USE OF EARTHQUAKE PREDICTION DATA FOR COST-BENEFIT EVALUATION OF RETROFITTING EXISTING HOUSES

by

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ABSTRACT

Retrofitting existing houses is the most urgent problem in earthquake disaster reduction in Japan. It is clear that some of the existing houses which remain without being reinforced, despite the low earthquake-resistance, will be the main factor of great loss and casualty during the coming earthquakes. Understanding the advantages of retrofitting our own houses in terms of cost-benefit will encourage the popularization of retrofitting. Hence, this research develops a method for evaluating the cost-benefit of retrofitting existing houses. In the process of evaluation, the earthquake occurrence probability which is a part of long-term earthquake prediction information is considered. Applying this method to real houses in Shizuoka Prefecture which may face a Tokai Earthquake in the near future, we tried to evaluate the effect of retrofitting on both the house owners and the regional government.

INTRODUCTION

The Hyogoken-Nanbu (Kobe) Earthquake in 1995 made it clear that retrofitting of existing houses is the most urgent problem in disaster reduction in Japan. Some of the buildings which are used for the public purpose such as schools, gymnasiums, hospitals, theatres and department stores have been obliged to be reinforced since 1995. However, retrofitting private buildings such as houses is difficult because the private buildings are not enforced to be retrofitted. The difficulties in recognizing the advantages of retrofitting for public people, high costs, complicated processes, difficulties in recognizing the necessities of retrofitting among others are factors that interfere the popularization of retrofitting. In this research, we turn our attention to the first of them, i.e. difficulties in recognizing the retrofitting advantages. Understanding the advantages of retrofitting our own houses in terms of cost-benefit will encourage the popularization of retrofitting. Hence, this paper suggests a method for evaluating the cost-benefit of retrofitting, considering earthquake occurrence probability. Applying this method to the real houses in Shizuoka Prefecture, we evaluate the influence that retrofitting may have on both house owners and the government in case of a Tokai earthquake. Through this paper, the way of making use of long-term earthquake prediction information is also discussed.

LONG-TERM EARTHQUAKE PREDICTION INFORMATION

Earthquake prediction information is generally classified into 4 groups:long-term, mid-term, short-term and very-short-term prediction. Each of them predicts a coming earthquake within several decades, several years, several weeks and from several hours to several days, respectively. This research deals with long-term earthquake information for which accuracy is comparatively high.

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For the study, Shizuoka Prefecture whose area is 7,779 km^2 and population is 3,770,000[2] is considered. This region has been historically attacked by Tokai earthquakes whose seismic centers are located along Nankai-trough. It is predicted that a coming Tokai earthquake with JMA (Japan Metrological Agency) seismic intensity 7. This region is the only area which has an alert system immediately after an earthquake prediction.

The Headquarters for Earthquake Research Promotion prepares maps of prospecting seismic ground motions. As a part of this project, it calculates the earthquake occurrence probability. According to this result, a Tokai earthquake will occur with the probability of 36.7 % within 30 years, 55.9% within 50 years and 84.3% within 100 years as shown in Fig.1[3]. In this research, we initially adopt the former, i.e. the object period is 30 years from 2001 to 2030.

