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FORECASTING DAMAGE RATIO OF WOODEN HOUSES IN AREAS HAVING A HISTORY OF LIQUEFACTION

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SUMMARY

This paper aims to investigate a method of forecasting rate of damage to wooden houses when liquefaction occurs. We examined the relation between damage rate to wooden houses and intensity of earthquake motion, dynamic shear resistance of the ground. As a result, we reached the following conclusions: (1) Maximum surface velocity and spectral intensity are better indices of rate of damage to wooden houses than is maximum surface acceleration. (2) As a rasult of investigating dynamic shear resistance to a depth of 20m, the factor most strongly influencing the rate of collapse was dynamic shear resistance within 5m of the surface.

INTRODUCTION

Currently, many different institutions in Japan are conducting seismic microzoning, consisting of anything from regional distribution of earthquake motion to forecasts of amount of damage to various kinds of structures. When the subject of this type of forecasting is wooden houses, this information directly concerns residential environment. As such, it constitutes a fundamental category of disaster research relating also to fires or human disasters. Many kinds of research have long been conducted such as that of Dr.Mononobe Nagaho (1926) on the relationship between seismic intensity and rate of complete collapse of wooden houses (Ref.1).

In this paper, as shown in Fig.1, we used data on damage of four earthquakes that occurred in Japan from 1923 to 1983 to determine damage to wooden houses. Next, we investigated whether or not liquefaction occurred in these areas of damage, and calculated maximum surface acceleration, maximum surface velocity, spectral intensity as indices of intensity of earthquake ground motion. From drilling data of these areas, we determined N value, underground water level, mean diameter of sand partcle. From these data, we calculated dynamic shear resistance. Then we determined the relationships between damage rate to wooden houses and intensity of earthquake ground motion. Also, we determined the relationships between rate of damage to wooden houses and dynamic shear resistance of the ground. From this, we identified the factors exerting the most influence on damage. Fig.2 summarizes this research.

DAMAGE RATIO OF WOODEN HOUSES AND CALCULATION OF INTENSITY OF EARTHQUAKE GROUND MOTION

Damage ratio of Wooden Houses Table 1 shows the specification of the earthquakes and their area names used in analysis. The following formula for rate of damage to wooden houses was calculated on the basis of references on these earthquakes, taking of villages as units (Refs.2,3,4,5):

$$YD = CD + 0.5 * HD \tag{1}$$

where,

YD : Damage Ratio of Wooden Houses

CD : Rate of Complete Collapse of Wooden Houses

HD : Rate of Half Collapse of Wooden Houses

Data on damage ratio of wooden houses in 253 places from all four earthquakes were used. The breakdown of these data are given in Table 1. Using the date on damage, we decided on the probability of liquefaction having occurred.

Calculation of Intensity of Earthquake Ground Motion Fig.2 shows methods of calculation on surface acceleration resulting from the earthquakes. The seismic bedrock of each area was determined, and the incident acceleration to that seismic bedrock was calculated. One-dimensional response analysis, using multiple reflection theory, was then conducted for the layers above the seismic bedrock, and surface acceleration waveforms were determined. This response analysis method uses equivalent linear analysis to take into account changes in rigidity(G) and damping constant(h) due to shear strain(γ). Table 1 shows how incident acceleration values were determined for each earthquake, incident waveform names, etc.

Maximum surface acceleration was calculated from the waveform determined by the above analysis. Then the waveform was integrated by fourier transformation and its velocity was calculated. Spectral intensity(SI) was determined using the formula below, after calculation of velocity response spectrum(Sv) where damping constant h=20%.

$$SI = \frac{1}{2.4}\int_{0.1}^{2.5} S_v(T,\ h=0.2)\,dT \tag{2}$$

Relation Between Damage Ratio and Maximum Surface Acceleration The curve in Fig.3 shows the relationship between complete collapse rate of wooden houses and horizontal acceleration, according to Mononobe's formula. Almost all the data where liquefaction probably took place fall above this curve.

