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AN EVALUATION STUDY ON DISTRIBUTION-CHARACTERISTICS OF PROPERTY LOSSES CAUSED BY EARTHQUAKES

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1. INTRODUCTION

A better understanding of the scale and distribution of disasters in future earthquakes, which may not be avoided only by physically technological countermeasures, is necessary in earthquake disaster mitigation programs. If areas vulnerable to earthquakes are identified in advance, relevant administrations can take the predisaster countermeasures such as retrofitting vulnerable structures, reallocating lifeline facilities and disseminating permeably disaster risk potentials to residents. Additionally as for post-disaster countermeasures, such activities as surveying the damage, rescueing and rehabilitating concentratively are very efficiently applicable. Therefore estimating accurately the scale and distribution of earthquake disa sters is very effective in both pre- and post-disaster countermeasures which should optimize utilizing limited resources for the disaster mitigation.

Quantitative estimations of earthquake disasters have been carried out for existing wooden houses1)~4), bridges5) and underground pipes6), In order to express the amount of losses, various kinds of indexes are used such as the equivalent ratio of razed houses to wooden houses, damaged spots per service line for underground pipes respec tively, however commonly usable indexes are necessary to evaluate the total loss of disasters and to compare them of various kinds of facilities. The property loss valued in money would meet this requirement.

The authors have investigated an evaluation method for property loss distribution by analyzing eighteen historical earthquakes in Japan.

2. METHODOLOGY OF THE ANALYSIS

The authors assumed a ratio of property losses caused by earthquakes as an index of earthquake disasters. The property loss ratio can be defined as a ratio between property losses (l) and existing assets (w) valued in money respectively, and expressed as functions of earthquake magnitudes, epicentral distances and subground conditions as follows :

$$D_{\mathrm{I}} = G_{\mathrm{I}}\ 10^{\alpha M+\beta\Delta}, \quad \cdots\cdots\cdots(1)$$

$$D_{\mathrm{II}} = G_{\mathrm{II}}\ 10^{\alpha M+\beta\Delta}, \quad \cdots\cdots\cdots(2)$$

where the suffixes of I and II mean older subgrounds than diluvial deposits and younger than alluvial respectively and,

$G_{\mathrm{I}}, G_{\mathrm{II}}$: constants for the subground types, I and II respectively,
M : earthquake magnitudes in Richter scale,
Δ : epicentral distances in km,
α, β : constants.

The ratio is to be evaluated in accordance with the subground condition as shown in Fig. 1 (a). The existing assets are distributed independently from it as shown in Fig. 1 (b). The property loss caused by an earthquake can be evaluated by multiplying the existing assets and the ratio as shown in Fig. 1 (c).

The constants in Eq. (1) and (2) were determined by a statistically optimum correlation for actual property losses of eighteen earthquakes that have occured in Japan since 1923.

A total property loss (L) in each earthquake can be estimated by summing up the losses of each mesh (l_i) which is appropriately divided into,

$$L=\sum_i l_i=\sum_i \{\delta_i (D_{\mathrm{I}})_i + (1-\delta_i)(D_{\mathrm{II}})_i\} w_i, \quad \cdots\cdots\cdots(3)$$

where

w_i : existing assets,
$(D_{\mathrm{I}})_i$: property loss ratios in subground type I,
$(D_{\mathrm{II}})_i$: property loss ratios in subground type II,
l_i : losses in mesh i,
δ_i : identification indexes,

$$\begin{cases} 1 \text{ for subground type I in mesh } i \\ 0 \text{ for subground type II in mesh } i. \end{cases}$$

