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Study on the Evaluation Model of Seismic Secondary Fire Disasters Based on AHP

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Abstract

In the paper, the seismic secondary fire estimation model for urban housing estates was established in China. In model, some of influence factors (such as the seismic damages of engineering structures, the influences of buildings density, population density, possible catching- fire density, structure types, fire-fighting facilities, fire-fighting arriving time , road density, etc.) were considered. The quantitative analysis of those factors was carried out by the analytical hierarchy process (AHP). The secondary fire hazard grades of urban areas are given in the light of the advanced gradation criterion. Finally, the method is applied to a typical medium-sized city for evaluating the hazard areas of seismic secondary fire disasters on the basis of GIS. It can provide a workable evaluation method for urban secondary fire by using this model. It is also conductive to the urban daily fire safety.

Keywords: the analytical hierarchy process (AHP), seismic secondary fire, quantitative analysis, high hazard area, GIS

1. Introduction

The huge losses of the people's life and property are caused by the earthquake and induced secondary disasters. It is an important to restrict development of the harmonious social. The frequency of secondary fire disaster is the highest and the loss of the one is the biggest in the all seismic secondary disasters. The well-known earthquakes include the Great San Francisco Earthquake (1906, M_s8.3), the Great Kanto Earthquake(1923,M_s7.9),the Kobe Earthquake(1995, M_s7.2)) and so on. Therefore, the secondary fires aren't to be neglected after the destructive earthquake in the modern metropolis.

The seismic secondary fires are uncertainty events. Therefore, it is very difficult to be quantitative studied. The analytical hierarchy process(AHP) was put forward in 70's in last century by L. Saaty. It is a kind of combining together qualitative and quantitative analytical method. The AHP generally can be divided into three steps: to build a multi-layer structure model according to the correlation factors and these subordinations, to quantify the opposite importance of each layer factors according to subjective judgment of the objective phenomenon, to determine the importance order of factors and to carry on a consistency examination.

The AHP method is a practical method for studying on the seismic secondary fires. In the method, the cases of happened seismic fires are analyzed and the factors induced fires are refined. The synthetic evaluation model of fires hazard district is given at last.

In this paper, the natural administration districts are treated as evaluation object in the city. The seismic damage synthetic evaluation models of structures, communications system and water supply system are built by comprehensive considering the factors(the fires probability of each damage structure, the population density, property density and fire-fighting abilities of districts). Finally, the judgment model of the seismic secondary fire high hazard districts is built by using AHP method.

2. The AHP method and the weights of factors

2.1 The influence factors of the judgment model

There are 3 main factors to influence the evaluation of the seismic secondary fires high hazard districts form a big level of view. They are the induced-disaster index (IDI), the fire-fighting abilities index(FAI) and the earthquake damage index(EDI). Then, the main factors are divided elaborately. The induced-disaster index of districts includes the structure density(SD), the population density(PD), the probable catching-fire point density(PCPD) and the classes of structures (CS)in the districts. The fire-fighting abilities index includes the fire-fighting facilities condition(FFC), the arrival time from fire station to the districts(ATFD) and the road density of districts(RD). The earthquake damage index includes the average damage index of structures(ADIS), communications system (ADCS)and water supply system(ADWSS).

2.2 The weights of factors

The comparison judgment between every two factors should be carried before computing by AHP method. Then, the judgment results are quantified and the judgment matrix is built. The biggest characteristic value and characteristic vector are obtained by solving the judgment matrix. The characteristic vector stands for the weights of factors. In the judgment matrix, the scaling adopts the value from 1 to 9. The judgment matrix and its' meaning are shown in the Table 1.

