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An expert evaluation system for earthquake damage

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ABSTRACT: An expert knowledge based evaluation system for earthquake damage to city is outlined in this paper, including block diagram, effective factors and the network relationship among them, construction of data base and knowledge base, application of search technique and applied example. The system can be used to predict earthquake damage to building stock in a city, to evaluate casualties and property losses, to identify high risk building types and subareas, to give the potential damage and risk distribution of the whole city; besides, it can yet be used to decide the goal of earthquake disaster mitigation and to take into account its countermeasures.

1 INTRODUCTION

Earthquake damage eviluation in a city, which can provide an important base for improving the aseismic fortifying state, evaluating the losses, drawing up the earthquake resistance and disaster prevention programme, laying down the countermeasures for hazard reduction and emergency measure and insurance, has been widely developed in China. Based on the characteristics of the domain that the evaluation depends on the knowledge and experience of expert as well as a great amount of data and effective factors, the development of an expert knowledge based evaluation system could provide a good way in this domain.

According to the experience of earthquake damage in China, casualties and property losses during an earthquake are mainly due to the damage to and collapse of buildings, and the losses are much larger in city than in countryside, thus prediction damage to urban buildings is a key point in the earthquake damage evaluation. Do because of this, the expert system is developed and used first there.

A expert knowledge based system PDKSCB for predicting earthquake damage to existing building stocks and evaluating casualties and property losses in a city was constructed in 1987. From then on,the system has been used in various cities from small city of 80 thousand population to middle cities of 300 thousand population and also to big city of more than one million population, meanwhile, obtaining a large amount of data and experience knowledge, and further improved and extended.

2 OBJECT AND BLOCK DIAGRAM

The object of the system is to predict the earthquake damage to urban buildings, to evaluate the casualties and direct economic losses, to identity high risk subareas and building types, to decide the goal of disaster mitigation and its countermeasures. The block diagram of the system is shown in Figure 1. The system includes 3 subsystems, ie., building, man–economic and diagram subsystem. The following results can be obtained.

1. The predicted earthquake damage, casualties and economic losses in the whole city under given earthquake intensity 6, 7, 8, 9 and 10, respectively, or / and under complete probability of seismic hazard assessment in the next 50 or some years.
2. The predicted earthquake damage, casualties and economic losses of various subareas, and the identified high risk subareas.
3. The predicted earthquake damage, casualties and property losses of various types of building, and the identified high risk types.
4. The potential earthquake damage and risk distribution diagram in the whole city.
5. The possibility and condition of realization for the goal of disaster mitigation.

3 DATA AND DATA BASE

Collecting a large amount of data for predicting damage to existing buildings in a city and storing them up in a computer, the data base can be constructed directly or supported

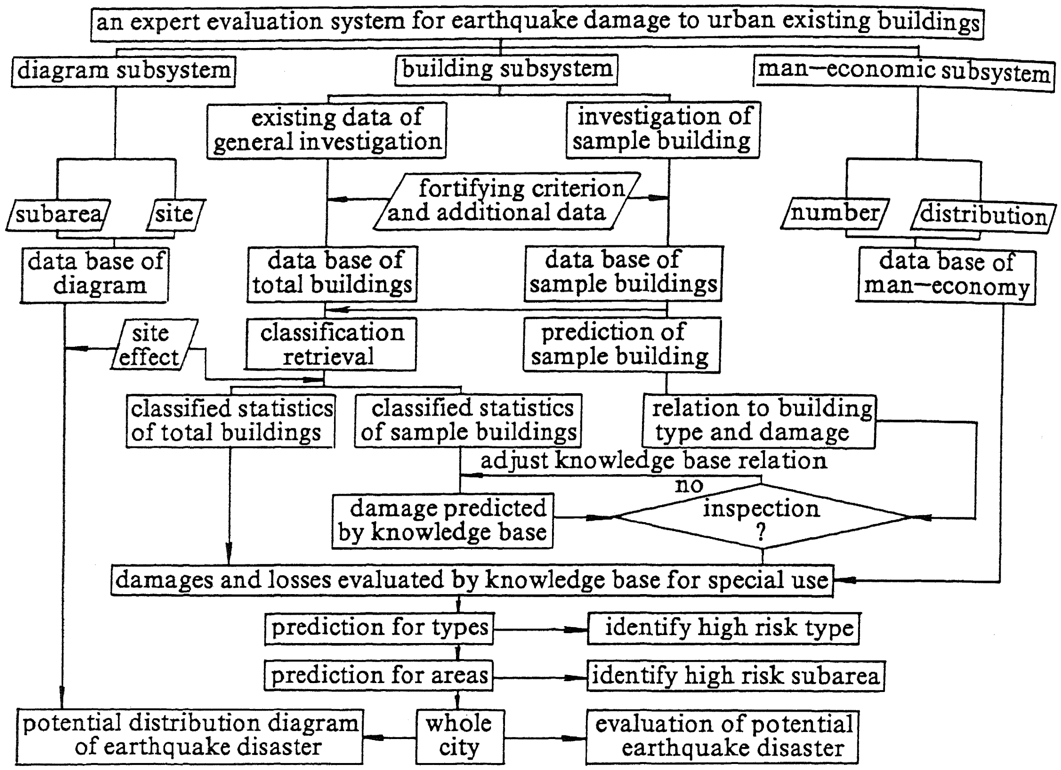

Figure 1. The block diagram of the expert evaluation system PDKSCB.

by knowledge base. Each data is represented by a character string with a definite length, a digit code or a numerical value. There are six basic data bases in the system .