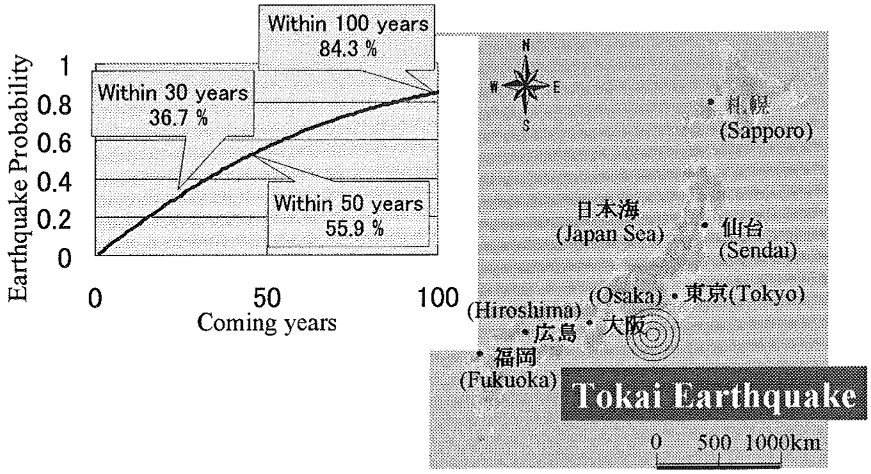

Fig.1 Probability of occurrence of Tokai Earthquake

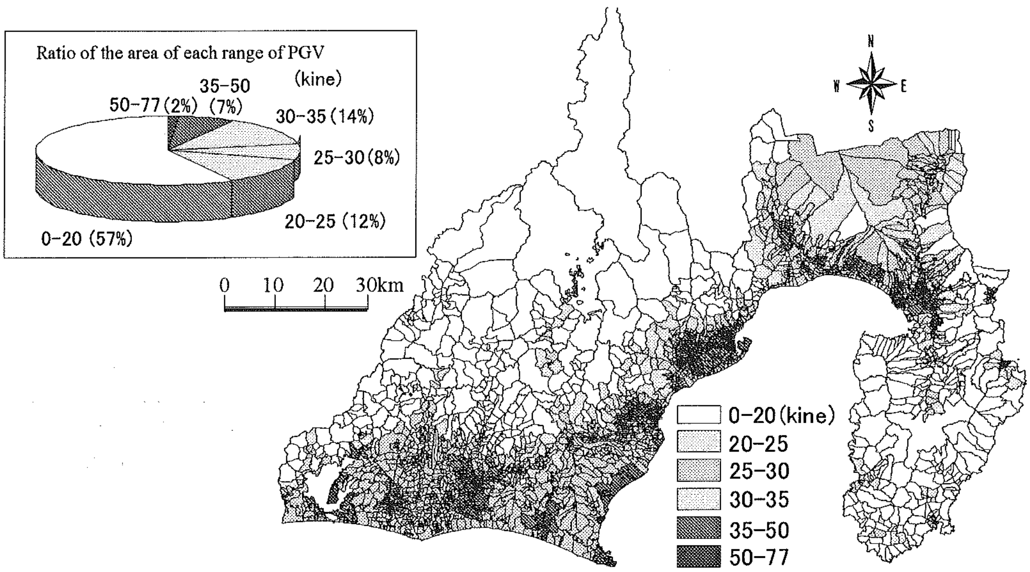

Fig.2 Distribution of PGV in Shizuoka Prefecture estimated when a Tokai Earthquake occurs

DISTRIBUTION OF ESTIMATED SEISMIC GROUND MOTION AND WOODEN HOUSES

Shizuoka Prefecture published The Third Earthquake Damage Estimation on May 30, 2001[4]. Figure 2 shows estimated Peak Ground Velocity (PGV) by a Tokai earthquake. In Shizuoka Prefecture, 846,384 wooden houses existed as of Jan.1, 1999. Among these, 62.8%(531,529 houses) were built before 1981 when Earthquake-proof standard in the Construction Standard Act was revised. Figure 3 shows the number of wooden houses classified by construction year and the estimated PGV at the location. This shows that many houses exist in the area where PGV is 30~35 kine, although 57% of land will tremble with PGV of 0~20 kine as shown in Fig.2.

