A STUDY ON URBAN FIRE PREVENTION IN CASE OF BIG EARTHQUAKE

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SUMMARY

This paper describes the results of a study which was done as a past research project investigating urban seismic fire. The study was executed over 5 years by the Ministry of Construction of Japan with the cooperation of a number of experts from universities and from private research organizations. In this paper, the the background of this research project is presented and an outline of the Urban Fire Prevention Unit System is introduced. This is followed by some background theories such as estimation of fire breakout, experimental study on urban fire, fire preventive function of trees and fire blocking effect of urban facilities.

BACKGROUND

Major Japanese cities such as Tokyo or Osaka, most vulnerable to fires because of the existence of a great number of wooden houses. This will cause the development of multiple fires which happen simultaneously after the earthquake and continue to grow up to the urban fire as large as the whole built up area.

At the time of Kanto earthquake in 1923, Tokyo suffered the damage of 34.71Km^2 burnt area, but if Tokyo were confronted with a same scale earthquake today, the damaged area would be much more severe, because the built up area has multipled and the density of buildings has also increased. In order to cope with this problem, adequate city planning for the reformation of urban structure has been provided and the promotion of construction of fireproof buildings has been continued for about 30 years after the 2nd world war. However actually Tokyo is still covered with tremendous number of wooden buildings and it is said that the vulnerability to a big earthquake is not reduced.

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The increasing tendency of fireproof building in Japan is shown on Table 1, where fireproof buildings are increasing 1% per year, but the increase of fireproof building mainly depends on commercial and office buildings in CBD and along arterial roads. However, the construction of fireproof residence is retarded by following reasons.

1. Climate of high temperature and high humidity in summer season
2. Difficulty of reconstruction and enlargement of the fireproof building
3. Difficulty of construction of fireproof building on rented land.

Tab.1 Increasing tendency of fireproof buildings

(number of buildings)

	1970	1975	1980
Japan as a whole	5.7%	10.3%	14.6%
10 major cities	9.5	16.9	22.7
cities without the above	6.4	10.9	14.6
town and villages	3.7	7.4	11.3

According to the result of a statistical analysis (Ref.1) in the built up area of Tokyo, the upper limit ratio of fireproof building will be 38% in CBD and 12% in the residential area by building area. So we can not expect the incombustible city without the arrangement of Urban Fire Prevention Units and others.

URBAN FIRE PREVENTION UNIT SYSTEM

The target of the research project of Ministry of Construction is to develop a practical planning procedure for mitigating the disaster from big fire after earthquake. For this target the best way is the reduction of wooden buildings within the boundaries of the densely built up areas. Computer simulation(Ref.2) has shown that the probability of fire spread can be reduced to a negligible amount when more than 60% of built up areas become fireproof. However this is not easy as was shown in the previous chapter.

As the second best way which is practical and effective for the japanese cities, Urban Fire Prevention Unit (U.F.P.U.) System is proposed. This basic concept of this system is the effective and concentrated allocation of a series of fire proof zones in wooden building built up areas. The large combustible zone is to be divided into a number of small combustible zones called U.F.P.U. by means of the construction of the Fire Blocking Belt (F.B.B.) network. It is known that some fire breakout may occur even with this system. However, past experience that most of fire breakout points are relatively concentrated, and a considerable number of units without breakout points could be saved through this system. In this meaning this U.F.P.U. system can be considered as effective and economic as is possible to realize in the big Japanese cities where big earthquakes are possible.

For the sake of the realization of U.F.P.U. system, the following planning procedure is proposed.

1st step: Fact-finding of Actual City Area

The results of investigation is to decide the applied zone(s) of the system where the incombustible area rate is less than 50%. For this applied zone, the total amount of fire breakout could be predicted with statistical relations between fire break out rate and seismic intensity.

2nd step: Decision Making of Planning Principle

Setting the target of the reduction of burnt area in consideration with the influence to the whole city, using the fire breakout rate for the applied area, the average size of U.F.P.U. could be decided by these two indices. (In the most possible case, the size is approximately $1km^2$) Depending on the knowledge of the average size of U.F.P.U. and on the condition of existing streets, railways, rivers or canals wider than 15m, the network of U.F.P.U. can be located in the applied area.

