# SOME RELATIONSHIPS BETWEEN INTENSITY OF HAZARDOUS NATURAL EVENTS AND AMOUNT OF DISASTER DAMAGE

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*Abstract* Regression equations which relate the amount of damage to the intensity of hazardous natural events are derived using statistical data of damages due to typhoon, flood, storm surge, landslide, earthquake and tsunami. Amounts of damages, especially casualties, are affected by such factors as locality, time, period, hazard type and so on. Regression coefficients and constants show quantitatively the effects of these factors on the amounts of damages. As physical indices to represent the intensity of natural events, radius of typhoon circle, central atmospheric pressure, maximum discharge, rainfall intensity, submerged depth, seismic scale, wave height *etc.* are considered. The relations may be used for damage prediction.

## 1. Introduction

The relation of the intensity of a natural event to the amount of damage has been analyzed using statistical data on disaster damages due to major natural hazards in Japan such as typhoon, storm surge, flood, landslide, earthquake and tsunami, in order to search for effective measures for reducing the damage. Since to minimamize human casualties is the primary role of disaster prevention activities, research efforts have concentrated on the analysis of casualty losses and related human factors. Human casualties are greatly affected by various kinds of conditions which influence behavior, mentality and preparedness of people against hazards. Therefore, there is much more room for human activities against hazards in order to reduce loss of lives as compared with such activities for reducing property damage.

A linear relationship between the intensity of a natural event and the damage caused does not always exist, since there are many factors which intervene in the processes from the time of impact of the natural event to the occurrence of damage and its social consequences. Such factors are locality (regionality of natural and social characteristics), time (human behavior at the time of impact), period (secular change of socioeconomic factors), type of natural event directly causing the damage, hazard experience *etc.* The quantitative effects of these factors on the scale of damage have also been estimated.

The number of houses damaged can be used as an index to represent the intensity of

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hazardous natural impact. Clear correlations between the number of damaged houses and casualties are recognized for all kinds of natural hazards. Research findings on the relation of the intensity of events to damage and on regulating factors of the relation are useful for preparing against hazards, as well as for damage prediction.

## 2. Disasters due to Heavy Rain and Strong Wind

The power of a typhoon is represented by the central atmospheric pressure and the radius of the typhoon circle. Most of the damage due to a typhoon occurs in the area where it lands, since its power generally weakens rapidly after landing. Fig. 1 represents the relationship between the power of a typhoon at landing time and number of deaths. Eighty-eight typhoons which landed in the period from 1946 to 1982 have been considered. By multiple regression analysis the power of a typhoon can be represented by $P^2R^{1.5}$ where P is the difference between 1010mb and the central atmospheric pressure, and R is the maximum radius of the typhoon circle.

Most of the data plotted on the upper left part, where degree of human life loss is higher, are from the typhoons which landed at midnight in Central Japan. In Kyushu and Shikoku, which are frequently struck by typhoons, the degree of human life loss is fairly low even in the case of midnight landings. The people living in the regions frequently struck by typhoons are always prepared against hazards and evacuate quickly.

Thus, the number of deaths due to typhoons is represented by a power function of P and R at landing time. The upper regression line in Fig. 1 is the one obtained for typhoons which landed during the middle of the night in Central Japan, and the lower one is for typhoons which landed during the daytime and early in the evening, before 10 pm. The gradient of the upper line is 1.4 times as large as that of the lower. That is, in the case of landings in the middle of the night, the number of deaths increases more rapidly with an increase in the power of the typhoon. If a middle magnitude typhoon with $P = 50$mb and $R = 400$km lands in Central Japan at midnight, 220 deaths are predicted, while if the same typhoon lands in the daytime or early evening 25 deaths (in more detail, 40 deaths before 1960 and 20 deaths after 1961) are predicted by the regression lines. Storm surges may cause disasters with a high degree of damage.

The degree of human life loss clearly differs with the time of the landing. Incidents with a high degree of damage occurred in the time zone from 10 pm to 2 am. Time affects human behavior and the perception of residents. It is obvious that recognition of danger, dissemination of warnings, execution of evacuation and various kinds of activities against hazards can be done more easily in the daytime than late at night. In the early evening before 10 pm, when most people are still out of bed, evacuation can be executed fairly easily though it is dark outdoors. Geographical location is also related to the level of preparedness of the residents. In rural areas, especially in mountain villages, there exist many factors favorable for prediction of risk, warning dissemination and execution of evacuation.

