Development of an Estimation Method for Direct Economic Damage Loss caused by Earthquake

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Development of an Estimation Method for Direct Economic Damage Loss caused by Earthquake

Hitoshi TANIGUCHI*

Keywords: Earthquake, Economic loss, Amount of direct damage

1. Introduction

The total amount of direct damage loss incurred by Hyogo Prefecture as a result of the Great Hanshin-Awaji earthquake was approximately 10 trillion yen (US$100 billion). This resulted in a huge economic crisis as far as reconstruction was concerned. Because of this, the problem of economic management after a disaster again came to focus in regional disaster prevention planning. However, this approach from an economic point of view, had been omitted in the initial draft of the regional disaster plan.

This study is based on the background mentioned above and tries to develop an estimation method for direct economic losses caused by earthquakes based on Japanese experience.

2. Fundamental policy of economic damage loss estimation

If we define the total amount of economic damage as Yi,k,t, the amount of direct damage as Y_Ci,k,t and that of indirect damage as Y_Di,k,t, then we can write the formula below.

$$Yi,k,t=\sum_{i=1}^{l}\sum_{k=1}^{m}\sum_{t=1}^{n}(Y_Ci,k,t+Y_Di,k,t) \quad \cdots\cdots(1)$$

Here, i shows the administrative unit of the city, towns, and villages, and k is the damaged components such as buildings, commercial and industrial damage and so on, and t is a time until the spread of earthquake damage. Although, for t, which is the time for the occurrence of direct damage, three days would be enough even considering earthquake fire damage, the time period for the occurrence of indirect damage, t, should be considered for a period of several years depending on the intensity of direct amount of damage. Most of the previous damage statistics were collected only considering direct damage as Y_C.

The direct damage, Y_C, can be expressed as the product of seismic hazard and vulnerability. The total amount of direct damage, Y_Ci,k,t, is shown in the following formula.

$$Y_Ci,k,t=f(N_Ei,S_Ei,k) \quad \cdots\cdots(2)$$

Here, N_Ei shows the seismic hazard as seismic intensity and the natural environmental conditions (topography/geological features), S_Ei,k is the social vulnerability in the damaged region, i. In the same way, if the amount of indirect damage, Y_Di,k,t, is expressed as a function of the direct damage, Y_Ci,k,t, socioeconomic structure of damaged region, E_Ei,k, and time taken for reconstruction of physical damages, Ti,k, then we arrive at the following formula.

$$Y_Di,k,t=f(Y_Ci,k,t,E_Ei,k,Ti,k) \quad \cdots\cdots(3)$$

Here, socioeconomic structure refers to the economic structure from the social characteristics of a region such as the ratio of 1st to 3rd industries, households, population and other indicators of the region. Time taken for reconstruction is a variable factor, determined by the direct damage loss, damaged items, and revival costs.

By keeping the above-mentioned fundamental general idea in mind and analyzing the previous major earthquake damage after the 1964 Niigata Earthquake, an experimental equation of economic loss was proposed relating to the direct damage. This analysis was done by the unit of a prefecture or the damaged region where the seismic intensity is over 5 on Japanese Meteorological Agency (JMA) scale.

3. Statistical analysis of previous earthquake damage

The amount of the direct damage caused by earthquakes after 1960 was collected as an object of statistical analysis. We have selected several earthquakes which caused various kinds of damage determined by the natural environment. The typical damage characteristics from previous earthquakes are

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listed in Table 1. Eleven earthquakes were analyzed to obtain the important damage items after the Niigata Earthquake in 1964 in areas where the maximum seismic intensity was more than 5. The damage characteristics may be divided into three types on the basis of the detailed earthquake disaster such as "Urban Seismic Disaster," "Local City Disaster," and "Hilly and Waterfront Disaster."

On the other hand, seven earthquakes in Table 1 were selected for the statistical analysis of an amount of direct damage, and epicenters and influenced areas caused by these earthquakes were shown in figure 1. In figure 1, the star (★) shows a location of epicenter and the circle (○) shows a damaged area in which seismic intensity was more than 5 (the numbers in the figure correspond to the earthquake number in Table 1). Figures 2 to 7 and 9 show a proportion of the total amount of direct damage to various kinds of damaged items such as agriculture, fisheries, forestry, public facilities and so on. As shown in figures 2 to 7 and 9, the proportional amount of each damaged items to the total amount of damage is clearly understood with the varying proportions of damage among the seven earthquakes, namely, the 1964 Niigata earthquake, the 1978 Miyagi-ken Oki earthquake, the 1983 Nihonkai-Chubu earthquake, the 1984 Nagano-ken Seibu earthquake, the 1993 Kushiro-Oki earthquake, the 1993 Hokkaido NanseiOki earthquake, and the 1995 Great Hansin-Awaji earthquake.

