URBAN POST-EARTHQUAKE FIRES IN JAPAN

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SUMMARY

Six major earthquakes occurred in Japan are analysed to obtain data for the estimation of fire outbreaks in future earthquakes. Number of fires, fires immediately extinguished by citizen are shown of a major damaged city on each earthquake. Causes and uses of buildings of fire origins are shown of all fires. Previous studies relating the rate of fire outbreaks with the rate of collapsed buildings are examined of their appliability to future earthquakes. The correlation between the seismic intensity and the rate of fire outbreaks per household, the rate of fires immediately extinguished by citizen are investigated, which shows the trend of fires in future earthquakes.

INTRODUCTION

Japan has suffered a lot of earthquakes which accompanied with conflagrations. The most disastrous example was the 1923 Kanto earthquake where 366,262 houses were destroyed by fire in Tokyo city (Ref.1). The same tragedy was repeated in the 1948 Fukui earthquake where 2,069 houses were burnt in Fukui city (Ref.1). In recent earthquakes occurred in the last 20 years, there were no serious fires that burnt lots of houses. This may be because of the changes of building structures, fire appliances and the fuels for them. However, as Japan has a lot of wooden houses continuously built each other in urban regions. there is still a potentiality that fire becomes the major agent of destruction in earthquake situations. The purpose of this study is to show the basic data of past earthquake fires and observe on a trend of fire outbreaks in future.

EARTHQUAKE FIRES IN URBAN JAPAN

Six earthquakes attacked large cities in Japan and accompanied with fires are used for analysis. They are the 1923 Kanto, 1948 Fukui, 1964 Niigata, 1968 Tokachi-oki, 1978 Miyagiken-oki and 1983 Nihonkai-chubu earthquakes which are shown in Tab.1. In Tab.1, the seismic intensity follows the scale of the Japan Meteorological Agency (JMA) and the general fires are those caused by usual fire appliances for cooking and heating, the chemical fires are those caused by catalytic reactions of chemicals and the fires put out at once by citizen are those extinguished in their early stages by dwellers, staff or occupants of the buildings without the aid of fire brigades.

Kanto Earthquake

The Kanto earthquake occurred at 11:58 on Sept. 1, 1923. According to the data of Nakamura (Ref.2), a representative survey of fires in Kanto earthquake, 129 fires broke out in Tokyo city of which 99 were general and 30 were chemical fires. As Nakamura had not reported the causes and the uses of buildings of all fires, the analysis of fire origin is conducted using the data of Inoue (Ref.3), another representative survey of Kanto earthquake fires.

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Tab.1 Fires of Major Earthquakes in Japan

Name of Earthquake		Kanto	Fukui	Niigata	Tokachi -oki	Miyagiken -oki	Nihonkai -chubu
Date of Occurrence		1923 Sept.1 11:58	1948 Jun.28 16:13	1964 Jun.16 13:01	1968 May 16 9:49	1978 Jun.12 17:14	1983 May 26 12:00
Major Damaged City		Tokyo	Fukui	Niigata	Aomori etc*	Sendai	Akita
Seismic Intensity (JMA)		6	7	5	5	5	5
Number of Households		324,969**	15,525***	71,700	117,697	214,627	92,340
Number of Totally Collapsed Households, ( ):Ratio in (%)		12,995** (4.00)	12,425*** (80.0)	2,338 (3.26)	588 (0.500)	715 (0.333)	35 (0.0379)
Number of Fires	General	99	18	2	17	4	1
	Chemical	30	6	3	4	3	0
	Oil(Gas) Tank	-	-	4	0	1	1
	Total	129****	24	9	21	8	2
Rate of Fire Outbreaks per Household (x 10^{-4})	General	1.55	11.6	0.279	1.44	0.186	0.108
	Chemical	0.471	3.86	0.418	0.340	0.140	-
	All Fires	2.02	15.5	1.26	1.78	0.373	0.217
Number of Fires Put Out at Once by Citizen	General	33	0	2	10	4	1
	Chemical	20	0	2	2	0	-
	Oil(Gas) Tank	-	-	0	-	0	0
	Total	53****	0	4	12	4	1
Rate of Fires Put Out at Once by Citizen (%)	General	33.3	0.0	100.0	58.8	100.0	100.0
	Chemical	66.7	0.0	66.7	50.0	0.0	-
	Oil(Gas) Tank	-	-	0.0	-	0.0	0.0
	All Fires	41.4	0.0	44.4	57.1	50.0	50.0

