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A UNIFIED CHAIN MODEL FOR ASSESSING AREAL-TO-HOUSEHOLD SEISMIC RISK POTENTIALS AS EMPHASIZED ON DISASTER SEQUENCES

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SUMMARY

This paper introduces a unified model by which seismic risk potentials of varous social bodies, either in administrative or household unit, can be assessed as emphasized on disaster sequences, and aims at applying actually to the assessments of all the prefectures in Japan and some hundreds of households in a core city in Central Japan. The results obtained by this method can give us basic materials for the prior and optimal earthquake protection plannings from regional to family levels.

INTRODUCTION

In spite of recent development of seismic risk evaluation techniques, no much consideration has been paid to sequential disaster events in an earthquake. Indeed, an earthquake produces not only direct damage to properties and instantaneous casualties, but also causes big fires which induce additional losses of properties and lives, and, its effects often become serious with significant social and economic deterioration. This requires a synthetic study in taking into account causal phenomena in an earthquake.

An attempt to respond to such demand was made in this study. The basic idea is that the direct-to-indirect earthquake disasters are determined uniquely by the severity of the seismic input in coupled with the environmental (natural, physical and socio-economic) characteristics of a social body suffering an earthquake. On this point, a new model composed of a set of sequential equations was first constructed in which the major part of causal aspects of earthquake disasters can be framed. Then, this model was implemented so as to be good for computer-aided processing. Instantiated as for the areal assessment was all the 47 prefectures in Japan. The evaluation of seismic risk potentials in a household level, as for the smallest social unit, was also made by use of the similar scheme of disaster chain model.

DISASTER CHAIN MODEL

Assume that "earthquake disasters" can be divided into m kinds of sequential aspects by their generation patterns, and serial and specific features; expressed as $y(i)$ $(i=1, 2,\cdots\cdots,m)$. In correspondence, define a receiver body - whatever it is - in terms of "characteristic variables" which act as controlling factors on earthquake disaster aspects and write them as $x(i)$ $(i=1, 2,\cdots,m)$. Also assume that the severity, S, of seismic input motion is described by a physical parameter as seismic intensity. The problem is how to build a functional relation among $[y(i), x(i)$ and $S]$. If we denote S, $y(i)$ and $x(i)$ respectively as the INPUT, OUTPUT and RECEIVER variables, a system structure is produced as shown schematically in Fig. 1.

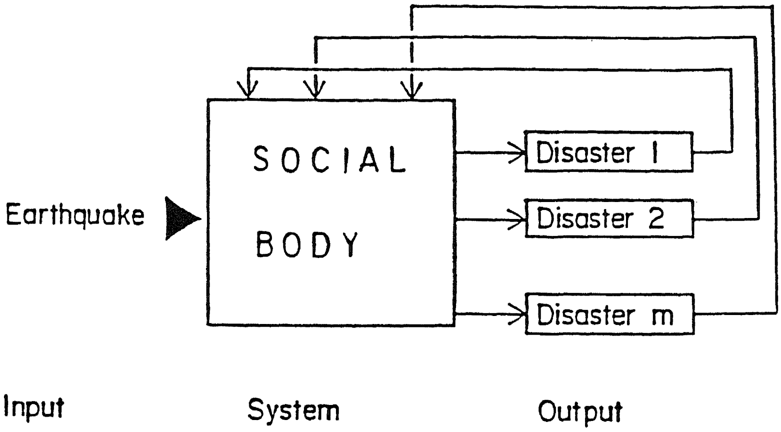

Fig. 1 Schematic diagram of a causal disaster chain model.

