STUDY ON THE SECONDARY FIRE OF EARTHQUAKE

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ABSTRACT: Firstly, the uncertainty of the secondary fire of earthquake has been discussed in this paper. Secondly, the secondary fire probability model which correlated with the damage states of buildings was provided by collecting and analyzing the datum of buildings secondary fire after earthquakes. Finally, the simple fire spread model among buildings was established. Then, on the base of analyzing fire cases, the relevant parameters of models were made certain. The models can be used in the disaster prevention of urban base on the Geographical Information System (GIS).

KEY WORDS: Secondary fire of earthquake, Fire spread model of buildings, GIS

1 INTRODUCTION

The earthquake-induced disasters generally mean a series of other disasters that are caused by the damaged structures or components in the strong shaking, Such as fire, flood, tsunami, landslide, mud-rock flow, poison leakage, explosion, radioactive pollution, etc. Sometimes, casualties and economic losses caused by the earthquake-induced disasters should be far more than the one of earthquake disaster. Among them, the secondary fire takes place most easily, and it is also the most dangerous.

As we know that historical destructive earthquakes often caused fires. As instances, the San Francisco Earthquake (American. 1906) and the Great Kantō Earthquake (Japan. 1923) are very persuasive. In China, the Ms 7.3 earthquake took place in Haicheng of Liaoning province (2. 4.1975). Although it had been forecasted accurately, and the casualties were reduced consumedly in shaking, after earthquake, there were still more than 700 deaths and 7000 injured caused by the freeze and the quakeproof fire. The Great Tangshan Earthquake (7.28.1976, Ms 7.8), the large fire didn't occur because of the heavy rain after earthquake in the Tangshan urban, but one hundred kilometers away, several fires were discovered in Tianjin.

With the development of the economy and the society, the fires will cause more losses. So the study on the secondary fire of earthquake is very important.

In this paper, the uncertainty of the secondary fire disaster has been discussed. The secondary fire probability models which correlated with the damage state of buildings are provided by collecting and analyzing the datum of secondary fires after earthquakes. Finally, the simple fire spread model among buildings is established. The models can be used in prevention disaster of cities on the base of the geographical information system (GIS).

2. QUANTITATIVE ANALYSIS IN THE SECONDARY FIRE

Many cases of the secondary fires past earthquake are summarized in America, Japan and China (seeing Table.1). Then earthquake intensity(MMI) is converted to the peak ground acceleration（PGA）. The probability of the secondary fire in each 100,000 square meters building area with correspond of PGA is calculated.

Because the datum of China are less (only 7), the matching curve according to a little amount datum can't explain a problem well. So comprehensive consider the domestic and international earthquake fire cases, the regression formula is built according to the datum (in Table.1). It can forecast the fire times in the urban earthquake in the future.

$$y = -0.11749 + 1.34534x - 0.8476x^2 \quad (2\text{-}1)$$

Where: y is the number of fires occurred in each 100,000m^2; x is PGA(*gal*)

