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A METHODOLOGY FOR SEISMIC RISK ASSESSMENT OF STREETS AND SURROUNDINGS IN URBAN AREA

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SUMMARY

By an assumption that the disasters in and along the urban streets in an earthquake are the compound results of a series of events in causal relation, a chain model of 11 configuration-specific disasters was first proposed, by which model the probable features of disaster aspects can be described in response to seismic input. Then a pilot test was conducted getting relevant data in a variety of streets in Kawasaki city, Central Japan. Namely, seismic risk potentials of all the 11 disaster aspects were calculated and compared among the surveyed streets. Through this survey we could see how preceeding disasters trigger those subsequent, and recognize the effectiveness as a tool for assessing seismic risk potentials for urban streets.

INTRODUCTION

During and after a destructive earthquake an urban street provides a special working zone through which most of immediate counter-measures and emergency processes are activated. Despite the recent advancement of the methodology of the seismic risk assessment, few studies have been devoted to the study of streets, and yet most of them have been confined within the scope of a single aspect of street disasters in an earthquake. This is not only due to the linear extention of a street configuration which does not fit in the conventional microzoning methods, but also due to the difficulty in evaluation since its emergency functions mainly correspond to the post-earthquake state of affairs.

Assuming that street disasters in an earthquake are ensembles of a series of events in causal relation, it is necessary to accept that aspects of disasters are unseparable from one to another. The needs for a methodology therefore should be stressed for integrating all the single disaster aspects in consideration of the art of earthquake performance.

In contrst to the significant development in the technology for estimating seismic damage to structures many problems still have been intact for functional damage and succeeding disasters. This requires an urgent integration of research results and technological information on the latter events. Based on such foundamental considerations stimulated by current demands a disaster chain model has been developed, with which we could simulate the major part of causal and sequential characters of disaster aspects from direct to indirect in response to seismic input.

FORMULATION OF THE PROBLEM

Conceptual model Past field data show that earthquake disasters of a street consist of many kinds of sequential aspects which can be identified by their generation patterns. To clarify their generation patterns, we arranged probable earthquake disaster items on a coordinate system with time and distance axes as shown in Fig.1. This figure illustrates how an individual disaster triggers others and how their aspects change, as time goes by, with distances from the center of a street; it should be pointed out that the multiplicity and degree of damage to which a street may suffer depends on aseismic strength of the street striken by the earthquake, as well as severity of the seismic input motion.

Write disaster aspects numbered in the order of sequence as

$$Yi\ (i=1,\cdots,11).$$

In correspondence, we define street characteristics which act as controlling factors on earthquake disasters and write their cmponent variables as

$$Xi\ (i=1,\cdots,11).$$

And also write severity of the seismic input motion as S which can be described as a function of seismic intensity. Assuming that the seismic risk of individual disaster aspects Yi can be determined uniquely by the seismic severity S, as well as the relevent street characteristic Xi, the seismic risks can be expressed consecutively in the order of appearance in Fig.1 as

$$\begin{array}{ll} Y1=f1(X1,S) & Y7=f7(X7,Y3,Y4,Y5) \\ Y2=f2(X2,Y1) & Y8=f8(X8,Y1,Y5) \\ Y3=f3(X3,Y1) & Y9=f9(X9,Y8) \\ Y4=f4(X4,Y1) & Y10=f10(X10,Y6,Y,9) \\ Y5=f5(X5,Y1) & Y11=f11(X11,Y10) \\ Y6=f6(X6,Y2,Y3,Y4,Y5). & \end{array} \qquad (1)$$

Street characteristics are to be derived by a field survey along the street we want to assess. If the seismic severity be given in Eq(1), we can evaluate all the disaster aspects of Yi recursively, and the problem is reduced to functional constructions of relaions among (S, Yi and Xi).

Here we should recall that the depths of our knowledge of these individual disaster aspects applicable to this study differ ; some aspects being described qualitatively as in the form of a function but others only qualitatively. The model is desired to be framed flexible enough to hold the existing results irrespective of the depths of our knowledge.

Related studies show us that a disaster aspect can be divided again into a certain number of sub-groups by identifying the damaging modes. For instance, there are two ways of damaging patterns for a building ; one being directly due to the failure of the grounds it stands on, the other due to the ground shaking. The seismic risk of buildings therefore can be obtained as the sum of the seismic risks calculated for those damaging modes. Table 1 lists probable damaging modes of disaster aspects and the corresponding controlling factors.