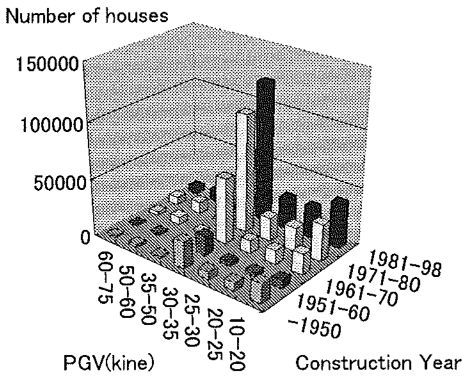

Fig.3 Number of wooden houses classified by constructed year and estimated PGV

METHODS OF EVALUATING THE EFFECT OF RETROFITTING

(a) Method considering earthquake occurrence probability

Retrofitting houses reduces the damage in case of an earthquake. The effect of retrofitting is regarded as the expected damage reduction within 30 years which is the period for a 36.7% probability of a Tokai earthquake occurrence. The effect of retrofitting in case of an earthquake at some point within 30 years, U, is calculated as the difference between damage due to an earthquake without retrofitting and damage due to an earthquake after retrofitting, as shown in equation 1. The expected value of damage reduction, E(DR), is calculated according to equation 2 using annual sums of damage reduction derived from equation 1 and earthquake probability within each year among 30 years. Finally, the expected cost-benefit, E(CB), is obtained by dividing the expected value by the retrofitting cost.

$$U = D_0^i - D_1^i + R_0^i - R_1^i \tag{1}$$

$$E(DR) = \sum_{i=1}^{N} (D_0^i - D_1^i + R_0^i - R_1^i) * P^i \tag{2}$$

$$E(CB) = \frac{E(DR)}{C} \tag{3}$$

Where D_1^i denotes damage after retrofitting in case of an earthquake in year i,
D_0^i represents damage without retrofitting, P^i is for earthquake probability within each year,
R_1^i denotes recovery cost after retrofitting, R_0^i represents recovery cost without retrofitting,
C^i is for retrofitting cost.

(b) Flow for the evaluation of the merits of retrofitting each house

If a house is old and weak and the ground is estimated to shake strongly, the effect of retrofitting the house increases. That is, the merit of retrofitting each house differs according to the damage probability which considers the construction year and estimated PGV at the location of the house. So, first of all, the probability of damage to houses is estimated using the new building damage function. This is step A in Fig.4. Our newly obtained function gives the damage probability which varies according to the construction year, structure and estimated PGV.

Next, damage reduction in case of an earthquake within 30 years is derived from equation 1. It includes the reduction of building damage in case of total and partial damage to the house, household goods damage in case of total and partial damage, reconstruction cost of building in case of total damage, repairing cost in case of partial damage and cost of new household goods in case of total and partial damage. This is step B in Fig.4. Several data used in this process are introduced in Table 1. To estimate the total damage to the building, property value for a new house is assumed 150,000 yen/m^2 [5]. Regarding the houses which are not new, property value is considered to depreciate from 150,000 yen/m^2 to 50 % in 25 years. In the estimation of total damage to the household goods, the value of household goods depreciate from 14 million yen, the cost of new household goods[6], to 50 % in 25 years. Building reconstruction cost in case of total damage is the same as the property value of the house. Repairing cost in case of partial damage is one-third of the property value of the house. Retrofitting cost is 15,000 yen/m^2 [5].

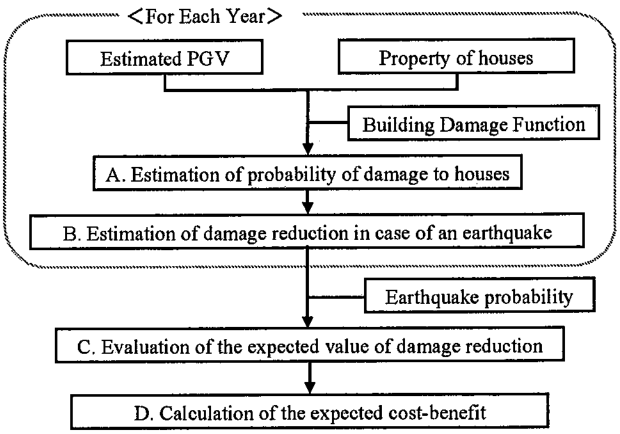

Fig.4 Flowchat for the evaluation of the merits of retrofitting for one wooden house

Table 1 Several data used in evaluation

Name	Price
Property value for a new house	150,000 yen/m^2
Retrofitting cost	15,000 yen/m^2
Cost of new household goods	14 million yen

Finally, the expected value of damage reduction is calculated according to equation 2 using annual sums of damage reduction derived from equation 1 and earthquake probability for each year in a 30-year period. This is step C in Fig.4. The expected cost-benefit is obtained in step D.

