SEISMIC HAZARD ANALYSIS IN MICROZONATION AND BUILDING DAMAGE EVALUATION

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SUMMARY

This paper deals with site effects on earthquake risk and its application to microzonation and building damage evaluation. By using earthquake damage index and average shear modulus of soils, the risk probability curve can be modified for different site condition and then geologically microzone will be able to transform into a microzoning map with consideration of risk probability. For building damage evaluation the ratio of repairing to replacement cost of building is utilized as a direct loss scale by total probability. Some problems concerning economic estimate of added risk reduction measures and decision criterion are also discussed.

INTRODUCTION

The seismic risk analysis can be, finally, expressed in terms of loss probability by the defination of total probability, i.e.

$$p\ (\text{Loss}) = \sum_j \sum_k p(\text{Loss}|DR_k)\ p\ (DR_k|\hat{I}_j)\ p\ (\hat{I}_j)$$

where $p(\text{Loss})$ — expected total loss probability due to earthquakes;

$p(\text{Loss}|DR_k)$ -- loss probability matrix, given the damage ratio;

$p(DR_k|\hat{I}_j)$ — damage probability matrix, given the intensity of ground shaking;

$p(\hat{I}_j)$ — annual mean probability of ground shaking exceeding a specific level I_j in a given site, it needs to be modified with site condition.

Sometimes, it can be rewritten as following:

$$p\ (\text{Loss}) = \sum_j p(\text{Loss}|\hat{I}_j)\ p(\hat{I}_j)$$

Obviously, where

$$p(\text{Loss}|\hat{I}_j) = \sum_k p(\text{Loss}|DR_k)\ p\ (DR_k|\hat{I}_j)$$

is nothing but the average loss probability, the summation is made over all damage states and resulting probability is a function of intensity. The task of this study is determination of each probability respectively and modification of site effects on risk probability based on earthquake data.

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SITE EFFECTS ON EARTHQUAKE RISK AND ITS APPLICATION TO MICROZONATION

Seismic microzonation study in China (Ref.1) was started in the fifties. In the early stages the basic intensity of seismic intensity zoning map served starting point, intensity value in a region was then adjusted according with soil condition and water table elevation. In the sixties soils were classified at the base of its physical-mechanical properties and predominant period measured in-situ, corresponding with that the design spectra were selected and microzonation map was prepared to meet the need of aseismic code draft. In the present stage the main tendency toward correct differentiation between two different kind of earthquake effects, i.e. ground shaking and ground failure has become more and more confident than ever. Synthesizing earthquake damage experience, engineering geological and hydrogeological condition, strong motion instrumentation data and theoretical analysis, microzonation map preparation and design earthquake parameter determination for engineering purpose are conducted.

Up to now, no matter which method is adopted, the concept of seismic risk probability has not yet been introduced in existing any microzonation method directly. In the same time the results of seismic risk analysis utilized are related to average site condition in general, because of the statistical data for attenuation equation in analysis are based on average site condition. Thus, for application of risk analysis to microzonation the necessary modification in accordance with site condition must be made. From the point of view of statistics the effects of site condition on ground shaking (or intensity) are of deviation from mean value of intensity. Therefore, how to consider the site effects in attenuation equation for seismic risk analysis becomes a key problem for application of risk probability to microzonation (Ref.2).

The approach of solving this problem might be divided into two categories: (1) attenuation equation is modified with different site condition and then risk probability curves are calculated by this modified equation; (2) risk probability curves are calculated by attenuation equation for average site condition and final result is modified by different site condition. In the former case it is always difficult to realize because of a scarcity of statistical data. The latter approach is more flexible for application and enables various site condition (soil, topography, water table elevation etc.) to be considered altogether if each condition can be expressed in terms of any ground shaking parameters. Having risk probability curves for different site condition the geological microzone can be transformed into microzonation map with consideration of seismic risk probability without any difficulty.

