assumes that all lives have the same value. (This could be modified if such is the desire of a policy maker.) The development of the model in this report will illustrate this theory of comparing decreasing marginal returns.

2. Evaluation of the Expected Seismic Loss

The evaluation of the expected seismic losses per year for a given region involves combining losses due to primary and secondary hazards associated with a seismic event (landslides, liquefaction, ground rupture, etc.).

The basis of damage potential evaluation for a given region is a set of iso-seismal or iso-acceleration maps (see Figure 1). These maps represent, for a given time period, the probabilities of exceeding various levels of seismic "loadings." If losses can be related to the levels of "loading," then the use of iso-seismal or iso-acceleration maps can give various loss levels and the associated probabilities of exceeding those levels.

For a given seismic loading, the losses are functions of human occupancy and the type of structure. Thus, for a given region, one can divide all the buildings by their use, occupancy and structural type. Knowledge of the present dollar value and the human occupancy as a function of time for each group is essential. Let B_{ij} be the dollar value of the building whose use is i and belongs to a structural type j. Also, let N_{ij} be the number of people in a building with use i and structural type j.

Expected performances of these buildings under various intensities can be evaluated using damage matrices. These matrices give, for a given seismic intensity, the expected proportion of property damage on the basis of functional replacement and the corresponding life loss. Using the above information, one could evaluate the probability distribution function on property damage and life loss for a given structural type and use. Let $\rho_j(I)$ be the proportion of the value of the structure of type j to be replaced under intensity I and let $\tau_j(I)$ be the proportion of the occupants killed in a structure of type j under intensity I. Then, using the information from iso-acceleration or iso-seismal maps on probabilistic loading, the information on occupancy and type of structure B_{ij} and N_{ij} and the damage matrix $\rho_j(I)$ $\tau_j(I)$, one could obtain the expected property damage per year D_{ij} and expected number of lives lost per year L_{ij}. D_{ij} is defined as the expected property damage per year for a region for buildings with use i and of structural type j. Similarly, L_{ij} is defined as the expected number of lives lost per year for a region for buildings with use i and of structural type j.

The damage and fatality ratios $\rho_j(I)$ and $\tau_j(I)$ are functions of not only the intensities due to ground shaking alone but also depend on secondary hazards such as ground rupture, liquefaction, landslides, etc. The above ratio due to the secondary effects can be derived as follows. Let $\rho_j^1(I)$ be the proportion of buildings of structural type j destroyed due to ground shaking I with or without landslide. Similarly, let $\tau_j^1(I)$ be the proportion of the occupants killed in structure type j with or without landslides.

	No Earthquake	Earthquake (I)
No land-slide	α_1	α_2 $\rho_2, \tau_2 = \rho_j, \tau_j$
Landslide	α_3 ρ_3, τ_3	α_4 ρ_4, τ_4

Then

$$\rho_j'(I) = \rho_4 \times \text{Prob (landslide/Intensity I)} + \rho_j \times \text{Prob (No landslide/Intensity I)}$$

$$= \rho_4 \frac{\alpha_4}{\alpha_2 + \alpha_4} + \rho_j \frac{\alpha_2}{\alpha_2 + \alpha_4} .$$

Similarly

$$\tau_j'(I) = \tau_4 \frac{\alpha_4}{\alpha_2 + \alpha_4} + \tau_j \frac{\alpha_2}{\alpha_2 + \alpha_4} .$$

α_1, α_2, α_3 and α_4 are the probabilities of events corresponding to the event matrix shown above.

3. Evaluation of Costs and Benefits Associated with Enforcement of Building Codes: Decrease in Risk Due to Earthquake Engineering

The method consists in starting from the information on the expected loss per type of building, (use and structure type) mentioned in the previous section. Then, for each type, compute the costs and benefits of improving the use group to the next possible grade of structure type. This would give an expected cost per year, associated with saving one extra life from seismic hazard. If one begins with the class of structures that could be upgraded at the lowest cost per life saved, then one could get the optimal allocation of investment through building code enforcement.