* Hachinohe, Towada and Misawa, ** Number of wooden buildings, *** Number of houses, **** After Nakamura

Tab.2 Fires of Kanto Earthquake

a) Causes of Fires

Causes	Numbers	Ratio (%)
Kitchen range	37	37.8
Clay charcoal cooking stove	15	15.3
Brazier	8	8.2
Gas	9	9.2
Candle	1	1.0
Electricity	1	1.0
Chemicals	17	17.3
Unknown	10	10.2
Total	98	100.0

b) Buildings of General Fires

Uses	Numbers
Dwelling houses	25
Boardinghouses	3
Restaurants	16
Confectionary shops	7
Tofu shops	3
Delicatessens	6
Bakeries	2
Caterers	4
Cartons manufactory	1
Garvanization factory	1
Photoengraver's shop	1
Dolls manufactory	1
Substation	1
Total	71

c) Buildings of Chemical Fires

Uses	Numbers
Universitiy	4
Medical college	1
Pharmaceutical college	1
Dental college	1
Technical high school	1
Military academy	1
Apotecaries	4
Soap factory	1
Dental clinic	1
Dwelling house	1
Takanawa palace	1
Total	17

According to Inoue, total fires in Tokyo city were 98 of which 71 were general and 17 were chemical fires. Of 71 general fires, 38 (53.5%) started in the food related facilities such as restaurants, cake shops and delicatessens and 28 (39.4%) started in residential facilities. And most of the causes of the general fires were kitchen ranges, clay charcoal cooking stoves and braziers. Of 17 chemical fires, 9 (52.9%) started in universities and schools and 4 (23.5%) started in apothecaries. The causes and the buildings of fires are shown in Tab.2. Based on the data of Nakamura, of 129 fires, 53 (41.1%) were extinguished immediately by citizen of which 33 were general and 20 were chemical fires. And based on the data of Inoue, of 98 fires, 27 (27.6%) were extinguished at once by citizen of which 18 were general, 6 were chemical and 3 were unknown fires.

Fukui Earthquake (Ref.4)

The Fukui earthquake occurred at 16:13 on June 28, 1948. The seismic intensity in Fukui city was 7 and 80% of houses were destroyed at once completely. Twentyfour fires broke out in Fukui city and none of them were extinguished at once because of the strong shaking. The buildings and the causes of 24 fires are shown in Tab.3. As most of the fires had broken out in dwelling houses, restaurants and delicatessens, the trend of fire outbreaks of Fukui earthquake is said to be almost the same as the Kanto's.

Tab.3 Fires of Fukui Earthquake

Buildings of Fire Origins	Causes of Fires
Dwelling houses (7)	Kitchen ranges Cooking stoves
Restaurants (2)	Kitchen range Tempura oil
Delicatessen (1)	Kitchen range
Tofu shop (1)	Frying oil
Textile factory (1)	Furnace
Casting factory (1)	Casting fire
Store (1)	Kitchen fire
Inn (1)	Bath pot
Bank (1)	Kitchen range
High school (1)	Kitchen range
Office (1)	Brazier
Elementary school (1)	Chemicals
Technical school (1)	Chemicals
Agricultural experimental station (1)	Chemicals
Dyeing materials shop (1)	Chemicals
Printing shop (1)	Chemicals
Matches warehouse (1)	Matches

Niigata Earthquake (Ref.5)

The Niigata earthquake occurred at 13:01 on June 16, 1964. Nine fires broke out in Niigata city of which four were extinguished by citizen. The buildings and the causes of the fires are shown in Tab.4. No fires broke out in dwelling houses but 4 fires occurred in oil factories have spread and caused conflagration which characterizes the Niigata earthquake.

Tab.4 Fires of Niigata Earthquake

Buildings of Fire Origins	Causes of Fires	State of Extinguishment
Ice making shop (1)	Propane gas bombe	Put out at once by clerks
Fried food shop (1)	Frying oil	Put out at once by clerks
Junior high schools (2)	Chemicals	Put out at once by staff
Metal factory,laboratory (1)	Chemicals	Spread, partly destroyed
Oil factories (4)	Oil tank	Spread, conflagration
	Fuel tank	Spread, conflagration
	Oil pipe line	Spread, conflagration
	Unknown	Spread, conflagration

1968 Tokachi-oki Earthquake (Ref.6)

The Tokachi-oki earthquake occurred at 9:49 on May 16, 1968. The seismic intensity of Aomori, Hachinohe, Towada and Misawa cities were 5 and 21 fires in total broke out in those cities (see Tab.5). In Tokachi-oki earthquake, most of the fires were caused by falls of portable oil stoves used at that time because of the cold weather (9°c) of the day.