In Figs.4 and 5, the relationship between rate of damage to wooden houses and maximum surface acceleration is shown, dividing the areas into those where liquefaction occurred and those areas where it did not occur. In the figures, we see that despite the fact that maximum surface acceleration is not large in those areas where liquefaction occurred, there is still a lot of damage to wooden houses. However, even though there are some differences in distribution patterns, it is defficult to distinguish the characteristics of areas where liquefaction did and did not occur using maximum surface acceleration.

Relation Between Damage Ratio and Maximum Surface Velocity or Spectral Intensity Figs.6 and 7 shows the relationships between rate of damage to wooden houses and maximun surface velocity. In these figures, maximum velocity range extends from 20 to 80 kine. Maximum surface velocity at the outer limit of where liquefaction occurred is around 30 kine. This is clearly different from the areas of non-liquefaction.

The relationships between rate of damage to wooden houses and spectral intensity are shown in Figs.8 and 9. The tendencies are very similar to those of maximum surface velocity. However, there is less discernible difference than those of the maximum surface velocity between areas of liquefaction and areas of non-liquefaction. This is probably due to the fact that there were no clear differences between those areas where liquefaction did and did not occur, where the spectral intensity is determined by the main peak of the velocity response spectrum.

Methods Rate of damage to wooden houses due to liquefaction area is influenced not only by intensity of input earthquake motion, but also by the dynamic shear resistance of the ground as well. The most accurate way of examining dynamic shear resistance is to take undisturbed samples from sandy layers and conduct cyclic triaxial testing on them in the laboratory. However, when wide areas are to investigated, it is also common to calculate dynamic shear resistance(R) from N value, mean diameter of sand particle(D_{50}) and effective overburden pressure(σ_v') data. The latter procedure was followed in this case. The formulas proposed by Iwasaki et al. and Tatsuoka were used to infer dynamic shear resistance (Refs.6 and 7). Fig.10 shows a drilling column chart for Noshiro City, distribution of N value and calculated dynamic shear resistance, as one example.

Relation Between Damage Ratio of Wooden Houses and Dynamic Shear Resistance

The rerationship between rate of damage to wooden houses at 68 places in Hamamatsu City and Noshiro City and calculated dynamic shear resistance was examined. This was done by using the formula below to perform multiple regression analysis on rate of damage to wooden houses (YD) and minimum values of dynamic shear resistance (R_1, R_2, R_3, R_4) per evenry depth of 5m in order to examine the various effects of factors R through R on rate of damage to wooden houses.

$$YD = a_1 R_1 + a_2 R_2 + a_3 R_3 + a_4 R_4 + b \tag{3}$$

In general, when dynamic shear resistance is big, rate of damage to wooden houses should be small. In other words, the factors R to R have a negative correlation to YD. Fig.11 shows regression coefficient (a_1 -a_4) obtained by multiple regression analysis. From this we see that the minimum values of dynamic shear resistance to a depth of 5m shows a negative correlation to rate of damage to wooden houses. This corresponds to the general tendency. From this we found that rate of damage to wooden houses is most strongly affected by dynamic shear resistance of the ground within 5m of the surface. Fig.12 shows the relationship between rate of damage to wooden houses and dynamic shear resistance according Tatsuoka's formula.

CONCLUSION

From the above results, first for the intensity of earthquake motion, there is good correlation of maximum surface velocity and spectral intensity to rate of damage to wooden houses in areas where liquefaction seems to have taken place. Also, there are differences between initial maximum surface velocity values when damage to wooden houses occurs in areas of liquefaction and areas of non-liquefaction. In areas of liquefaction, critical maximum surface velocity is approximately 30 kine. These results are compatible with those of Midorikawa et al.(1988) (Ref.8). According to this research, maximum surface velocity is a more critical determiner than maximum surface acceleration of whether or not liquefaction will take place.

