Estimation of Damage Caused by Earthquake and its Application to the Seismic Risk Assessment in Nagoya City, Japan

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名古屋市における地震被害予測と地震危険度評価

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Earthquake damage and its prevention in a city were investigated for three assumed large eatrhquakes with magnitude of 8.0 or more, similar to past destructive ones occurred around the city. Estimated damages are breakdown houses, destruction man-made ground, fire damage and a loss of life. These damages are estimated mainly from empirical equations between the maximum acceleration at the ground surface and the damages of the past large earthquakes. The acceleration was obtained from wave propagation analysis from hypocenter to ground surface. Based on the estimation of various damages caused by an earthquake, the major prevention factors for damages are discussed.

1. INTRODUCTION

Among natural disasters occurring in urban areas, earthquake damage is the most dangerous one because of its variety such as destruction of houses, outbreak of fires and human panic. Furthermore, the earthquake damage develops mostly in regional scale. Hence, it is very important to study the estimation of earthquake damage, especially in a big city where enormous damage will possibly occur in near future.

Large earthquakes have frequently occurred in Japanese Islands, especially in the Pacific Ocean region. Nagoya city, located along the central Pacific Ocean coast, is one of the big cities in Japan, and has suffered enormous damages from past earthquakes. Since a large earthquake is expected in the near future, we chose Nagoya as an urgent work to estimate the damage by earthquake and to reduce the damage.

In the estimation of earthquake damage in Japan, it is presently difficult to simply refer and apply the past earthquake damages to estimation in the present city. This is because the present circumstances are quite different from the past one, even those of thirty years ago. The population and dwelling area in each city have been expanded during the last thirty years by rapid growth of Japanese economy. Surrounding country have been converted into urban areas and many houses have been built on undesirable places such as man-made slopes and riverbasins. Due to these developments recent earthquake damage in urban areas is different from the past damage. The most significant difference is in the liquefaction damage of ground. In the Niigata (1964) and the Nihonkai-chubu (1983) Earthquake, many houses on the sandy ground were severely damaged by liquefaction on the ground. The damage was considered to be due to the rapid construction of houses in rural areas previously undeveloped. In the present damage estimation of Nagoya city, we paid particular attention to areas recently reclaimed for human use.

Assuming earthquakes occur around Nagoya city, the following four estimations are carried out. The estimations of the earthquake damage are summarized briefly below.

(1) Maximum acceleration at the ground surface.
(2) Damage to wooden houses.
(3) Damage to man-made ground.
(4) Outbreak and spreading fire damage.

All the above estimations were done in each 500 × 500 m² mesh area. A total of about 2500 mesh areas in Nagoya city were estimated.

2. GROUND STRUCTURE AND ASSUMED EARTHQUAKE

2-1 Ground structure and seismic basement

Ground structure of Nagoya city is shown in Figure 1. The Alluvium of the uppermost layer widely develops in the western half of Nagoya. The thickness of the Alluvium varies from place to place as shown in Figure 1 (b). Under-laying layer of the

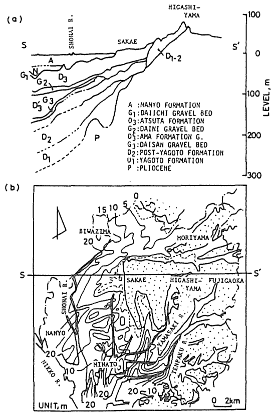

Figure 1 Geolographical map in Nagoya city.

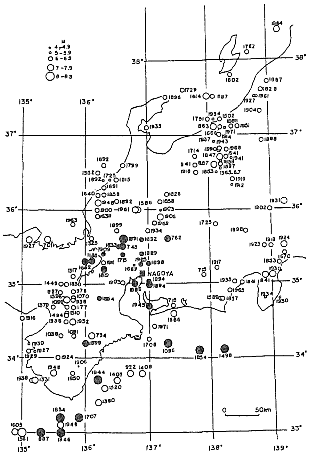

Figure 2 Epicenter of earthquake with damage and its magnitude

Alluvium is called Atsuta, Ama and Yagoto formations which belong to the Diluvium. Further underlaying layer are Yadagawa and Idaka formations of the Pliocene in the Tertiary. The Pliocene formations occur uniformly in all the areas of the city. The Pliocene formation partly outcrops around Fujigaoka, eastern end of the city, whereas in the western end, they occur as deep as 300 meters. Although S-wave velocity and density in upper most Pliocene layer have been measured, layer structure, S-wave velocity and density have not been clarified in the deeper past.

To obtain the characteristics of the ground motion, we should set up the seismic basement with a suitable depth, and then calculate incident seismic wave from the basement. In the set-up of seismic ground, the following assumptions are made.

(1) The basement spreads in regional scale and mechanical parameters of the basement are roughly uniform in all the areas.

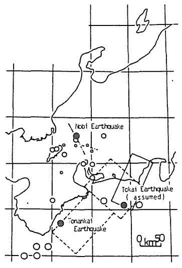

Figure 3 Fault models for the earthquake-1 to -3

Table 1 The fault models using the estimation of earthquake motion

Earthquake	Earth. 1	Earth. 2		Earth. 3	
		1	2	1	2
length (km)	100	130	93	80	40
width (km)	50	65	82	25	25
dislocation (m)	3	4.5	3.0	8	1

(2) Layer structure, mechanical parameter and S-wave velocity structure show smaller variation in the basement than those in the surface layer.

Although the depth of the Pliocene formation is not uniform in Nagoya city, the formation will almost satisfy the condition (1) and (2). Hence, we can choose this formation as seismic basement.

2-2 Assumed earthquake

When we assumed an earthquake which will bring damage in Nagoya city, it is necessary to refer the past earthquake occurring around the city. Only earthquakes with Japanese Seismic Intensity more than V which are marked with the black circle are shown in Figure 2 where their epicenter and magnitude into three types; giant earthquakes with magnitude about 8 (Ms scale) occurring off the Tokaido and Nankaido regions, big to medium earthquakes with magnitude from 6 to 8 in inland area and relatively small earthquakes from 5 to 6 around downstream of Kiso River and in the Owari district.

Recently, the possibility of earthquake occurring in the Tokai province has been discussed and earthquake observations have been strenghthened in the province. Shizuoka prefecture and its surrounding areas were designated as important prevention areas. Based on the above reasons and the past earthquakes, the following earthquakes are assumed for calculation of the damage estimation in Nagoya city.

(1) Assumed earthquake-1; earthquake occurring in Tokai district, about 160 km east of Nagoya city. This earthquake is most likely to cause damage in Nagoya in near future. For convince this earthquake is called "earthquake-1" in this paper. The same usage is done in the following two earthquakes.