Tab.5 Fires of Tokachi-oki Earthquake

Buildings of Fire Origins	Causes of Fires	State of Extinguishment
Dwelling houses (12)	Oil stoves (10)	Put out at once by dwellers (4) Spread, partly destroyed (2) Spread, totally destroyed (4)
	Coal stove (1)	Put out at once by dwellers
	Oil range (1)	Put out at once by dwellers
Laundry (1)	Oil boiler	Put out at once by workers
Seafood processing factory (1)	Leaked heavy oil	Put out at once by workers
Paint shop (1)	Oil stove + paint	Spread, partly destroyed
Office (1)	Oil stove	Put out at once by occupants
Hospital (1)	LPG gas range	Put out at once by occupants
High schools (2)	Chemicals	Put out at once by staff
Drugstores (2)	Chemicals	Spread, totally destroyed

1978 Miyagiken-oki Earthquake (Ref.7)

The Miyagiken-oki earthquake occurred at 17:14 on July 12, 1978. Eight fires broke out in Sendai city of which 4 were put out at once by occupants. The uses of buildings and the causes of fires are shown in Tab.6. No fires broke out in restaurants and delicatessens but the chemical fires have still broken out in universities. Oil leaks had occurred at at an oil factory because of a breakage of an oil tank but did not cause a fire.

Tab.6 Fires of Miyagiken-oki Earthquake

Buildings of Fire Origins	Causes of Fires	State of Extinguishment
Dwelling house (1)	Kitchen gas range	Put out at once by dwellers
Dormitory	Kitchen gas oven	Put out at once by dwellers
Die casting factory (1)	Leaked heavy oil	Put out at once by workers
Sanitary Engineering company, pipe yard (1)	Spilled gasoline	Put out at once by workers
Universities (3)	Chemicals	Spread, partly destroyed
Gas making plant (1)	Escaped gas	Spread, partly destroyed

1983 Nihonkai-chubu Earthquake (Ref.8)

The Nihonkai-chubu earthquake occurred at 12:00 on May 26, 1983. The seismic intensity was 5 in Akita city where 2 fires broke out. One occurred in a dwelling house by an electric cigarret lighter ignited accidentaly by a fall of furniture on it, but was put out at once by occupants. The other fire broke out in an oil tank of a thermoelectric power plant by a crash of a floating roof and was extinguished by fire brigades.

ESTIMATION OF FIRE OUTBREAKS IN EARTHQUAKES

Previous Studies

(1) Kawasumi's model

In Japan, Kawasumi (Ref.9) was the first who studies the outbreaks of fires in earthquakes. Using the data of Tokyo city in the Kanto earthquake, he has shown the relation between the outbreaks of fires and the damage of buildings which is shown in Fig.1. In Fig.1, the vertical axis shows the rate of fire outbreaks of wooden buildings and the horizontal axis shows the rate of wooden collapsed buildings, both of which are shown in logarithmic values. As he has not shown how and from where the data points of Fig.1 were derived, it is unable to check the propriety of the regression directly. But using the data of 15 wards of Tokyo city obtained from the report of Earthquake Disaster Prevention Committee (Ref.10),it was confirmed that the log-log type regression could give a positive correlation between the rate of fire outbreaks and the rate of collapsed buildings when the former was given excluding chemical fires. However, for applying to the estimation of fire outbreaks in future earthquakes, the Kawasumi's model has a problem that it was based on only the data of the Kanto earthquake which occurred almost 60 years ago when they were using old-fashioned fire appliances burnig solid fuels such as wood and charcoal that are scarecely used nowadays.

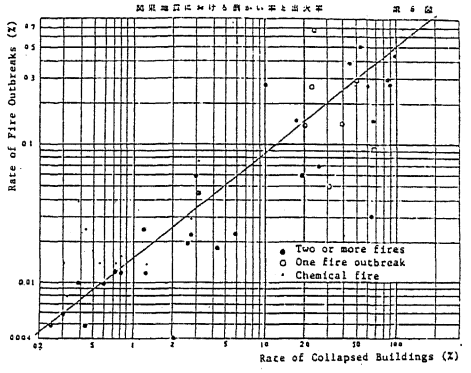

Fig.1 Rate of fire outbreaks and rate of collapsed buildings in Kanto earthquake (after Kawasumi)