Next, we found that rate of damage to wooden houses is most strongly affected by dynamic shear resistance within 5m of the surface. We may conclude that if there is a thick clayey surface soil, and even if liquefaction occurs in a lower sandy layer, the effects will not reach the surface and there will be no damage to wooden houses.

Accordingly, if maximum surface velocity, spectral intensity surpass a certain level, rate of damage to wooden houses in areas having a high likelihood of liquefaction can be easily forecast from strength of ground concerning liquefaction, such as dynamic shear resistance. Hereafter, consideration must also be made of effective stress analysis and dynamic soil-structure interaction, in regard to intensity of earthquake motion.

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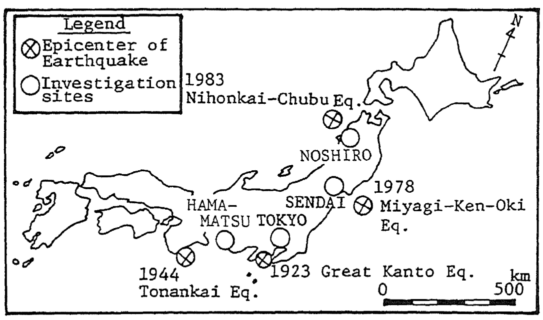

Fig.1 Location of Investigation Sites

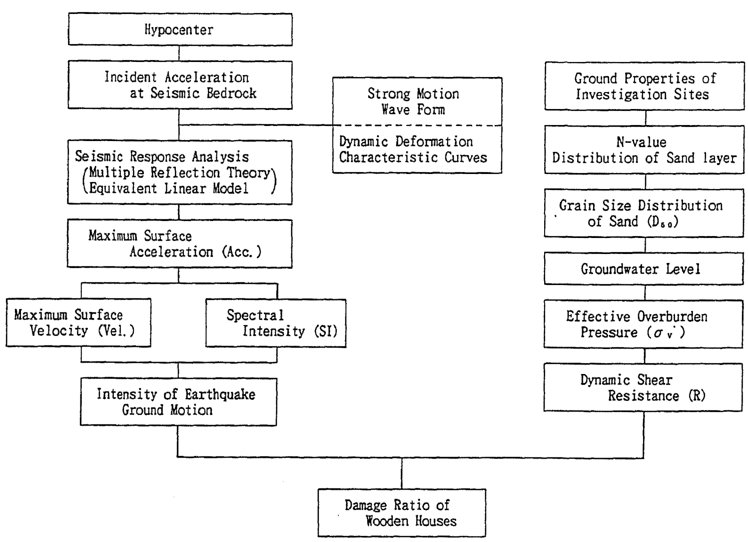

Fig.2 Flowchart of This Study

Table 1 Specifications of the Earthquakes and Methods of Response Analysis

No.	Earthquake Name	Occurrence Year Date	Magnitude (M)	Investigation Sites Name	Number of Data on Damage Ratio of Wooden Houses	Evaluation Method of Incident Acceleration at Seismic Bedrock	Incident Wave using for Response Analysis (Earthquake Name)	Method of Seismic Response Analysis
1	Great Kanto Earthquake	1923 1, Sep.	7.9	Downtown Tokyo Saitama-Prefecture	94	Attenuation Relation at Seismic Bedrock deduced from Complete Collapse Ratio of Wooden Houses	Hachinohe NS comp. converted waveform to the Seismic Bedrock (1968 Tokachi-oki Earthquake)	Multiple Reflection Theory of SH Wave (Equivalent Linear Model)
2	Tonankai Earthquake	1944 7, Dec.	8.0	Hamamatsu City	33	Attenuation Formula at Seismic Bedrock after Tamura et.al. (1979)	Hachinohe NS comp. converted waveform to the Seismic Bedrock (1968 Tokachi-Oki Earthquake)	
3	Miyagi-Ken-Oki Earthquake	1978 12, June	7.4	Sendai City	90	Attenuation Formula at Seismic Bedrock after Tamura et.al. (1979) and Modified with Observed Strong Motion Records	Sumitomo Bulding B2F NS comp. converted waveform to the Seismic Bedrock (1968 Miyagi-Ken-Oki Earthquake)	
4	Nihonkai-Chubu Earthquake	1983 26, May	7.7	Noshiro City	36	Calculation of Acceleration at Seismic Bedrok using the Observed Strong Motion Record (Akita-S)	Akita-S EW comp. converted waveform to the Seismic Bedrock (1983 Nihonkai-Chubu Earthquake)	