A general functional relation for this system would be

$$[y(1), y(2),\cdots,y(m)]) = f[\ S;\ x(1), x(2),\cdots,x(m)] \qquad (1).$$

The simplest way to embody this formal equation is to introduce a linear relation between $x(i)$ and $y(i)$. Recalling the field evidence that disaster aspects are mostly causal and progress one directionally, Eq (1) can be simplified as

$$y(i) = a(i)x(i)+[b(0)S+b(1)x(1)+\cdots\cdots+b(i-1)y(i-1)] \qquad (2).$$

This equation suggests that the i-th disaster aspect, $y(i)$, is expressed as a linear combination of S with $(i-1)$ kinds of individual disaster aspects of $y(i)$ $(i=1, 2,\cdots,i-1)$ and the i-th characteristic variable $x(i)$. Therefore, if there is a way to determine the characteristic variables $x(i)$, and to estimate all the coefficients in Eq (2) one can compare all the disaster aspects of $y(i)$, having S as a parameter. The unknown coefficients in Eq(2) are somehow determined in account of field experiences of disaster aspects in past great earthquakes. Characteristic variables, $x(i)$, are determined by a summation of numbers of normarized environmental (natural and social) indicators for all the receiver bodies under consideration, for which existing statistical data sets are useful.

APPLICATIONS

Seismic Risk Potentials for 47 Prefectures in Japan Considered in this application are 9 disaster aspects. Those are listed in Table 1, with corresponding 9 characteristic variables which are evaluated by a summation of natural and social indicaters normarized by the denominators such as population or area in a given region.

Table 1 List of EQ disaster aspects and regional characteristics

EQ disaster aspects		Reg. characteristics
Major	Sequential	
Primary	Y1 damage to grounds	X1 natural conditions
	Y2 damage to houses	X2 housing conditions
	Y3 damage to life lines	X3 supply systems
	Y4 damage to facilities	X4 industrial activity
Secondary	Y5 fire and diffusion	X5 social background
	Y6 casualties	X6 welfare and rescue
Tertiary	Y7 social disruption	X7 social life
	Y8 reg. activity down	X8 transport etc
	Y9 extra-regional impacts	X9 core functionality

If one assumes a plausible disaster model with a series-parallel coupled chains as illustrated in Fig. 2,

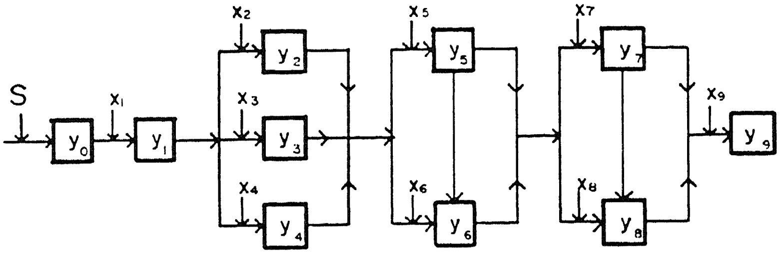

Fig. 2 Disaster chain model used for assessment.

Eq(2) can be reduced to

$y(0) = 0.25[x(1)+S]$, $y(1)= 0.25[x(1)+3y(1)]$,

$y(2) = 0.25[x(2)+3y(1)]$, $y(3) = 0.25[x(3)+3y(1)]$,

$y(4) = 0.25[x(4)+3y(1)]$, $y(5) = 0.05[5x(5)+6y(2)+3y(3)+6y(4)]$,

$y(6) = 0.025[10x(6)+6y(2)+3y(3)+6y(4)+15y(5)]$ (3),

$y(7) = 0.25[2x(7)+3y(5)+3y(6)]$, $y(8) = 0.25[x(8)+y(5)+y(6)+y(7)]$,

$y(9) = 0.125[2x(9)+3y(7)+3y(8)]$,

where seismic input parameter, S, is expressed some consideration as

$$4.5(I(JMA)-4.75)^{1.25}.$$

A computation provides the comparative understanding of regional seismic risk potentials in Japan with emphasis on disaster sequences. Characteristic features for all the prefectures in Japan are shown in Fig. 3, in which earthquake risk potentials at a seismic input equivalent to the 1923 Kanto earthquake(VI^- in JMA scale, equivalently IX in MSK scale) are summarized into primary, secondary and tertiary disasters and arranged in bar graphs in order of prefectures from north to south.