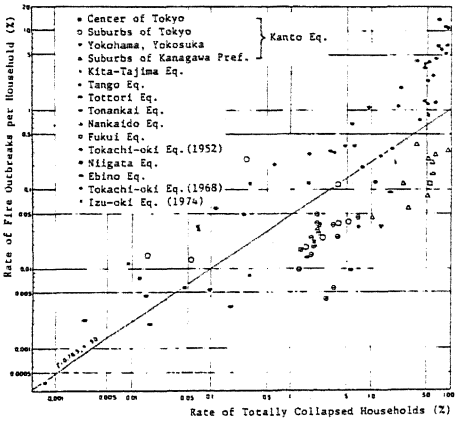

Fig.2 Rate of fire outbreaks and rate of totally collapsed households in earthquakes (after Mizuno)

(2) Mizuno's model

Following the Kawasumi's idea, Mizuno (Ref.11) has also conducted a regression analysis. The result is shown in Fig.2 where the vertical axis shows the rate of fire outbreaks per household and the horizontal axis shows the rate of totally collapsed households, both of which are given in logarithmic values. The regression was based on 90 data points of 12 different earthquakes dating from 1923. But as it was using logarithmic values, the districts of damaged that had collapsed buildings but had no fire outbreaks had been eliminated from the data used for regression, which causes to overestimate the

rate of fire outbreaks. Moreover, of 90 data points, 31 (34.4%) were from the 1923 Kanto earthquake and 31 (34.4%) were from the Tango earthquake. And furthermore, of 31 data points from the Tango earthquake, 23 (74%) were of the small villages with less than 500 households while some data points from another earthquakes were of the large cities with more than 200,000 households. Because of the biased selection of the data used for regression, it is questioned to use the Mizuno's model for the estimation of fires in future earthquakes.

Trend of Fire Outbreaks in Recent Earthquakes

(1) Causes of fires and buildings of fire origins

In the Kanto and Fukui earthquakes, most of the causes of general fires were kitchen ranges, clay charcoal cooking stoves and braziers burnig wood and charcoal as fuels while those of in the recent earthquakes were the appliances using oil, gas or electricity as fuels. According to this change, fires occurred in the dwelling houses, restaurants and delicatessens have decreased. In the 1968 Tokachi-oki earthquake, many fires occurred in the dwelling houses because of the falls of portable oil stoves. And as the result, the oil stoves have become to be equipped with automatic flame suppression devices by fire code. The effect of this measure was observed in the 1982 Urakawa-oki earthquake occurred at 11:32 on March 21, 1982. Urakawa is a small town in Hokkaido with 6,476 households and experienced the tremor of intensity 5 (partly 6) at the earthquake. According to a questionnaire of the Urakawa fire department distributed to 1,771 households, 95% of them were using stoves at the earthquake of which 92.5% were oil stoves. And of the stoves in use, 99.4% did not fall and 94% had equipped with automatic flame suppression devices of which 92.1% worked sufficiently. Based on this data, the fires caused by oil stoves may decrease in future earthquakes. In recent earthquakes, fires have not occurred in restaurants and delicatessens. But those places and the factories where they use fire constantly could have latent possibility to cause fires in earthquahe situations. Chemical fires have occurred in almost all earthquakes in universities, schools or drugstores and this trend may continue in future, too. The noteworthy in the recent earthquakes is the fires occurred in oil factories. The fires in the 1964 Niigata earthquake were the typical examples but even in other earthquakes, oil leaks had occurred in oil tanks and have had enough chances to cause fires. Because of the difficulty of fire extinguishment and the size of damage given to vicinity, special attention shall be paid to the facilities where they store a large quantity of inflamable or explosive materials and products.

(2) Rate of fire outbreaks per household

As shown by Kawasumi, the logarithmic value of the rate of fire outbreaks of wooden buildings had positive correlation with the logarithmic value of the rate of totally collapsed wooden buildings in the Kanto earthquake. But analysing the data of Inoue, fires have not necessarily started from the collapsed buildings. Of 71 general fires, only 30 (42.3%) started from the collapsed buildings and in the case of 17 chemical fires, it was only one. In addition, since the 1964 Niigata earthquake, fires have occurred not only in wooden buildings but also in fireproof buildings but none of them have started from the collapsed buildings. Therefore, it is more appropreate to analyse the fire outbreak rate not in the relation with the rate of collapsed