As shown in the Reference 7) it can be said that

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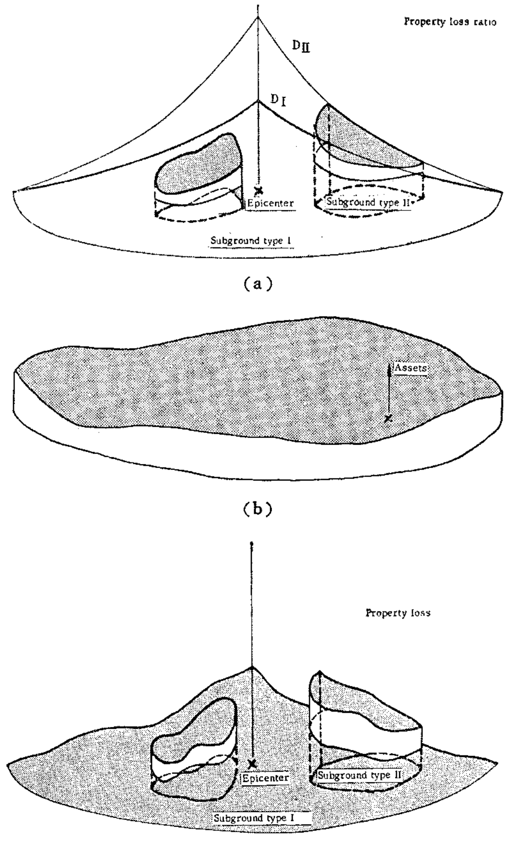

(a)

(b)

(c)

Fig. 1 Abstract of Property Loss Evaluation Caused by Earthquakes.

the assets correlate with the population in each district in Japan,

$$A_T=2.77\,P-0.891, \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(4)$$

where

A_T : gross tangible fixed assets in trillion yen (1970),

P : population in million (1970).

Accordingly the assets at each mesh were estimated from the relationships between the assets and local populations as shown in the following. In Eq. (4), the regression constant of 0.891 is negligible compared to the assets. After the neglection of the constant, Eq. (3) can be simply expressed as follows :

$$L=\sum_i\{\delta_i(D_{\rm I})_i+(1-\delta_i)(D_{\rm II})_i\}\,W\frac{P_i}{P}, \quad \cdots(5)$$

where

W : national wealth in yen,

P : population of whole country,

P_i : population of mesh i.

The population of mesh i (P_i) was estimated from an average of population densities which were obtained from the population for a unit area as municipalities suffered from an earthquake. Therefore the total property loss can be expressed by

$$\begin{aligned} L&=\frac{W}{P}\,\frac{P_D}{A_D}\sum_i\{\delta_i(D_{\rm I})_i+(1-\delta_i)(D_{\rm II})_i\}\,a_i\\ &=\frac{W}{P}\,\frac{P_D}{A_D}\sum_i\{\delta_iG_{\rm I}+(1-\delta_i)G_{\rm II}\}\,10^{\alpha M+\beta\Delta_i}a_i, \end{aligned}$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(6)$$

where

P_D : populations of the quake-damaged area,

A_D : dimensions of the quake-damaged area in km^2,

a_i : dimensions of mesh i in km^2,

Δ_i : epicentral distances of the graphical center of the mesh in km.

Fig. 2 shows the procedure stated above to estimate the losses caused by an earthquake.

The mesh used in this analysis was made to coincide with that of one hundred times of dimensions to the standard mesh of the National Land Information Mesh Data administrated by National Land Agency.

The loss was summed up within the area where damage possibly occurred as shown in Eq. (7)$^{8)}$,

$$\log R=0.5\,M-1.5, \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(7)$$

where

R : radii of the area where damage possibly occurred, in km,

M : Magnitude in Richter scale,

The unknown constants $G_{\rm I}$, $G_{\rm II}$, α and β were determined by employing the Least Square Method