The characteristics of the total losses are reflected in the type of socioeconomic activity and the natural environmental conditions in the damaged

Table 1 Summary of earthquake disaster aspects and characteristics of the damage

No.	Earthquake	Seismic Intensity	Geography Geology	Damaged region	Damage item and Characteristics
1	1964 Niigata	5	Plain (sandy layer)	Local city	Liquefaction, Collapsed bridge, houses. Ground destruction
2	1968 Tokachi-Oki	5	Plain (volcanic ash)	Local city	Reclaimed ground
3	1974 lzu-Hanto	5	Mountain	Village	Destruction of steep slope, fill-up ground. Hilly region disaster
4	1978 Izu-Oshima	6	Mountain Village	Village	Steep lope, land slide Transportation Hilly region disaster
5	1978 Miyagiken Oki	5	Plain (alluviun)	Urban city	Lifeline, reclaim ground Information panic, Urban disaster
6	1982 Urakawa-Oki	6	Hilly, Slope	Local city	Bridge, Steep slope, Transportation Local city disaster
7	1983 Nihonkai-Chub	5	Plain (sandy layer) Waterfront	Local city Fishing Village	Tsunami, Liquefaction, Local city disaster
8	1984 Naganoken-Seibu	5	Mountain (volcanic rock and ash)	Village in mountain	Transportation, land slide, steep slope Mt. Village disaster
9	1993 Kushiro-Oki	6	Hilly, Slope	Local city	Collapsed building, Ligeline, Transportation. Local city disaster
10	1993 Hokkaido-Nans	6	Hilly, Waterfront	Fishing Village	Tsunami, Fire, Strong motion, Tsunami Dis
11	1995 Great Hanshin-Awaji	7	Plain, Waterfront	Megalopolis	Strong motion, Lifeline, Collapsed building, Fire Transportation, Loss of lives

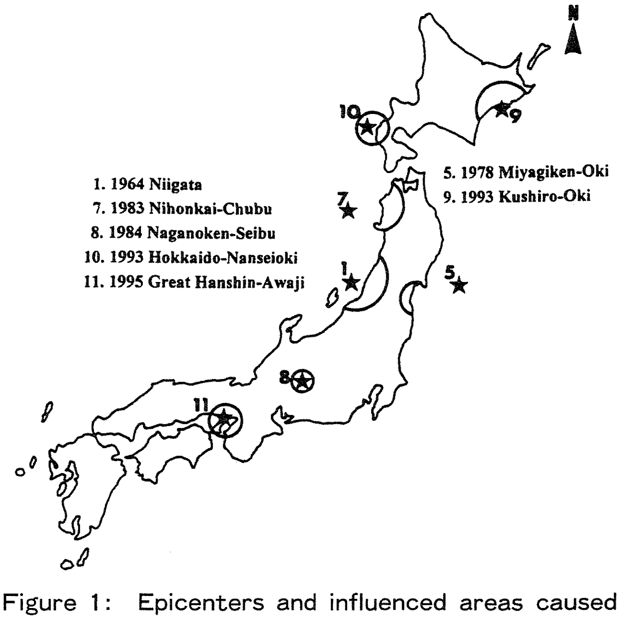


Figure 1: Epicenters and influenced areas caused by selected earthquakes.

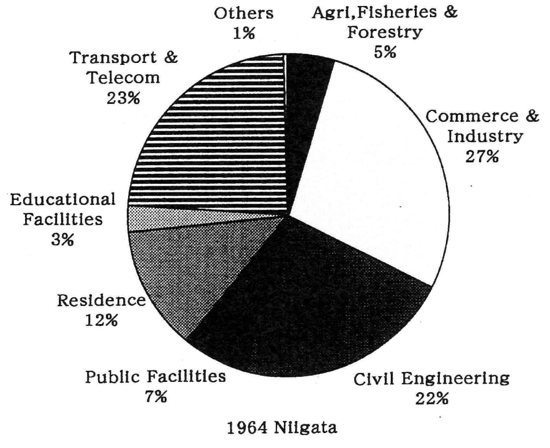


Figure 2: Proportions of direct damage caused by the 1964 Niigata earthquake.

regions. For example in the case of a local city in Niigata, as shown in figure 2, which is one of the biggest cities and a commercial center in the Hokuriku region, the highest amount of damages are the commercial and industrial losses with 27% of the total amount, the second largest damage category is transport and telecommunication systems with 23% and civil engineering facilities (infrastructure) with 22%. These losses represent about 72% of the total losses, and are not only caused by ground liquefaction in the damaged areas but was also a result of the characteristics of the socioeconomic structure of Niigata city.