(c) Flow for the evaluation of the influence on governmental budget due to the popularization of retrofitting

This chapter shows the flow for evaluating the influence by popularisation of retrofitting on governmental budget. If landlords are induced to reinforce their houses by the announcement of calculated expected cost-benefit of each house, the popularisation of retrofitting decreases the governmental expenses. This expense includes construction cost for temporary housings for the people who lost their houses, the cost for debris removal among others.

In Shizuoka Prefecture, earthquake damage was estimated three times. In 1993 the second estimation[7] used the house stock data of 1990 and in 2001, the third estimation used the data of 1999. In this study, we simulate the change in distribution of houses due to rebuilding, subdivision, new construction and increase of reinforced houses based on the real number of houses, as of Jan.1, 1999. In each year during a 30-years period, existing houses have the possibility of being rebuilt, subdivided or retrofitted as shown in Fig.5. The ratio of change in the number of houses is inputted using real data utilized for the second and third damage estimations (Table 2).

Using this estimated city model, not only the damage of houses by an earthquake but also the governmental expenses due to the damage to private houses can be estimated in the case that some of the houses are reinforced according to the calculated cost-benefit. The governmental expenses are estimated as the sum of the construction cost for temporary housing and the cost for debris removal using the statistics at Kobe Earthquake. The cost for debris removal is 3.27 million yen for single totally damaged house and the initial construction cost for temporary housing is 2.8 million yen and 29,178 temporary housing were constructed for 67,421 totally damaged houses and 55,145 partially damaged houses at Kobe.

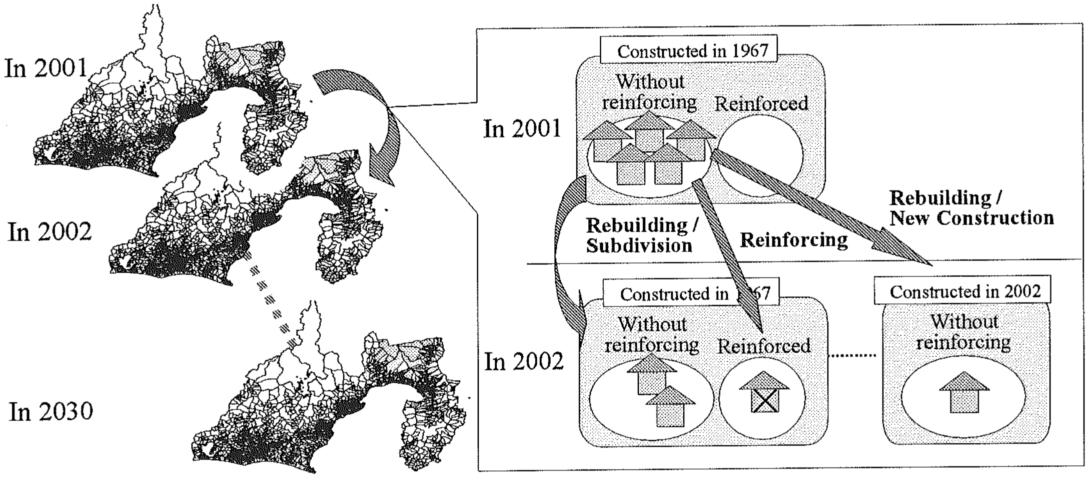

Fig.5 City model which estimates the change in distribution of houses

Table 2 Comparison between the second and third damage estimations

Construction year	Before 1960	1961-78	After 1979
Number of houses at the Second damage estimation	188,173	436,067	234,252
Number of houses at the Third damage estimation	118,335	361,687	359,217
Ratio of decrease in 9 years	0.63	0.83	
Ratio of decrease of each year	0.95	0.98	
Number of houses newly constructed in 9 years			124,965
Number of houses newly constructed in each year			13,885

BUILDING DAMAGE FUNCTION

In this section, the method for making the new building damage function used for estimating damage probability is presented.