The number of houses destroyed by typhoons can also be represented by a power function of P and R. By multiple regression analysis, 4.8 and 0.5 are obtained for the exponents of P and R respectively. Typhoons which accompanied high storm surges and

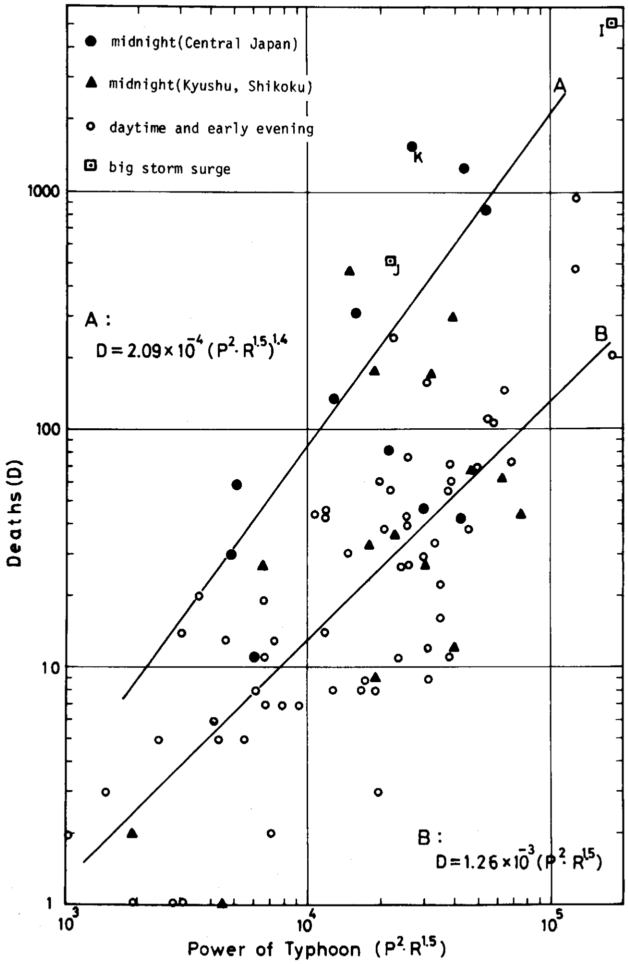

**Fig. 1** Relationship between power of typhoon at landing time and number of deaths (88 typhoons, 1946–1982)
P: (1010–central atmospheric pressure) mb, R: radius of typhoon circle, A: regression line for typhoons landed at midnight in Central Japan, B: regression line for typhoons landed in the daytime, I: Isewan Typhoon, J: Typhoon Jane, K: Typhoon Kathleen

strong winds destroy large number of houses.

The degree of damage changes with the lapse of time due to the change in socioeconomic conditions. The ratio of death toll to the power of typhoon was high and greatly fluctuated until 1960. Since 1961 the ratio has shown a nearly constant value at a lower level (about a half of that before 1960). After the worst disaster caused by the Isewan Typhoon in 1959, various kinds of disaster prevention measures have been executed more earnestly. Also, the dissemination of information on typhoons by means of TV has become widespread. As a result, the degree of human life loss was reduced remarkably in the mid-1960's. However, from then until the present no further decrease has been observed. This may suggest that there is a certain limit for reducing damages by means of typhoon forecast and warning dissemination systems.

A remarkable decreasing tendency can be seen in the ratio of destroyed houses to the power of typhoon. This may have resulted from an improvement in the quality of houses. The degree of damage for the last decade (1973–82) is one fifth of that for the earliest decade (1946–55).

The Isewan Typhoon which attacked Central Japan in 1959 caused catastrophic damage with more than 5,000 deaths. The greater part of the damage was caused by a high storm surge which occurred in the Ise Bay at 9:30 pm. Deltaic lowland and reclaimed land situated at the innermost part of the bay was innundated for a long time. Inland areas were damaged by strong winds and landslides.