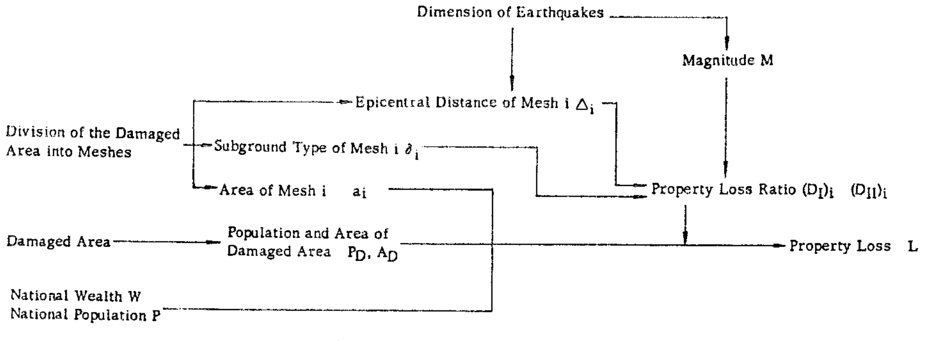

Fig. 2 Flow Chart to Evaluate Property Loss.

for differences of $\log\left(\frac{LPA_D}{WP_{Da}}\right)$ and its estimate $\log\left(\frac{\widehat{LPA_D}}{WP_{Da}}\right)$.

$$\sum_j\left\{\log\left(\frac{LPA_D}{WP_{Da}}\right)_j-\log\left(\frac{\widehat{LPA_D}}{WP_{Da}}\right)_j\right\}^2\to\text{Min.},\qquad\cdots\cdots(8)$$

j : suffix to denote j th earthquake,

a : average dimension of one mesh, about 100 km^2.

3. DATA USED IN THIS ANALYSIS

(1) National Wealth

National Wealth Survey has been conducted 12 times, once every 5 years until the year 1970. However there exists a twenty year blank of survey before and after World War II. Therefore the national wealth during the blank years was estimated from the relationship to the gross national product (GNP) as shown in Eq. (9)[7],

$$\log_{10}W=1.03+0.937\log_{10}N,\ \text{(unit : million yen)}\qquad\cdots\cdots(9)$$

where N means Gross National Product.

(2) Populations and Dimensions of the Damaged Area

The population and dimension of the damaged area to be used in Eq. (6) were the sum of those of municipalities which were involved within the radius (R') given by Eq. (10).

$$\log_{10}R'=0.5-1.85,\qquad\cdots\cdots(10)$$

where the radius R' corresponds to the area, within which the seismic intensity of Japan Meteorological Agency is expected to be greater than fifth degree[9].

The data of the population and area as of 1970 were used. The local population must have changed, but the distribution of the population, which was used in Eq. (6), is assumed to be steady before and after 1970.

(3) Subground Condition

Each mesh was classified into subground type I or II according to the Reference 10). Fig. 3 shows