In China, the existing middle-long term earthquake prediction and seismic zoning map compiled are mainly based upon historical earthquake data. For the scarcity of instrumental data today the attenuation equation of earthquake intensity obtained from macroscopic data of historical earthquakes in given region is much more appropriate than using an attenuation equation of ground motion parameters quoted arbitrarily from references. Certainly, the intensity itself is a rough scale, it reflects an average damage degree of a region and not represents completely the intensity of ground shaking, but the damage of same kind of buildings under same site condition is closely correlated with intensity (or damage index).

In this study the average shear modulus (ASM) of soil $\bar{G}$ is treated as a variable of site condition, because it reflects the effects of physical and mechanical properties of soil and its thickness, it can be defined as:

$$\bar{G} = \frac{\sum_j h_j G_j}{H} = \frac{\sum_j h_j \rho_j V_{sj}^2}{\sum h_j}$$

where $\bar{G}$ — average shear modulus of soil (T/M^2);

G_j — shear modulus of the j th layer (T/M^2);

h_j ← thickness of the j th layer (M);

H —— effective depth of the surface layer (M);

ρ_j — soil density of the j th layer $(T \cdot sec^2/M^4)$;

V_{sj} — velocity of shear wave in the jth layer (M/sec).

In accordance with the damage index i of historical earthquakes the relationship of

$$i = \eta + \xi \bar{G}$$

can be established, where η and ξ are regression constants. Although ξ value varys in a wide range, the general tendency is decrease with increasing of $\bar{G}$. For a given $\bar{G}$ related to average site condition, ξ value can be obtained in fig. 1. Thus, the increment of damage index for studied site k is

$$\Delta i_k = \xi \Delta G = \xi (\bar{G} - G_k)$$

It is apparent that Δi_k will be negative if $G_k > \bar{G}$, and positive if $G_k < \bar{G}$. On this occasion the earthquake intensity increment

$$\Delta I_k = \Delta i_k / 0.2$$

i.e. intensity increment in 1 unit is equal to increment of damage index in each 0.2 .

Having the ΔI_k value, the modified seismic risk probability of exceeding a specific intensity level once in 100 years for given site condition

$$p(\hat{I} > I)_{100\ years} = 1 - (F_{\hat{I}}(I)_{1\ year})^{100}$$
$$= 1 - (1 - \sum_{i=1}^{n} p_i (\hat{I} > I | E_i) V_i)^{100}$$

can be obtained directly in the figure, where $F_{\hat{I}}(I)$ — cumulative distribution function of intensity; V_i — annual mean occurrence rate of earthquakes with $M \geqslant M_o$ in source i; E_i — the occurrence of an earthquake with $M \geqslant M_o$ in source i; n — total number of earthquake sources. It is generally recognized that the basic intensity in China means the reasonably expected maximum average intensity in a given region of average site condition for a relative long period, says 100 years, and the lifetime of the structures is also 100 years or so. So that the 100 years are chosen for standard interval. Of course, the modified risk probability curve is not parallel to the original one, it might be defined with reference 3., i.e. to move ΔI_k at 10^{-2} probability level and 2 ΔI_k at 10^{-4} level (fig.2). The results of A.S. Kiremedjien and H.C. Shah (Ref.4) show that the peak ground acceleration at 10^{-4} probability level is 4 times more than that at 10^{-2} level, it means that the intensity increment is 2. Strictly speaking, it is doubtful that risk curve modification can be determinated by only two points at 10^{-2} and 10^{-4} levels, but it is complete acceptable when the original probability curve is straight and smooth enough. This is more approximate to actual state in comparison with whole parallel modification proposed by R.V. Whitman et al (Ref.5).

Mentioned above indicates that the risk probability curve modification by means of ASM of soil is very simply, its accuracy depends on ξ and modified amplitude for each probability levels. The accuracy of modification should be improved with cumulation of statistical data in future. The proposed method enables all other effect factors to be incorporated into modification and is useful of utilizing historical information for microzonation purpose, particularly in a scarcity of instrumental data.