1. Data base of buildings in the whole city;
2. Data base of sample buildings;
3. Data base of population in buildings;
4. Data base of property in building and value of building itself;
5. Data base of diagram;
6. Data base of site condition.

The existing data of general investigation and registration of building owners can be utilized for constructing data base, if it is necessary, investigation in site should be conducted.

The type of a building in the data base is represented by 5 items, ie., kind of building structure, amount of the story, construction age, building status quo and present use. There are 6 kinds of structure, 9 kinds of story, 5 kinds of age, 5 kinds of status quo and 8 kinds of present use. The type of building can be retrieved either by one—element or multi—elememts. There are 33 types according to one—element retrieval and 10800 types according to 5—elements retrieval, but most of them in the 5—elements retrieval are empty sets, generally, there are only about one thousand types of building in a middle or big city.

4 KNOWLEDGE BASES

The effective factors and their network relationship for evaluating earthquake hazard is shown in Figure 2, in which there are 5 effective factors to be considered, ie., earthquake effect, earthquake damage, economic losses, casualties and building importance. There are four major knowledge bases in this system.

1. Knowledge base for predicting damage to existing building. It is the basic and the largest knowledge base, in which the probability matrix of different damage degree under 6, 7, 8, 9, 10 earthquake intensity for 10080 types of building according to 5—elements retrieval is constructed. Damage degree is divided into 6 ranks, ie., basically intact, slightly damaged, moderately damaged, seriously damaged, partial collapse and total collapse.The six ranks damage degree represented by corresponding damage indices in Table 1.

2. Knowledge base for evaluating direct economic loss. The losses are related to the damage degree and the earthquake effect and they are also related to factors for evaluating both the property in building and that of building itself, such as floor area, structure, stories, age, status quo and present use .

3. Knowledge base for evaluating casualty.

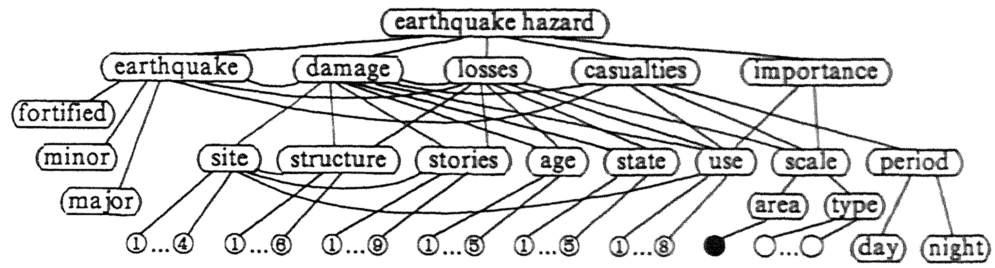

Figure 2. Effective factores and their network relationship.

Table 1. Relation of damage degree and damage index, casualty and economic loss.

Damage degree		basically intact	slightly damaged	moderately damaged	seriously damaged	partial collapes	total collapse
Damage index	region	[0–0.1]	(0.1–0.3]	(0.3–0.5]	(0.5–0.7]	(0.7–0.9]	(0.9–1.0]
	value*	0	0.2	0.4	0.6	0.8	1.0
Property loss of building (%)	region	[0–1]	(1–8]	(8–20]	(20–60]	(60–95]	(95–100]
	value	0.4**	3.8	12	36	82	100
Property loss in building (%)	region	0	(0–1]	(1–5]	(5–20]	(20–50]	(50–100]
	value	0	0.2	2.2	10.5	32	75
Injury (%)	region	0	(0–0.02]	(0.02–0.1]	(0.1–3]	(3–30]	(30–70]
	value	0	0.006	0.05	0.5	10	50
Death (%)	region	0	0	(0–0.01]	(0.01–1]	(1–10]	(10–30]
	value	0	0	0.001	0.15	3	20

* Represented value. ** Damage index is equal to zero when degree is intact.

The casualties are related to the damage degree and earthquake intensity and also related to the scale (floor area and type) of the building and occurred time (day or night).

The casualties or economic losses under given intensiy i are calculated according to the following formula, thus

$$L_i = \sum_{j=1}^{6} P(D)_{ij}\, l_j\, N m_i \qquad (1)$$

where i is the intensity, and j is the damage degree, $N$is the population or the total value of property,$P(D)_{ij}$ is the predicting damage probability for the degree $j$under intensity i, l_j is the casualties ratio or economic losses ratio when predicting damage degree belong to j (see Table 1), m_i is the coefficient of cause disaster under intensity i.