In Sendai city, as shown in figure 3, an urban area which is the economic and political centre of the Tohoku district, the highest ratio of losses to total amount of damage is the commercial and industrial losses with 37%, the second worst damaged component is a residential houses and buildings with 29%. Civil engineering facilities (infrastructures), however, with 10% losses were very low even though the city is developed and infrastructure is completely established in the urban wards. The commercial and industrial losses and the residential houses and buildings losses reached about 65% of the total losses, and was mainly caused by, firstly, destruction in reclaimed ground for residential use and, secondly, the characteristics of socioeconomic structure for commercial and industrial losses.

In the case of the Nihonkai-Chubu earthquake, as shown in figure 4, Noshiro and Akita cities were affected by tsunami and liquefaction. The agricultural, fisheries and forestry losses with 27% were caused by tsunami. Of the civil engineering facilities losses with 39%, almost all of the losses were caused by liquefaction. Noshiro and Akita which are local cities have been developed as fisheries towns. The chief industries in these cities are mainly primary industries, so agricultural, fisheries and forestry losses are high compared relatively to other losses. This phenomenon would explain the correspondence to the industrial structures in the damaged areas. The proportion of direct losses caused by this earthquake is quite different from the other cases mentioned above.

The 1984 Naganoken-Seibu earthquake affected Ohtaki village which was located at the foot of Mt. Ontake, 3,063m above sea level in central Japan. Ohtaki village is a typical town in the mountain area, and has been developed based on forestry and tourist industries. As shown in figure 5, the highest amount of damage results from agricultural and forestry losses with 48% of the total amount, the second worst damaged item is civil engineering facilities (infrastructures) with 47%. These losses represent about 95% of the total losses, and are not only caused by a landslide in the damaged area but was also dependent on the characteristics of the socioeconomic structure of Ohtaki village.

In the case of the Kushiro-Oki earthquake, as shown in figure 6, Kushiro city was affected by very

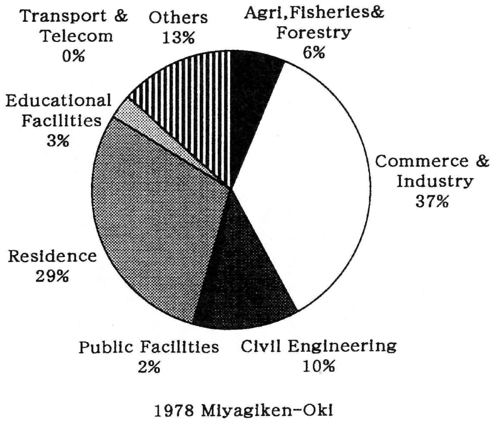


Figure 3: Proportions of direct damage caused by 1978 Miyagiken-Oki earthquake.

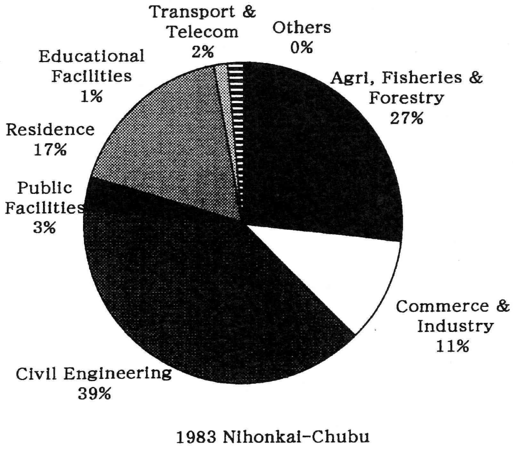
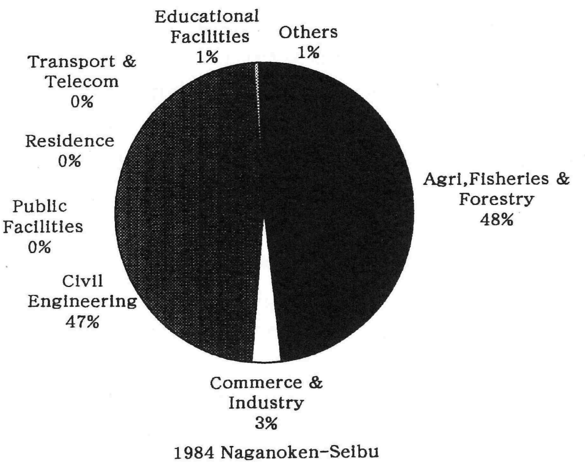


