EFFECTS OF LIQUEFACTION ON DAMAGE TO WOODEN HOUSES DURING EARTHQUAKES

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SUMMARY

This paper is concerned with the damaging effects of liquefaction on wooden houses, which are commonly found in Japan. It is based on two examples of earthquake damage, from the 1923 Great Kanto Earthquake, and from the 1944 Tonankai Earthquake. For the Great Kanto Earthquake, response analysis of the ground beneath 43 villages showed surface accelerations to be in the range of 265-385 gal. For the Tonankai Earthquake, surface accelerations for 28 villages ranged from 181-267 gal. For both earthquakes, the rate of damage to wooden houses in villages where liquefaction did not occur was 8% or less. Where liquefaction is thought to have occurred, damage rate was 5-40% for the Great Kanto Earthquake and 4-24% for the Tonankai earthquake. Investigation showed a clear distinction between extent of damage to wooden houses in cases where liquefaction did and did not occur.

INTRODUCTION

From ancient times, there have been records of liquefaction as sand boiling or water spouting during earthquakes. Liquefaction was long feared as an incomprehensible phenomenon. The 1964 Niigata Earthquake provided vivid evidence of the frightening effects of liquefaction. The damage extended to roads, bridges, river embankments, harbors, homes, pipelines, and many kinds of structures. As a result of this earthquake, a number of detailed studies of liquefaction have been carried out.

To begin with, these studies included such qualitative considerations as the looseness and grain size distribution of sandy layers in areas where damage occurred. Next, Seed, et al (1967) proposed a quantitative method of evaluation. Since then, a great number of evaluation methods have been proposed. These methods basically compare critical shear stress during the earthquake with generated shear stress. They range from those which directly determine shear stress by dynamic soil testing and response analysis to those employing formulas for inferring shear stress. Although these methods are various in their approach, all are concerned with the mechanism of liquefaction and the conditions under which it occurs. None of the studies

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to date have been greatly concerned with the kinds and extent of damage that results from liquefaction.

The latter is the objective of this paper. It examines the Great Kanto earthquake, which caused extensive damage, and on which a wealth of documentation is available, and the 1944 Tonankai earthquake. The location of two earthquakes are shown in Fig.1. Both historical records of damage to wooden houses and geological information on the ground are used, the latter in response analysis to determine seismic force which is then compared to the damage records. In addition, material on the occurrence of sand boiling and water spouting was examined to evaluate the probability that liquefaction occurred in each village, as way of identifying the effect of liquefaction on the damage to wooden houses.

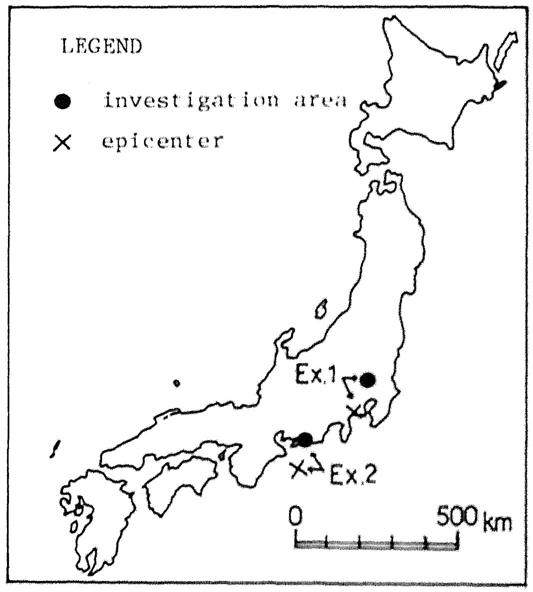

Fig.1 Information Map

EXAMPLE 1: INVESTIGATION OF 1923 GREAT KANTO EARTHQUAKE (M =7.9) DAMAGE TO WOODEN HOUSES

There is a great deal of material available on damage to wooden houses from the Great Kanto Earthquake. The survey by Matsuzawa (1925), which provides information by individual village, gives a good overview of the situation. In the Nakagawa and Edogawa river basins, located in the eastern part of Saitama Prefecture, a high rate of damage was suffered despite the relatively great distance from the hypocenter(see Fig.1), suggesting that the characteristics of the ground surface had some kind of effect. Figure 2 shows the distribution of damage rate in the area around 43 villages. Here, damage rate is defined as the rate of houses suffering total destruction plus 1/2 the rate of houses suffering partial destruction.

