VALUATION OF HUMAN LIFE IN SEISMIC RISK ANALYSIS

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SUMMARY

This paper presents some shortcomings of the existing methods of valuation of human life in earthquake risk-benefit analysis. It discusses the main difference between the earthquake risk and other types of risk as it effects human life valuation. It develops a new method for assessment of the economic value of human life which can be used in seismic risk protection. The proposed method relates the optimum level of expenditure for life protection in a country to factors such as level of ecomomic development, per capita income, and level of ambient risk to life. The necessity of treating the loss of life and property separately in seismic risk studies and inclusion of this dual treatment in seismic codes are stressed.

INTRODUCTION AND MOTIVATION

During the past few decades the methodology of seismic risk analysis has advanced greatly. One aspect of this analysis deals with cost-benefit analysis. In this type of analysis, typically the estimated costs of various levels of seismic strengthening of a building is compared with the expected benefits derived from the reduction in the loss of life, limb, or property under probable future earthquakes. A similar approach can be used for risk-benefit analysis of various seismic requirements of building codes and for evaluation and assessment of numerous policy decisions regarding earthquake protection by local or national governments in countries at various stages of socio-economic development. In the evaluation of the expected benefits, monetary values have to be assigned to human lives saved and to injury and property damage avoided due to the use of a superior design. Based on the expected extent of loss, the benefits derived from various design improvements can be approximately estimated. Assigning monetary value to human life is an important issue in the area of public policy decision analysis. Assessment of value for human life has economic, social, political, legal, ethical, and moral dimensions which has attracted attention of economists, public policy decision makers, engineers, courts, and moralists. Review of the literature shows that in the past this subject has not attracted sufficiently the attention of earthquake engineers. Valuation of human life is needed in seismic risk decision analysis by individuals, profit motivated firms and

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governments. An individual may wish to minimize the risk of death or injury to himself and his family by upgrading the seismic strength of his residence. In the process of deciding how much to pay for the extra level of seismic protection, he subconciously assigns a value to his own life and the lives of his family members. Profit motivated firms, especially in those countries where building code requirements have not been sufficiently developed, need to consider human life valuation for a rational and optimum seismic risk-benefit analysis. Government agencies must select a course of action that leads to the use of limited public or private resources to optimally enhance public safety. They need to use cost-benefit analyses to evaluate the impact of their policy decisions.

EXISTING METHODS OF VALUATION OF HUMAN LIFE

The general methods and many variations of these two methods have been used in the past by economists, engineers, policy and decision makers responsible for making cost-benefit or risk-benefit analysis in government or private business (1,2).

Deferred Future Earning (DFE)

This method, which also is called Discounted Future Earnings, and its variants has been used in many U.S. government studies (2). This method can be used for a particular individual as well as an average person representing a group or a population. Based on the age of a person, and assuming he has a normal life expectancy, his expected future earnings and his contribution to the Gross National Product (GNP) is estimated using available statistical data. The present value of the expected stream of future income is then computed using discounting methods and appropriate discounting rates. This calculated present value is assumed to be the average value of life for the person or the population under study. The results of studies reported so far in literature (3) have been very different and sensitive to age, country, discount rate, income level, productivity, sex, and education. Some economists have used the net earning of an individual in their model (3). This has been done by subtracting the expected future consumption of an individual from his expected future gross earning.

Willingness to Pay (WTP)

This method is based on the economic axiom that the value of a commodity to a person is equal to the amount that he is willing to pay for it. The willingness of an individual to pay for life insurance or for reducing risk to his life can be used to estimate the value he assigns to his life. The shortcomings of this approach are: 1) the values of variables cannot be obtained easily and accurately, 2) this method may be appropriate for an individual who is paying for additional life protection for himself or for his family. But in case of decision making by government officials on a public project requiring use of tax money the method of WTP becomes irrational to apply. This method has not been used much in risk-benefit analysis for public works, however it has provided a powerful basis for most theoretical approaches to life valuation (4).