Differences in the degree of human life loss by geographical location and by the kind of hazard were examined using the damage data. Fig. 2 represents the relationship between the number of houses destroyed and the number of deaths. Each dot shows the damage data for

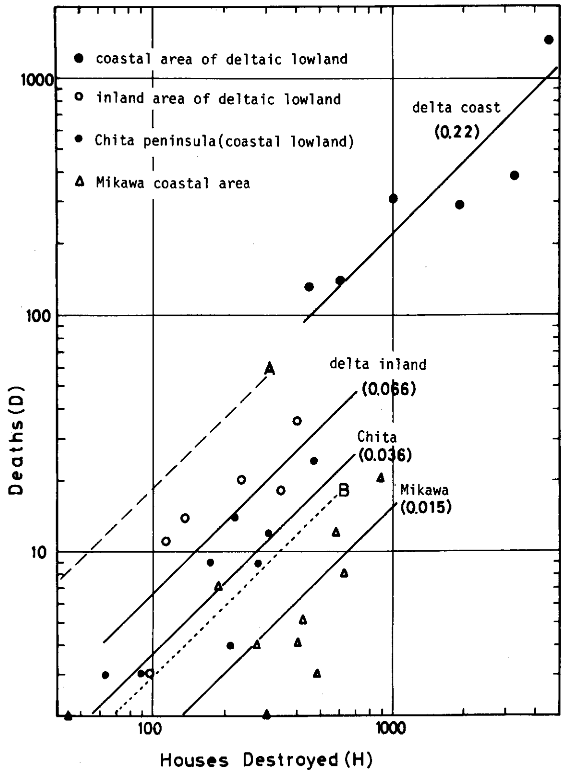

Fig. 2 Regional difference of the degree of human life loss (D/H) due to storm surge by the Isewan Typhoon in 1959. Numbers in parentheses are regression constants in cases when regression constants are fixed at 1, A: regression line for landslide disasters, B: regression line for disasters caused by strong winds

each city, ward, town or village. The number of houses destroyed can be used as an index to represent the magnitude of natural impact which actually acted in residential areas. The highest correlation is obtained when the number of houses destroyed is given by $H_c + H_w \times 2$ where $H_c$ is the number of completely destroyed houses and $H_w$ is that of washed away.

In Fig. 2, the data for the coastal area of the deltaic lowland are plotted at the places with a high degree of human life loss. Using the values of the regression constant in cases where the regression coefficient is fixed at 1, the degree has been calculated as being about 3 times as large as that for the inland area of the deltaic lowland. Since the greater part of the delta is below sea level, storm surges invaded far inland. In Chita and Mikawa Districts, where mountains and hills are not far off the coast, the degree of human life loss is smaller. In Mikawa District which was damaged by a storm surge in 1953, the degree is much smaller. It is about 1/15 of that for the delta coastal area. Many hazard incidents show that recent hazard experience is the most effective for reducing casualty losses. The degree of human life loss due to landslides is as large as that due to storm surges in the coastal area of the delta, and 7 times as large as that due to strong winds, though the scale of damage is smaller.

By using damage data from 9 drainage basins in Northern Kyushu which suffered from the Nishinippon Flood in 1953, the number of houses destroyed can be represented by a function of the flood discharge, basin gradient and household density of each drainage basin, as shown in Fig. 3. High correlation is also obtained when the product of the amount of rainfall and basin area is used instead of flood discharge.

The amount of rainfall is a major index for representing the intensity of hazardous

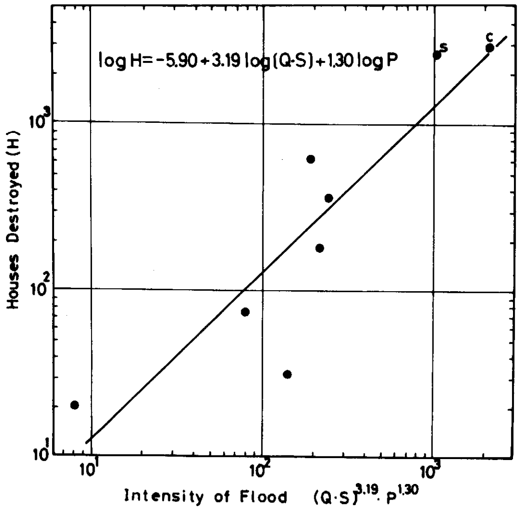

**Fig. 3** Relationship between intensity of flood and number of houses destroyed by the Nishinippon Flood in 1953 in Northern Kyushu
Q: maximum discharge ($m^3$/sec), S: relief ratio, P: density of dwellings ($km^{-2}$), C: Chikugo River drainage basin, S: Sira River drainage basin

