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CASUALTY ESTIMATION MODEL BASED ON THE MECHANISM OF HUMAN INJURY IN DAMAGED BUILDINGS

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SUMMARY

This paper discusses a method of precise estimation for earthquake casualties while uncovering the mechanism of human injury in building damage based on various kinds of data concerning the 1995 Hyogo-ken Nanbu Earthquake (Kobe Earthquake). As a result of this, a new formula for estimating death toll in earthquakes is proposed as a mulch-regression form with a lot of factors as seismic ground motion intensity, load-carrying capacity of dwelling, the age of dwelling, earthquake occurrence time, the number of inhabitants, internal space loss of damaged building, and so on.

INTRODUCTION

It is crucial to estimate the death toll for earthquake risk reduction planning conducted by local governing bodies. The estimation is generally achieved by a simple formula under the assumption that death occurs in damaged buildings no matter how degree buildings are damaged[1]. The situation requires a more precise estimation method for death toll based on the mechanism of human injury in building damage. Okada [2] proposed the definition of the state of internal space loss in damaged building (named it as W-score) and its measurement, and Takai et al. [3] formularized the relation between W-scores and damage patterns of buildings. On the basis of the forwarding researches we try to form the precise equation for estimating the death toll in damaged buildings by following the events from ground shaking, building collapse, indoor space loss, and to entrapping and killing people.

THE RESEARCH METHOD

The new estimation model is built in the following procedures based on the data related with damage of the Kobe Earthquake in Japan. We consider casualty only in wooden dwellings because almost all of casualty in the earthquake occurred in this type of building. From the standpoint of precise estimation of death toll, we must classify dwellings into detached house and apartment house, and we also pay attention to a difference in the rate of dead caused in the first or second floor of houses.

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1.Making the database on input ground motion severities represented by seismic intensity in the Japan Meteorological Agency scale (Fig.1), the number of dwellings in each block of research target region, the number of damaged houses as completely collapsed, heavy damaged and partial destroyed houses, and the rate of inhabitants being at house when the earthquake occurred to registered inhabitants

2.The earthquake resistance of buildings can be expressed as a probability distribution function characterized by the construction year of buildings (Fig.2). Following the idea, we assume the frequency distribution of earthquake resistance of houses in the research target region in terms of the frequency on the construction year of houses [4].

3.After the procedure 2, we calculate the number of housing units for every seismic capacity evaluation value.

4.On the other hand the damage state of individual building can be estimated by the Damage Index Function with the parameters of load-carrying capacity of building and input ground motion severity (Fig.3 [5]). We estimate the number of housing units for every states of damage by means of the Damage Index Function.

5.Both the structural damage (Fig.4,5) and the internal space loss of damaged building affect directly the occurrence of death (Fig.6,[2]) Formulating the relation between the W-score and the Damage Index representing the damage state of building (Fig.7), we compute the number of housing units for every degree of internal space loss.6.The rate function of the dead to internal space loss can be derived from the above-mentioned consideration (Fig. 8).

7.The number of inhabitants being at house for every degree of internal space loss can be found by taking into consideration of the rate of inhabitants being at house to registered inhabitants at the time of the occurrence of the earthquake (Fig.9).

8.As results of the above procedures, we derive the regression equation estimating the death toll in damaged houses.

9.Finally, we compare the estimating precision of any other existing equations with the proposed equation in this study.