Table 1– The judgment matrix and its' meaning

the scaling	**The meanings**
1	The **same** importance between two factors
3	One factor is **slightly** more important than another factor
5	One factor is **obviously** more important than another factor
7	One factor is **strongly** more important than another factor
9	One factor is **extremely** more important than another factor
2，4，6，8	The **mean** between the adjoining judgments
The reciprocal	bij: Factor *i* comparing with Factor *j*, and $b_{ji}=1/b_{ij}$

It is obvious that the frequency of seismic secondary fires is higher than the one of daily fires. The weight of the earthquake damage index is the biggest in the 1st level factors for considering the hazard of seismic secondary fires. The induced-disaster index of districts is the fundament of secondary fires. It is the second important influence for secondary fires. The influence of the fire-fighting abilities index is the smallest in the three main factors. In the 2nd level factors, the influences to secondary fires are considered by using the same method. The judgment matrixes and calculated weights of factors are shown from Table 2 to Table5.

Table 2 –The weights of the 1st level factors

	IDI	**FAI**	**EDI**	**Weights**
IDI	1	2	1/2	0.286
FAI	1/2	1	1/4	0.143
EDI	2	4	1	0.571

Table 3 –The weights of IDI

	SD	**PD**	**PCPD**	**CS**	**Weights**
SD	1	2	1/2	1/3	0.154
PD	1/2	1	1/4	1/6	0.077
PCPD	2	4	1	2/3	0.308
CS	3	6	3/2	1	0.461

Table 4 –The weights of FAI

	FFC	ATFD	RD	Weights
FFC	1	2	1	0.4
ATFD	1/2	1	1/2	0.2
RD	1	2	1	0.4

Table 5 –The weights of EDI

	ADIS	ADCS	ADWSS	Weights
ADIS	1	3	2	0.545
ADCS	1/3	1	2/3	0.182
ADWSS	1/2	3/2	1	0.273

3 The quantitative criterion of factors

3.1 the induced-disaster index (IDI)

3.1.1 the structure density of districts(SD)

The structure density is also called to the structure coefficient. It is a physical quantity that it reflects the concentrated degree of structure in a flat. It equals the ratio of the 1st floor structure area to the districts area. The value is bigger. The probability of fire occurrence is higher. The fires can easy spread to the surroundings buildings.

According to the actual situation of the structures fires study, the structure density of districts are divided into 5 grades in the paper. The detail is shown in Table 7.

3.1.2 the population density(PD)

The population density reflects the distribution of population in the district. It is important composition of social economy information. The district that the population density is bigger is advantageous to fires occurrence and spread. The population density of districts is also divided into 5 grades in the paper. The grade criterion is shown in Table 7.

3.1.3the probable catching-fire point density(PCPD)

The probable catching-fire point density(PCPD) of single building reflects the number of the secondary fires source. The district that the value is bigger stands for the more probability of fires occurrence. The value can be calculated by using the method in References[3]. It is also divided into 5 grades. The grade criterion is shown in Table 7.

3.1.4 the classes of structures (CS)

The classes of structures (CS) are not only influence to the seismic secondary fires occurrence but also important to fires spread. In general, the constructing material combustibility of buildings is the higher and the vulnerability of buildings is the lower. It can easily result in occurrence and spread of secondary fires.

The index of classes of structures (CS) can be expressed by used a dimensionless quantity.

The combustion index of structures is defined to describe the combustibility of different structures classes firstly. Their values are used from 0 to 1 to stand for. The details are shown in Table 6.

Table 6 –The combustion index of different classes

	High buildings	**Reinforced concrete**	**Masonry**	**Other classes**	**Single storey buildings**	**Wood buildings**
The combustion index	0.1	0.3	0.5	0.5	0.7	0.9

The combustion index of the district can be calculated by the expression 1.

$$r_i = \frac{\sum_i r_i A_i}{\sum_i A_i} \tag{1}$$

In which, r_i is the The combustion index of the district. A_i is the sum of i class structure area. i is the class structures（i=1，2…6）.They stand for High buildings, Reinforced concrete, Masonry, Other classes, Single storey buildings and Wood buildings differently. The value of r_i also is divided into 5 grades. The grade criterion is seen in Table 7.