As mentioned previously, D_{ij} and L_{ij} are the expected property damage and lives loss per year for use type i and structure type j. Let C_{jk} be the cost of improving the structure of type j to type k, keeping i, the use constant. Then, for each element of the expected loss matrix (D_{ij}, L_{ij}), one could consider the next possible improvement in the structural type at cost C. This cost C would reduce the damage D by ΔD and life loss L by ΔL. Then, minimize $\frac{C-\Delta D}{\Delta L}$. After this minimization, the expected loss matrix can be modified. This way, the expected return of investment in earthquake engineering and code enforcement can be evaluated. It should be noted that such an increasing investment has decreasing marginal return.

4. Evaluation of Costs and Benefits of Earthquake Prediction

Whether or not to invest in earthquake prediction is an often asked question. The answer to this question depends on the value of prediction, its cost, the reliability of prediction and the type of prediction. The state of prediction technology plays an important role in the above discussion. The state of this technology can be represented by the conditional probabilities of magnitudes m_i having being predicted given that magnitudes m_j actually occurred.

Consider the following decision tree of figure 2. Let m_0 represent no earthquake whereas m_1 to m_5 represent five different magnitude events. Let $p_i(m_i)$; i = 0 to 5 represent the probability of occurrence of different events m_i. Let L_i and D_i represent the life loss and property damage due to an event m_i. Then, $\bar{L}$ and $\bar{D}$ the expected life loss and property damage can be calculated by $\bar{L} = \sum_0^5 D_i p_i(m_i)$. The above calculations can be carried out for the branch where no investment in earthquake prediction is made.

Consider now an investment of C_1 for research and development in prediction and C_2 for monitoring the data, warning, evacuation, etc. Let $p_i(m_i/m_j)$ be the probability that an event of magnitude m_i would be predicted if in fact an event of m_j would occur. In other words, this conditional probability gives the reliability of prediction. Again, knowing the life loss L_i and the property damage D_i due to an occurrence of m_i, one could calculate the new $\bar{L}$ and $\bar{D}$ due to prediction. The gain (or loss) due to prediction is then given by

$$\text{Gain (or Loss)} = \bar{L} - \bar{L}_{pred.} = \Delta L$$

$$= \bar{D} - \bar{D}_{pred.} - (C_1 + C_2) = \Delta D .$$

The investment per life saved is then given by

$$\frac{(C_1 + C_2) - \Delta D}{\Delta L}$$

If one compares this investment in prediction per life saved with similar investment per life saved in earthquake engineering, then the value of predictions versus value of earthquake engineering - code enforcement, etc. - can be determined.

It can be seen that as the conditional probability and hence reliability of prediction improves, its value-benefit increases with respect to other means of loss reduction such as code enforcement. Such an evaluation can also help in determining the point at which the value of prediction and hence its benefit is greater than its cost. A global investment strategy can be developed by using the methodology presented in this paper. In conclusion, it should be pointed out that only the conceptual methodology is presented in this paper. A detailed analysis with numerical examples for a region is being developed currently as a Ph.D. dissertation by one of the authors.

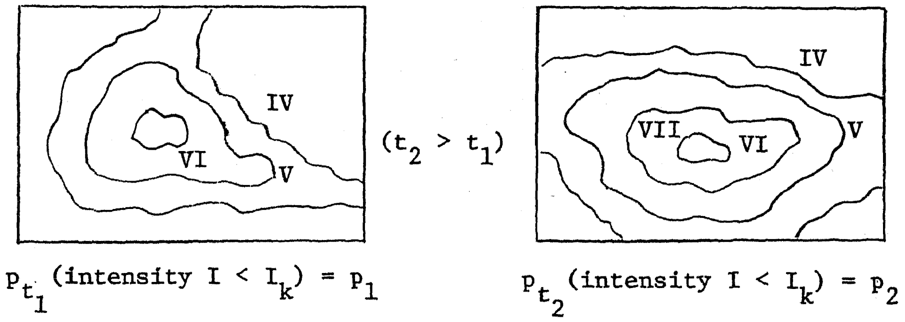

Figure 1. Iso-seismal or Iso-acceleration Maps - Description of the Seismicity in Probabilistic Terms