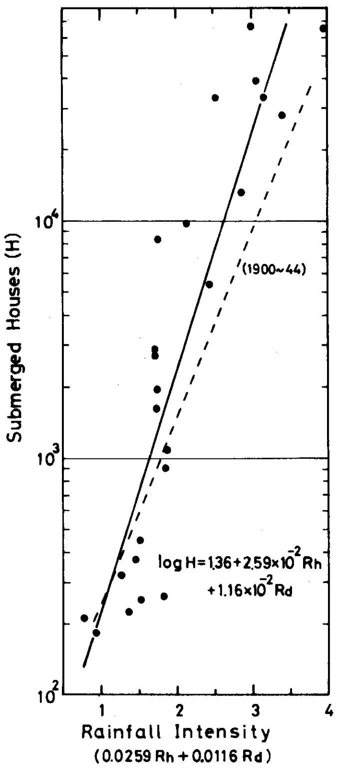

**Fig. 4** Relationship between rainfall intensity and number of submerged houses (Nagoya City, 1965–1980)
$R_h$: maximum hourly, $R_d$: maximum daily, chain line: regression line for the period from 1900 to 1944

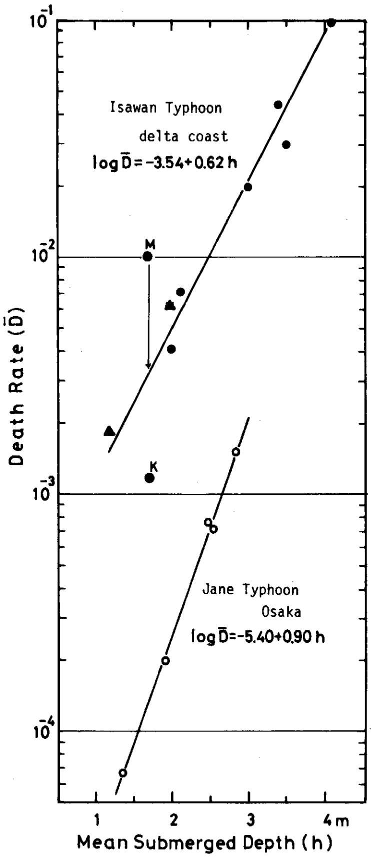

**Fig. 5** Relationship between mean submerged depth and death rate due to storm surges and flash floods
black circle: storm surge by the Isewan Typhoon, black triangle: flood by the Kanogawa Typhoon, blanck circle: storm surge by Typhoon Jane

natural events. However, rainfall itself does not cause damage directly. Secondary events such as flood, lanslide, debris flow etc. which are initiated by rainfall in fairly limited areas, cause the damage directly. Therefore, the amount of damage is not always quantitatively related to the amount of rainfall. Within a limited area, such as a large city, correlation is generally recognized between rainfall intensity and number of submerged houses, as shown in Fig. 4. In this case the physical meaning of the correlation between both factors is clear.

The depth of flooding water is one of the major indices representing the intensity of a flood. The death rate due to storm surge and flash flood can be represented by an exponential function of mean submerged depth (Fig. 5). The upper regression line is the one obtained for the coastal areas of the deltaic lowland which suffered from storm surge caused by the Isewan Typhoon, and the lower one is for coastal areas of Osaka which suffered from storm surge caused by Typhoon Jane in 1950. The data of the Kanogawa Flood (black triangles) are plotted near the upper regression line. Many lives were lost due to drift woods from lumber yards at Minami-ku, Nagoya City, denoted by M. Deaths caused by the drift woods are estimated at about 1000 persons, from the distance between M and the line. The data, K, of a town situated in the inland area of the delta is plotted fairly well below the line. The lower regression line is the one obtained for the damage caused by Typhoon Jane, which attacked Osaka at 1 pm. On the other hand, the incidents of the upper group occurred at night. The difference of the two regression lines may be caused mainly by the difference in the time of the disaster. There is a possibility that the death rate for night time disasters amounts to ten times that in the daytime.