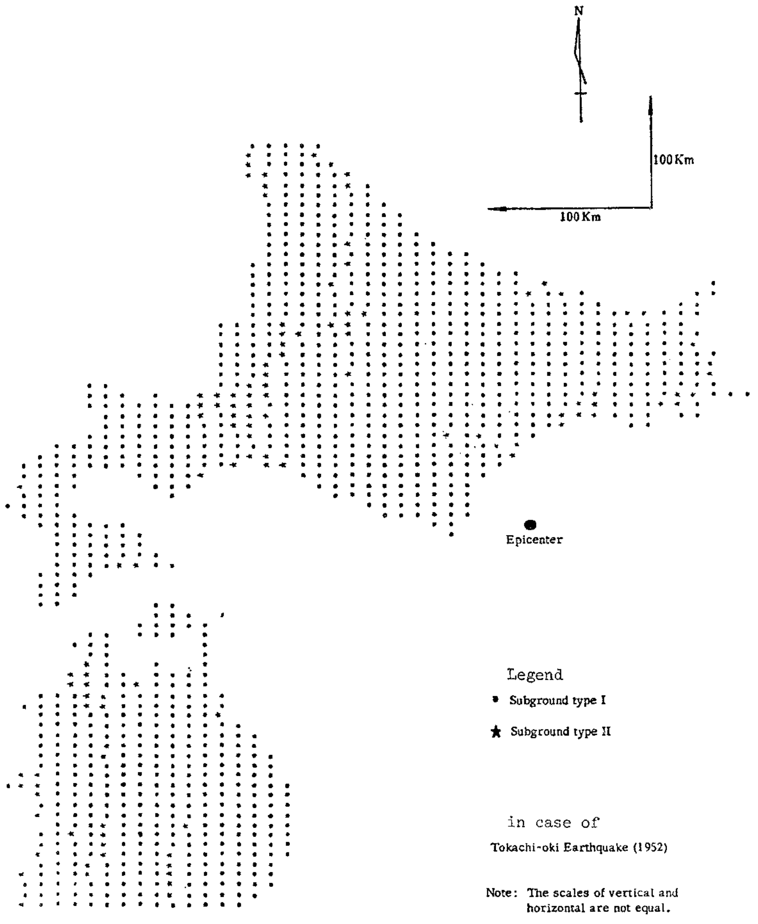

Fig. 3 An Example of Subground Types.

an example of the classifications of subgrounds in the northern part of Japan.

(4) Earthquakes Used in the Analysis

Eighteen earthquakes, whose recorded property losses are listed in Table 1, were used in this analysis. The influence of inflation were not taken into consideration of the loss value, because both the loss and existing assets were valued in current prices.

Table 1 Property Loss Caused by Earthquakes

Earthquake	Year	Magnitude	Property Loss (Unit : million yen)	Estimated National Wealth (Unit : million yen)
Kanto	1923	7.9	5 500	77 000
Kita-Tajima	1925	6.5	89	78 000
Kita-Tango	1927	7.5	82.18	68 000
Kita-Izu	1930	7.0	25.46	63 000
Shizuoka	1935	6.3	10.32	96 000
Oga	1939	7.0	7.73	182 000
Tottori	1943	7.4	160	337 000
Nankai (Kochi Pref.)	1946	8.1	2 792	2 206 000
Fukui	1948	7.3	305 000	11 120 000
Imaichi	1949	6.7	3 500	13 860 000
Tokachi-oki	1952	8.1	15 183	24 200 000
Hyuganada	1961	7.0	163	70 380 000
Miyagiken-hokubu	1962	6.5	4 049	77 500 000
Niigata (Niigata Pref.)	1964	7.5	130 000	103 700 000
Yebino	1968	6.1	8 876	178 200 000
Tokachi-oki*	1968	7.9	58 395	178 200 000
Nemuro-hanto-oki	1973	7.4	3 925	265 400 000
Ohitaken-chubu	1975	6.4	4 493	482 700 000

note :

*	
for Hokkaido	11 356
for Aomori Pref.	47 039

4. RESULTS OF THE ANALYSIS

The regression formulas for Eqs. (1) and (2) were introduced as follows :

$$D_{\mathrm{I}}=7.9\times10^{-7}\times10^{0.62M-0.0028\Delta}, \quad\cdots\cdots\cdots\cdots(11)$$

$$D_{\mathrm{II}}=1.9\times10^{-6}\times10^{0.62M-0.9928\Delta}, \quad\cdots\cdots\cdots\cdots(12)$$

for $6.1\leqq M\leqq 8.1$.

The multiple correlation coefficient by Eq. (13) was 0.82,

$$R=\sqrt{1-\frac{\sum_j\left\{\left(\frac{LPA}{WP_{Da}}\right)_j-\left(\frac{\widehat{LPA}}{WP_{Da}}\right)_j\right\}^2}{\sum_j\left\{\left(\frac{LPA}{WP_{Da}}\right)_j-\left(\frac{\overline{LPA}}{WP_{Da}}\right)\right\}^2}} \quad\cdots\cdots\cdots\cdots(13)$$

where

$\left(\frac{\overline{LPA_D}}{WP_{Da}}\right)$: average of $\frac{LPA_D}{WP_{Da}}$ for all earthquakes,

$\left(\frac{\widehat{LPA_D}}{WP_{Da}}\right)_j$: regression estimate calculated by Eqs. (11) and (12) for jth earthquake.