(2) Earthquake occurring in Enshu-nada about 130

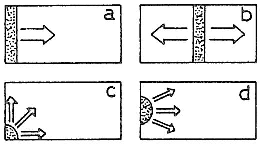

Figure 4 Fracture propagation models

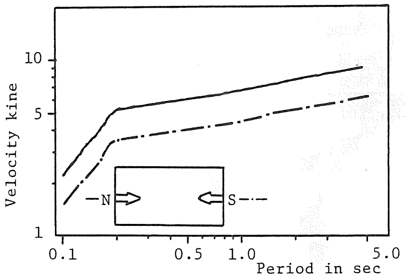

Figure 5 The calculated result of maximum response velocity for the earthquake-1

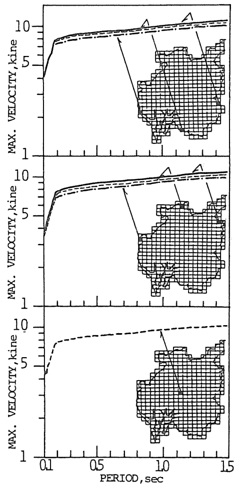

Figure 6 The calculated result of maximum response velocity for the earthquake-2

km south of Nagoya city. Tonankai Earthquake (1944) is similler to this earthquake 2.

(3) Earthquake occurring in inland area, 40 km north of the city. Nobi Earthquake (1891) is reference of this earthquake 3.

As a fault model for earthquake-1, we chose that of The Committee of the Ministry of Construction for The Assumed Tokai Earthquake. The model is reproduced in Figure 3. And also, the model for earthquake-2 in Figure 3 is of the Tonankai Earthquake, proposed by Iida (1976)[1]. Parameters to represent the faults of both the earthquake-1, -2 and -3 are summarized in Table 1, where fault model for the earthquake-3 is of Mikumo, et. al (1976)[2].

3. ESTIMATION OF MAXIMUM ACCELERATION ON THE SURFACE

3-1 Maximum response acceleration at the upper plane of seismic basement

Seismic response spectra were calculated by the method proposed by Midorikawa and Kobayashi (1979)[3]. Major factors are parameters of earthquake fault, fracture velocity, fracture propagation of S-wave velocity along the propagation path. Although fracture velocity and propagation velocity were determined in each case of the assumed earthquakes, the other necessary condition for calculation are of Midorikawa and Kobayashi.

(1) Assumed earthquake-1

Response value by the fault model strongly depends on the distance from the fault plane to a place on a surface. However, it takes an enormous time to calculated in each 500 $\times$ 500 m^2 mesh area. Hence, considering that distance from fault plane and Nagoya city are 160 km shorter than east-west distance (25 km) of Nagoya, the average data of four corners and center of city are applied to all the area for calculation.

As a fracture propagation, four types shown in Figure 4, will be probable ones. Response calculation was done in all the types. As the highest response value was given at the type of one-direction fracture propagation as shown in Figure 4 (a), the propagation type was adapted for the following calculations.

As a S-wave velocity propagation path, we used Mikumo's data in the earth's crust, which were obtained from earthquake observations and gravity measurements. Figure 5 shows the calculated results of maximum response velocity of incident wave based on the many factors mentioned above. Solid and broken lines in Figure 5 correspond to the initial fracture of southern and northern ends, respectively. As the response values are higher in the former fracture at all the range of periodic time than the latter, the former southern end initialization was adopted for our calculations.

Response spectra of acceleration were calculated numerically differentiating the maximum response spectra of incident wave. The maximum acceleration of incident wave is calculated by means of Kobayashi's method. Average calculated acceleration was about 70 gals at the upper plane of the seismic basement for the assumed earthquake-1.

(2) Assumed earthquake-2

As the fault plane of the earthquake-2 is closer to Nagoya city compared with the earthquake-1, responses of incident wave are calculated at nine localities; four corners, one center and four middle points of side lines. The type of fracture propagation and dynamic parameter in propagation path for the earthquake-2 are the same as those in the earthquake-1. The calculated results of maximum response

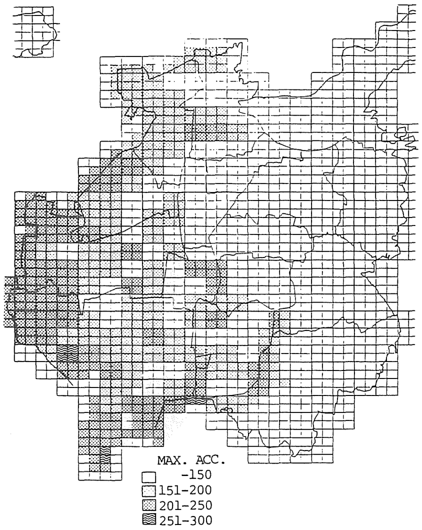

Figure 7 The calculated result of maximum response acceleration on surface for the earthquake-1 in Nagoya city

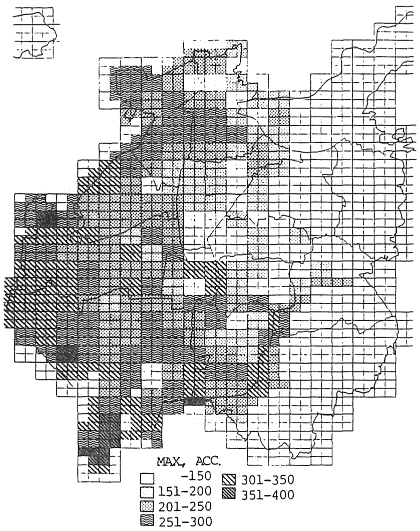

Figure 8 The calculated result of maximum response acceleration on surface for the earthquake-2 in Nagoya city

spectrum are shown in Figure 6. The maximum response acceleration of incident wave is given by the mentioned above method. The result was about 100 gals as an average data from nine localities.

(3) Assumed earthquake-3

The maximum acceleration of incident wave for this earthquake has been calculated by Midorikawa and was 120 gals. We independently obtained about 120 gals for the acceleration at the basement. The value is calculated from distribution of acceleration at the surface which was estimated from fallen

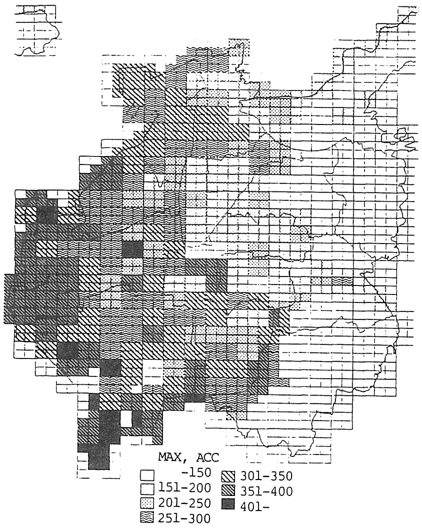

Figure 9 The calculated result of maximum response acceleration on surface for the earthquake-3 in Nagoya city

tombstones in Nagoya city by Omori. This value was used in the following chapters.

3-2 Maximum response acceleration on the surface

Maximum response acceleration on surface ground is obtained multiplying maximum response acceleration on seismic basement by seismic amplification factor in the surface layer. The calculated results for the assumed earthquake-1, -2 and -3 are shown in Figure 7, 8 and 9, respectively.

Maximum acceleration for the earthquake-1 is about 260 gals corresponding to VI as Japanese Seismic Intensity, which is observed partly in the southern end of the city. Seismic intensity is V to VI in the other areas. In earthquake-2, maximum acceleration is about 370 gals in the southern areas, followed by 360 gals in the north-western areas. The areas with more than 360 gals are concentrated mainly in land required for the Shonai River. Most of the areas have the acceleration less than 250 gals, corresponding V as Seismic Intensity.