In 1961, the Muroto Typhoon II struck Osaka City at about 1 pm, and caused storm surges of the same tide level as that caused by Typhoon Jane. Nevertheless, no deaths were directly caused by the storm surge. This may be due to the quick evacuation of citizens urged on by the hazard experience of Typhoon Jane and the Isewan Typhoon only two years before. In general, those who suffered from disasters have high hazard awareness, react sensitively to unusual situations, perceive a risk ahead of time, and evacuate quickly.

## 3. Disasters due to Earthquakes

Many empirical equations which relate the intensity of seismic vibration to the number or the rate of houses damaged have been presented so far. In the case of earthquake disasters, the rate of houses damaged is a good index for representing the intensity of hazardous natural impact.

In Japan the most significant natural hazard is the earthquake, especially in urban areas. Fig. 6 shows the relationship between the number of houses damaged and deaths due to earthquake disasters which occurred in urban areas in the period from 1891 to 1978. By regression analysis the highest correlation is obtained when the number of houses damaged is represented by $H_c + H_b + 0.2\ H_p$, where $H_c$ is completely destroyed, $H_b$ is burnt and $H_p$ is partially destroyed. The regression coefficient is a little more than 1, which means that casualties in an urban area increase at a slightly increasing rate with the increase in the intensity of natural impact. A multiple regression equation which has the term of the scale of fires has also been derived (represented in Fig. 6). It is feared that big fires after an earthquake shock may cause a tremendous number of deaths.

Recently the quality of houses has been very much improved and heavy tiled roofs have been replaced by light zinc roofs. Therefore, houses at present are not easily collapsed completely. As a result recent incidents, denoted by S and N, are plotted fairly far below the regression line. However, on the other hand, in modern cities there are various kind of dangerous factors such as high speed traffic, poisonous gasses, petroleum tanks, crowds etc.

In Fig. 7 the relationship between the rate of houses damaged and death rate of earthquake disasters in urban areas is shown. In cases when a city is hit by an earthquake of the 6th degree on the seismic scale, the death rate resulting from it is assumed to be about 1%, and in case one of the 5th degree, about 0.01%.

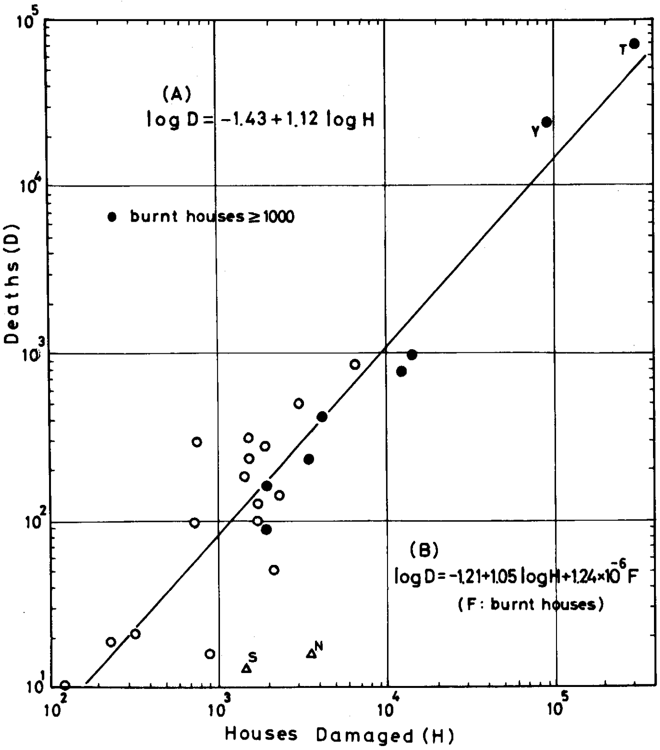

**Fig. 6** Relationship between number of houses damaged and deaths due to earthquake disasters occurred in urban areas in the period from 1891 to 1978
B: multiple regression equation which has the term of the scale of fires, T: Tokyo (1923), Y: Yokohama (1923), N: Niigata (1964), S: Sendai (1978)

The Sanriku coastal region was seriously damaged by tsunami in 1896, 1933 and 1960. Fig. 8 represents the relationship between wave height and the number of houses destroyed in each village in the Sanriku coastal region. The absolute wave height can not always be correlated with the amount of damage since the ground altitudes and topographic locations of villages differ. Then, in abscissa the ratio of wave height in 1933 to that in 1896, and in ordinate the ratio of the number of houses destroyed in 1933 to that in 1896 are taken respectively. A clear linear relation can be found.