Table. 1 The earthquake fire cases in America, Japan and China

NO.	City	Time of earquake	PGA	Intensity	Number of fire	fire rate /100,000m2
1	Santa Rosa	1906.4.17，5:12	0.71	Ⅹ	1	0.149
2	San Mateo Co	1906.4.17，5:12	0.36	Ⅷ-Ⅸ	1	0.151
3	Santa Clara	1906.4.17，5:12	0.44	Ⅸ	1	0.237
4	San Jose	1906.4.17，5:12	0.36	Ⅷ-Ⅸ	1	0.086
5	San Francisco	1906.4.17，5:12	0.44	Ⅸ	52	0.28
6	Oakland	1906.4.17，5:12	0.44	Ⅸ	2	0.065
7	Berkeley	1906.4.17，5:12	0.44	Ⅸ	1	0.172
8	Norwalk	1933	0.28	Ⅷ-Ⅸ	1	0.054
9	Los Angeles	1633	0.15	Ⅶ-Ⅷ	3	0.011
10	Long Beach	1933	0.53	Ⅸ	19	0.28
11	San Francisco	1957	0.12	Ⅷ	0	0
12	Anchorage	1964.3.28	0.71	Ⅹ	7	0.258
13	Santa Rosa	1969	0.36	Ⅷ-Ⅸ	1	0.065
14	Burbank	1971.2.9,6:00	0.21	Ⅷ	7	0.172
15	Glendale	1971.2.9,6:00	0.15	Ⅶ-Ⅷ	9	0.14
16	Los Angeles	1971.2.9,6:00	0.15	Ⅶ-Ⅷ	128	0.097
17	Pasadena	1971.2.9,6:00	0.21	Ⅷ	2	0.043
18	San Francisco	1971.2.9,6:00	0.53	Ⅸ	3	0.398
19	Coalinga	1983.5.2,16:42	0.36	Ⅷ-Ⅸ	1	0.32
20	Morgan Hill	1984	0.21	Ⅷ	4	0.43
21	San Jose	1984	0.36	Ⅷ-Ⅸ	5	0.022
22	Whittier	1987	0.28	Ⅷ	6	0.108
23	Daly City	1989.10.17,17:04	0.12	Ⅶ	3	0.054
24	Berkeley	1989.10.17,17:04	0.07	Ⅵ-Ⅶ	1	0.014
25	Marin Co.	1989.10.17,17:04	0.12	Ⅶ	2	0.022
26	Mountain View	1989.10.17,17:04	0.21	Ⅷ	1	0.022
27	Oakland	1989.10.17,17:04	0.07	Ⅵ-Ⅶ	0	0
28	San Francisco	1989.10.17,17:04	0.21	Ⅷ	27	0.086
29	Santa Cruz	1989.10.17,17:04	0.36	Ⅸ	1	0.043
30	Santa Cruz Co.	1989.10.17,17:04	0.28	Ⅷ-Ⅸ	24	0.032

31	Tokyo	1923.9.1, 11:58	0.8	X	163	0.0102
32	Yokohama	1923.9.1, 11:58	0.8	X	60	0.24
33	Fukui	1948.6.28, 16:13	0.6	IX-X	24	0.618
34	Maruoka Machi	1948.6.28, 16:13	0.6	IX-X	4	0.91
35	Kanatsu Machi	1948.6.28, 16:13	0.6	IX-X	3	0.976
36	Matuoka Machi	1948.6.28, 16:13	0.6	IX-X	4	0.992
37	Harue Machi	1948.6.28, 16:13	0.6	IX-X	5	0.799
38	Morita Machi	1948.6.28, 16:13	0.6	IX-X	3	0.675
39	Niigata Shi	1964.6.16, 13:01	0.7	IX-X	9	0.09
40	Towada Shi	1968.5.16, 9:19	0.2	VIII	9	0.6
41	Miyagi Ken	1978.6.12, 17:14	0.35	VIII-IX	12	0.072
42	Urakawa Kinkai	1982.3.21, 11:32	0.3	VIII-IX	2	0.08
43	Nihonkai Chubu	1983.5.26, 11:59	0.35	VIII-IX	4	0.16
44	Higashinada-ku (Kobe)	1995.1.17, 5:46	0.8	X	28	0.368
45	Nada Ku	1995.1.17, 5:46	0.8	X	22	0.409
46	Chuo Ku	1995.1.17, 5:46	0.8	X	35	0.698
47	Hyogo Ku	1995.1.17, 5:46	0.7	IX-X	28	0.509
48	Kita Ku	1995.1.17, 5:46	0.3	VIII-IX	2	0.028
49	Nagata Ku	1995.1.17, 5:46	0.8	X	27	0.505
50	Suma Ku	1995.1.17, 5:46	0.4	IX	20	0.301
51	Nishi Ku	1995.1.17, 5:46	0.3	VIII-IX	2	0.032
52	Amagasaki Shi	1995.1.17, 5:46	0.3	VIII-IX	8	0.041
53	Ashiya Shi	1995.1.17, 5:46	0.4	IX	13	0.389
54	Nishinomiya Shi	1995.1.17, 5:46	0.4	IX	41	0.256
55	Itami Shi	1995.1.17, 5:46	0.2	VIII	7	0.103
56	Takarazuka Shi	1995.1.17, 5:46	0.15	VII-VIII	4	0.055
57	Kawanishi Shi	1995.1.17, 5:46	0.1	VII	3	0.062
58	Akashi Shi	1995.1.17, 5:46	0.15	VII-VIII	6	0.06
59	Dali Yunnan	1925.3.24	0.35	VIII-IX	10	0.33
60	Fengyi Yunnan	1925.3.24	0.2	VIII	6	0.3
61	Haicheng. Liaoning	1975.2.4, 19:36	0.3	VIII-IX	12	0.068
62	Tangshan	1976.7.28, 3:42	0.8	X	5	0.125
63	Tianjin	1976.7.28, 3:42	0.2	VIII	38	0.317
64	Cangyuan Yunnan	1988.11.6, 21:03	0.2	VIII	1	0.111
65	Yongsheng Yunnan e	1992.12.18, 19:21	0.1	VII	1	0.1