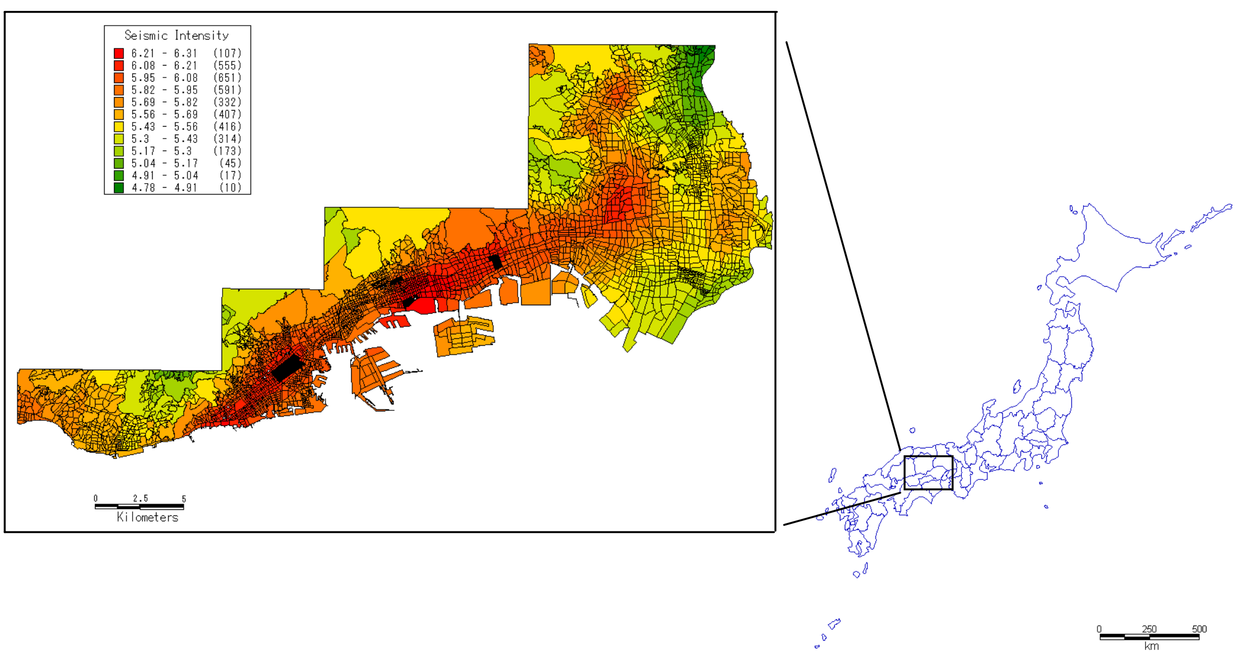


Fig.1 Research region in Kobe city

SEISMIC CAPACITY EVALUATION VALUE

In 1978, The Japan Building Disaster Prevention Association defined the Index (abbreviated to Is_wd) that expresses the earthquake resistance of wooden buildings. The value means risky in the range of 0.0 to 0.7, nearly risky in the range of 0.7 to 1.0, nearly safe in the range of 1.0 to 1.5, and safe over 1.5. Analyzing the data of Is_wd in Japan, we found the fact that the frequency distribution of Is_wd is closely concerned with construction year of buildings and can be expressed with log-normaldistribution by Eq. (1), where P (y) is relative frequency, y0 is the average of the distribution, σ is the standard deviation and y is variable of Is_wd. The function for each age of buildings is shown in Fig. 2. It shows clearly that the newer buildings are, the structurally stronger they are. . Considering the total number of houses in the research region and the rate of construction years of buildings, which is given in the building almanac [4], we can calculate the number of housing units for every Is_wd values.

$$p(y) = \frac{1}{\sqrt{2\pi}\sigma\, y} e^{-\frac{(\ln(y)-y_0)^2}{2\sigma^2}} \qquad (1)$$