The degree of damage caused by the Sanriku Tsunami in 1896 is 5 times as large as that of the storm surge caused by the Isewan Typhoon. The districts seriously damaged by the tsunami in 1960 suffered only slight damage from the tsunami in 1933. Emergency evacuation promoted by hazard experience and awareness of danger is the most effective way for reducing casualties due to tsunami.

The author wishes to dedicate this paper to Professor Takamasa Nakano in commemoration of his retirement from Tokyo Metropolitan University.

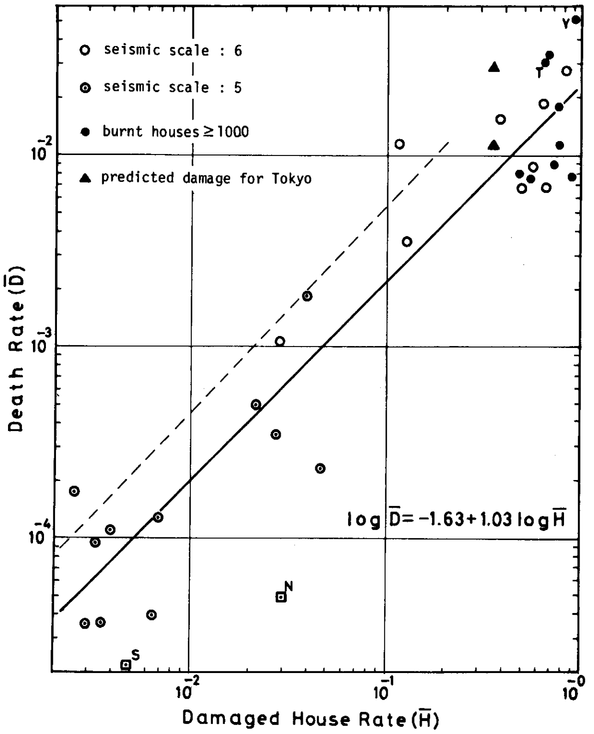

Fig. 7 Damage rate of earthquake disasters in urban areas. Chain line: regression line for landslide and flood disasters in urban areas, Y: Yokohama, T: Tokyo, N: Niigata, S: Sendai, upper triangle: predicted by Eq. A, lower triangle: predicted by Eq. B

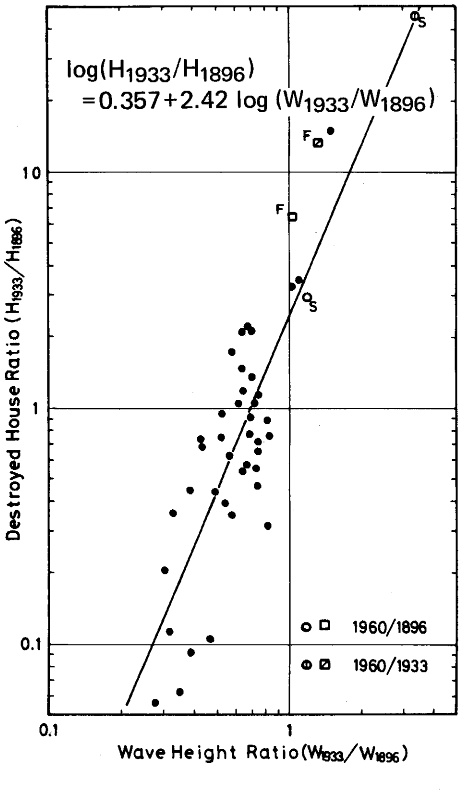

Fig. 8 Relationship between wave height and houses destroyed by tsunami in Sanriku coastal region
$H_{1933}$: means the number of houses destroyed in each village by the tsunami in 1933, and $W_{1933}$ means wave height by the tsunami in 1933, F: Ofunato, S: Sizukawa

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