3.2 the fire-fighting abilities index(FAI)

3.2.1 the fire-fighting facilities condition(FFC)

The fire-fighting facilities condition of cities is lack to unify plan at present in China. The number of facilities is not enough and the fire-fighting radius is too big. The fire hydrants could not reach the request of fire-fighting standard. The distance between two fire hydrants is bigger than 120 meters. In generally, the fire-fighting facilities condition(FFC) can be divided into 5 grades(higher than state standard, reaching the state standard, slightly lower than state standard, not reaching state standard and seriously not reaching to state standard).

3.2.2the arrival time from fire station to the districts (ATFD)

The layout of fire stations should abide by the principle that should receive to the jurisdiction edge in 5 minutes after instructing fire-fighting. It can't satisfy the so-called"5 minutes fire-fighting" request in fact in the cities in China. The arrival time is divided into five time segments (0, 4) (4, 8), (8, 12), (12, 15), (15, 200). The fire-fighting truck speed follows 35 Km|h to calculate.

3.2.3the road density of districts (RD).

The road density of districts can reflect the traffic circumstance in the district. The value is bigger. It is more beneficial to getting into by fire-fighting vehicle. The road density can be computed by the main road and the subordinate road respectively. The weight of the main road is 1and the one of the subordinate road is 0.5. The detail calculation should follow the expression 2.

$$\rho_{rz} = \frac{\sum_i l_{zi} + 0.5\sum_j l_{zj}}{A_z} \tag{2}$$

In which, ρ_{rz} is the road density of z district. l_{zi} is the length of main road in z district. l_{zj} is the length of subordinate road in z district. A_z is the area of z district. The calculation is divided 5 grades. The detail is seen in Table 7.

3.3 The earthquake damage index

3.3.1the average damage index of structures(ADIS)

The seismic damage index of buildings is a dimensionless quantity to represent the seismic damage degree of buildings. The concept firstly was put forward by Mr. Huyuxian for investigating after earthquake in China. 1 stands for ruined and 0 stands for intact on the whole. The middle values corresponding mean slightly damage, moderately damage and seriously damage. The average damage index of structures(ADIS) can be calculated by the damages of all structures in the district. The value is also divided into 5 grades. The grade criterion is seen in Table 7.

3.3.2the average damage index of communications system (ADCS)

The average damage index of communications system (ADCS) is a dimensionless quantity to represent the seismic damage of communications system. The seismic damage indexes of road and bridge are applied to calculate the average damage index of communications system (ADCS). The value is also divided into 5 grades. The grade criterion is seen in Table 7.

3.3.3 the average damage index of water supply system(ADWSS)

The average damage index of water supply system(ADWSS) is a dimensionless quantity to represent the damage degree of water supply system. The damage of water supply system effects on the water supply of fire-fighting. The damage of water supply will take into account the damages of the main and subordinate water supply pipe network.

The average damage index of water supply system(ADWSS) are divided into 5 grades. They are *intact on the whole*, *slightly damage*, *moderately damage*, *seriously damage* and *ruined*.

4 The standards of grading of factors

Every factor is divided 5 different grades from A to E according to the analysis of impact factors. It is correspondence with the synthesize grating from 1 to 5.The grade criterion, the standards of grading and weights of factors by AHP method are list in table 7.

Table 7 – The grade criterion, the standards of grading and weights of factors

Partitions	**A**	**B**	**C**	**D**	**E**	**Weights**
SD	<0.1	0.1~0.15	0.15~0.25	0.25~0.35	>0.35	0.044
PD	<0.1	0.1~0.5	0.5~1.0	1.0~2.5	>2.5	0.022
PCPD	<1	1~2	2~5	5~10	>10	0.088
CS	<0.2	0.2~0.4	0.4~0.5	0.5~0.7	>0.7	0.132
FFC	higher than state standard	reaching the state standard	slightly lower than state standard	not reaching state standard	seriously not reaching to state standard	0.057
ATFD	<4	4~8	8~12	12~15	>15	0.029
RD（km/ km^2）	>4.5	3.5～4.5	2.5～3.5	1.5～2.5	<1.5	0.057
ADIS	≤0.1	0.1~0.3	0.3~0.55	0.55~0.85	>0.85	0.311
ADCS	≤0.2	0.2~0.4	0.4~0.6	0.6~0.8	>0.8	0.104
ADWSS	Intact on	Slightly	moderately	seriously	ruined	0.156