3rd step: Evaluation of Planning

Before the determination of the detail of U.F.P.U. system, the characteristics of the planning should be verified in relation to the fire spread condition. Under the condition where the every F.B.B. is perfectly reinforced in order to block the big fire, the ultimate consequence of fire spread is easily known because the burnt areas in this case are limited only to the fire breakout units. While, under the existing condition where imperfect F.B.B. are used, the prediction of fire spread depends on the location of fire breakout and on the fire blocking effect of urban facilities included in each F.B.B..In both cases, the distribution of fire breakout points is necessary. The relative coefficient of fire breakout for each unit is discussed in the proceeding chapter. Moreover, the fire blocking effect for evaluating each F.B.B is also explained in the following chapter.

4th step: Programming of Operation

The period for the total necessary operation to reinforce F.B.B. depends on the financial and urban activity conditions of the city and on the urgency against big earthquake, therefore, it is rather difficult to give a systematic operational program. Essentially that is a question of policy making.

But it is certain that there exist two typical strategies for carrying out the planned operation. One is the so called dividing method, with which the total applied zone is to be subsequently divided by the lines(ie. streets, railways, etc.) which are required by daily life. The other is called the increasing method. The specific area where the risk of fire breakout is very low can be turned into a safety zone if the fire from the outer regions could be blocked by the surrounding F.B.B.. Further, it is possible to enclose the areas where fire breakout points are heavily concentrated. In these two cases the total applied area will be able to increase the number of U.F.P.U. one by one . Practical limitations require the use of combinations of two typical strategies in accordance with the situation of each urban area.

5th step, Making Design of F.B.B.

As for the composition of F.B.B., there are two type. One is a series of incombustible areas such as parks, or other open spaces. In this case all the elements should be connected each other by some newly built incombustible facilities. The other one is the type of basic line and reinforcing zones, where the basic line can be a linear facility wider than 15m, and the reinforcing zone is composed of row(s) of fire proof building and open spaces.

The most important thing in the design of F.B.B. is to make use of existing facilities. When some new incombustible facilities are needed for the complement of existing facilities, it is also important to take advantage of potential private activities and to stimulate these activities by some specific institution of subsidy for the reconstruction to fire proof buildings. The width and height can be decided in use of the calculation method which is developed in the project based on the theoretical and experimental studies as are shown in the proceeding chapter.

THEORETICAL BACKGROUND

Estimation of Fire Breakout

This section describes a model for estimating the degree of danger for fire breakouts in case of a big earthquake in an urban area. By this model proposed, it is possible to predict the distribution of outbreak points within an urban area where the total amount of outbreak is already known. Further details and background data are shown in Refs.2 and 3.

(a)Outline of the Model

It is appropriate to consider that the degree of danger for fire breakouts is dependent on the frequency of fire sources. And it is also dependent on the kinds of fire source and on the usage of the building where the fire sources are initiated. Therefore, the degree of danger, d_{ij}, for fire breakouts caused by fire source, i, in building usage, j, can be expressed as follows;

$$d_{ij} = a_i b_j x_{ij} \tag{1}$$

where a_i : a coefficient of danger of fire source i
b_j : a coefficient of danger of building use j
x_{ij} : frequency of use for fire source i in building use j

From the formula(1), we can obtain the following equation;

$$\left.\begin{aligned} \sum_j a_i b_j x_{ij} &= p_i \\ \sum_i a_i b_j x_{ij} &= q_j \end{aligned}\right\} \tag{2}$$

where p_i : number of fire breakouts caused by fire source i
q_j : number of fire breakouts in building use j

On condition that p_i, q_j and x_{ij} are known, we can solve the equation(2). And using the solutions a_i and b_j of these equations, total degree of danger, D_k, for fire breakouts of area, k, can be calculated as follows;

$$D_k = \sum_i \sum_j a_i b_j x_{ijk} \tag{3}$$

where x_{ijk} is a frequency of fire source, i, building usage, j, of area, k.

(b)Case Study in Tokyo City

The data of p_i , q_j and x_{ij} for Tokyo city were obtained, and the equation(1) was solved. By these solutions, it became clear that the values of coefficient a_i for gas grill, electric cooking stove, and electric stove are relatively larger than those of other fire source coefficient, and that the values of coefficient b_j for restaurant, hotel, storage and house with shop are also larger than those of other building use coefficient. Further, according to the formula(3), the total degree of danger for fire breakout in Tokyo city was estimated as shown in Fig.1. It shows that the distribution of the D_k is reasonable.