Figure 4: Proportions of direct damage caused by the 1983 Nihonkai-chubu earthquake.



(the damage to residential losses is not included in this statistical data).

Figure 5: Proportions of direct damage caused by the1984 Naganoken-Seibu earthquake.

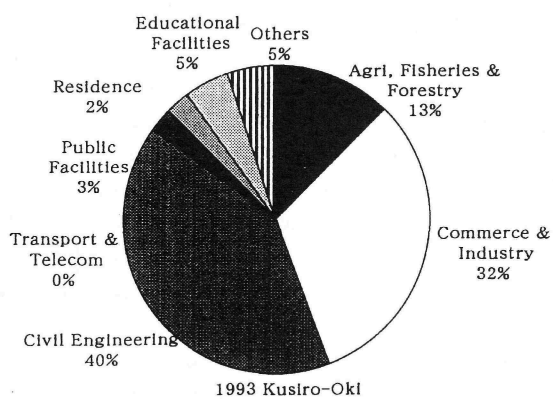


Figure 6: Proportions of direct damage caused by the 1993 Kushireo-Oki earthquake.

strong ground motion, a local city in Kushiro which is one of the biggest cities and a commercial center in the eastern part of Hokkaido, the highest amounts of damage are the commercial and industrial losses with 32% and civil engineering facilities (infrastructures) with 40% of the total amount of damage. Second worst damaged item is the agricultural, fisheries and forestry losses with 13%. The losses represent 85% of the total losses, and were not only caused by the ground motion but were also dependent on the characteristics of the socioeconomic structure of Kushiro city.

In 1993, a big earthquake occurred just under Okushiri island which is located off the western coast of Hokkaido. Okushiri town was affected by strong ground motion and tsunami, as shown in figure 7, so that agricultural, fisheries and forestry losses, with 39%, would be caused by tsunami. And also the civil engineering facilities losses, with 37%, almost all were caused by tsunami. Okushiri and the other small

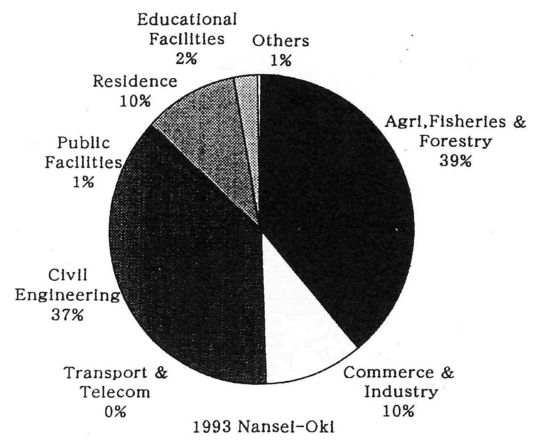


Figure 7: Proportions of direct damage caused by the 1993 Hokkaido-Nansei-Oki earthquake.

towns have been developed as fisheries towns. The chief industries in these towns are mainly primary industries, so that fisheries losses increased relative to the other losses. This phenomenon would explain the correspondence to the industrial structures in the damaged areas. The proportion of direct losses caused by this and the Naganoken-Seibu earthquake are quite different from other cases mentioned above.

The Great Hanshin-Awaji earthquake abruptly occurred breaking the silence of the early morning of 17 January 1995. The epicenter of the earthquake was located about 15 km to the southwest of Kobe city. The total amount of direct damage incurred in Hyogo Prefecture by the earthquake was approximately 10 trillion yen (US$100 billion). Kobe which is the biggest city in Hyogo prefecture developed along with the opening of the international trading port of Hyogo in 1868 and it has a long history, being one of the 31 cites where a municipal administrative system was introduced in 1889. With a population of approximately 1.52 million, Kobe is currently the sixth largest city in Japan. The Hanshin industrial area, which centers on Kobe, is the west-central base of the Pacific industrial belt area. Kobe City totals US$ 45 billion in