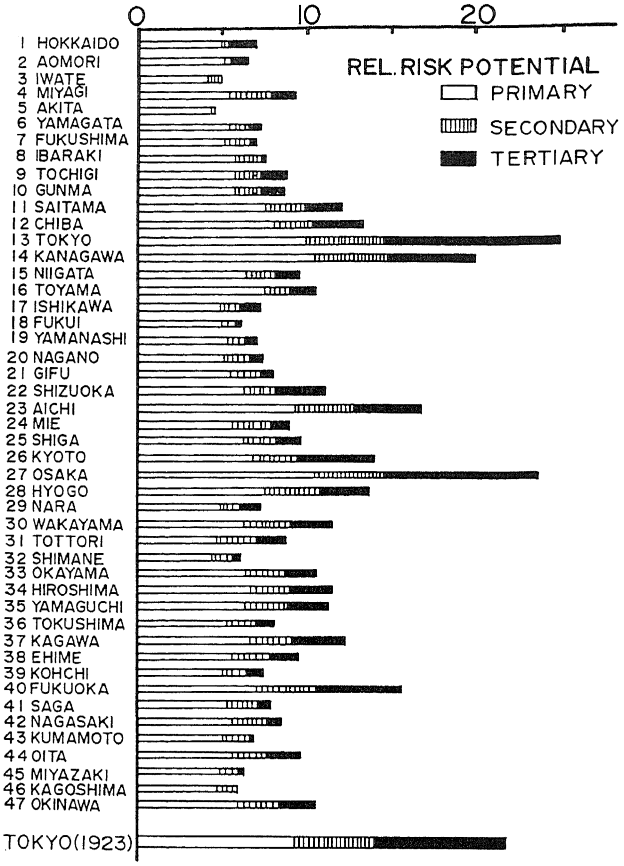

Fig. 3 Seismic risk potentials for all the prefectures in Japan.

The bar graph at the bottom depicts the 1923 Tokyo earthquake for comparison. This figure confirms that in several prefectures centered around Tokyo, Nagoya and Osaka — the major Japanese cities — not only are all the risk potentials large, but they also are dominant especially those for tertiary disasters. The result simply can be said as all the seismic risk potentials from direct to indirect are, even under an equal seismic input, distinctive according to prefecture in reflecting the environmental background. Therefore, regional disaster mitigation programs should be prepared optimally in consideration of such sequential aspects caused by an earthquake. Details of processings and results are seen in Ref. 1.

Earthquake Safety in Household Unit By the similar approach a simple and effective method for making a diagnosis of the earthquake safety in a household unit has been developed, for finding out the optimal earthquake preparedness in the family level. A case study was made in a size of 800 households from different environmental block areas in Kawasaki City, Central Japan.

First, the essential earthquake disaster items were rearranged on a coordinate system with time and distance axes, and the assessing earthquake risks are selected not only for the instantaneous disasters of structural and other physical damages and human casualties but also for the succeeding short-and-long term impacts. In this case, however, the characteristic data are to be collected mostly by an actual survey to the respective households, and the questionnaire survey was found most convenient.

A causal chain model was also introduced so as to explain the sequential changes of earthquake disasters from the early to later stages in relation with corresponding numbers of household characteristic variables. As listed in Table 2 it has 11 disaster aspects and orresponding 11 household characteristics. The causal chain character is somewhat complex compared to the one shown in Fig. 2.