In the earthquake-3, the areas with high acceleration more than 400 gals (Seismic Intensity VII) area concentrated in the southern part, especially in the seaside industrial belt. The areas with seismic intensity VI are the western half of the city and along the Tenpaku River.

4. DAMAGE ESTIMATION OF DESTROYED WOODEN HOUSE

4-1 Method

Two different methods are used for the estimation of number of totally destroyed wooden houses. One is calculated from the maximum acceleration at the surface, and the other from the degree of liquefaction

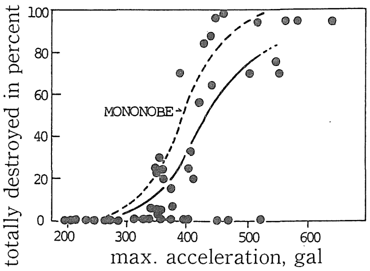

Figure 10 Relation between maximum acceleration on the ground and totally destroyed ratio of wooden house

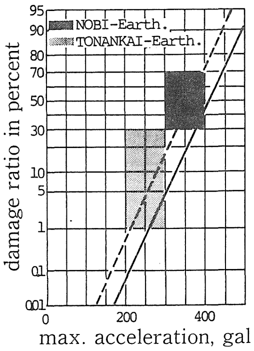

Figure 11 Relation between maximum acceleration on the ground and damage ratio of wooden house

according to the maximum acceleration. The number of half-destroyed houses is also estimated for the relation between totally destroyed and half-destroyed houses obtained for the past earthquakes.

(1) Relation between maximum acceleration and totally destroyed ratio

This method is referred from the correlation between acceleration and the totally destroyed ratio proposed by Mononobe[4] and Kagami[5]. Mononobe proposed the relation between totally destroyed ratio and seismic intensity by Gaussian distribution curve based on the damages due to the past earthquakes. By used of the damage in the Kanto Earthquake in 1923, Kagami studied the relation between maximum acceleration and totally destroyed ratio of the wooden houses with natural period of 0.4 second in Kawasaki city. His original data in addition to the Mononobe's data are reproduced in Figure 10. The solid circles show the calculated data by Kagami. They are plotted in concordant with the Mononobe's result.

When we define "the damage ratio" as the totally destroyed ratio plus half of half-destroyed ratio, is Nagoya city, the relation between maximum acceleration and the damage ratio was obtained two cases of the Nobi and the Tonankai Earthquakes, as shown in Figure 11. The straight lines show the relation in

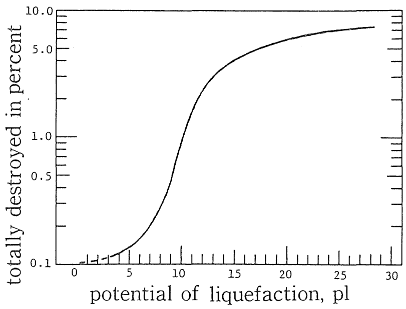

Figure 12 Relation between the degree of liquefaction and totally destroyed ratio.

Kawasaki city calculated by Kagami (Figure 10), assuming that they have the Gaussian distribution. The solid and broken lines are calculated from all the data and data with the highest damage ratio, respectively. The damage ratios in Nagoya are plotted along the broken line. If we consider improvement of recent house such as lightening of roof and increase of wall ratio, the damage ratio curve for present or near future will run below those for the past earthquakes. Hence, for estimation of number of totally destroyed houses, we used the curve which is shown in solid line in Figure 10.

(2) Estimation of degree of liquefaction risk and relation between PL value and totally destroyed ratio

There are several methods to estimate a degree of liquefaction risk. Some of them are by Seed, Iwasaki et. al and Ishihara. As Iwasaki's method[6] gives the numerical values (PL) as a degree of liquefaction risk, we chose their method. The subjects to the calculation of PL values are all the localities where sandy layers occur and ground-water levels are high.

Among all the PL data for the three assumed earthquakes, only the localities with PL value more than 10 and past liquefaction localities are summarized in Table 2. The PL values at the liquefaction localities at the Tonankai Earthquake in 1944 range from 17.9 to 28.6, and the values from 17.6 to 34.7 for the Nobi Earthquake in 1891. In these localities, totally destroyed ratio was larger than the other areas in Nagoya city. Based on the correlation between PL value, past liquefaction and earthquake damage, we propose the relation between PL value and totally destroyed ratio as shown in Figure 12, assuming the maximum ratio as 10 per cent. The value is due to the maximum ratio of totally destroyed houses in liquefaction area at Niigata Earthquake in 1964.

(3) Damage estimation of half-destroyed house

The number of half-destroyed house. is estimated for the relation between totally destroyed and half-destroyed ratios obtained for the past earthquakes in Japan. As shown in Figure 13, the result is not

Table 2 The calculated result of degree of liquefaction for earthquake-1 to -3

Observation Site		Earthquake 1	2	3	Occurrence of Liquefaction
NAKAGAWA	Tomita	15.2	19.8	22.8	
	Tomita	10.4	13.5	15.6	
	Higashiokoshi	24.9	32.4	37.4	
	Shimonoishiki	16.1	20.9	24.2	O Nobi, Tonankai
	Tamafune	11.4	14.8	17.1	
	Hokke	11.5	15.0	17.3	
	Tsutamoto	14.2	18.5	21.3	
	Nagara J.H.S	14.5	18.9	21.8	
MINATO	Inae	18.7	24.3	28.1	O Tonankai, Mikawa
	Kinjo	10.7	13.9	16.1	
	Ooe	22.0	28.6	33.0	O.Tonankai
	Shiomi	18.7	24.3	28.1	
	Shiomi	16.2	21.1	24.3	
	Inae 2	33.5	43.6	50.3	
	Sorami	33.1	43.0	49.7	
	Koei	14.4	18.7	21.6	O Tonankai, Mikawa
	Shiowa	13.8	17.9	20.7	O Tonankai
	Funami	15.6	20.3	23.4	
NAKAMURA	Yashukuni	11.7	15.2	17.6	O Nobi
	Iwatsuka	12.8	16.6	19.2	O Nobi
	Nishie	6.2	18.7	26.5	O Nobi
NISHI	Yamada	15.6	20.3	23.4	O Nobi
	Yamada	16.1	20.9	24.2	O Nobi
	Horikoshi	23.1	30.0	34.7	O Nobi
	Yatsuzaka	17.5	22.8	26.3	O Nobi
	Sakaido	21.5	28.0	32.3	
	Kasatori	20.8	27.0	31.2	
ATSUTA	Hatano	23.1	30.0	34.7	
MINAMI	Takiharu	12.5	16.3	18.8	
	Tobeshimo	24.6	32.0	36.9	
	Daido	15.2	19.8	22.8	
	Shidori S.H.S	13.2	17.2	19.8	
Midori	Oodaka	13.4	17.4	20.1	

o; Occurrence of liquefaction due to Earthquake

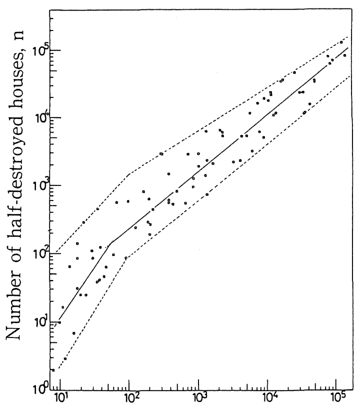

Figure 13 Relation between the number of totally destroyed houses and half-destroyed houses