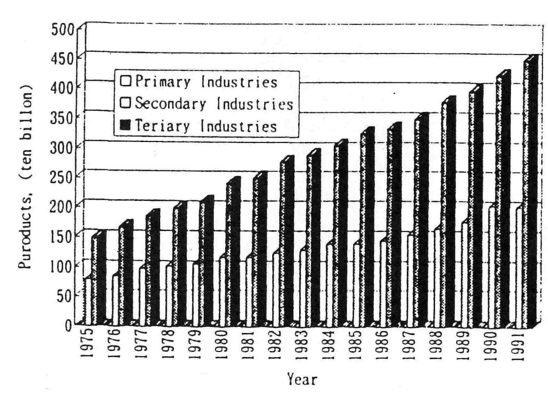


Figure 8: Transition of the gross domestic product from 1975 to 1991 in Kobe city.

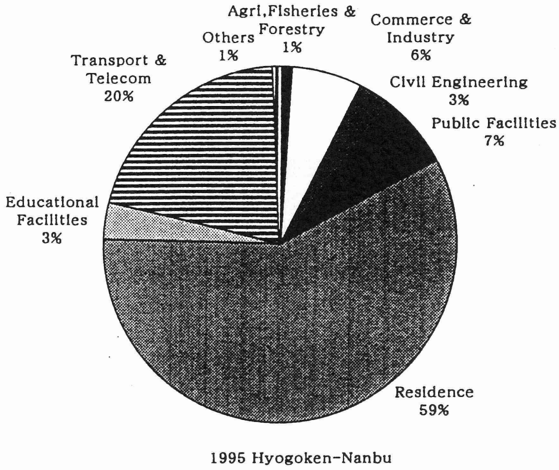


Figure 9: Proportions of direct damage caused by the 1995 Great Hanshin-Awaji earthquake.

domestic industrial shipments, ranking seventh nationally. About 70% of the total losses occurred in Kobe city.

Figure 8 shows Kobe's growth of gross domestic product (GDP) based on the primary, secondary and tertiary industries from 1975 to 1991. Primary industries include agriculture and fisheries which account for 11.6 billion yen (US$116 million). Secondary industries was composed of two industries: manufacturing, 1.527 trillion yen (US$15.3 billion) and construction, 500 billion yen (US$5 billion). The tertiary industries mainly consisted of three industries: transport and communications, 674 trillion yen (US$6.7 billion); domestic trade and services, 1.06 trillion yen (US$10.6); and wholesale and retail trade, 1.18 trillion yen (US$11.8 billion). As shown in figure 8, the amount produced by tertiary industries in Kobe comprise the highest part of the domestic product with an output reaching about 4.5 trillion yen (US$45 billion), 68.8% of the total domestic product for fiscal year 1991 in Kobe. The amount produced by secondary and primary industries were 2.03 trillion yen (US$20.3 billion) and 11.6 billion yen (US$116 million), respectively. Kobe Port handles approximately 170 million tons of cargo each year, out of which 4,000 tons are international containers, 30% of Japans foreign imports. As indicated by the above statistics, Kobe is literally the biggest international port in Japan.

Figure 9 shows the proportions of direct damage losses, in the waterfront and central part of Kobe city and northern part of Awaji island which were affected by very strong ground motion which almost reaching 1g. The highest amount of damage is residence losses with 59%, second worst damage is to transport and telecommunications with 20% in Hyogo Prefecture. The proportions of direct losses caused by this earthquake are quite different from other cases mentioned above, especially, direct damage to residences which reached 5.8 trillion yen (US$58 billion). This phenomenon would explain the correspondence to the natural environmental and industrial structures in the damaged areas.

Table 2 shows the amount of direct losses for 15 affected areas caused by ten earthquakes (including the Tokai and Minami-Kanto earthquakes of which have been indicated as possible in the near future by the Meteorological Agency). In Table 2, the amount was adjusted for inflation in 1994 through the use of GDP from 1964 to 1995. The amount of direct damage in Shizuoka Prefecture and Tokyo due to the Tokai and Minami-kanto Earthquakes is estimated by the Government of Shizuoka Prefecture and by Haresh