The casualties or economic losses under complete probability of seismic hazard assessment in the next 50 years is evaluated as

$$L_{50} = \sum_{i=6}^{10} \{P(\hat{I} > i)_{50} - P[\hat{I} > (i+1)]_{50}\} L_i \qquad (2)$$

where $P(\hat{I} > 1)_{50}$ and $P[\hat{I} > (i+1)]_{50}$ are the exceeding probability in the next 50 years, when $\hat{I} > i$ and $\hat{I} > (i+1)$.

4. Knowledge base for site condition. Some new knowledge bases in specific site condition can be constructed making use of the following formula, thus

$$P(D)_{ijs} = a_i P(D)_{(i-1)j} + b_i P(D)_{ij} + c_i P(D)_{(i+1)j} \qquad (3)$$

where s is the specific site, a_i, b_i and c_i are the coefficient of site condition and the sum should be equal to 1,if the effect of site exceed 1 grade for intensity, $(i \pm 1)$could be instead of $(i \pm 2)$or $(i \pm 3)$in the formula(3).

The knowledge base for predicting damage is constructed according to earthquake damage data, aseismic behavior analysis and experts' experience. Because of considerable difference in aseismic capacity of same type of building in different cities, the key step to construct the knowledge base for special use is consistent inspection. Its means to let the earthquake damage to building samples predicted by the knowledge base for special use be identical to that predicted as building unit. It is controled by the Hamming distance in two fuzzy sets, the distance of total deviation is limited in 0.02, the distance of point deviation is required to be less than 0.05, ie., 1 / 10 and 1 / 4 rank of damage degree, respectively. The distances can be expressed as follows:

$$d(A,B)=\frac{1}{5n}\sum_{c=1}^{n}\sum_{l=6}^{10}\left|I_A(X_c)_l-I_B(X_c)_l\right| \quad (4)$$

$$d_{c,l}=\left|I_A(X_c)_l-I_B(X_c)_l\right| \quad (5)$$

where $d(A,B)$ and $d_{c,l}$ are the distance of total and point deviation, n is the number of type of building samples, $I_A(X_c)_l$ and $I_B(X_c)_l$ are the predicting damage indices of X_c type buildings according to one–element retrieval statistics that predicted by current method one by one and by knowledge base, respectively.

5 SEARCH OF HIGH RISK

To evaluate the potential earthquake risk, a synthetic decision analysis is conducted in the system based on 3 elements, ie., building damage, casualties and property losses. Each of the 3 elements is represented by 3 risk factors, ie., damage index, vulnerability index and easy damage probability for building damage; the number, rate and density for both the casualties and property losses. The high risk subarea is searched according to 9 undimensional risk factors which is obtained by dividing the 9 factors that have different dimension by their corresponding mean value of the whole city .

Identification of high risk type of building would be conducted in two steps, since the amount of building types is too many. The first step is searching vulnerability index reached threshold value, the search is conducted according to the 9 risk factors of the 3 elements as the second step.

6 APPLIED EXAMPLE

Output of the system is a series of table in fixed form and can also represented by colour figure. Take Taiyuan city as an example, the predicted earthquake damage matrix to existing buildings is shown in Table 2, the total results of predicted damage and losses are in Table 3, there are 3 high risk subareas and 7 high risk building types searched.

From developing prediction in Taiyuan city, we can see for the goal of disaster mitigation up to 2000, in which China will make effort to reduce disaster by 30%, the goal of building damage mitigation can be reached by efforts, the casualties can be reduced by about 50%,

Table 2. The damage probability (%) matrix to buildings in Taiyuan city.

Earthquake intensity	6	7	8	9	10
Basically intact	79.7	26.0	6.8	0.4	0.0
Slightly damaged	15.9	39.6	23.1	5.6	0.3
Moderately damaged	3.5	27.1	40.4	23.6	4.3
Seriously damaged	0.8	6.1	23.6	43.8	23.6
Partial collapse	0.1	1.1	4.8	19.5	30.3
Total collapse	0.0	0.3	1.3	7.2	41.7

Note: Total floor area 41049151 m^2.

Table 3. The predicted damage & evaluated loss (million yuan)& casualty(people)in Taiyuan city.

Intensity	6	7	8	9	10
Damage index	.052	.235	.401	.596	.818
Loss of building	31	352	1001	2568	5209
Loss in building	13	150	618	2063	6418
Total losses	45	502	1619	4631	11628
Injury on day	51	924	6710	51791	306201
Death on day	11	281	2129	17512	115600
Casualty on day	62	1205	8839	69303	421801
Injury at night	73	1404	9307	63769	360158
Death at night	17	444	3088	21751	135629
Casualty at night	90	1848	12395	85520	495787

but the goal of economic losses reduction is difficult to be reached if only by engineering measures according to the current aseismic fortifying standard and method. For losses reduction the sociology countermeasures and new aseismic method must be developed.

7 CONCLUSION

The system PDKSCB has been developed and used widely in China, as used in Sanmenxia city Henan province, Xiamen city Fujian province, Zhanjiang city Guangdong province, Taiyuan city Shanxi province and Tieling city Liaoning province. It has proved in practice that the inference is reliable, the results are right and the decision making is efficient.

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