apparently linear, but the slope seems to change the point where the number of totally destroyed house is 50. Hence, the two curves for the relations are calculated by the method of least squares. The equations of solid lines in Figure 13 are written as follows;

$$n = 10^{0,838.\log N+0,663} \quad (N \geqq 50) \quad \cdots\cdots(1)$$

$$n = 10^{1,492\log N-0,436} \quad (N < 50) \quad \cdots\cdots(2)$$

Where n; number of half-destroyed house

N; number of totally destroyed house

4-2 Estimation result of damaged house

Two different methods are used for the estimation of totally destroyed wooden houses to all the wooden houses. One is calculated from the maximum acceleration at the surface, and the other from the PL values. Comparing two methods of damage estimations by maximum acceleration and PL value, the results of the higher totally destroyed ratio is accepted for calculating of total number of damaged wooden house. The number of the damaged houses can be obtained simply multiplying the ratio by all the wooden houses in each 500 × 500 m^2 mesh area. For the estimation of the half-destroyed wooden house, we used the equation (1) and (2) according to the number of totally destroyed houses. Calculated results for the three assumed earthquakes are as follows.

(a) Assumed earthquake-1 (Assumed Tokai Earthquake)

Figure 14 shows the estimation results of totally destroyed houses. The number of the damaged house is negligible in the eastern and central part of Nagoya, but it exceed 50 in the high PL value area in the western part such as Nishi, Nakamura and Nakagawa regions. The average of totally destroyed ratio of all the areas is 0.28 per cent.

The damage of half-destroyed house occurs mainly in the western part of the city as shown in Figure 15. The areas with half-destroyed house more than 100 concentrate in Nakamura and Nishi wards. Ratio of half-destroyed house is 0.49 per cent as an average in Nagoya city.

(b) Assumed earthquake-2 (Tonankai Earthquake in 1944)

Figure 16 shows the estimation results. The damaged house is scarce in the eastern part, but exceeds 100 in Nakamura, Nakagawa and Kita wards. The average of totally destroyed ratio is 2.24 per cent.

The areas with the half-destroyed houses more than 100 are observed commonly in Nakamura and Nishi wards, and along the Shonai River in Nishi ward as shown in Figure 17. Average destroyed ratio is 4.42 per cent.

(c) Assumed earthquake-3 (Nobi Earthquake in 1891)

Figure 18 shows the estimation results. The areas with the damaged houses more than 100 are common in the western half of the city and in Minami and Midori wards along the Tenpaku River. The damage is quite low at the seaside industry belt of the southern part of Minato ward. This does not show security against earthquake, but is due to the low abundance of wooden house.

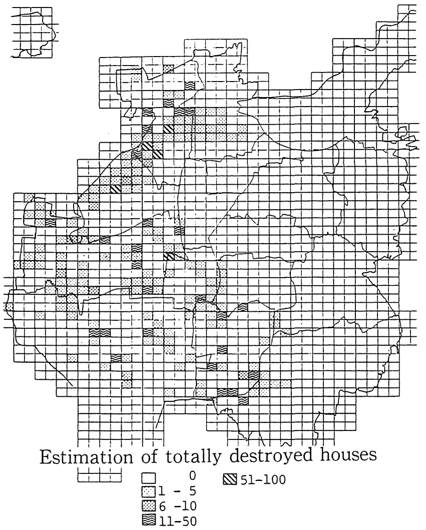

Figure 14 Estimated result of totally destroyed wooden houses for earthquake-1

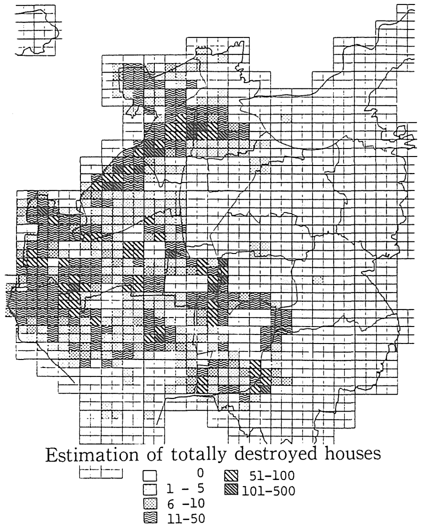

Figure 16 Estimated result of totally destroyed wooden houses for earthquake-2

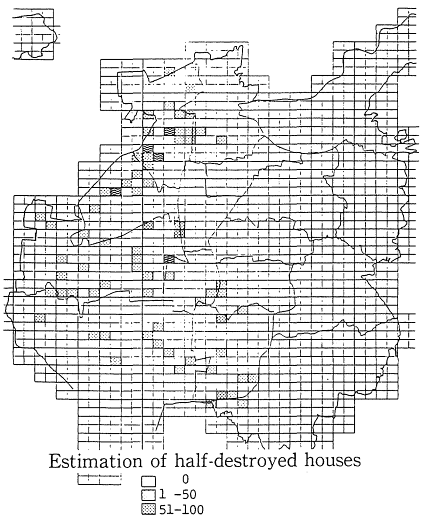

Figure 15 Estimated result of half-destroyed wooden houses for earthquake-1

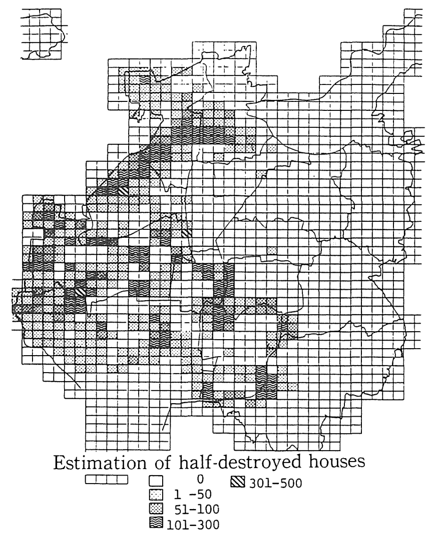

Figure 17 Estimated result of half-destroyed wooden houses for earthquake-2

As shown in Figure 19, the areas with the half-destroyed houses more than 300 are common in Nakagawa and Nakamura wards, along the Shonai River in Nishi ward, Nakagawa Canal and the Tenpaku River basin. The average damage ratio is 11.34 per cent.

4-3 Validity of the estimation results

We discuss the validity of estimation result of totally destroyed and half-destroyed houses. We study the relation between the damage ratio and the maximum acceleration or observation results of the past earthquakes. The relation of damage ratio and maximum acceleration for the assumed earthquake-1 is shown in Figure 20. The plotted data concentrate in two areas, one between the broken and solid lines, and the other around the point with 180～200 gals and 10 per cent damage ratio. This results can be explained by the difference of calculation method. As mentioned previously, we adapted larger damage ratio of the two calculation methods. The former corresponds to maximum acceleration method. The latter is from the PL value method, i, e, liquefaction. The damage ratio is affected strongly by liquefaction. This phenomena corresponds to the result of liquefaction observed in the southern part of the city at the past earthquakes.