Table 2 List of EQ disaster aspects and household characteristics

EQ disaster aspects		Household characteristics	
Y1	damage to grounds	X1	natural conditions
Y2	damage to dwellings	X2	structural conditions
Y3	indoor damages	X3	indoor space
Y4	damage in surrounding	X4	outdoor space
Y5	outbreak of fire	X5	fire prevention
Y6	immediate casualties	X6	family constituent
Y7	spread of fires	X7	outdoor conditions
Y8	hindrance to evacuation	X8	surrounding conditions
Y9	succeeding casualties	X9	livind standards
Y10	lowering of living level (short-term)	X10	preparedness
Y11	lowering of living level (long-term)	X11	housing economy

The disaster chain model in this case can be written as

$$y(1)= x(1), \qquad y(2) = 0.5[x(2)+y(1)], \qquad y(3) = 0.5[x(3)+y(1)],$$

$$y(4) = 0.5[x(4)+y(1)], \qquad y(5) = 0.167[3x(5)+y(2)+y(3)+y(4)],$$

$$y(6) = 0.125[4x(6)+y(2)+y(3)+y(4)+y(5)], \qquad y(7) = 0.5[x(7)+y(5)],$$

$$y(8) = 0.25[2x(8)+y(6)+y(7)], \qquad y(9) = 0.25[2x(9)+y(7)+y(8)],$$

$$y(10) = 0.167[3x(10)+y(7)+y(8)+y(9)], \qquad (3),$$

$$y(11) = 0.25[2x(10)+y(7)+y(8)+y(9)],$$

here the seismic input term is skipped in a tentative assumption that it is as large as VI or greater.

Based on this model and the household characteristic data by the questionnaire survey, the diagnostic analysis per household was conducted first for the individual safety to each of disaster aspects and then for the total earthquake safety as a sum. The final diagnosis which classifies the total earthquake safety of a household into 3-5 grades from "safe" to "risky" under the seismic intensity around VI or greater in JMA scale was made accordingly, and the results with some guidelines for improving the family level earthquake preparedness were sent back to the surveyed households. Fig. 4 shows 5 major patterns in the household seismic safety.

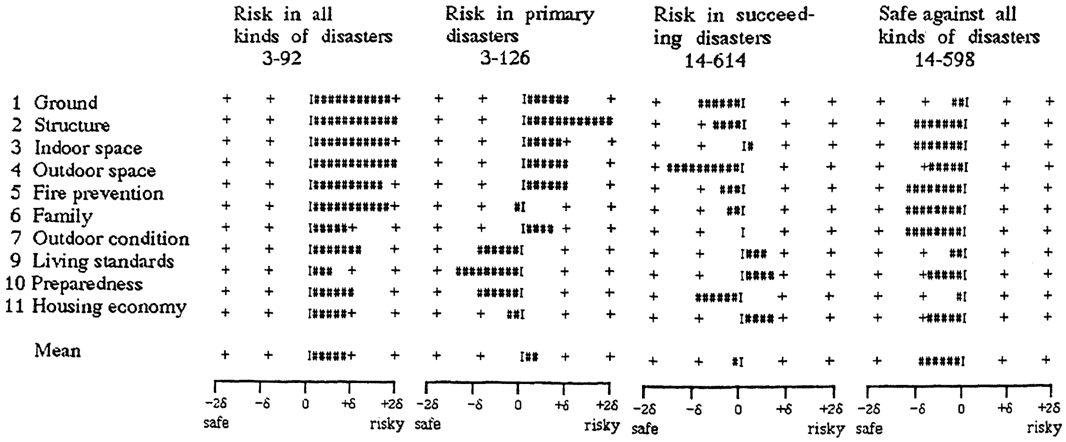

Fig. 4 Typical patterns of earthquake safety in households.

A comparison made clear that the aerial changes of the earthquake safety averaged per block are in good correlation with those of land use and other natural and social characteristics and that this is effective as for the first-stage screening method. More details from the field survey to the diagnosing processes are described in Refs. 2 and 3.

CONCLUDING REMARKS

It is summarized that the new model is effective for a systematic understanding of the seimic risk potentials of any social bodies and therefore is valid in use for the comprehensive earthquake preparedness planning from regional to family levels. Applications to other social bodies as municipalties, urban streets (Ref. 4) and so forth have been counducted after some modification in integration of disaster aspects. The methodology is sure to have wide applicablity to a comparative study of seismic risk potentials among earthquake-prone countries as well.

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