CHARACTERISTICS OF EARTHQUAKE RISK AS THEY AFFECT PROTECTION AND VALUATION OF HUMAN LIFE

Risks from earthquakes are different from other risks with regards to valuation of human life. Earthquake can affect large areas which may include numerous villages, towns or cities. The protection of life against earthquake is not the sole duty of an individual; the government as protector of public safety and welfare has a role to play in the form of regulator and enforcer of codes and standards. Seismic regulations, codes and standards should be based on a rational risk-benefit analysis using suitable values for human life. Earthquake overprotection is costly, especially for countries with a low level of per capita income where the resources can be used for other higher priorities in life saving activities. Therefore care must be taken against both under and overprotection. Table 1 shows different methods for seismic protection and valuation of life which due to the incentives of the participants will be different. These methods are represented by an arrow in each condition. In the case when the decision-maker, payer and beneficiary are the same individual, such as when one builds a residence for himself, willingness to pay determines the common level of protection, however in no case should the level of protection be allowed by the government to go below lower limits established by the code (L).

In the case of a private corporation which builds houses or condominiums for rent or sale the corporation is the payer and the decision maker but the beneficiaries are the future tenants or owners. In this case the builder generally provides a level of protection equivalent to the lower limits (L) specified by the legal codes. Therefore these limits should be established by rational, economic risk analysis.

In the case of public buildings, government decision makers use of either tax money to pay for seismic protection or they will ask the beneficiaries through a tax levy or bond issue to provide the needed funds for the project or for seismic improvements of existing buildings. In many cases the decision maker may not be the beneficiary. In these cases complex situations can be created resulting in under or overprotection. When decision makers are beneficiaries and the costs are paid from tax revenues or provided by special tax levies from beneficiaries, then the incentive may be for overprotection which should also be prevented by establishing legal upper limit standards (U).

THE PROPOSED METHOD FOR VALUATION OF LIFE

In allocating limited resources to various life saving activities the following assumptions are made. These assumptions are based on generally accepted moral and ethical values and standards.

a) Money can be expended to save human life, but human life should not be spent to save money.

b) All human lives are valuable and under normal conditions no one's life should be sacrificed to save someone else's life.

c) In any decision making concerning saving human life or reducing risk to one's life the Pareto Principle should be observed. On

Table 1 Valuation of Life Methods for Different Conditions

	D=P=B(1)	D=P≠B	D=B≠P	D≠P=B
Individual	WTP ↑ Personal Residence L	WTP For Rent or Sale ↓ L	U ↑ L	WTP OP ↑ L
Private Firms	WTP OP ↑ Factories Offices L	WTP Built for Sale ↓ L	U ↑ L	WTP OP ↑ L
Governments	U ↑ Offices L	U Low-Cost Housing ↓ L	U ↑ L	WTP OP ↑ Schools L

1) D = Decision Maker, P = Payer, B = Beneficiary
2) U = Upper Limit Standards
3) L = Lower Limit Standards
4) WTP = Willingness to Pay Method
5) OP = Optimum Level or DFE

the basis of this principle (1) the decision maker should choose a course of action so that while no one's lot is made worse somebody's lot is improved. This means we should try to reduce the risk of life for some people while not increasing the risk of life for the rest of the population.

d) The future will be optimistic. This means that we never will be in a situation where we are faced with cutting back a life saving program and with the moral dilemma of choosing which life to sacrifice.

e) Resources are limited and are not sufficient to remove all risks.

f) Subject to the assumptions and constraints established in items a through e above, the constrained theory of Marginal Utility in economics can be applied to resource allocation in life saving activities. According to this theory the optimum allocation of resources is obtained when the marginal lives saved (quantity of life saved per unit of resource expended) is the same for all activities. This allocation results in saving a maximum number of lives per available resources. For this optimality condition to be true it is necessary to allocate the resources to various risk reducing activities such that the marginal risks reduction will be the same for all activities, subject to constraints.

Figure 1 shows a hypothetical distribution of the per capita income in various contries between the survival and non-survival needs. Survival needs are those needs such as physiological (food, shelter, clothing), safety and security needs. The non-survival needs are higher level wants which are not essential for maintenance of life. As shown in Figure 1, less developed countries spend a major share of their per capita income on survival needs. As countries develop and their per capita income increases the percentage of funds used for survival needs are reduced and that of non-survival needs are increased. This development follows the general pattern shown by curve E-E. In the region around this curve the development path of some hypothetical countries A and B between years 1980 to 2000, are shown. Each country follows a different trajectory similar to E-E due to its initial and inherent conditions.