In order to observe the long-range effect of retrofitting, it is necessary to consider the phenomenon that strength of buildings decreases with time. The building damage function given by Murao and Yamazaki (2000)[8] (see Fig.6) is one of the highest accurate functions. But it corresponds to building damage data which was

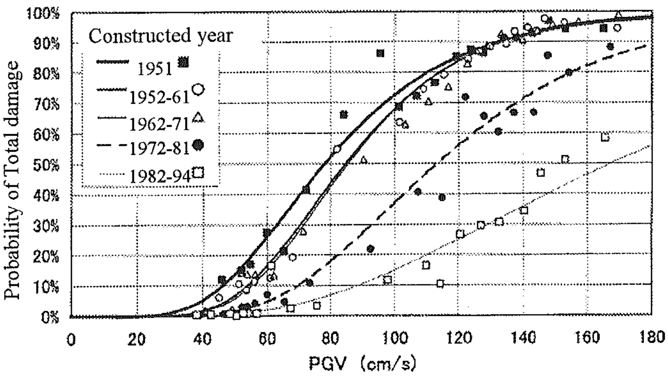

Fig.6 Building damage functions (Murao and Yamazaki, 2000)

classified into several groups according to the construction year considering the revision of Construction Standard Act. Therefore, even if buildings are in same group, the difference of building strength, due to time passage, cannot be evaluated.

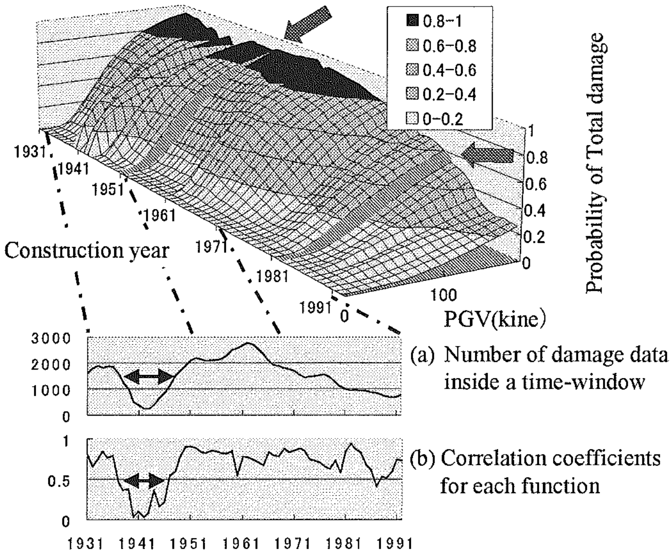

Fig.8 Building damage function of the total damage

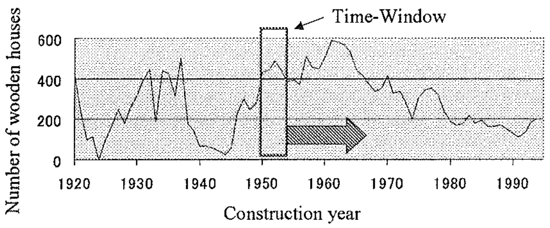

Fig.7 Time-window for building damage function calculation

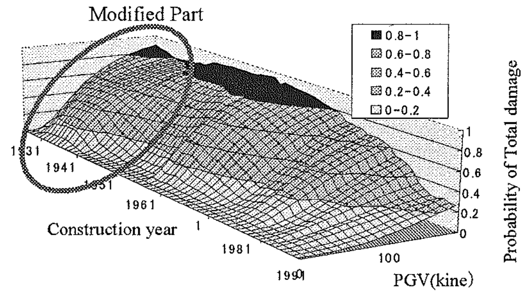

Fig.9 Modified Building damage function

Therefore, for the purpose of obtaining the building damage function which corresponds to each constructed year, first of all, the building damage data in Nada ward at Kobe Earthquake was classified according to the structure and construction year. This data includes the damage to 30,544 houses in total and 22,710 wooden houses. Next, by putting a time-window on this data, damage data inside a time-window is gathered to one data set which corresponds to one constructed year as shown in Fig.7. As this time-window is moved along the construction years, all the data sets are obtained for evaluation of the damage function. From these data sets, the three-dimensional building damage function which has three axis: constructed year, PGV and damage probability is obtained.