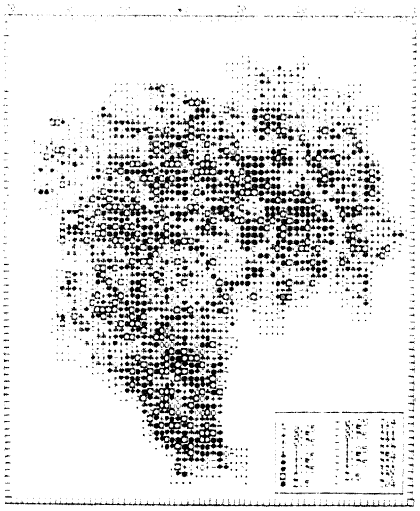

Fig.1 Estimation of D_k

Fire Preventive Function of Trees in Urban Area

The purpose of this study is to make clear the fire preventive function of trees which is one of the most important elements for sustaining the safety against fire. This study consists of several experiments which show the fire preventive function of trees and the results of these experiments are taken into consideration as a countermeasure for the fire prevention in urban area.

At the first stage of this study the effects of open spaces and the relationship between the physical feature of existing trees and the safety are discussed.(Ref.4) From this stand point, the fire preventive function of trees can be thought as the integrated concept of the fire resistance based upon the low ignitability of leaves and the heat shielding capacity due to the difficulty of heat transmission.

(a) Fire resistance

The limit condition of a tree at the moment of non flamable ignition was examined. In case of radiation the limit is 13,400 Kcal/m^2 hr for broadleaf evergreen trees, 13,900Kcal/m^{2}hr for broadleaf deciduous trees and 12,000 Kcal/m^2 hr for coniferous trees. The temperatures are 455°C, 407°C and 409°C respectively. Critical ignition points by pilot flame are 5,400 Kcal/m^2 hr for broadleaf evergreen trees and 5,800 Kcal/m^2 hr for coniferous trees.

(b) Heat shielding capacity

The rate of thermal insulation of a leaf is at least 40% for evergreen trees and 30% for deciduous trees. For one whole tree, the rate is at least 80%, but it depends on the difference in species and on the difference in heat capacity. The radiation shielding capacity when trees are planted in a row is in the seventies, when in two rows in the eighties and in three rows more than 90%. From the point of view of the radiation shielding capacity, it is thought that the most effective arrangement of trees is the case where they are planted alternately in three rows with a distance of one tree apart.

Trees in urban areas provide a refuge safety for human body as well as the shielding factor for buildings, etc. In accordance with such roles, linear type(roadside trees), areal type(woods), and spot type(garden trees) were taken into consideration and methods of usage were proposed in this project. A calculation method for the effects of fire shielding capacity of trees based upon the results of previous investigation was also referred to in this project.

Experimental Study on the Big Urban Fire

In order to complete the calculation system of fire blocking effect which is discussed in the next section, it is necessary to know the characteristics of urban big fire just in front of F.B.B.. On this subject, this section introduces the results of fire experiments which were executed in this project.

(a) Characteristics of the big urban fire

It is said that a urban scale fire is different from an ordinary fire mainly in its size of flame. The height of flame of a 2 storied wooden house burning is approximately 15m but in case of urban scale big fire, it is believed that the height of flame would become much higher as the consequence of the confluence of flames out of the many smaller sources which are burning at the same time.

For the verification of this phenomenon, a full scale fire experiment was performed at Saganoseki in 1979. Eighteen wooden houses were burnt almost simultaneously. However, the confluence of flame did not take place and the height of flame was more or less same as an ordinary single house fire. In spite of this fact, it cannot be said that an urban fire is merely the repetition of a single house fire, because the actual reports on the big fire at Shizuoka city in 1940 or on the big fire at Ohdate city in 1955 where the heights of flame recorded flame heights up to 35-40m.

On the other hand, the analysis of the model fire experiment at Ariake-cho, Tokyo suggested that the average height of flame in an urban fire would be 20-30m. This average height does not conflict with the above-mentioned observations which can be thought to be the maximum values. The calculation method for the fire blocking effect was based on the results of this model experiment.

(b) Radiation from the flame

The full scale fire experiment of Minami-suna-machi in 1979 showed that the intensity of radiation of fire is different within the surface of flame. Therefore, another full scale fire experiment was performed at Tachikawa, Tokyo in 1980 for the development of a quantitative analysis. These observation resulted in the distribution of radiation intensity along the vertical direction shown in figure 2 (A) and the model of emission rate for the calculation system proposed in figure 2 (B).Further details of the analysis are in Ref.5.