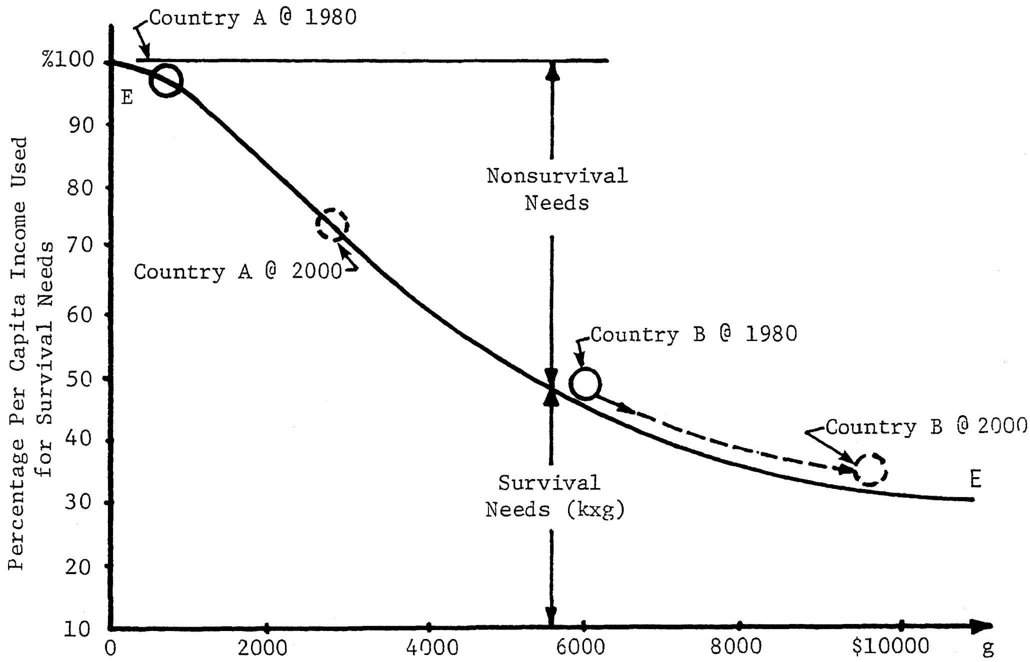

Figure 1 Expenditures of Countries with Various Per Capita Income at Various Stages of Development for Survival and Nonsurvival Needs

Figure 2 shows the relationship between the average life expectancy (L_e) of the population of a region or country with the annual per capita expenditure on survival needs. This figure shows the position of same hypothetical countries A and B and the trajectory of their development between years 1980 to 2000. This curve shows that the law of diminishing return is valid for life expectancy. A small per capita expenditure for survival needs in a less developed country increases life expectancy many times more than if the same amount is spent when that country becomes highly developed. The marginal rate of return is shown by U, which is the slope of the trajectory curve of the country in a given year as shown in Figure 2.