Figure 8 shows the function of total damage in case of the time-window whose span is 5 years. From this, it can be concluded that new houses are more earthquake-resistant because curved surface of total damage declines. This curved surface enables us to examine the decrease of strength due to time passage and influence of the revision of Construction Standard Act on building strength. Chart (a) in Fig.8 is the number of damage data inside a time-window which corresponds to each construction year. Chart (b) in Fig.8 shows the correlation coefficients between each function and the data. Because of the decline of correlation coefficients due to the decrease of newly constructed houses during the World War II, the curved surface becomes rough. After 1950, when the Construction Standard Act was established, and in 1981 when the earthquake-proof standard in that Act revised, the curve becomes discontinuous. This seems to indicate the increase of earthquake-resistance after these revisions.

When the probability of damage to houses is estimated, building strength decreases according to the time elapsed from the first year of a 30-year period. The damage surface around the World War II was modified as shown in Fig.9 by extrapolating data from periods immediately before and after the World War II because correlation coefficients was below 0.5. The houses after retrofitting are supposed to be as strong as the houses constructed with present standard revised in 1981.

CASE STUDY: SHIZUOKA PREFECTURE

This section describes the application of the proposed method to Shizuoka Prefecture.

(a) Advantage of retrofitting houses for individuals

As mentioned before, the long-term earthquake prediction information indicates that an earthquake may occur within 30 years with 36.7% probability. The expected cost-benefit within coming 30 years in case of retrofitting in 2001 was calculated in Table 3. The obtained expected cost-benefit is different according to PGV and the construction year. The effect of retrofitting seems to be low in the case that the expected cost-benefit is below 1.0. The values on this table show that as the houses are old and located at the area where strong PGV are estimated, the advantages of retrofitting will become larger because the expected cost-benefit increases. Especially, the merits are larger for the houses constructed before the revision of earthquake-resistant standard in 1960.

Table 3 Expected cost-benefit

Construction Year	PGV(kine)				
	10	20	30	40	50
1960	0.23	1.18	2.56	4.34	6.28
1975	0.09	0.72	1.85	3.26	4.75
1985	0.04	0.30	0.72	1.23	1.80

Figure10 shows how the expected cost-benefit varies according to the earthquake occurrence probability and the object period. From this, we can understand the cost-benefit under all the situations, while the result shown in Table.3 is only for the case of 36.7% earthquake probability within 30 years. The points which are marked with '+' on Fig.10 correspond to the case of 36.7% earthquake probability that was initially adopted.

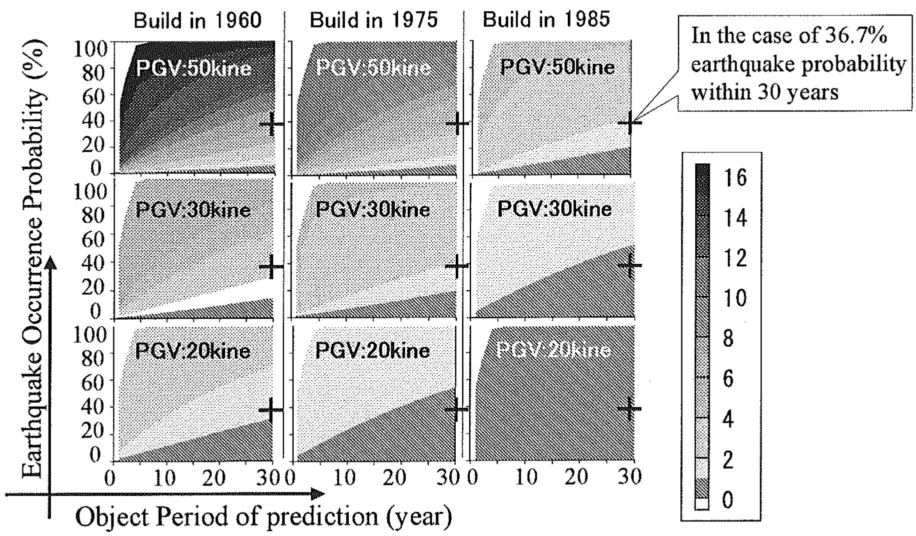

Fig.10 Change of cost-benefit according to the earthquake occurrence possibility and the object period

This evaluation can be carried out for all wooden houses and all the owners can understand the situation of their own houses by being informed of the results. This information may help them to consider the advantages of retrofitting houses and promote the popularisation of retrofitting.