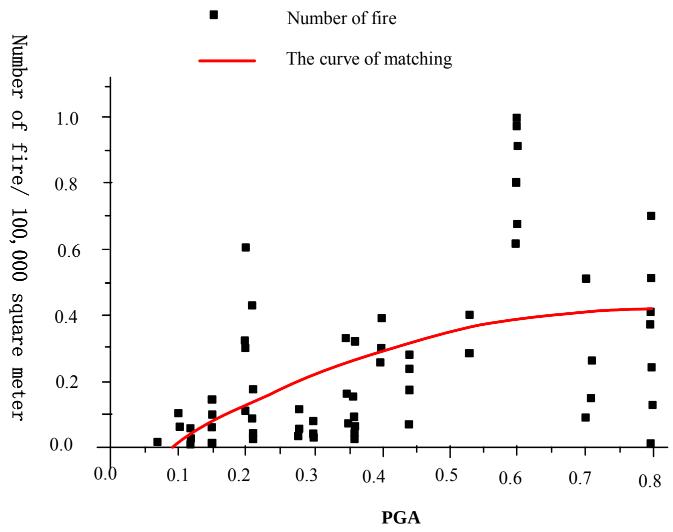

Figure 1 The matching quadratic curve diagram between the number of fires and PGA

3 THE PROBABILITY MODEL OF THE FIRE IN THE SINGLE BUILDING

The fire is a common secondary disaster after earthquake. Because the uncertainty of the secondary fire and a lot of relevant influence factors. The probability model of the single building is followed.

$$P(P_{Ii}) = P(F_K/M)P(C_J/D_J)P(S_J/D_J)P(G) \qquad (3\text{-}1)$$

Where: $P(R_{Ii})$ is the probability of earthquake-induced fire and spread among buildings; $P(F_K/M)$ is the probability of fire influenced by materials' combustibility. its value is zero when those are not combustible; $P(C_J/D_J)$ is the probability of accidental release and spread of combustibles inside buildings at the damage level D_J; $P(S_J/D_J)$ is the probability of ignition sources inside buildings at the damage level D_J; $P(G)$ is the fire and spread influenced by other factors (such as weather, season, surrounding, density of buildings etc.). The values of the parameters are given in the list of references [2].

4. THE SECONDARY FIRE SPREAD MODEL AMONG BUILDINGS

Building up the secondary fire spread model among buildings need consider the characteristic of fires after earthquake firstly. The characteristics mainly have been influenced two factors as follows. 1)the fuel special; Buildings will be the main fuel of fire a disaster to spreading. The speed of fire spread is decided by the inner part structure, the structure type, the fire prevention function, the high difference of the buildings, and so on. In addition, the breakage characteristic of buildings still relates to the whole combustibility of the building structure after the earthquake. 2)the weather condition influences the way fire to spreading; The weather condition(the temperature, the degree of humidity, the velocity and direction of wind) are the important factors to fires spread. Among them, the wind is the most decisive factor. The direction of wind controls the fire direction to spreading. The velocity of wind comes to influence the velocity of fire spread.