	the whole	damage	damage,	damage		
Grading	1	2	3	4	5	

5 The demarcation standard of seismic secondary fire high hazard districts in cities

The synthetic score can be calculated according to the grading and weight of factors. The demarcation standard of seismic secondary fire high hazard districts was given in Table 8 by comprehensive consideration city civil fire statistical data and synthetic score of districts.

Table 8 – The demarcation standard of seismic secondary fire high hazard districts in cities

Hazard degree	**Extreme few hazard**	**Few hazard**	**Ordinary hazard**	**High hazard**	**Extreme high hazard**
Synthetic score	0~1.6	1.5~2.2	2.2~2.8	2.8~3.6	3.6~5

6 Example and results

The south-east small city of China that has already done seismic damage prediction work is selected to an example in the paper. The city proper is divided into 37 small districts by neighborhood committees. The detail foundation data and seismic damage prediction result are seen in Reference[5]. The evaluation model of seismic secondary fire high hazard district is established in the GIS by applying the foundation data in report. Then, the evaluation results of earthquake intensities can be obtained. The evaluation result of hazard districts map of intensity Ⅷ is shown in Fig.1.

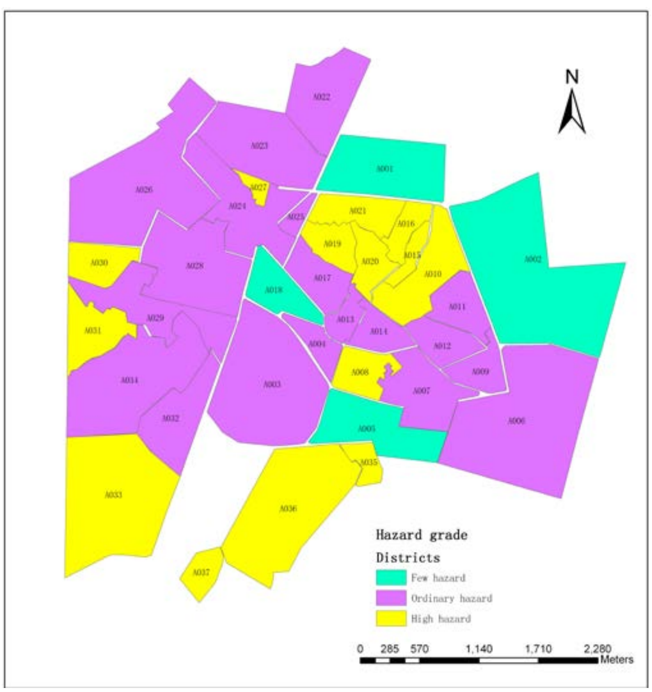

Fig. 1 – The evaluation result map of intensity Ⅷ

In Figure1, there are 3 hazard grade(Few hazard, Ordinary hazard and High hazard) in the example city when the earthquake intensity is Ⅷ. The Extreme Few hazard and Extreme hazard are not existed. We known the relatively important districts for taking precautions against secondary fires when the earthquake intensity is Ⅷ from Figure1. It is helpful to earthquake emergency and making a strategic decision.

7 Conclusion

In the paper, various factors influence to seismic secondary fires are taken into account firstly. Then, the factors are quantified by using AHP method in view of the seismic damage of engineering structures. Finally, the evaluation model of seismic secondary fire high hazard district is established in GIS. The model is a half quantitative analysis method. It is a brief convenient method and the maneuverability is strong. It is not only to provide a set of workable method for the evaluation of seismic secondary fires hazard in cities but also to provide a reference to daily preventing fire plan in city.

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