Table 2 Direct damage losses caused by previous earthquakes

No.	Earthquake	Damage Area	Direct Damage (JPY/trillion)
1	1964 Niigata	The whole area of Niigata Pref	2.003
2	1964 Niigata	Niigata City	1.614
3	1978 Izu-Oshima Kinkai	Izu•Atami•Shunto area	0.068
4	1978 Miyagi-Oki	The whole area of Miyagi Pref.	0.591
5	1978 Miyagi-Oki	Sendai•Sennan•Ishimaki area	0.591
6	1983 Nihonkai-Chubu	Tsugaru area ①	0.083
7	1983 Nihonkai-Chubu	Noshiro•Akita City•Honjo ②	0.236
8	1983 Nihonkai-Chubu	The Areas ① and ②	0.319
9	1984 Nagano-Seibu	Kiso Area (Otaki Village)	0.038
10	1993 Kushiro-Oki	Kushiro•Nemuro Area (Kushiro City)	0.046
11	1993 Hokkaido-Nanseioki	Donan-ken (Okushiri Island)	0.124
12	1995 Hyogo-Nanbu	The whole area of Hyogo Pref.	9.916
13	1995 Hyogo-Nanbu	Kobe City	6.915
14	?? Tokai (estimate)	The whole area of Shizuoka Pref.	12.238
15	?? Minami-Kanto (estimate).	Tokyo and the neighbourhood 3 Pref.	166.000

Note: The Tokai earthquake is modeled on the 1854 Ansei-Tokai Earthquake. The Minami-Kanto earthquake is modeled on the 1923 Kanto Earthquake*

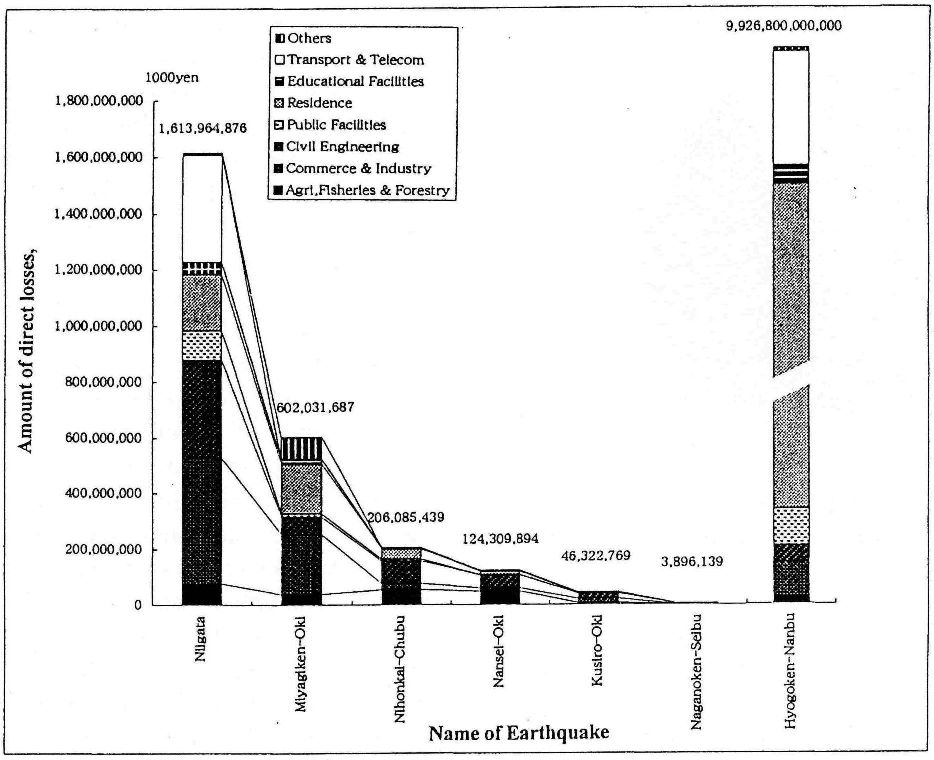


Figure 10: Comparison of direct damage losses and ratio of each damage component among seven previous earthquakes.

Shah of Stanford University, respectively.

Figure 10 shows the difference in direct damage losses and the ratio of each damage component among seven previous earthquakes listed in Table 2. Compare the direct damage losses caused by earthquakes, the highest direct damage losses amounted 10 trillion yen which resulted from the Great Hanshin-Awaji earthquake, and second was the Niigata earthquake with 1.6 trillion yen in Niigata city. In the case of the 1978 Miyagiken-oki earthquake, which was well known as the first urban earthquake disaster in Japan, the direct damage losses were only 602 billion yen. And also, although the 1983 Nihonkai-Chubu earthquake had widespread damage caused by tsunami and liquefaction, the direct damage losses only amounted to 206 billion yen.