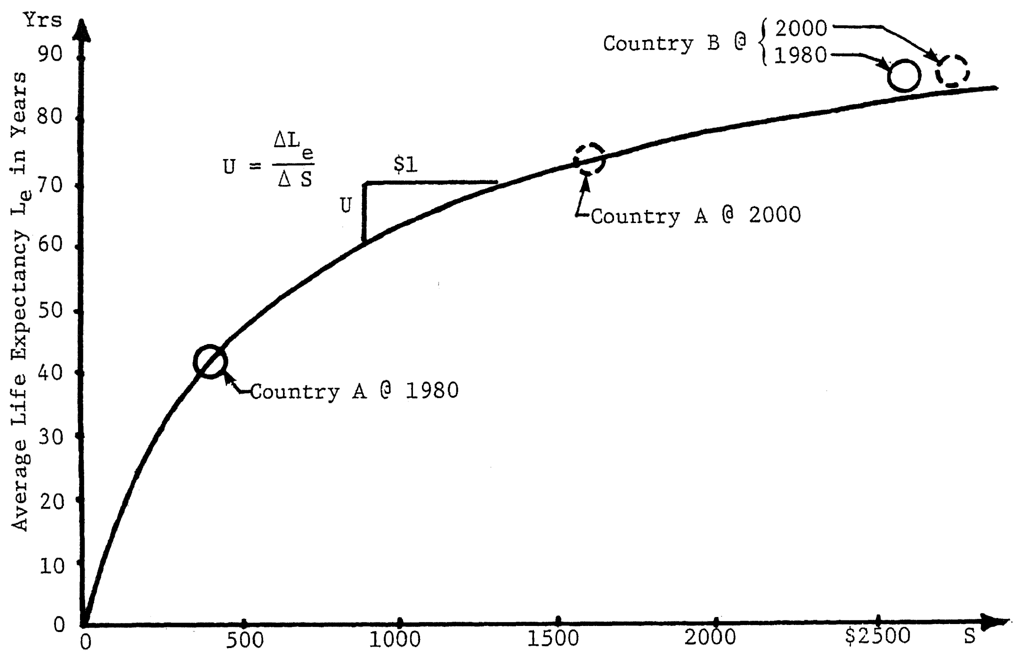

Figure 2 Relationship of Average Life Expectancy to Per Capita Expenditure for Survival Needs at Various Stages of Development

The marginal rate of life saving (number of years of life expectancy increased by spending one dollar) can be found from Figure 2 using the following formula:

$$U = \Delta L_e/\Delta S \tag{1}$$

where: U is the amount of increase in life expectancy in years per one dollar annual expenditure

L_e is the average life expectancy of the population

S is the per capita expenditure for survival needs obtained from equation (2)

$$S = k \times g \tag{2}$$

k = percentage of per capita income used for survival needs as shown in Figure 1.

The relationship between an increase in life expectancy and reduction of the risk of death for a population can be found from the following formula.

$$\Delta L_e = \Delta P(L_e - L_m) \tag{3}$$

where: ΔL_e is the change in life expectancy
ΔP is the change in level of risk
L_m is the average age of the population

Substituting in equation (3) for ΔL_e from equation (1) we obtain:

$$U \times \Delta S = \Delta P(L_e - L_m) \tag{4}$$

From equation (4) we can obtain an estimate of the value society assigns to the average life of a population. We will call this value the Average Economic Value of Life (EVL) for the population under consideration. EVL can be estimated using the following assumptions:

a) The perpetuity, R, with a present value of EVL is equal to the following equation which is obtained from equation (4).

$$R = \Delta S/\Delta P = (L_e - L_m)/U \tag{5}$$

b) The rate of growth in per capita income will compensate for the effect of inflation.

c) The real rate of interest with no inflation to be used for discounting is assumed to be i = 3% to 5%.

On the basis of the above assumptions EVL is:

$$EVL = R/i$$

$$EVL = (L_e - L_m)/(U \times i) \tag{6}$$

As an example: L_e = 80 yrs, L_m = 40 yrs, U = 1/200, and i = 0.04 we obtain EVL = $200,000.

VALUE OF LIFE IN SEISMIC RISK STUDIES

Review of reports of past earthquake enables us to recognize the main causes of death and injury during past earthquakes and to rank them according to their importance. Average EVL increases as time goes on and as countries further develop. In contrast, the value of existing buildings diminishes due to depreciation. Seismic protection criteria should be specified with a dual objective of protecting against loss of life and against injury and property damage. This duality is needed because technological methods for achieving each objective is somewhat different, the valuation of cost differs and the required level of protection against each type of damage may vary.

Risk-benefit analysis of earthquake protection has been discussed in detail in the literature and will not be treated here. The inclusion of loss of life in this analysis requires use of simulation techniques to determine the level of human loss in various types of buildings during earthquake. In this simulation various models such as; occupant distribution model, earthquake generation model, structural seismic behavior and failure mode model, human loss estimation and valuation model, and risk-benefit evaluation models should be used. Discussion of the model is beyond the scope of this paper.

The level of protection in an area should commensurate with the average EVL in that area. EVL may be modified by multipliers reflecting the economics and life sustaining importance of a particular location or activity within the region or the country. Important buildings which house strategic, emergency, or life saving activities must remain functional after an earthquake. For such buildings, risk-benefit analysis will lead to a safe design if the total magnitude of contribution of these projects to life protection is taken into consideration.

CONCLUSIONS

A model has been developed for determination of the average EVL as given by equation (6). In this equation the effect of level of development, per capita income, life expectancy and discount rate are used. The role of individual, privately motivated firms and governments in earthquake protection are explored. An outline for a model for simulation of expected loss of life due to earthquake and for risk-benefit analysis is proposed. A method for optimal allocation of resources between earthquake protection and other risk reducing activities is shown. This approach is useful for some developing countries which have a very low level of per capita income. It is concluded that the level of seismic life protection in each environment should reflect the economic realities of that environment.

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