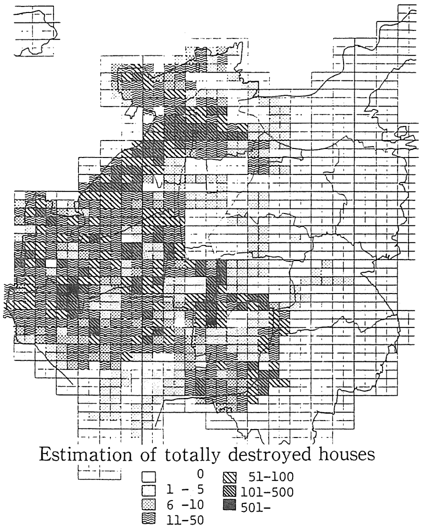

Figure 18 Estimated result of totally destroyed wooden houses for earthquake-3

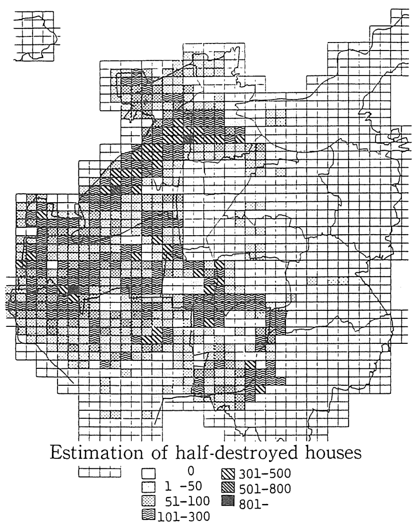

Figure 19 Estimated result of half-destroyed wooden houses for earthquake-3

Figure 21 is for the earthquake-2. Most of the damage ratios are plotted between solid and broken lines. The damage ratios at the Tonankai Earthquake are plotted in a block of bar-dot line. The observed ratios are located in a center of the calculated ratios, and both the average values of the ratios are similar each other. It suggests that the calculated damage ratios are available and it is important to estimate the damage in a small area such as 500 $\times$ 500 m^2 mesh area.

The results for the earthquake-3 (Figure 22) show similar to those for the earthquake-2. However, damage ratios observed at the Nobi Earthquake are

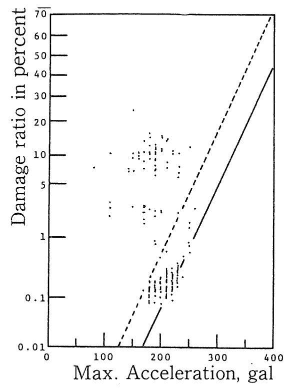

Figure 20 Relation between the maximum acceleration and the calculated damage ratio for earthquake-1

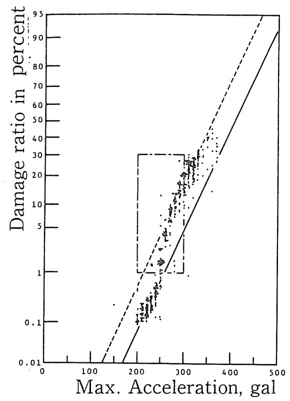

Figure 21 Relation between the maximum acceleration and the calculated damage ratio for earthquake-2

located above the calculated ratios.

To sum up all the results, it is considered that the calculated values are available in a megascopical sense. Judging from the present poor data of liquefaction and soil parameter for PL estimation, the calculated results from the PL method seem to be satisfiable as first approximation.

5. DAMAGE ESTIMATION OF MAN-MADE GROUND

5-1 Method

Authors study the relation between characteristics of the ground motion and damage of man-made ground, using the seismic response analysis of man-made ground suffered from the past earthquakes. Subsequently, authors apply the relation to the man-made grounds in Nagoya city and estimate the seismic response of the ground, damage of houses and risk of man-made ground.

In the estimation, the following investigations are

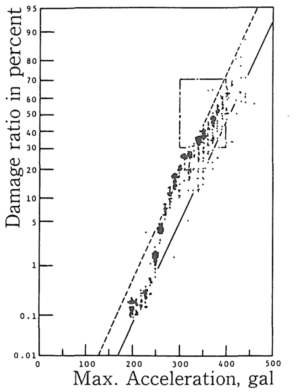

Figure 22 Relation between the maximum acceleration and the calculated damage ratio for earthquake-3

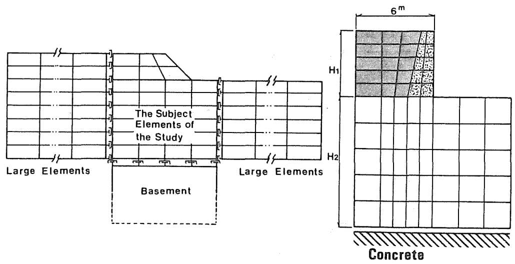

Figure 23 Calculation model for the man-made ground

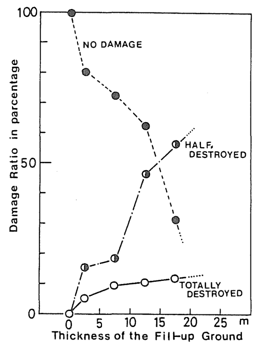

Figure 24 Relation between the thickness of fill-up ground and the degree of damage caused by Miyagiken-oki Earthquake in Midorigaoka, Sendai city

done in Nagoya city.

(1) Distribution of slopes which is constructed in the eastern part of the city.

(2) Number of houses on the slopes.

(3) Field survey of the man-made ground, including number of house, slope, geology and form.

The investigations (1) and (2) are due to aerial photographs. Number of house is counted in each $500 \times 500\ m^2$ mesh area. The field survey is necessary not to collect data shape and others but also to judge whether the slopes found in photograph are man-made or not.

In seismic response analysis of man-made ground, we set a model of ground considering shape and form of each investigated man-made ground as shown in Figure 23, and use two-dimensional finite element method. The quantitative estimation of degree of seismic risk and estimation of number of damaged house in the city is based on the detail analyses of the Midorigaoka man-made grounds damaged during the Miyagiken-oki Earthquake in 1978.

5-2 Seismic response analysis and damage of man-made ground by the Miyagiken-oki Earthquake

Damage of houses on the man-made grounds during the Miyagiken-oki Earthquake are considered to mainly secondary ones induced by destruction of man-made grounds. Asada[7] (1982) investigated the relation between the man-made grounds and damages houses, and reported that seismic damage was scarce in cut-off ground but it occurred mostly in fill-up ground and remarkable in the fill-up ground developed around stream basin.

Based on his report, the relation between thickness of fill-up ground and damage ratio of house is obtained in the case of Midorigaoka, Sendai city. As shown in Figure 24, totally destroyed ratios of houses are directly proportional to the thickness of the fill-up ground.

Based on the data in Midorigaoka ground as a model, authors consider the relation between damage conditions and characteristics of man-made ground motion. Figure 25 shows the geographical maps and cross section before and after construction of the Midorigaoka ground. The ground was developed as a dwelling area from a stream basin with a steep slope. The size is horizontally 200 m in length with 50 m as a difference of height and about 14 degrees as average slope angle. The cross section of the Midorigaoka ground was used for preparing the model ground shown in Figure 26. Density and S-wave velocity of ground, which are necessary for the calculation, are estimated from N-value (Standard Penetration Test) by the following empirical equations (Iida, et. al, 1978).[7]

$$Ro = 1.635 \cdot N^{0.044} \quad (3)$$

$$Vs = 103.62 \cdot N^{0.312} \quad (4)$$

Although most of the N-value for the equations are from Asada (1982), in cases of debris and sandstone without N-value data, S-wave velocity and density are assumed as 250 m/s and 1.80 in the debris and 1200 m/s and 2.30 in the sandstone.