Fig. 4 and 5 show the value of D_{I} and D_{II}. As far as the multiple correlation coefficient is concerned, the regression formulas can be considered to estimate the property loss caused by an earthquake.

5. COMPARISON OF PROPERTY LOSSES AMONG FACILITIES

Fig. 6 shows the breakdown of the social capital according to the National Wealth Survey of 1970. If the composition of the social capital can be assumed to be constant for a decade before 1970, the ratio calculated by Eq. (14) of various kinds of facilities for seven earthquakes in Japan from 1961 till 1970 represents the individual loss ratios of

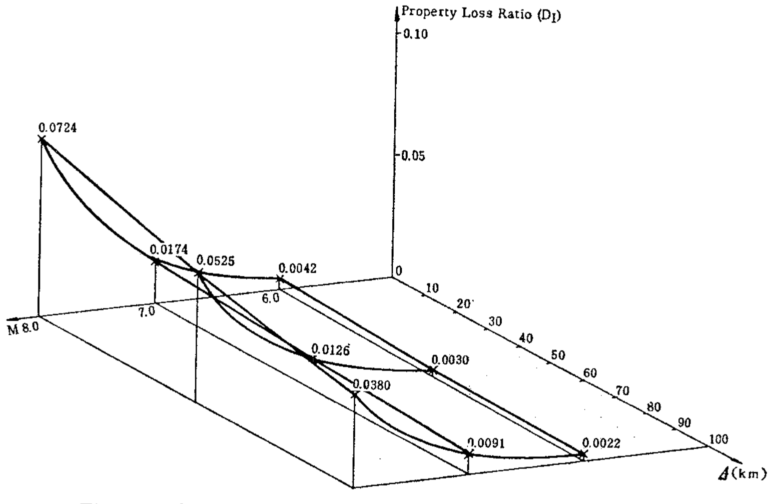

Fig. 4 Relationships among Magnitude, Epicentral Distance and Property Loss Ratio (Subground Type I).

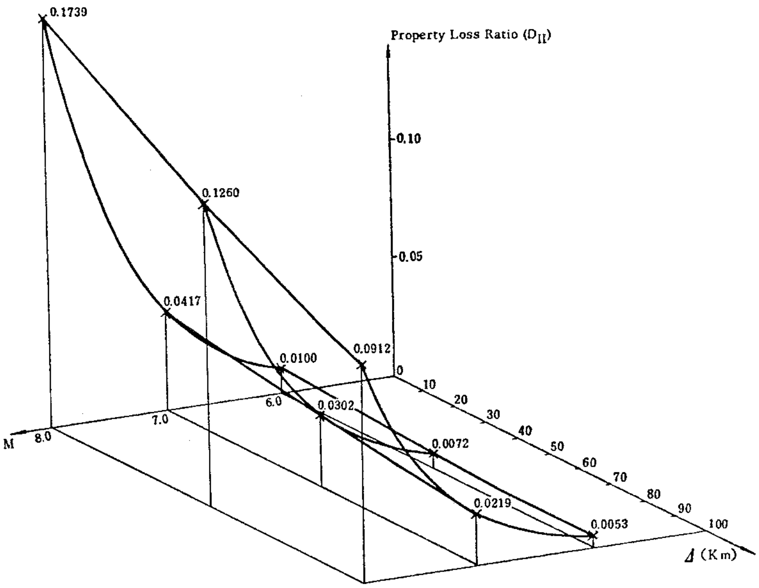

Fig. 5 Relationships among Magnitude, Epicentral Distance and Property Loss Ratio (Subground Type II).