Subsurface soil layer distribution and points where liquefaction occurred

Figure 3 shows the types of subsurface ground in the area of investigation, as well as the points where liquefaction occurred. The area consists of loamy tableland, scored by the Nakagawa and Edogawa river basins. It is characterized by loose sand river deposits. In addition, alluvial layers of humus and clayey soil can be seen in valleys and back marshes. At the time of the Great Kanto earthquake, the points where liquefaction could be seen in the sand layers found in the area, running north-south along the rivers.

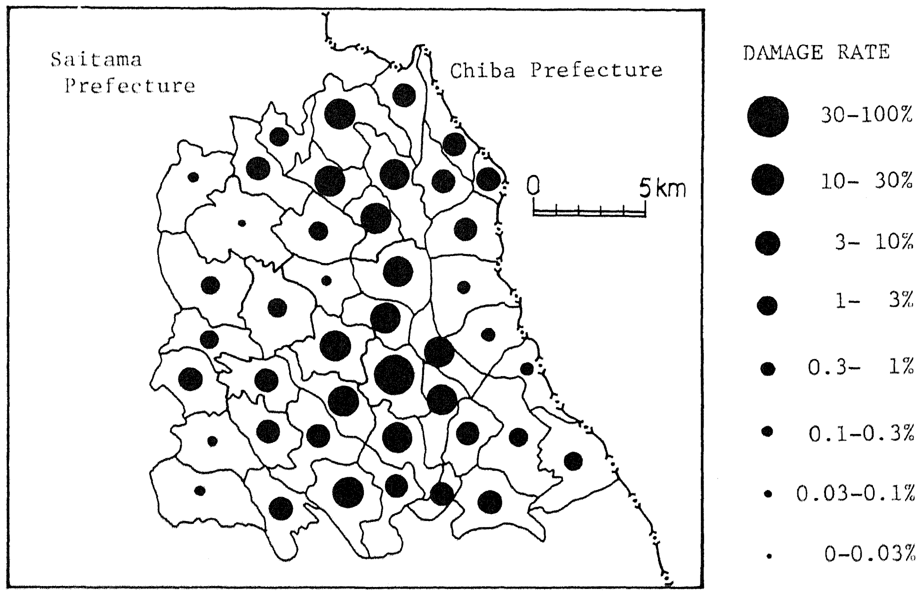

Fig.2 Distribution of Damage Rate to Wooden Houses during Great Kanto Earthquake

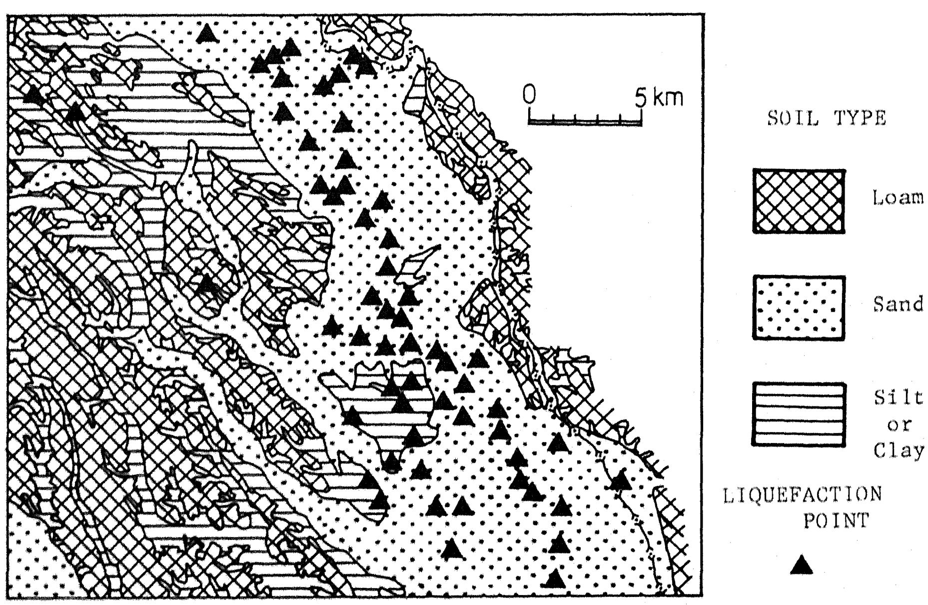

Fig.3 Subsurface Soil Distribution and Liquefaction Point during Great Kanto Earthquake