Figure 27 shows parts of results of seismic response calculated from the physical parameters mentioned above. They are corresponding to the response spectrum at sites 1 to 4 in Figure 26. As the site 1

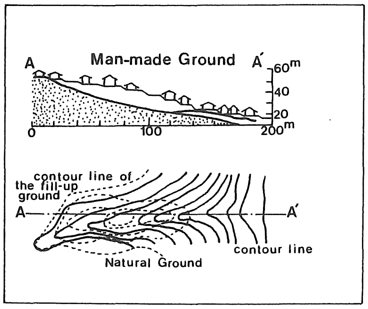

Figure 25 Geological and geographical map in Midorigaoka man-made ground

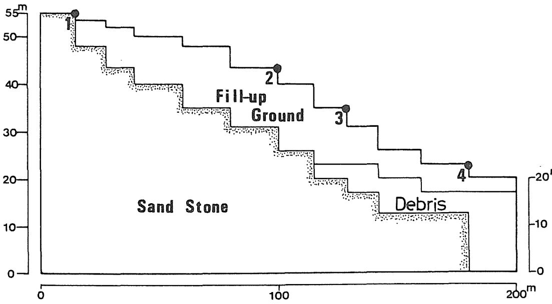

Figure 26 The calculation model of man-made ground in Midorigaoka

consists of sandstone layer, amplification factor is obtained about 1 in all frequency ranges. On the other hand, the site 2 and 3 have spectrum structures with two peaks around 1.0 Hz and 3.8 Hz, and amplification factor in the site 2 and 3 are about 7 and about 3.8 around 1 Hz, respectively. The site 4 has a peak around 1.3 Hz and its amplification factor is about 6. 8. If we assumed that the upper layer of sandstone is fill-up ground, we can find tendency of the amplitude mentioned above increasing with thickness of the ground. However, peak frequencies show no systematic relation with the thickness, but are usually around 1.0 Hz and 3.8 Hz. From these results, it is clear that amplitude is directly related with the thickness of fill-up ground. As the relation is also agreement with damage condition, we can infer the relation between amplification and damage conditions.

Figure 28 shows the relations between thickness of fill-up ground and totally destroyed ratio of houses and/or amplification factor. The two relations obtained from the least square method are given as follows;

$$Yp = 1.83 + 0.67 \cdot H \quad \cdots\cdots(5)$$

$$Ya = 1.60 + 0.29 \cdot H \quad \cdots\cdots(6)$$

where Ya and Yp are amplification factor and totally destroyed ratio, respectively. H : thickness in meters.

From these two equations, the relation between

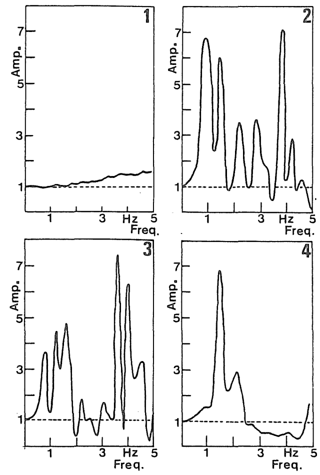

Figure 27 Characteristics of the response spectrum on the site 1 to 4

amplification factor and the totally destroyed ratio is calculated as follows.

$$Yp = -1.87 + 2.31 \cdot Ya \quad \cdots\cdots(7)$$

This equation means that amplification factor, 10, is corresponding to totally destroyed ratio of 20 %.

We calculate maximum acceleration of the basement around Sendai city. Kunii (1979)[8] calculated acceleration seismograph in basement from strong ground motion records at surface in Shiogama city north of Sendai city. His results are shown in Figure 29. The maximum acceleration calculated from the seismograph is about 100 gals in basement. On the other hand, Taniguchi et, al (1979)[9] gave 320 to 450 gals as a maximum acceleration on the ground surface by used of fallen tombstones and amplification of seismic wave calculated from the surface ground structure in the Sendai city. The maximum acceleration in seismic basement is estimated about 70 to 100 gals.

The two estimation methods mentioned above give similar values for maximum acceleration in basement. Hence, we assume that incident wave passing though basement has maximum acceleration of 100 gals. Referring this data and Figure 28, the equation 7 is re-written as the relation between totally destroyed ratio and maximum acceleration, Ga, at surface as follows;

$$Yp = -1.87 + 0.033 \cdot Ga \quad \cdots\cdots(8)$$

where Yp is the totally destroyed ratio.

5-2 Estimation result of damaged man-made ground

For damage estimation of man-made ground, the following items are mainly investigated in the field survey; type of fence, height and angle of the slope are form of the man-made ground. According to the survey, fence protecting the slope are classified into

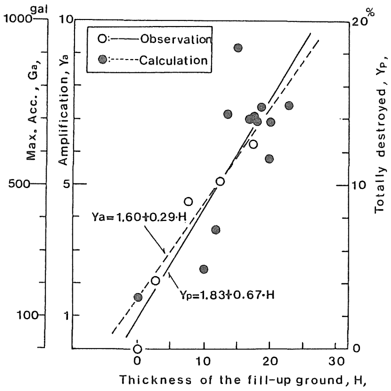

Figure 28 Relation among the thickness of the fill-up ground, totally destroyed ratio and the estimated maximum acceleration of the man-made ground for the Miyagiken-oki Earthquake

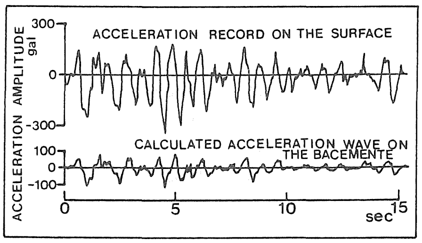

Figure 29 Acceleration record on the surface and calculated seismic wave on the basement in Shiogama city (Kunii)

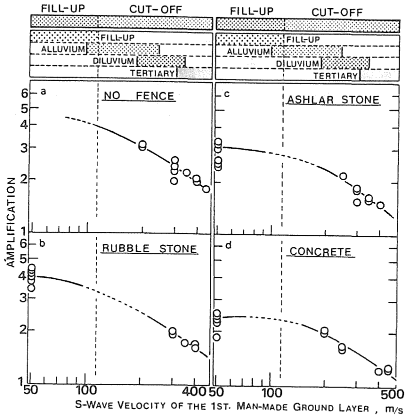

Figure 30 Response characteristics to the various man-made ground type

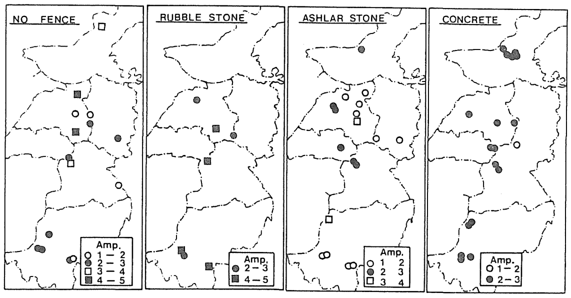

Figure 31 Calculated result of response amplification in eastern part of Nagoya

four types ; no-fence, ashlar stone fence, concrete and cobble stone fence. All forms of the man-made ground are divided into fill-up and cut-off.