32,876.2 bil.yen	Assets of Public Corporations (39.7)	Transportation (44.2)
		Electric Power (24.7)
		Telecommunication (14.8)
		Water Supply (13.7)
		Gas Supply (2.6)
21,082.7 bil.yen	Public Service Assets (25.5)	Education (49.4)
		Public Organizations (16.6)
		Religion (12.4)
		Medical Service (11.0)
		Cooperation (8.1)
		Public Insurance (2.5)
20,986.3 bil.yen	Public Assets (25.4)	Highway (38.7)
		Agriculture, Fishery, Forestry (26.5)
		River (19.9)
		Harbor (9.9)
		Others (5.0)
7,769.8 bil.yen	Governmental Assets (9.4)	Central (29.8)
		Local (70.2)

( ): percentage.

82,715.0 bil.yen in total

Fig. 6 Breakdown of Social Capital in 1970 National Wealth Survey.

facilities.

$$\text{individual loss ratio} = \frac{L_k P}{W_k P_D}, \cdots\cdots\cdots\cdots\cdots (14)$$

where

L_k : loss valued in money of facility k,

W_k : existing assets of facility k,

$$= \text{national wealth as of the year of the earthquake} \times \frac{\text{assets of facility } k \text{ as of 1970}}{\text{national wealth as of 1970}}$$

Fig. 7 to 14 show the relationships between the individual loss ratio of various kinds of facilities and the total property loss.

The procedure to evaluate the loss value is not always completely the same in each facility. However there is a tendency that the loss ratios of building and highway facilities are almost the same as that of the total property loss. The loss ratios of agriculture, river and harbor facilities are higher than the total. The loss ratios of electric power, telecommunication and water supply facilities are lower than that of the total, but they gradually reach the same level as the ratio itself comes to a greater value as shown in Fig. 15.

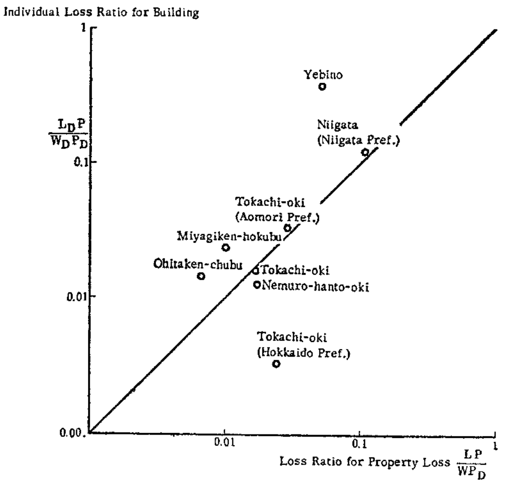

Fig. 7 Relationships between Loss Ratios of Property Loss and of Buildings.

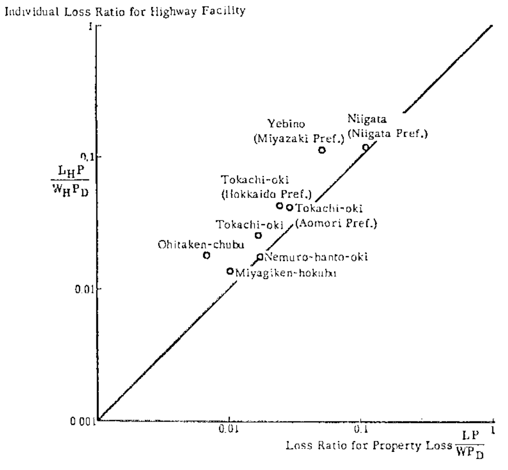

Fig. 8 Relationships between Loss Ratios of Property Loss and of Highway Facility.