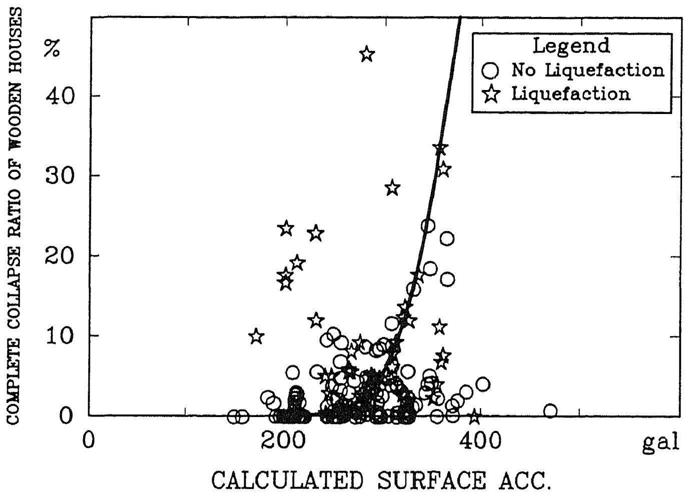

Fig.3 Relation between Complete Collapse Ratio of Wooden Houses and Maximum Surface Acceleration

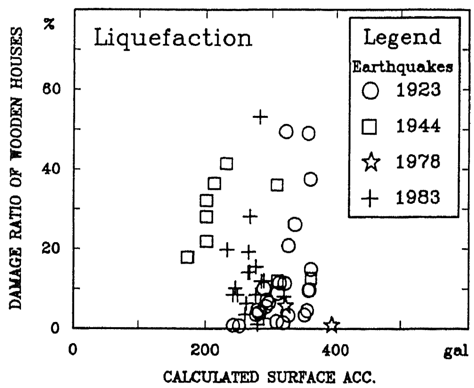

Fig.4 Relation between Damage Ratio and Minimum Surface Acceleration (Areas of Liquefaction)

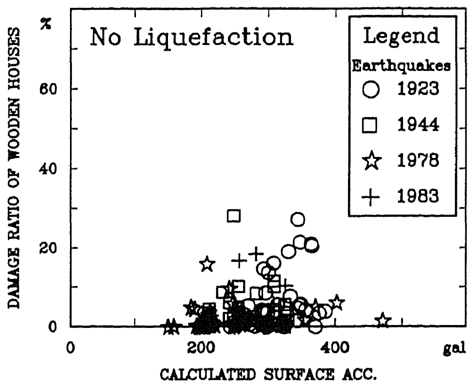

Fig.5 Relation between Damage Ratio and Maximum Surface Acceleration (Areas of Non-Liquefaction)

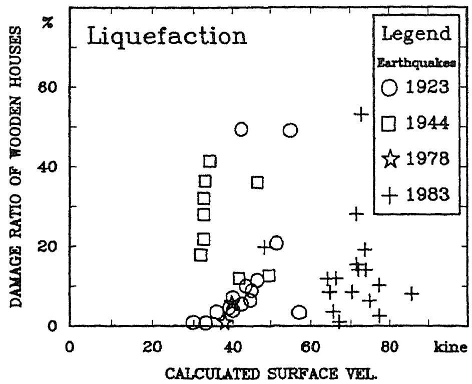

Fig.6 Relation between Damage Ratio and Maximum Surface Velocity (Areas of Liquefaction)