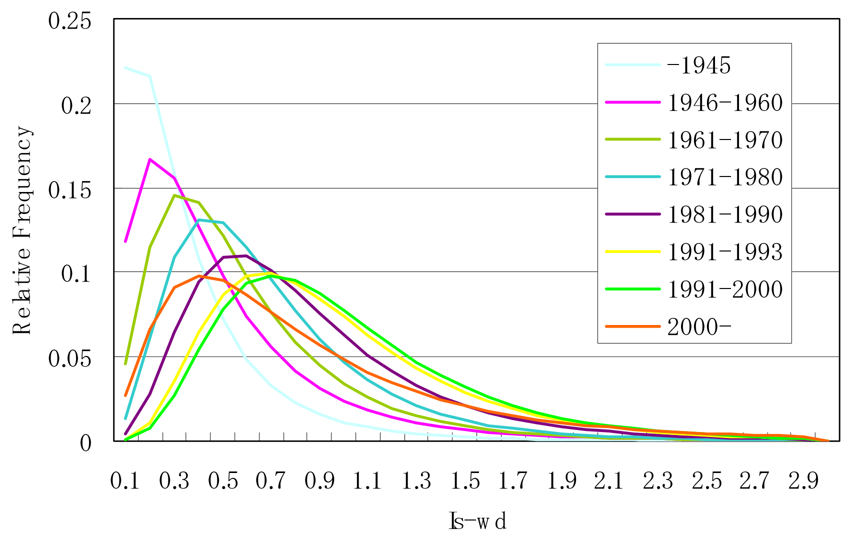


Fig.2 Relative frequency of Seismic capacity evaluation value in Osaka city area

THE DAMAGE STATE OF INDIVIDUAL BUILDING

The damage state of individual building can be expressed by the accumulation probability distributions of the following Weibull distribution (Eq.(2)) [5]. **F (s)** is the degree of damage (abbreviated to Damage Index), where the parameters are **m** controlling the form of distribution, and η controlling the average of the distribution. The function is shown in Fig. 3. The number of housing units for every Is_wd can be transposed to the number of housing units for every Damage Index by using this function.

$$F(s) = 1 - e^{-\frac{s^m}{s_0}} = 1 - e^{-\left(\frac{s}{\eta}\right)^m} \qquad (2)$$

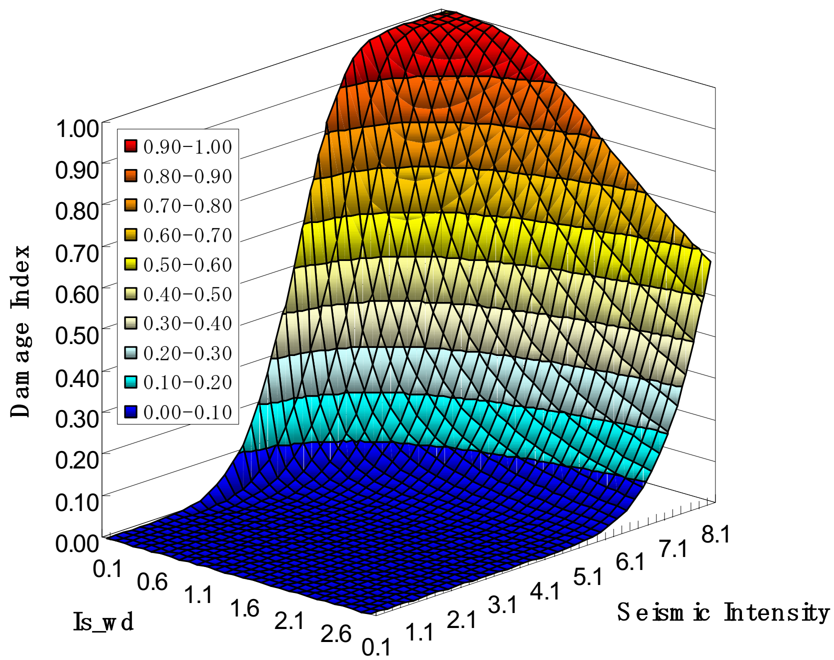


Fig.3 The Damage Index Function

INTERNAL SPACE LOSS MECHANISM

It is natural that inhabitants in seriously damaged house faced with death. Okada [2] proposed the definition of the state of internal space loss to explain the relation with occurrence of human injury. The definition is shown in Fig. 4. There are four sorts of internal space loss, namely plan loss, cross-sectional loss, volume loss and air pollution. We express them at a loss rate of the domain [0.0, 1.0] respectively and call their values by the name of W-Score.