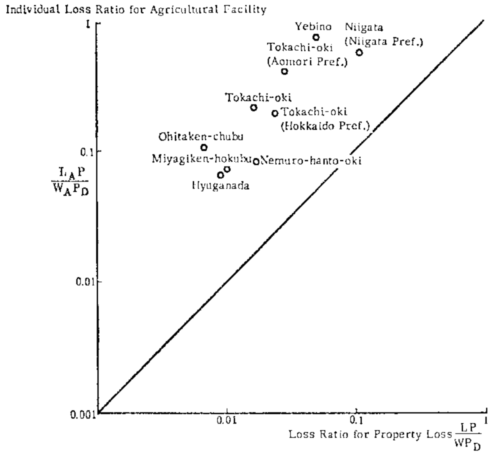

Fig. 9 Relationships between Loss Ratios of Property Loss and of Agricultural Facility.

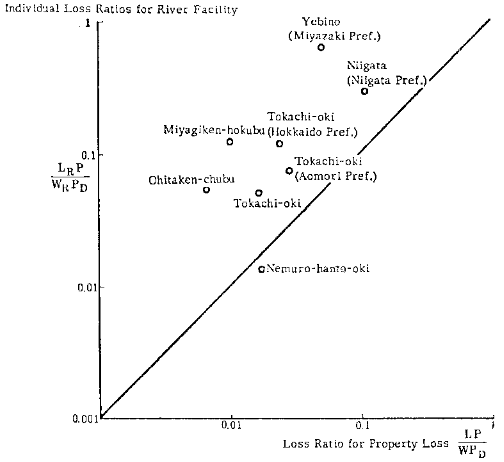

Fig. 10 Relationships between Loss Ratios of Property Loss and of River Facility.

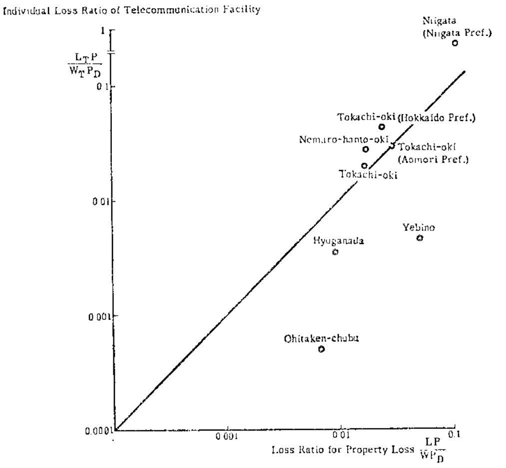

Fig. 11 Relationships between Loss Ratios of Property Loss and of Telecommunication Facility.

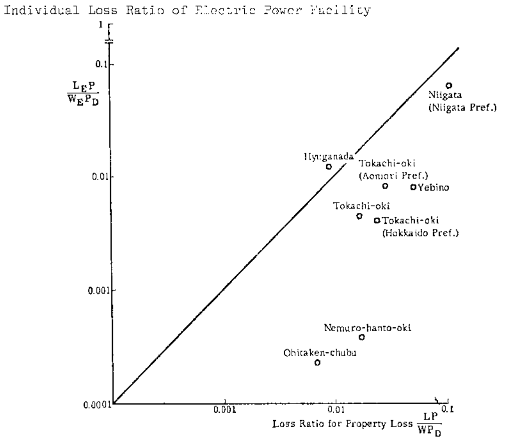

Fig. 12 Relationships between Loss Ratios of Property Loss and of Electric Power Facility.

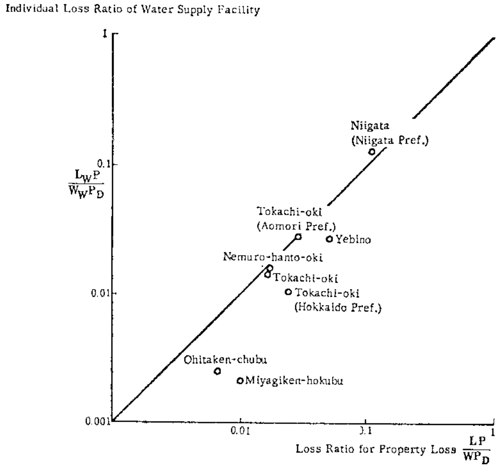

Fig. 13 Relationships between Loss Ratios of Property Loss and of Water Supply Facility.