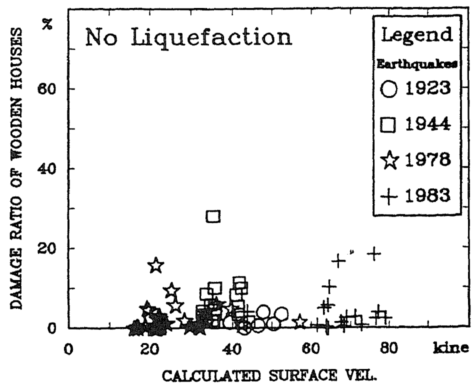

Fig.7 Relation between Damage Ratio and Maximum Surface Velocity (Areas of Non-Liquefaction)

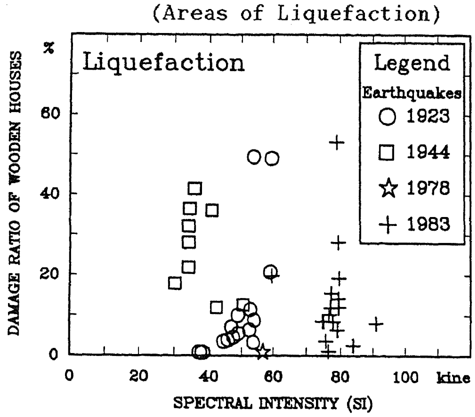

Fig.8 Relation between Damage Ratio and Spectral Intensity (Areas of Liquefaction)

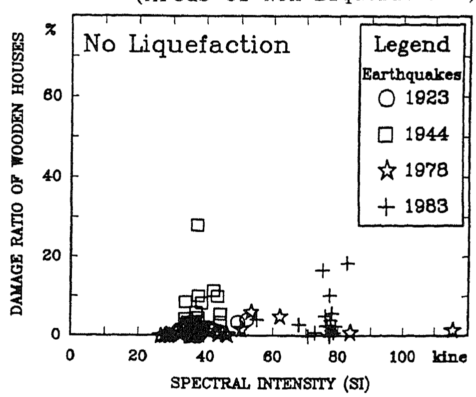

Fig.9 Relation between Damage Ratio and Spectral Intensity (Areas of Non-Liquefaction)

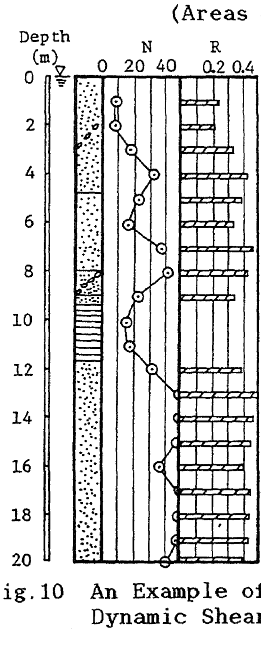

Fig.10 An Example of Calculated Dynamic Shear Resistance

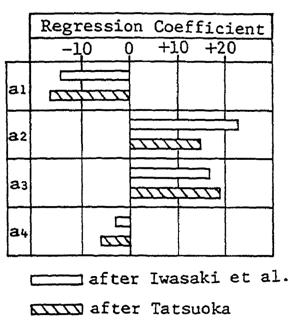

Fig.11 Results of Multiple Regression Analysis

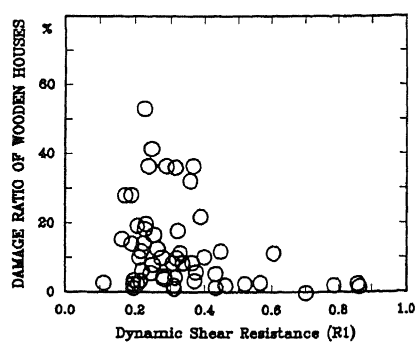

Fig.12 Relation between Damage Ratio and Dynamic Shear Resistance