If we define the seismic damage function of the jth sub-group (damaging mode) of the ith disaster aspect using mi_j, and Eq(1) being expressed as the sum of corresponding seismic damage functions and if introduce the connecting function of max() which is equivalent to the maximun value among alternatives, we can rewrite Eq(1) as

$$
\begin{aligned}
&Y1=\max(m1_1(X1,S),m1_2(X1,S),m1_3(X1,S))\\
&Y2=m2_1(X2,M1_1,M1_2)\\
&Y3=\max(m3_1(X3,M1_1,M1_2),m3_2(X3,M1_3))\\
&Y4=m4_1(X4,M1_3)\\
&Y5=\max(m5_1(X5,M1_1,M1_2),m5_2(X5,M1_3))\\
&Y6=\max(m6_1(X6,Y2),m6_2(X6,Y3,Y4,Y5))\\
&Y7=m7_1(X7,Y3,Y4,Y5)\\
&Y8=m8_1(X8,M1_3,Y5)\\
&Y9=m9_1(X9,Y8)\\
&Y10=m10_1(X10,M6_1,M6_2,Y9)\\
&Y11=m11_1(X11,Y10)
\end{aligned}
\tag{2}
$$

where Mi_j denotes the calculated value of function mi_j. We can recursively obtain disaster aspects of Yi in the order of disaster sequences as seen in Fig.1.

Appropriate variables in Eq(2) depend on how we define their seismic damage functions. Such a hierarchical tree model of earthquake disasters can be expanded by deepening and broadening of our knowledge on disasters. In this study, for simplification, the model is confined to that of two-level structure.

Construction of the model in a computer-aided way   Seismic damage functions are determined by the following procedures.

1) If there have already been empirical functions applicable to this model, some of them should be adopted for use (Ref.1 for ground amplification ; Ref.2 for the risk of outbreak of fires, for example).

2) As for disaster aspects for which no empirical equation has been constructed yet, a tentative equation should be proposed, with which we attempt to describe disaster features.
  2-1) As for direct damage of which main factor is the severity of amplified ground motion, its construction of vulnerability function is straight forward. Figure 2 illustrates the vulnerability functions of buildings, degree of building damage by building type v.s. severity of ground shaking in terms of seismic intensity. This kind of functions should be constructed for every structural element of a street in referring to foundamental data (Ref.3, for example).
  2-2) For indirect damage which is triggered with the preceeding disaster aspects, the constructing seismic damage functions is not easy compared with the case for direct damage. Functions should be constructed with emphasis on their logical relations with regarded controlling factors.

From the reason that the above disaster chain model must in reality be developed in a computer-aided way, it was implemented as a prototype model of Expert System by use of a logic programing language, Prolog, because ;

(1) The causal and hierarchical structure of earthquake disasters and their seismic damage functions can be stored within a set of batabase which is separate from executing part of the program and therefore can be modified and maintained

easily.

(2) A logic programing language fits better in describing causal and hierarchical relations of disaster aspects than the conventional ones.

APPLICATION

Pilot test The above-stated methodology was applied to streets in Kawasaki city (Fig.3) of Central Japan, as a test field. Kawasaki was chosen because of its high seismicity, various types of soils and buildings and therefore of streets. Careful selection was made for 10 streets from downtown, commercial town, and uptown areas. The numbers of the street characteristic items listed in Table 1 were surveyed along the streets and were complemented with the background data from the city office.

Result A computational derivation for 11 disaster aspects was made for all the street segments with Eq(2) using the data derived from the survey, and some of results are shown in Fig.4 for the purpose of comparing the two typical streets.

STREET A This picture suggests us the unsafeness of this street in an earthquake: collapse of the block fence walls and fall of other architectural additions may block the street easily. The curve indicating the risk of hindrance to emergency services means the risk for blockage of this street. In the first stage the curve goes up almost in paralell with the curve indicating the risk of damage to the ground. This phase implies general deterioration of the road pavement. And then the next phase rises up steeply, reflecting the blockage because of the collapses of streetside constructions. Human casualties are rather low because of low population passing there.

STREET B This street seems really safe in contrast to STREET B. Although the risk of the construction collapses appears to be rather high, the other items seem to be kept very low because of considerable width of the street on the better ground condition.