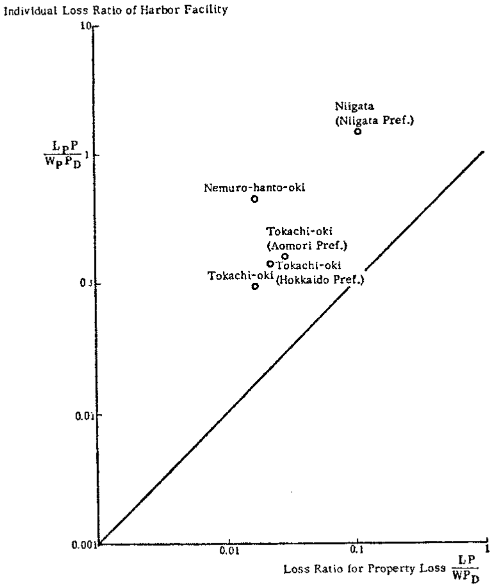

Fig. 14 Relationships between Loss Ratios of Property Loss and of Harbor Facility.

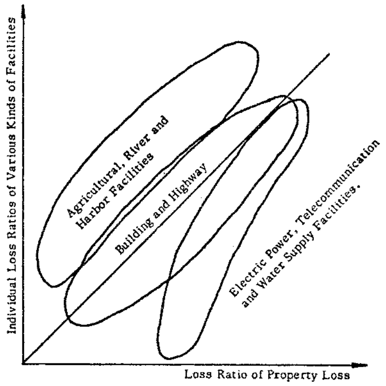

Fig. 15 Characteristics of Individual Loss Ratios of Various Kinds of Facilities.

6. CONCLUSIONS

By this analysis the following conclusions can be made.

(1) The property loss can be used as the index satisfactorily elucidating the scale of the earthquake disaster.

(2) The property loss ratio can be estimated from the magnitude of the earthquake, epicentral distance and subground condition.

(3) By comparing the property loss of various kinds of facilities, buildings and highway facilities are likely to suffer the average property loss. Agricultural, river and harbor facilities are likely to suffer greater loss than average. Electric power, telecommunication and water supply facilities are likely to suffer less than the average.

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REFERENCES

All references listed below are written in Japanese except 7).

1) Kawazumi, H. : Damage Distribution and Earthquake in Tokyo, Architecture Magazine, 773, 1951.
2) Omote, S. and S. Miyamura, : Relationships between Damage Distribution and Subground Conditions in Earthquake in Yokohama and Nagoya City, Architecture Magazine, 773, 1951.
3) Kuribayashi, E., et al. : Investigation on the Damage of Fukui, Yebino and Izuhanto-oki Earthquakes, Technical Memorandum of PWRI No. 1196, March 1976.
4) Kuribayashi, E., et al. : Investigation on the Estimation Method of Razed Houses and Fire Distribution Caused by Earthquakes, Technical Memorandum of PWRI No. 1256, May 1977.
5) Katayama, T. : A Methodology to Estimate the Bridge Capability against Earthquakes, Journal "Karamu No. 59" January, 1976.
6) Kubo, K., et al. : Quantitative Analysis of Seismic Damage to buried Pipelines, Proc. of the 4th Japan Earthquake Engineering Symposium, 1975.
7) Kuribayashi, E., et al. : An Evaluation Study on the Distribution Characteristics of Property Losses Caused by Historical Earthquakes, 10th Joint Meeting of UJNR, May 1978.
8) Katsumata, M. : Earthquake Magnitude and the Area Possibly to Suffer Damage., Proc. of the Spring Session of Seismological Society of Japan, 1977.
9) Usami, T. : List of the Earthquakes Causing Damage in Japan, Tokyo University Press, March, 1975.
10) Economic Planning Agency and National Land Agency : Classified Maps of Subgrounds.

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