Result of the response analysis on the man-made ground in each fence is shown in Figure 30, where it is clear that amplification decreases with increase of S-wave velocity in every ground. Rapid decrease of the amplification is obtained when the velocity exceeds more than 200 m/s. Amplification in the man-made ground decreases in the following order ; no-fence, cobble stone fence, ashler stone fence and concrete fence. Compared with the amplification in no-fence ground to concrete fence ground, the latter is about 60 % of the former one.

Based on the response analysis mentioned above, amplification in the man-made ground in Nagoya city is estimated taking into consideration of sort of fence, its heigh and angle form and distribution of the ground and geology. The calculated amplification factor is shown in Figure 31 and 32. In half of all the no-fence grounds, amplification is 2 to 3. It exceeds 3 in 27 % of the grounds. Very high amplification, more than 4, is obtained in the grounds with height of 10 meters formed in the north-eastern site of the central city. On the other hand, in most of the concrete fence grounds, amplification is less than 3. In the cut-off ground, amplification exceeds 3 only in no-fence ground with height more than 10 meters, whereas such high amplification is obtained in most of the ground except concrete fence ground. Hence, it can be concluded that concrete fence in both the fill-up and cut-off grounds will be effectible to reduce the amplification. Height of ground is also important factor to reduce it.

Number of totally destroyed houses are calculated in a case of earthquake-3 by the following empirical equation.

$$Nt = \sum_{i=1}^{4} Ni \cdot Ypi \quad \cdots\cdots(9)$$

where i ; type of fence, N ; number of houses on the man-made ground, Yp is obtained from equation 8 mentioned previously.

Ga in equation 8 is given here as Gai = Ab•Ai•Alb. Ab is the amplification at the natural ground surface. Ai is an amplification at the edge of the man-made ground. Alb is the maximum acceleration on the basement. As the amplification, it was assumed that there is no damage if the maximum acceleration is

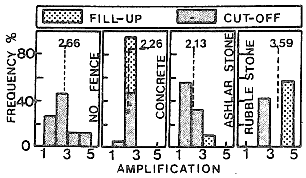

Figure 32 The frequency of the calculated amplification into consideration of sort of the fence

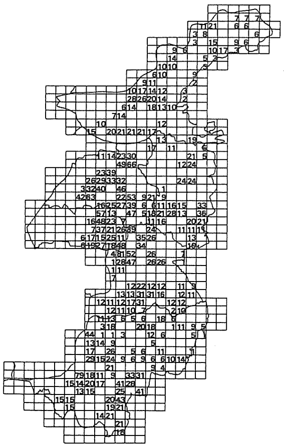

Figure 33 The estimated result of the number of totally destroyed wooden houses due to earthquake-3

less than 230 gals which is obtained from the investigation of damage by the Miyagiken-oki Earthquake in 1978. The number of destroyed houses in the eastern past of Nagoya city are estimated as shown in Figure 33. The damage on the man-made ground is quite high in the central past of eastern Nagoya.

6. ESTIMATION OF FIRE DAMAGE

6-1 Method

Fire damage caused by earthquake depends the number of outbreak fire and their spreading. In this study, number of outbreak fire are assumed as outbreaks estimated from the ratio of destroyed house mentioned in the previous chapters plus those estimated from degree of outbreak fire risk depending on number of dangerous conditions such as boilers, dangerous chemicals, factories and restaurants. As shown in Figure 34, the relation between the totally destroyed ratio and outbreak ratio is obtained from the observation of fire caused by past earthquakes after 1872. As a relation between the outbreak risk degree and outbreak ratio, we used the formula proposed by Tokyo Fire Defence Board. A number of outbreak fire in each mesh area is obtained from the number of houses multiplied by the outbreak ratio.

On the other hand, damage caused by spreading fire is estimated from complex social circumstances

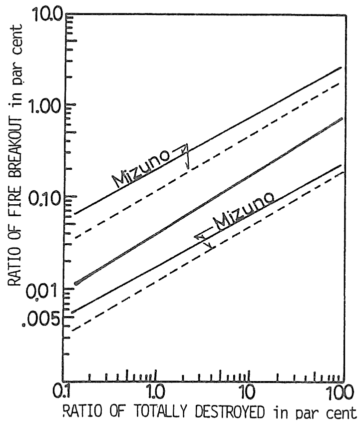

Figure 34 Relation between the totally destroyed ratio and the ratio of outbreak fire

around the outbreak site and weather conditions, especially wind velocity and its direction. We studied the big fire damage on the past twenty big fires to discover the major factors which cause fire spreading. Consequently we found that wind velocity, mixed ratio of wooden house and narrow distance between the houses increased spreading, whereas open space, rivers, fire-proof buildings and fire-prevention facilities work against spreading. At first, we estimated fire damage using only the former spreading fires. Subsequently the damage is re-evaluated by the latter reduction factors of spreading velocity equation, we used Horiuchi's equation (1978). We assumed that fire stops at the open space, river or fire-proof building with widths more than 20 meters. The fire prevention power is exceeded as spreading velocity multiplied by reduction factor, as shown in Figure 35, of spreading depending on water content in the fire prevention pool of earthquake proof.

From many factors mentioned above, number of house damage by fire is estimated in each 500×500 m^2 mesh area, assuming that outbreak fire occurs in a site composed of wooden houses. Spreading fire estimation was done subdividing the 500×500 m^2 mesh area into 20×20 m^2 mesh area to take the complex frame work of dwelling area into consideration. The spreading fire was estimated in sixty one 500×500 m^2 mesh areas in the western and northwestern part of the city where wooden houses are concentrated.

6-2 Estimation result of fire damage

The fire spreading in one drawing area is shown in Figure 36. The solid and dotted lines are corresponding to wind velocity with 3.7 m/s and 10.0 m/s, respectively. Duration time of the spreading are 20, 40 and 60 minutes on both cases. The relation between outbreak number and fire spreading area is obtained on data calculated in the 61 mesh areas. One example

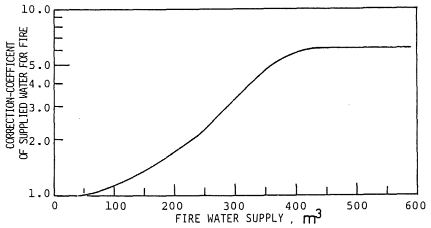

Figure 35 The correction coefficient to quantity of the fire water supply

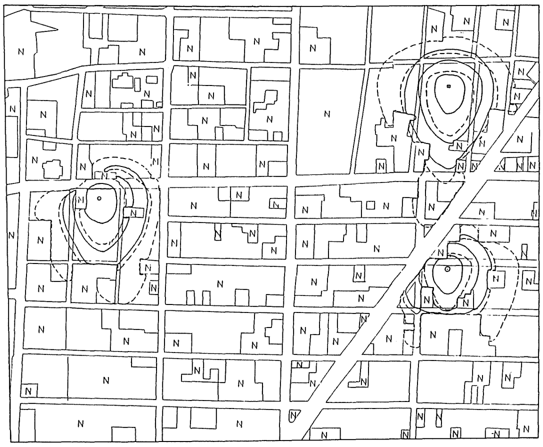

Figure 36 The estimated result of spreading area due to earthquake-3

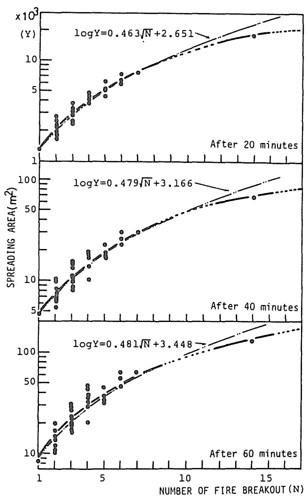

Figure 37 Relation between the number of outbreak fire and spreading area in a case of wind velocity with 3.7m/s