To build up the spread model need mainly consider a fire spread among the buildings. The spread includes two processes. The one is the fire development process in the inner of catching fire building. The other is the development process between the close buildings together. The establishment of fire spread is based on the two processes. Moreover, the distance of the close buildings is decisive factor for fire spread.

4.1 The Combustion Inside The Building

According to the structure classification and definition in *Code for earthquake disaster evaluation and its information management system（GB/T 19428-2003）*, the structure is divided into five major types: the tall building, the multi-stories reinforced concrete building, the multi-stories brick building, the single-stories civil house and the other categories. Making reference to research result of cultural heritages, the combustion speeds inside the building are given according to the structure type. In the next table the values don't consider the different of indoor decorates and products.

Table 2 The combustion speed inside the building

The structure classes	the combustion speed	
	m/min	m/h
tall building	0.54	32.4
reinforced concrete building	0.54	32.4
Multi-stories brick masonry building	0.62	37.2
single-storey civil house	0.65	39
the other categories	0.65	39
Wooden house	0.87	52.2

The correction combustion speed should to be carried on considering the influence of the wind velocity.

$$V_i = V_i^{'} r(v) \qquad (4\text{-}1)$$

$$r(v) = 0.048v + 0.822 \qquad (4\text{-}2)$$

Where: v is the velocity of wind; $V_i^{'}$ is The combustion speed inside the building(inside Table 2); V_i is The correction combustion speed inside the building.

4.2 The Combustion Among Buildings

The combustion among the close buildings can adopt the index expression of the distance. The Japanese scholars gave combustion time expression of the wood structure house in tallying up more than tens city building fire cases.

The expression is followed.

$$T = 100.6e^{0.510d} \qquad (4\text{-}3)$$

where : d is the distance of the close buildings(m); T is the combustion time(t).
Obviously, the wooden structure comparison is the more burnable than the un-wooden buildings. So, we adopt experience coefficient method to get expression of the other type house combustion time.

$$T = k_i 100.6e^{0.510d} \qquad (4\text{-}4)$$

In which: k_i is the correction coefficient that different buildings(Seeing Table.3).

Table 3 the combustion velocity among close buildings

The structure classes	the correction coefficient
tall building	1.6
reinforced concrete building	1.6
Multi-stories brick masonry building	1.4
single-storey civil house	1.2
the other categories	1.2
Wooden house (references [3])	$T = 100.6e^{0.510d}$

Similarly, the correction combustion speed also should be carried out by considering the influence of the wind velocity.

$$V_d = \frac{d}{T} \times r(v) \qquad (4\text{-}5)$$

$$r(v) = 0.048v + 0.822 \qquad (4\text{-}6)$$

Where: v is the velocity of wind(*m/s*); V_d is the correction combustion speed of the close building（*m/s*）; T is the time of catching fire between close buildings; d is the distance of the close buildings(*m*).
The correction combustion speed also should be carried out by considering the influence of the wind direction.

With the wind: $V_d^{'} = V_d$; Against the wind: $V_d^{'} = 0.73 * V_d$; the side wind: $V_d^{'} = 0.84 * V_d$

where: $V_d^{'}$ is the correction combustion speed of the close building according wind direction(m/s); V_d is the combustion speed with the wind(*m/s*).