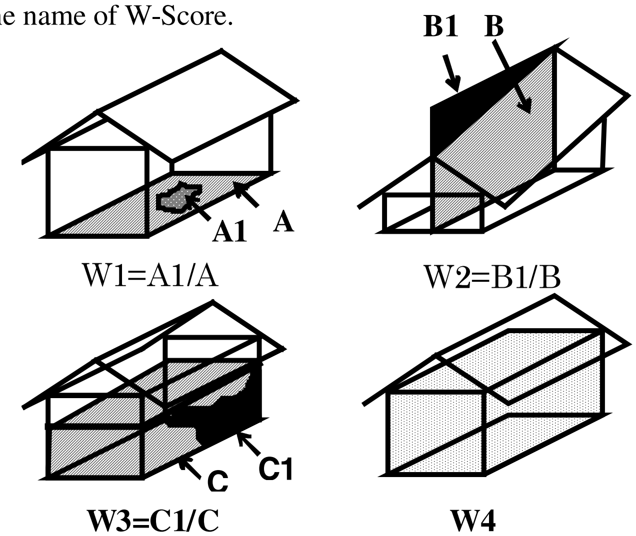


Fig.4 Four sorts of internal space loss

THE DEATH RATE FUNCTION

In this chapter, we explain the relationship between building internal space loss (W-Score) and the rate of death. Fig.5 shows the structural damage state of building (abbreviated to Damage Pattern) and some scales. Fig.6 shows the rate of the dead calculated with Eq.(3) for every Damage Pattern. It is clear that structural damage affects the occurrence of dead. We can transpose the relationship between Damage Pattern and the rate of death to the relationship between Damage Index and the rate of death while considering Fig.5. By the way, the relationship between Damage Index and W-Score is shown with a group of points in Fig 7. W-Score shows a tendency to high increase, it is possible to express the relation between the Damage Index and W-Score with curve by fitting beta distribution (Eq.(4), Fig.7).

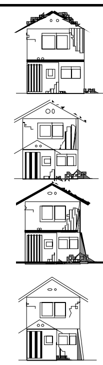
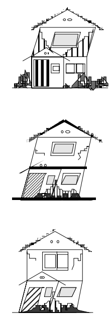
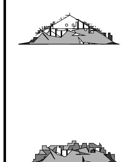
DamagePattern					
Damage Grade	D2	D3	D4	D5	D6
Damage Index	0.3	0.5	0.7	0.9	1.0

Fig.5 The Structural damage scales of building

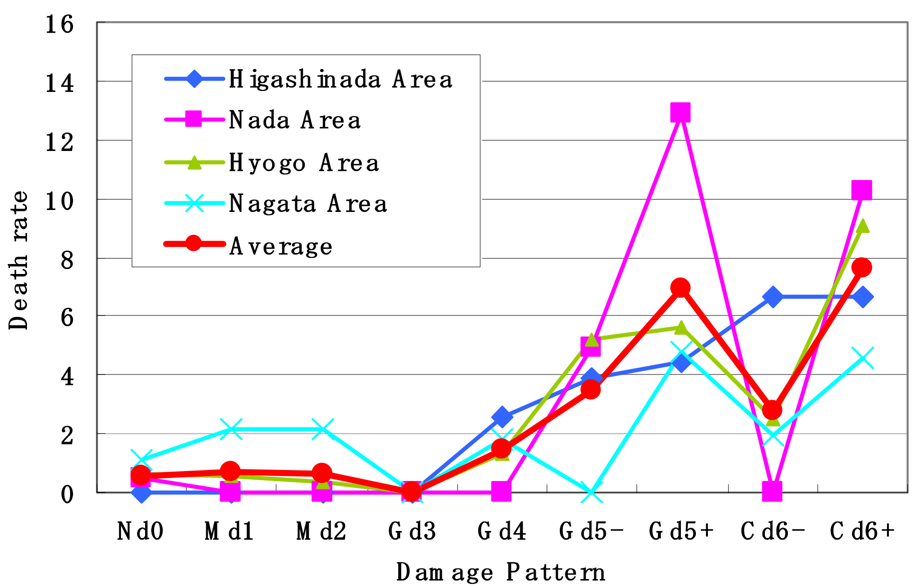


Fig.6 The Death rate for every damage pattern

The result of the questionnaire survey [6] in Higashinada Ward (severest human damage occurred) shows that the inhabitant rate in the 1st floor to the 2nd floor is 43:57, and the death rate in the 1st floor to the 2nd floor is 32:7. These can make the death rate function Dp (Eq.(5), Table1) with the parameter of W_Score for every housing type and every floor. The form of the function is shown in Fig.8. The first floor has about 4 times as high rate of death than the second floor and it turns out that the second floor is safer than the first floor. The higher W_Score becomes, the larger difference becomes.