Figure 5 illustrates the integrated seismic risk potentials for all the 10 surveyed streets, which are evaluated by a simple summation procedure. SREET A proves to be the riskiest and STREET B the safest.

In this manner each of seismic risk was compared both among disaster aspects and among the surveyed streets. Through this comparison we found that the changes of the earthquake safety from street to street are in good correlation with those of natural and environmental characteristics.

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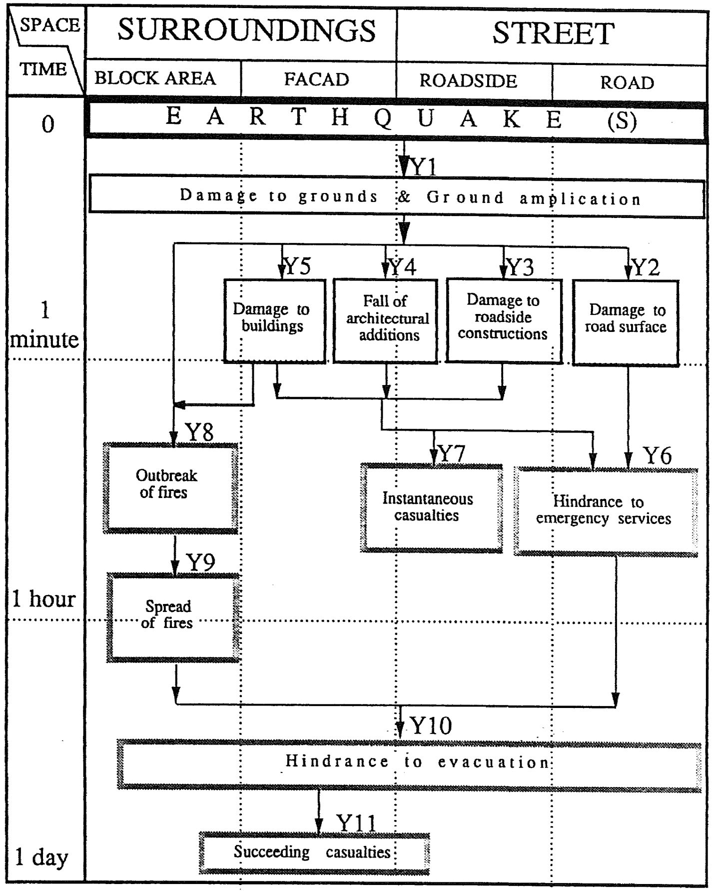

Fig. 1 Earthquake disaster sequences in time and space coordinates centered in a street.

Table 1 Classification of earthquake disasters, damaging modes, and associated affecting factors

EARTHQUAKE DISASTERS		CONTROLING FACTORS	
DISASTER ASPECT	DAMAGING MODE	PRECEEDING DISASTER ASPECTS	STREET CHARACTERISTICS
Damage to ground & Evil effect Y1	Ground failure M11	S Severity of seismic input motion	Geology X1
	Liquefaction M12		
	Ground amplification M13		
Damage to road surface Y2	Caused by ground failure M21	M11 M12	Classification of pavement X2
Damage to roadside constructions Y3	Caused by ground failure M31	M11 M12	Length of fence walls, retaining walls X3
	Caused by ground motion M32	M13	
Fall of objects from facad Y4	Caused by ground motion M41	M13	Windows, exterior walls of buildings, billboards, advertizing towers X4
Damage to buildings Y5	Caused by ground failure M51	M11 M12	Occupation ratio of buildings by structural type X5
	Caused by ground motion M52	M13	
Hindrance to emergency activities Y6	Caused by pavement failure M61	Y2	Width of street, traffic volume X6
	Caused by blockage of objects M62	Y3, Y4, Y5	
Instantaneous casualties Y7	Caused by falling objects M71	Y3, Y4, Y5	Sidewalk width, pedestrians X7
Outbreak of fires Y8	General fire M81	M13 Y5	Density of dwellings, fire sources X8
Spread of fires Y9	Fire of block area M91	Y8	Street width, flamable buildings X9
Hindrance to Evacuation Y10	Evacuation from conflagration M101	M61 M62 Y9	Distance from refuge place X11
Succeeding Casualties Y11	Caused by failure of evacuation M111	Y10	Human population density X12