BUILDING DAMAGE EVALUATION

The central problem of building damage evaluation is how to determine the elements of damage probability matrix and loss probability matrix, latter is usually expressed in terms of ratio of the cost of repairing the damage to the replacement cost of buildings, such approach is rather convenient if the actual loss cost is given. Except for statistical data obtained in post-earthquake inspection the elements of damage probability matrix can also be expressed in terms of structural response parameters (such as interstory drift, ductility factor etc.) by theoritical computation.

The relation of average damage probability to earthquake intensity for different kind of buildings is proposed such as by Sauter and Shah (Ref.6). The data of loss probability matrix are even less in references. As an example both matrices for brick-masonry building are cited below (Ref. 7) (Ref.8).

Loss and damage matrices for multi-story brick buildings

Tab.1.

damage degree k.	damage state	$p(\text{Loss} \mid DR_k)$ (%)	$p(DR_k \mid \hat{I}_j)$ (%)					
			VI	VII	VIII	IX	X	XI
1	none	0	52.9	41.4	12.2	1.4	0.4	0.3
2	light	1 - 5	32.8	27.7	18.9	10.1	10.5	1.6
3	minor	7.5 - 15	11.8	18.5	34.5	28.9	9.2	5.6
4	heavy	18 - 25	2.4	11.2	25.9	37.3	20.4	11.5
5	partial collapse	35 - 60	0	1.1	7.5	11.0	16.4	11.9
6	total collapse	60 - 100	0	0	1.0	11.3	43.1	69.1

When some added risk reduction measures are adopted, the building damage probability will be able to reduce from $p(DR_k|I_j)$ to $p'(DR_k|I_j)$ depending on effectiveness of measures, as proposed by Vanmarcke (Ref. 9)(Ref.10) it leads to

$$p'(DR_k|\hat{I}_j) = p(DR_k|\hat{I}_j)(1-r)$$

where r — a scale of risk reduction effectiveness of the added risk reduction measures, it might be determined from model test, theoritical analysis or response measurement under actual earthquakes. An ineffective scale is characterized by $r = o$ which implies no change in the risk, i.e. $p'(DR_k|I_j) = p(DR_k|I_j)$. The value $r = 1$ indicates complete effectiveness, i.e. the risk is eliminated. ($p'(DR_k|I_j) = o$). Therefore the economic benefit of risk reduction measures is

$$B = p(\mathrm{Loss}|DR_k)\,p(DR_k|\hat{I}_j)\,p(\hat{I}_j)\ (1 - (1 - r))$$

$$= p(\mathrm{Loss}|DR_k)\,p(DR_k|\hat{I}_j)\,p(\hat{I}_j)\,r$$

BENEFIT-COST ANALYSIS

For earthquake engineering purpose the benefit-cost analysis can be attributed to following (Ref.11):

(1) Objective function: the total expected cost, i.e. the sum of added investment for risk reduction measures as well as potential loss due to earthquake should be minimized.

$$\Delta c + p(\mathrm{Loss}|DR_k)\,p(DR_k|\hat{I}_j)\,p(\hat{I}_j)\ (1 - r) = \mathrm{min.}$$

where Δc — the ratio of added investment to first cost;

(2) constraint conditions:

A. budget constraint condition: the economic benefit must be great than the ratio of added investment to first cost.

$$p(\mathrm{Loss}|DR_k)\,p(DR_k|\hat{I}_j)\,p(\hat{I}_j)\,r > \Delta c$$

or Δc must be less than maximum added investment available.

B. acceptable probability constraint condition: the probability in the case of added risk reduction measures adopted should not be exceeded the acceptable probability, i.e.

$$p(\mathrm{Loss}) < p_{\mathrm{accept}}.$$

For further detailed analysis the present value (or discount) must be taken into consideration. In this case mentioned above constraint conditions should be substituted by following:

(1) Net present value (NPV) for 100 years

$$\mathrm{NPV} = \sum_{t=1}^{100} p(\mathrm{LOSS}|DR_k)\,p(DR_k|\hat{I}_j)\,p(\hat{I}_j)\ r\ (1 + \theta)^{-t} - \Delta c$$

where θ — present value rate, the economically effective of added risk reduction measures is acceptable and appropriate if NPV > o.