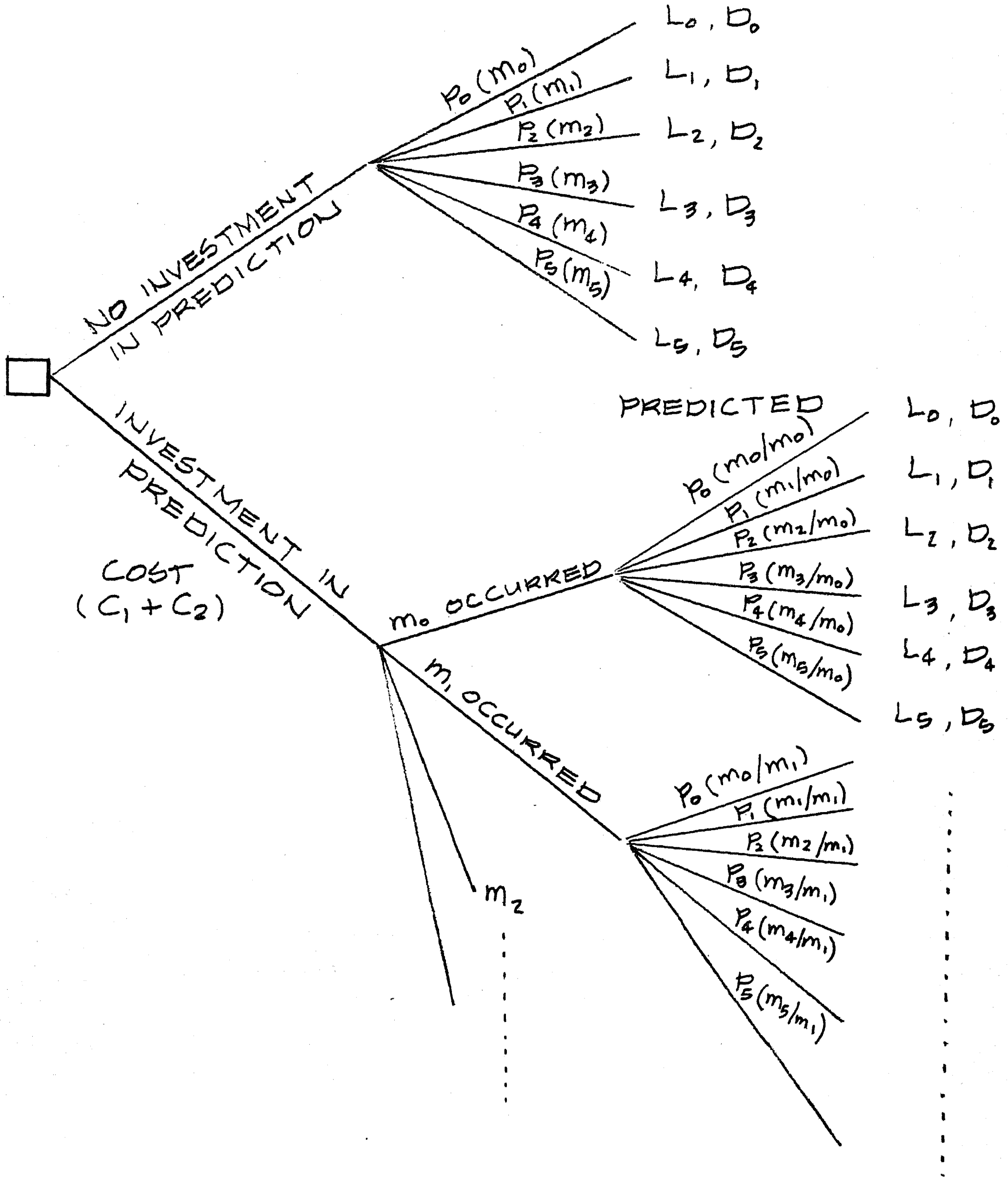

Figure 2. Decision Tree

DISCUSSION

P.V. Rao (India)

1. In assessing the risk costs value of human life needs to be quantified. The ASCE Task Committee (Jl Hyd Div., Vol. 99, No. HY 2, Proc paper 9571, Feb 1973 p. 359) adopts the value of human life as $ 150,000 for a death and $ 200,000 for a permanent disability for the purpose of assessing flood damage. The authors may comment on these figures and quote values as adopted in USA and other countries for quantifying the value of a human life.

2. In a developing country with a socialistic pattern where the insurance companies are owned by the public sector, it is really hard for the engineer to convince the public about risk as a design criterion. The authors may give their experiences and suggestions in this regard.

Author's Closure

Not received.