4.3 The Spread Critical Distances Between Buildings

A fire can't pass by the close buildings when the distance of the close buildings attains certain distance. It is called critical distance of structure fire spread. According to *The manual of extinguishing fire* and the research result (seeing Table 4), the spread critical distances are given by *Code for earthquake disaster evaluation and its information management system（GB/T 19428-2003）.*

Table 4 The critical spread distance (*m*)

The structure class	the critical spread distance (*m*)
tall building	2
reinforced concrete building	2
Multi-stories brick masonry building	3
single-storey civil house	6
the other categories	10
Wooden house	12

4.4 The Secondary Fire Spread Route In Urban Among Buildings

We made three hypothesizes as follows for sampling the model of the fire spread route. The one is that the fire always passes from the fire source buildings to the close one by the nearest distance during the period of the secondary fire spread. The one is that the combustion time inner the building should be calculated according to the biggest distance of all points on the all sides of building. The other is that the fire source buildings can spread to the close one when the fire one combustion arrives certain degree. In the paper, we supposed that the degree is 80% of complete combustion.

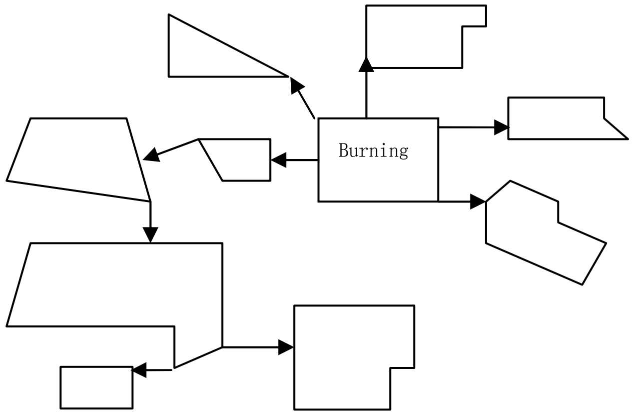

Figure 2 The fire spread process among buildings

The fire spread shape is a similar oval according to the research result and seismic fire cases. Here, for imitating the result of fire spread among buildings, we supposed that the fuel density is consistent resulted in the breakage of the building after earthquake.

5. CONCLUSION

On the basis of analyzing the indetermination of the secondary fire occurrence and spread and Summarizing the historical datum of earthquake fire in American, Japan and China, the regression formula between the number of fire and PGA is given in the paper. Then, it can forecast the fire times in the urban earthquake in the future. The secondary fire probability models which correlated with the damage state of buildings and the quantitative evaluate method of single building fire probability are put forward. Considering the main factors of influencing fire spread, the fire spread model is built up. It is applicable to GIS for emulating the seismic fire in urban in China. The result can apply to the establishment and modification of the aseismatic and reducing disaster programming and the emergency prepare case for providing a reference.

In the built regression model, the applied abroad datum is more. So it doesn't match the actual situation of seismic secondary fire in China. It needs more earthquake cases to revise coefficient. In spread the model, some other factors also have influence to the dissemination of fire. But they are neglect in setting up model. How to consider the factors and to certain the parameter in the model need a further research work. Then, some parameters even need test datum for supporting.

References:

[1] Yu Shizhou, *Numerical simulation of secondary disasters of earthquake*[D], Master degree thesis, Institute of Engineering Mechanics，CEA. 2004.

[2] Zhao Zhendong, et al. (2003). Probability model for hazard analysis of post-earthquake fire occurrence and spread among buildings[J]. Earthquake engineering and engineering vibration 23:4, 183-187.

［3］Investigation and study on the simulation system of seismic fire spreads. Toyko Fire Deparment,1989.3

［4］David D. Evans. William D. Walton and Frederick W. Mowrer. Progress report on fires following the Northridge earthquake[A]. Thirteenth meeting of the UJNR panel on fire research and safety[C],1996.3

[5] Frank W. Borden. The 1994 Northridge Earthquake and the Fires that followed[A]. Thirteenth meeting of the UJNR panel on fire research and safety[C],1996.3

［6］Xie xuyang, et al. Emulation of the seismic secondary fire spread based on GIS[J], China Safety Science Journal, 2005.4，15（5）: 3-7

［7］China fire protection association troops construction and extinguishing tactics committee, *The manual of extinguishing fire*,[M], Shanghai, Shanghai scientific and technical publishers, 1989.9