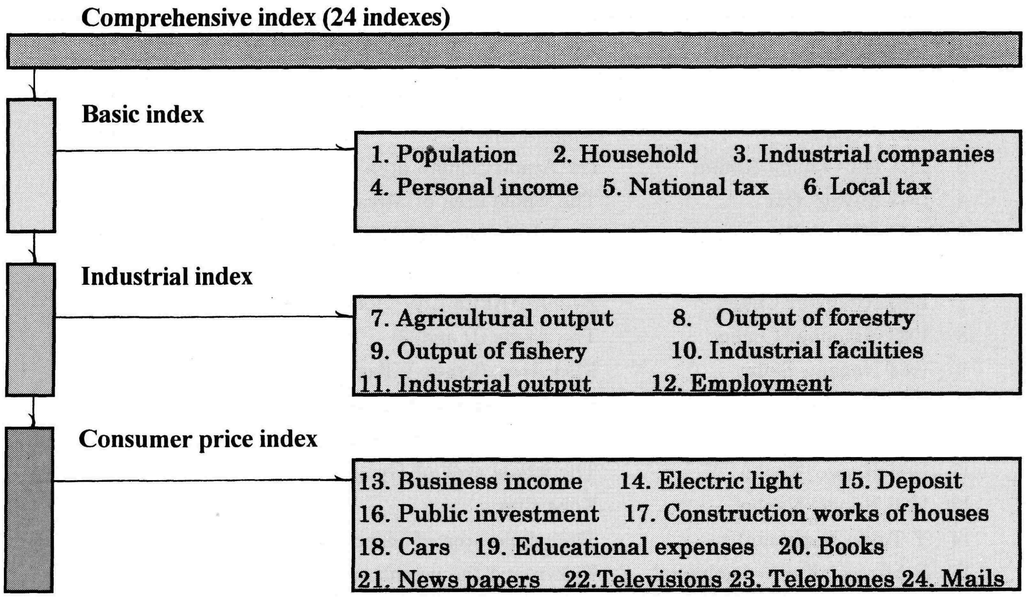
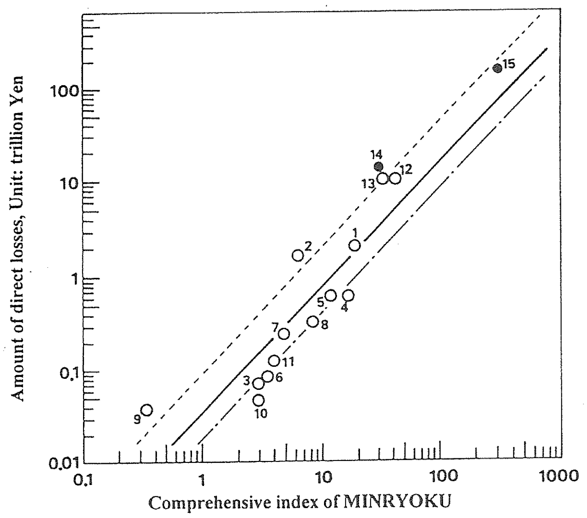


Figure 11: Detailed contents of indexes of the MINRYOKU database.



The figures correspond to the earthquake numbers in Table 2. Fourteen and fifteen represent the projected Tokyo and Shizuoka earthquakes.

Figure 12: Relationship between the amount of direct damage and comprehensive index of MINRYOKU.

4. Estimation of direct damage losses

As shown in equation (2), the direct losses can be expressed as the product of seismic hazards and vulnerability. Hazards can be replaced with seismic intensity, liquefaction, steep slope disaster and tsunami which are dependent on the natural environmental conditions. On the other hand, in order to evaluate the social vulnerability, the possibility of direct damage should be quantitatively estimated according to the socioeconomic stocks.

In this study, MINRYOKU, a database of accumulated social information is used for the evaluation of social vulnerability. The database of MINRYOKU is composed of 24 indexes: 6 basic indexes, 6 industrial indexes and 12 consumer price indexes. Figure 11 shows the content of a detailed index of the MINRYOKU database.

As shown in Figure 11, the comprehensive index consists of a basic index, industrial index, and consumer price index, and considering the whole country as having a value of 1,000 in each index, which are referred to as sum and average individual indices.