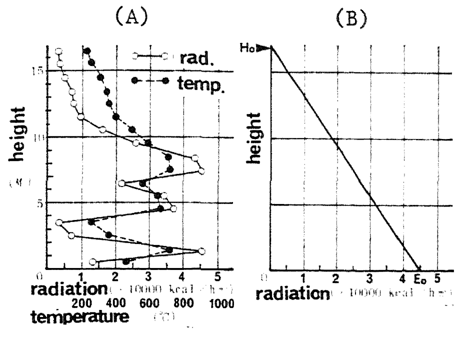

Fig.2
Distribution of radiation intensity along the vertical direction(A) and the model for calculation(B)

(c) Condition of ignition

The temperature of non-flamable ignition at the surface of timber test pieces and the radiation intensity in that moment are observed at the full scale fire test at B.R.I. in 1982, since they are needed in the design of fire blocking.

Fire Blocking Effect of Urban Facilities

This section deals with a comprehensive method for an evaluation of Fire Blocking Belt(F.B.B.) which consist of urban facilities such as wide streets, green spaces, river or canals, railways, or fire proof buildings.

The basic factors of spread of city fire are considered to be
(a) Intensity of radiation from the flame
(b) Convection to the leeward.

(a) Intensity of radiation from the flame

To estimate the intensity of radiation, it is necessary to clarify height(H°) and inclination(θ°) of flame. Following formulae are introduced by an analysis of the results of the model fire experiments in 1968-1971 at Ariake-cho Tokyo.

$$H^\circ=4.7\cdot\beta\cdot((D^\circ)^3/U)^{0.2} \quad (m) \qquad (4)$$
$$\theta^\circ=\sin^{-1}(U/2.0)^{0.2} \quad (deg) \qquad (5)$$

where D°: Depth of burning area (m)
U : Wind speed (m/s)
β : Coefficient for burning rate of urban area

With the height and inclination of flame, it is possible to calculate the configuration factor(f) of the flame which can be seen from an observation point at the opposite side of F.B.B.. As the result, the intensity of radiation at an observation point can be assessed by

$$R=\int_0^{H^\circ} E^\circ\sqrt{\varphi}\, e\, f\, dh \qquad (6)$$

where φ is the combustible rate of burning area, and is found by

$$\varphi=(1-0.6c)\cdot m \qquad (7)$$

c: rate of fire proof building space
m: rate of total building space

E° is the radiation from the surface of flame, which is constantly 44,000 Kcal/m hr.

In reality, radiation is not homogeneous within the surface of flame if a rectangle surface is assumed as the source of radiation. Thus, another factor, e, must be introduced as emission rate of surface. It was verified by a full scale fire experiment at Tachikawa Tokyo, and the relation between the emission rate (e) of surface and the height (h) of a point on the surface can be determined by

$$e=(1-h/H^{\circ}) \qquad (8)$$

(b) Convection to the leeward

Based on the result of the analysis of the Ariake-cho model fire experiments, the following formula is introduced.

$$T=284\ Lx\ U/(X\ (X+D/2)^{0.8}) \qquad (9)$$

where T : temperature of air flow in the leeward (°c)

Lx: width of fire source which means the burning rate of a linear heat source (m)

U : wind speed (m/s)

X : distance from the edge of fire source to an observation point (m)

(X+D/2) : distance from the center of fire source (m)

For the application of this formula to an urban fire, the scale effect should be taken into account. When the similitude ratios of length, wind speed, and burning rate per length are presented as rL, rU, rQ, respectively, the scale effect rules are

$$rU^{2}= rL \quad ; \quad rQ^{2}= rL^{3} \qquad (10)$$

Using this relation, formula(9) is consequently redefined for the actual size as follows

$$T=190\ U\ D/(X\ (X+D/2)^{0.8}) \qquad (11)$$

where Lx at formula(9) is considered to be the same as D

(c) Determination of fire blocking

When the size and composition of F.B.B. are given, it is possible to calculate R and T at the opposite side of the F.B.B., and the increase in temperature at the surface of a timber material (dT) can be estimated as

$$dT=T+R/20 \quad (°c) \qquad (12)$$

If the value of this formula is less than 200°c, it is believed that the F.B.B. is efficient against the city fire.

Reference

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