buildings but in the relation with the seismic intensity. And the fire outbreak rate itself should be given by the number of fires per household and to adjust the size of samples alike, a district to find a rate should be coodinated to a city or an area with, for instance, at least 100,000 households. Fig.3 shows the relation between the rate of fire outbreaks per household and the seismic intensity of major damaged cities in six earthquakes. In Fig.3, the fire outbreak rate of the Tokachi-oki is as high as the Kanto's. But considering the change of the appliances of fire origins and the spread of oil stoves equipped with automatic flame suppression devices, such rate may not be repeated if the same intensity of earthquakes occurred again. It is estimated that in the case of earthquakes of less or equal to intensity 6, the fire outbreak rate of total fires may not exceed 2.0×10^{-4}, that of general fires may not exceed 1.5×10^{-4} and that of chemical fires may not exceed 0.5×10^{-4}. But in the case of earthquakes of intensity 7, the possibility that the fire outbreak rate becomes much higher can not be denyed because we have only one example in the past which is the 1948 Fukui earthquake. The rate of fire outbreaks of oil tank fires is not shown here because they have become to appear on and after the Niigata earthquake and the numbers are not enough to calculate the rate. Besides, the facilities that have possibility to cause oil tank fires are limited, the rate should be given not per household but per the facility and if it was given in that manner, the rate may become considerably high.

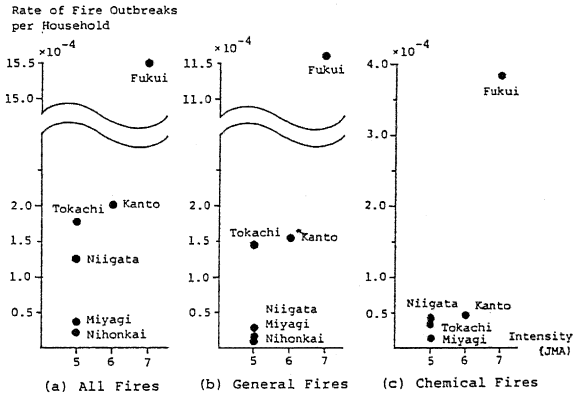

Fig.3 Rate of fire outbreaks per household and seismic intensity

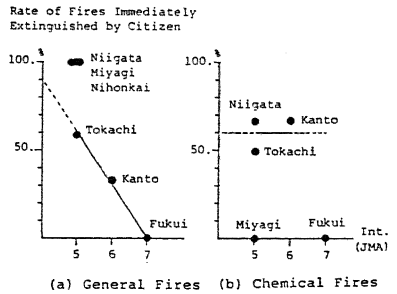

Fig.4 Rate of fires immediately extinguished by citizen and seismic intensity

(3) Rate of fires immediately extinguished by citizen

According to the data of Nakamura of 129 fires in the Kanto earthquake, the rate of fire extinguishment by citizen of general fires was 33.3% and that of chemical fires was 66.7%, which were different each other. And analysing the fires and the building damage of 15 wards of Tokyo city, it was found that the rate of fire extinguishment had negative correlation with the rate of totally collapsed wooden buildings. But based on the data of Inoue, of 71 general fires, 18 were extinguished immediately by citizen and as much as 10 (55.6%) of them were the fires that had started in the collapsed buildings and among 53 spreading fires, only 20 (37.7%) were those started in the collapsed

buildings. Therefore, as the spreading fires as well as the fire outbreaks had not always started in the collapsed buildings, the rate of fire extinguishment should be analysed also in the relation with the seismic intensity. Fig.4 shows the rate of fire extinguishment of six earthquakes and according to this, the fire extinguishment rate of general fires is expected to be about 60% at intensity 5, 30% at intensity 6 and 0% at intensity 7 and that of chemical fires is expected to be about 50% at intensity 5 to 6. But in the case of oil tank fires, as it's very hard to extinguish them without the aid of fire brigades once they've started, the fire extinguishment rate by citizen should be counted to be 0% for safety's sake.

CONCLUSION

Six major earthquakes in Japan have been analysed to obtain data for the estimation of fire outbreaks in future earthquakes. Changes of fuels and fire appliances have decreased the fires in dwelling houses, restaurants and delicatessens but has given rise to oil tank fires. Chemical fires have constantly occurred in universities, schools or drugstores in almost all earthquakes. Analysis of six earthquakes of the rate of fire outbreaks per household and the rate of fire extinguishment by citizen in the relation with the seismic intensity shows that so long as the earthquakes are less or equal to intensity 6, the spreading fires may not occur at so high rate as in the Kanto earthquake.

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