(2) Internal rate of return (IRR)

$$NPV = \sum_{t=1}^{100} p(Loss|DR_k)\, p(DR_k|\hat{I}_j)\, p(\hat{I}_j)\, (1+IRR)^{-t} - \Delta c = 0$$

where present value rate θ = IRR.

In general case the added risk reduction measures can be acceptable only for IRR great than social present value rate (8-15%). There is not a identical present value rate in China now, so economic effectiveness evaluation by using IRR seems available.

For a set of investment alternatives the optimum alternative S^* might be obtained by minimum of expected cost of objective function i.e.

$$NPV(S^*) = \min_{s} \sum_{t=1}^{100} p(Loss|DR_k)\, p(DR_k|\hat{I}_j)\, p(\hat{I}_j)\, (1-r_s)\, (1+\theta)^{-t} + \Delta C_s$$

Of course, S includes "do nothing alternative" (i.e. r_s=o). The engineering decision of risk reduction requires an quantitative analysis of the balance between cost and the benefit of risk reduction.

CONCLUSIONS

The proposed in this study modification of site effects on earthquake risk probability with average shear modulus of soils is quite simple for application to microzonation purpose, it can incorporate effect of added risk reduction measures on damage probability matrix or loss propability matrix into building damage evaluation. Economic estimate of risk reduction measures by benefit-cost analysis should be expressed by an present value rate over time. The important task now is to establish data-base which is suitable to chinese specifics related to type of buildings, design level, measures effectiveness, average loss statistics, safety criterion etc. A detailed development being conducted at the present time will be presented later.

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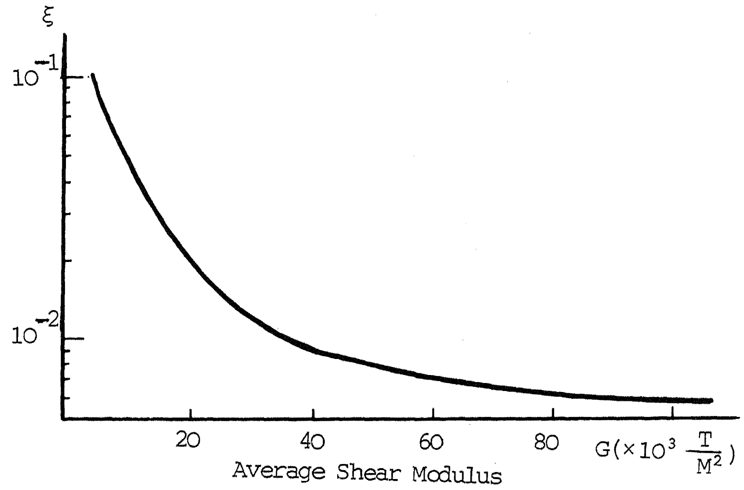

fig. 1.

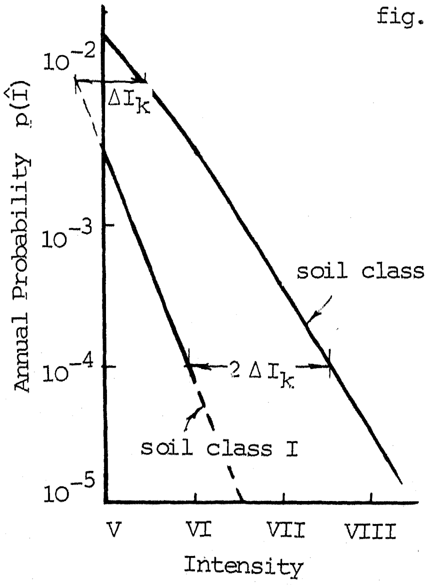

fig. 2.