$$Dr_{All}(ptn) = (Dn(ptn) / Hn(ptn)) \times 100 \qquad (3)$$

where
$Dr_{All}(ptn)$: The death rate per house
$Dn(ptn)$: The death toll for every damage pattern
$Hn(ptn)$: The total number of inhabitants classified by damage pattern

$$B(p,q) = \int_0^1 x^{p-1}(1-x)^{q-1}\,dx \qquad (4)$$

$$Dp = ae^{bx} \qquad (5)$$

Dp : The death rate for every floor

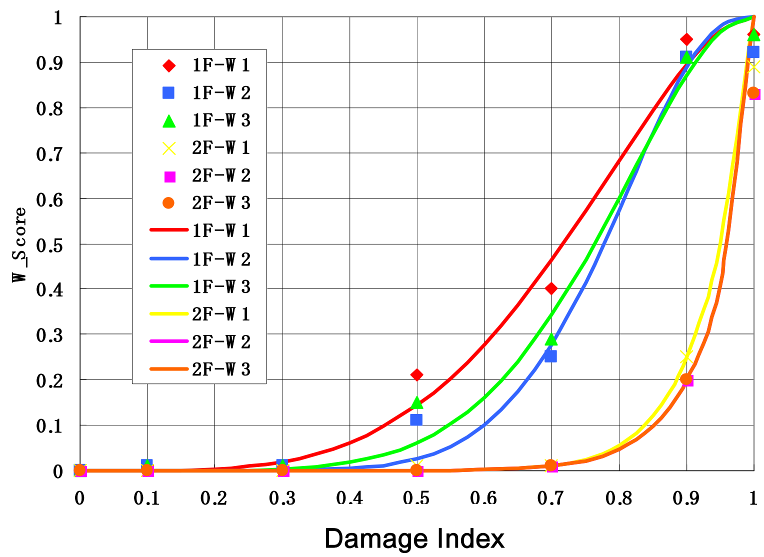


Fig.7 The equation between Damage Index and W-Score

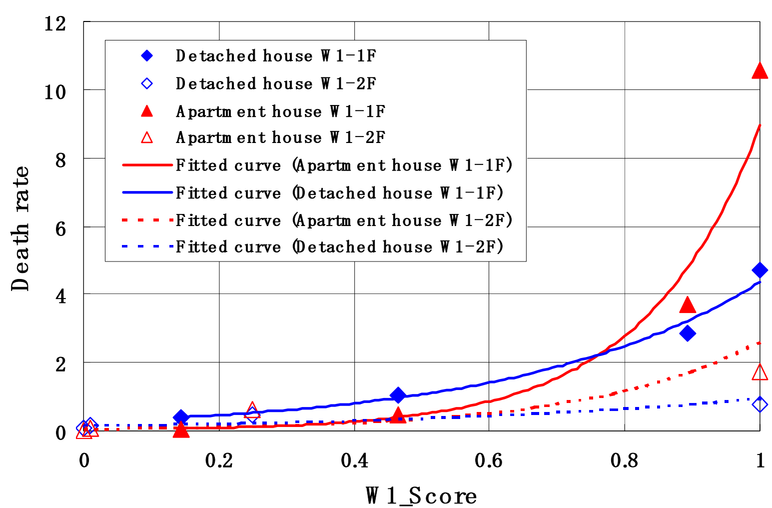


Fig.8 The Death rate function with the parameter of W-Score (Ex.W1)

Housing Type	Floor	W_Score	a	b
Detached house	1F	W1	0.1358	1.938
	2F	W1	0.2601	2.8176
Apartment house	1F	W1	0.0465	4.022
	2F	W1	0.0258	5.8475

TIME EFFECT ON DEATH TOLL

Earthquake occurrence time influences the death toll greatly. For example, in the case of the Kobe earthquake it occurred in the early morning and large number of people were killed; on the other hand in the case of the 2000 Tottori-ken Seibu earthquake with the almost same magnitude, almost all of people survived owing to no inhabitants staying indoor when it occurred in the daytime. Fig.9 shows the variation in indoor occupancy for inhabitants in the time history in Hyogo prefecture. This figure indicates that the rate of being in a house is lower in the daytime than in the night and early morning. The time factor on the above should be taken into consideration of death toll estimation.