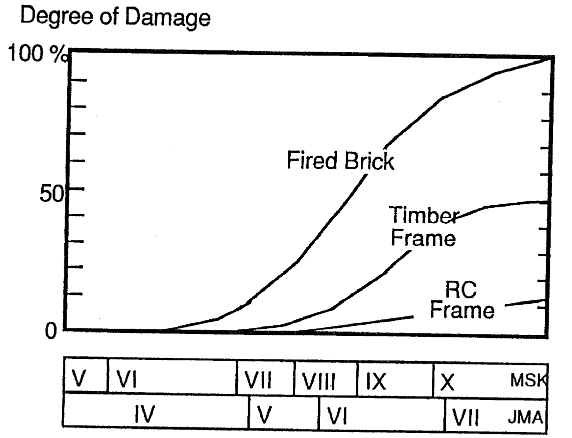

Fig. 2 Vulnerability curves for building types popular in Japan.

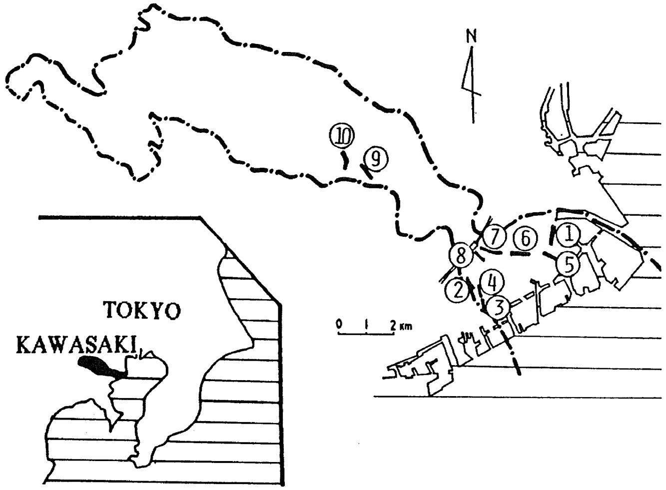

Fig. 3 Location map of surveyed 10 stree segments in Kawasaki city, Central Japan.

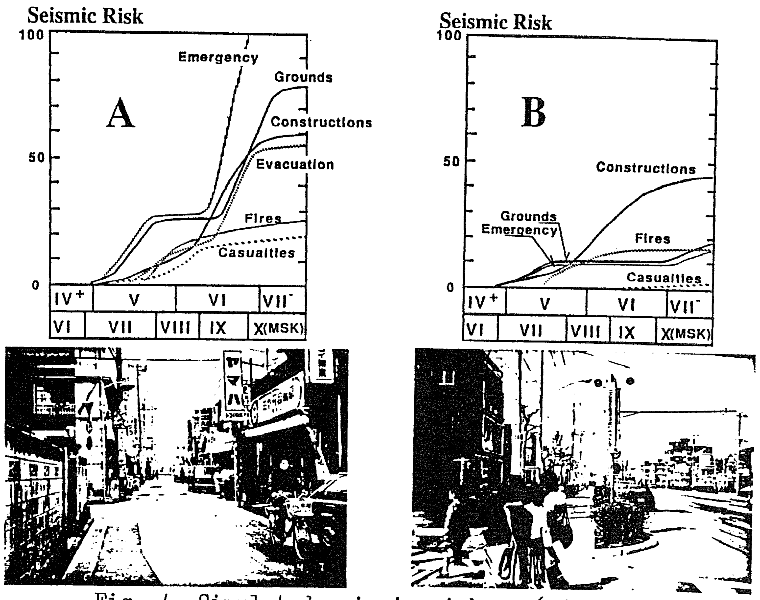

Fig. 4 Simulated seismic risk on 6 disaster items for two typical streets.

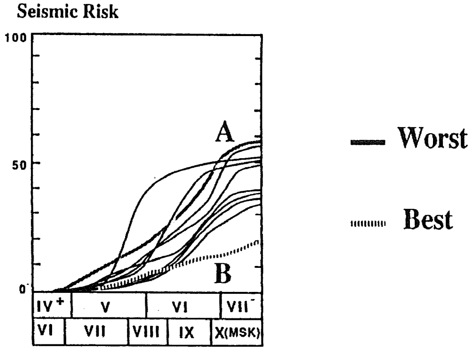

Fig. 5 Aggregated seismic risk potentials of 10 streets.