Figure 12 shows the relationship between the amount of direct damage as shown in Table 2 and the comprehensive index of the MINRYOKU database. The amount of losses include the earthquakes which occurred after the Niigata earthquake in 1964 and the results of the amount of direct damage losses in the whole of Shizuoka prefecture were estimated by Shizuoka Prefectural Government in case the Tokai earthquake occurrs in the area. Also, the Tokyo metropolitan area estimates the Minami-kanto earthquake assuming the same characteristics as the Great Kanto earthquake in 1923. The amount of the previous damage is inflated using 1994 as the base year.

As shown in Figure 12, on the basis of the relations among 11 damaged areas, we can get an experimental equation of direct damage loses as in the following equation

$$Yci,k,t = 0.0347 * S_E^{1.3119} \quad \cdots\cdots(4)$$

The decision coefficient of equation (4) is 0.90 which gives a strong correlation. Considering equation (4) as the average relation between social vulnerability and damage potential, the damaged regions situated in the upper part of this formula will have more damage than potentially social vulnerability. For this reason, the increase in the natural environmental condition, the seismic intensity and the damage influenced by the socio-economic structure are considered.

On the other hand, the regions located in the lower part may have been damaged locally or may have had relatively low seismic intensity. When an approximate formula on these spots is calculated by making the gradient of equation (4) equal, it becomes similar to equation (5) in the upper regions, and similar to equation (6) in the lower regions.

$$Yci,k,t = 0.0858 * S_E^{1.3119} \quad \cdots\cdots(5)$$

$$Yci,k,t = 0.0177 * S_E^{1.3119} \quad \cdots\cdots(6)$$

If the constant (0.0347) in equation (4) is assumed to be 1.000, equation (4) considering the change of constant number of three experiences formula as the difference of the earthquake ground motion, the ratio of the constants in each equation, i.e. (0.0858/0.0347= 2.47 and 0.0177/0.0347=0.51) are considered as the correct coefficients corresponding to the seismic intensity. The constants 2.47 and 0.51 correspond to the seismic intensity of more than 6.5, but less than 5. 5.

Using the above-mentioned consideration, the correct coefficient depending on the natural conditions such as steep slope damage or liquefaction damage is simply estimated based on the damage of liquefaction caused by the Niigata earthquake, and the correction coefficient of steep slope damage is estimated from the Naganoken-Seibu earthquake. The former coefficient is 2.47, and the latter is 4.51.

From these correct coefficients, equations (4) to (6) can be derived:

$$Yci,k,t = 0.0347 * S_E^{1.3119} * \begin{bmatrix} I1 \\ I2 \\ I3 \end{bmatrix} * \begin{bmatrix} D1 \\ D2 \\ D3 \end{bmatrix} \quad \cdots\cdots(7)$$

The values of I1, I2, I3 are **2.47, 1.00, 0.51** respectively. The values of D1, D2, D3 are **1.00, 2.47, 4.51** respectively.

Here, **I1-I3** show the range of seismic intensity as follows;

I1: $I \geq 6.5$, **I2**: $5.5 \leq I < 6.5$, **I3**: $I < 5.5$

And also, D1-D3 show the characteristics of damage caused by reasons as follows; **D1; Strong ground motion, D2; Liquefaction, D3; Steep slope**.

5. Conclusions and remarks

In the present study, the previous damage from earthquake is analyzed from an economic point of view and the method for estimating the amount of direct damage is developed relating to the potential of socioeconomic power based on the analysis of previous earthquake damage. The characteristics of the total losses have been clarified on the basis of an analysis of the economic damage due to seven earthquakes which occurred from 1964 to 1995.

The characteristics of total amount of direct damage and of the proportion of the total amount of direct damage to damage components are shown. Comparison of the direct damage losses caused by the previous seven earthquakes, indicates that the highest direct damage losses were 10 trillion yen which were caused by the Great Hanshin-Awaji earthquake; second was the Niigata earthquake with 1.6 trillion yen in Niigata city. In a case of the 1978 Miyagiken-Oki earthquake, which was well known as the first urban earthquake disaster in Japan, the direct damage losses were only 602 billion yen. Based on these results, it was established that the ratio of damage losses are not only determined by seismic intensity, the ground liquefaction, and tsunami, but also the type of socioeconomic activity taking place in the damaged area.

On the other hand, regarding the direct damage losses; an estimation method is proposed as shown in equation (7). In future, it will be necessary to bear in mind that the relation between the amount of direct damage and that of indirect damage depends upon the characteristic of the economic and industrial area classified.

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