THE ESTIMATED DEATH TOLL

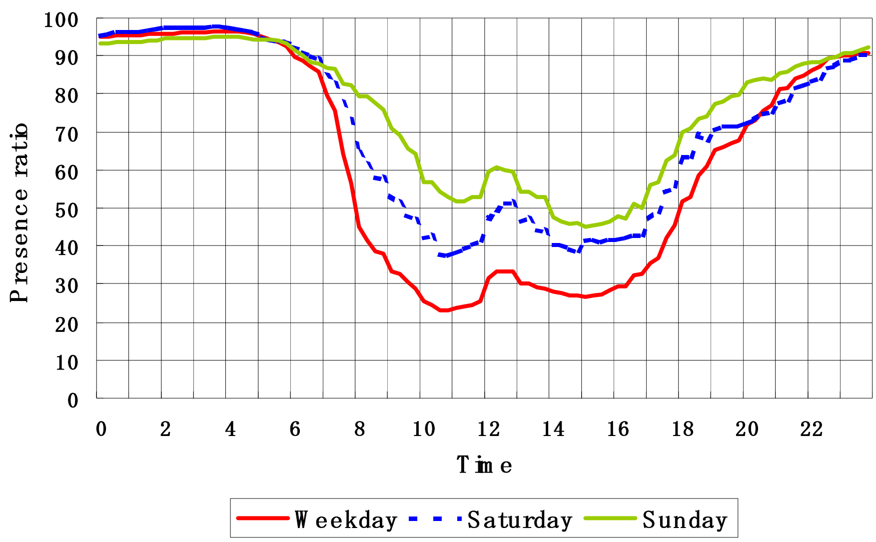


Fig.9 The rate of being at home in time history in Hyogo

Death toll is calculated by multiplying the number of inhabitants at home by the rate function of the dead. This composition is made into one equation and it is shown below (Eq.6). Fig.10 shows the estimated death toll by Eq.6 compared with other equations and the actual death toll (Fig.10). The fire defense agency formula always overestimates and Kawasumi formula [1] estimates so little than actual toll. This research formula shows more precise estimation than them.

$$D = \sum [\sum (Wn \times Ap \times Ed) \times Df \times Rn \times Hp \times Hr \times Bf \times Dp] \qquad (6)$$

where

D: Death toll,
Wn: The number of wooden housing units for every area,
Ap: Rate of building construction age
Ed: Frequency distribution of Is_wd
Df: The Damage Index Function
Rn: The number of inhabitants per building,
Hp: Rate of inhabitants being at home on earthquake occurrence time classified by all prefectures
Hr: The rate of the houses of 1 story and 2 stories,
Bf: Beta function (Relation between Damage Index and W-Score)
Dp: Rate function of the dead

CONCLUSION

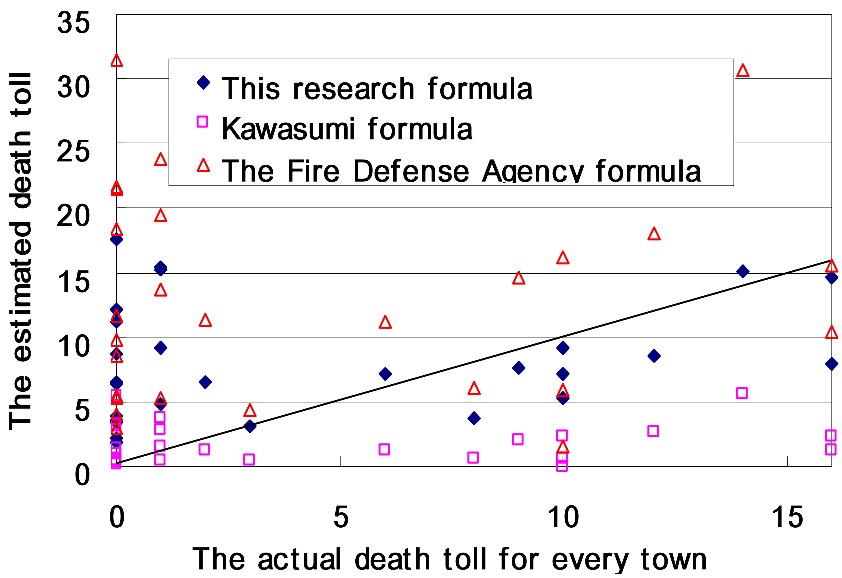


Fig.10 Comparison of the death toll (the Kobe earthquake)

In this study, it was able to propose a minute estimation model by describing the rate of the dead for every building damage pattern, the Damage Index Function for every age, the mechanism that results in the death occurrence and the rate of inhabitants being at home etc as a chain model of a phenomenon, and formulizing a phenomenon. Unlike other equations, it excels in the point that the rate of death on the first floor and the second floor, and detached house and apartment house can be expressed independently. The proposed equation has higher precision than the existing equations, such as the Fire Defense Agency formula and Kawasumi formula.

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