(b) Advantages of the spreading of retrofitting for the government

Table 4 shows the reduction of governmental expenses if an earthquake occurs in 2020 and half of the houses with the expected cost-benefit of retrofitting above 1.0 are gradually retrofitted from 2001 to 2010. In this case, the governmental expenses are reduced by 24.4 billion if the total number of reinforced houses is 93,997. We can estimate the distribution of the reduction of governmental expenses as well as its total amount as shown in Fig.11. If half of the reduced cost is paid to the owners whose houses are totally or partially damaged by a ratio of 2:1, each household will get 491,400 yen and 245,700 yen respectively. In total, 6 million yen will be assigned to the totally damaged houses whreas12 million yen will be given to the partially damaged house.

With the publication of the Third Earthquake Damage Estimation, Shizuoka Prefectural Government decided to promote the program of economical assistance for retrofitting individual houses. The previously presented evaluation can also show the government the advantages of retrofitting and the importance of providing governmental assistance as a means of making retrofitting popular among the population. Moreover, the previous analysis may help to establish the areas of highest priority.

Table 4 Reduction of governmental expenses

	Without retrofitting	With retrofitting	Damage reduction
Number of retrofitted houses		93,997	
Number of totally damaged houses	20,614	12,461	8,153
Number of partially damaged houses	191,371	74,386	26,985
Governmental expense(billion yen)	125.7	101.3	24.4

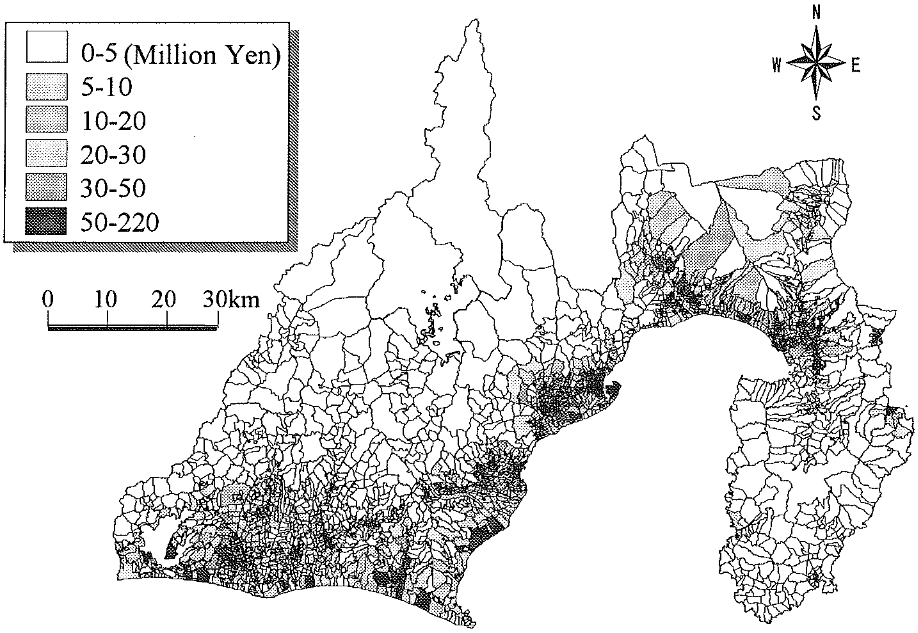

Fig.11 Distribution of the reduction of governmental expenses

CONCLUSIONS

This research suggests a method for evaluating the cost-benefit of retrofitting existing houses. In the process of evaluation, the earthquake occurrence probability which is a part of the long-term earthquake prediction information was considered. Applying this method to real houses in Shizuoka Prefecture, which is expected to face a Tokai Earthquake in the near future, we tried to evaluate how much effect retrofitting may create on both the owners of houses and the regional government. Through this research, the possibility of using earthquake prediction data for the evaluation of countermeasures for earthquakes such as retrofitting is explored. With the publication of the probability of occurrence of various earthquakes including Tokai Earthquake, methods for using these prediction data practically become necessary.

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