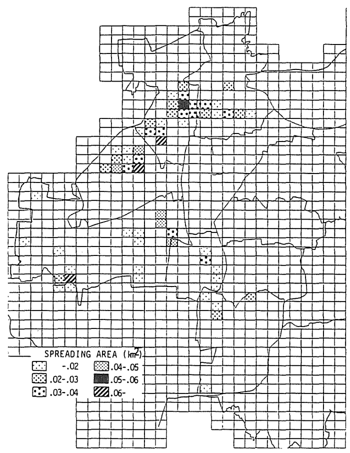

Figure 38 The estimated fire damage due to earthquake-3 in Nagoya city

with velocity of 3.7 m/s and duration time of 20, 40 and 60 minutes is shown in Figure 37. It is apparent that spreading areas are proportioned to square root of outbreak fire number. The relation is given as;

$$\log Y = a \cdot N^{1/2} + b \qquad (10)$$

where Y ; spreading area, N, outbreak fire number, a, b ; constant parameter. Parameter, a, is within 0.46 to 0.48 in spite of variation of wind velocity and duration time. On the other hand, b varies from 2.7 to 3.4 depending on duration time. Figure 38 shows fire spreading area estimated for the assumed earthquake-3. Duration time and wind velocity are 60 minutes and 3.7 m/s, respectively. In the northwestern past of the city, burnt ratio in the mesh areas are more than 12.5 %. Such dangerous areas are corresponding to the areas condensed in wooden houses. The burnt area in the northwestern part exceeds 4 % of the mesh area even if outbreak starts from one site.

To check the validity of estimation results and dense the general tendency of spreading style. The relation between mixiing ratio of and ratio of burnt premise of wooden house is shown in Figure 39. Solid in the figure is of the simulation result by Tachibana (1973),[10] and broken line and circles are of our results. Both the results are quite similar to each other in increasing pattern of the burnt premise. In Tachibana's analysis the burnt premise increases rapidly from 55 % of mixing ratio of wooden house, whereas in our results it increases from 65 %. The 10 % difference will be explained to be reflected by the usage of fire prevention power in our analysis. The damage of fire spreading is closely related with the mixing ratio of wooden house. It can be decreased more than 50 % at an area of mixing ratio less than 65 %, compared with an area of higher mixing ratio.

7. CONCLUSIONS AND REMARKS

Assuming three earthquakes occur around Nagoya city, the earthquake damages were estimated. Estimated damages are breakdown of wooden houses, destruction of man-made ground and fire damage.

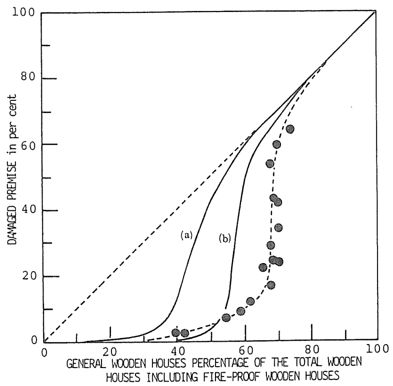

Figure 39 Relation between the mixing ratio and damaged premise

Validity of the estimation results are confirmed compared to the results with the observed damages at the past earthquakes and numerical simulation analyses. Although earthquakes are inevitable, the damages can be reduced by the careful planning of construction of houses and man-made ground.

Based on the present damage analyses, we can summarize the major damage factors as follows ;

(1) Damaged houses are found at first on river basins, reclained land and along cost line where liquefaction risk is high.

(2) Damage on man-made ground varies greatly by the type of fence protecting the slope on the ground. That is, it is affected greatly by vibration characteristics of the fence, which reduce amplification. The amplification in concrete fence, ashler and cobble stone fences are 0.62, 0.72, 0.83, respectively, when it is as assumed as 1.00 in no-fence ground. Reduction effect of the amplification is large in fill-up ground.

(3) Earthquake damage by spreading fire is increased by wind velocity, outbreak number and mixing ratio of wooden house. It is proportioned to square root of outbreak number and increase rapidly at an area with mixing ratio more than 65 %.

There are many factors which contribute to earthquake damage, some of which can not be controlled. However, some of factors can be controlled to reduce earthquake damage. The concrete fence is one good example of a controllable factor and should be used in man-made ground, especially in fill-up ground. Another one is the wooden house mixing ratio and this ratio should be kept at less than 65 %.

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REFERENCES

1. K. Iida ; On the Earthquake Damage, Crustal Deformation and Occurrence of the Tonankai Earthquake, 1944. Bull. Aichi. Ins. Tech, Vol. 11, 1976 (in Japanese)
2. T. Mikumo and M. Ando ; A Search into the Faulting Mechanism of the 1891 Great Nobi Earthquake, J.P.E, Vol. 24, 1976
3. S. Midprikawa and H. Kobayashi ; On Estimation of Strong Earthquake Motions with Regard to Fault Rupture, Trans. of A.I.J, No. 282, August, 1979 (in Japanese with English abstract)
4. N. Mononobe ; *Doboku Taishin-gaku*, Tokiwa Books, 1938 (in Japanese)
5. H. Kagami and H. Kobayashi ; Intensity of Ground Motions During the Kanto Earthquake 1923 in Kawasaki (Subsoil Conditions and Damage Ratio of Wooden Houses due to Earthquake), Trans. of A.I.J, No. 176, Oct. 1970 (in Japanese with English abstract)
6. T. Iwasaki, F. Tatsuoka, K. Tokita and S. Yasuda ; Estimation of Degree of Soil Liquefaction During Earthquake, J.S.S.M.F.E, Vol. 28, No. 4, 1980 (in Japanese)
7. K. Iida, K. Masaki, H. Taniguchi and T. Tsuboi ; Seismic Characteristics of the Ground and Earthquake Risk in Nagoya City, Pro. of J.E.E.S, Dec. 1978 (in Japanese with English abstract)
8. T. Kunii ; On the Maximum Acceleration Estimated from Investigation of Tombstones. Comprehensive Urban Studies, No.8, 1979. (in Japanese with English abstract)
9. H. Taniguchi, K.Masaki, T. Tsuboi and K. Iida ; Damage to ground, Structures and Grave Stones Stones Caused by the 1978 off Miyagi Earthquake, Bull. Aichi. Ins. Tech, Vol. 14, 1979 (in Japanese)
10. F. Tachibana ; Investigation of the Spreading Fire in Urban Area, Fire Prevention Society of Japan, Vol. 23, No. 4, 1973 (in Japanese)

(Recieved January 30th, 1985)