Evaluation of seismic motion

Using data by drilling investigations, the most representative types of ground found in the region were specified, and a numerical model was constructed. Applying the attenuation equation of Tamura,et al (1979), basement acceleration for this region, in which epicentral distance was 80-95 km, was calculated. Tamura took basement acceleration as that which occurred in the Tertiary layer. Since the basement of the authors' ground model was the diluvial layer, the reasoning of Midorikawa,et al (1980) was used, and a range of incidental acceleration values of 90-110 gal were obtained. Because this is not a very wide range, and for the sake of simplicity, incidental acceleration was taken to be a uniform 100 gal. Input waveforms were those recorded at Hachinohe Bay during the 1968 Tokachi offshore earthquake (M=7.9).

In carrying out response analysis, strain dependency of ground rigidity and damping factor was taken into account. Calculation based on S wave multiple reflection theory was carried out, changing the model until strain converged. In this way, surface acceleration for each ground type was determined. Finally, taking into account the distribution of houses at the time of the earthquake, representative surface acceleration values for each village were determined. Thus, areas in which houses were few or non-existent were ignored, regardless of the ground type.

In this way, the acceleration values obtained for each of the 43 villages were in the range of 265 to 385 gal.

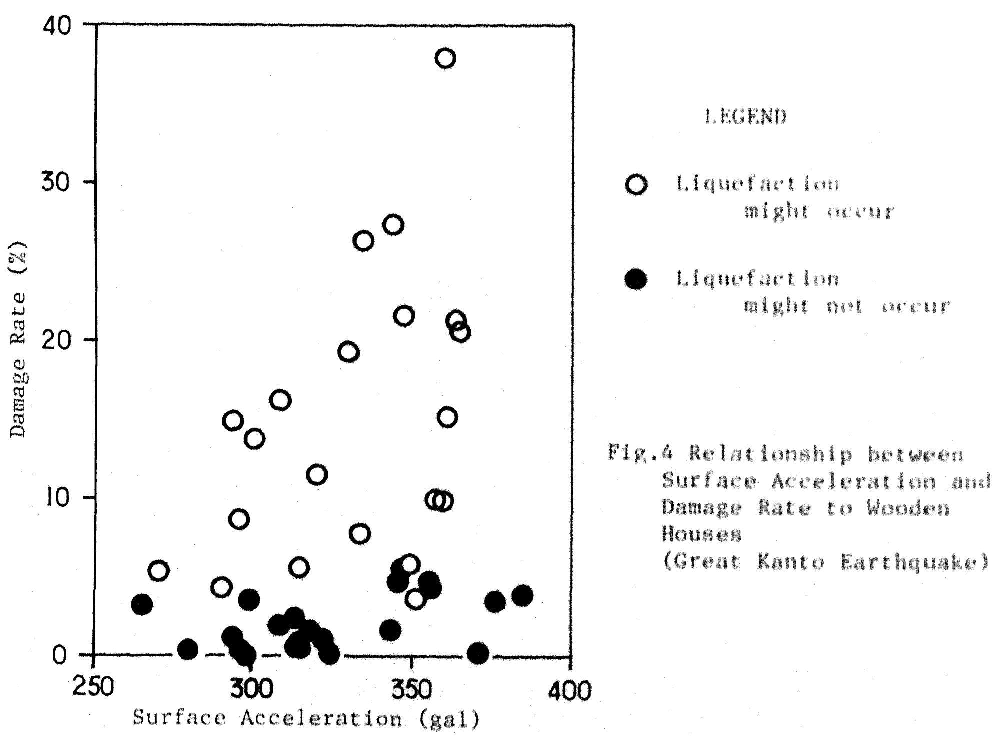

Fig.4 Relationship between Surface Acceleration and Damage Rate to Wooden Houses (Great Kanto Earthquake)

Relationship between surface acceleration and damage rate of wooden houses

Figure 4 shows the relationship between surface acceleration values calculated for each of the 43 villages and the damage to wooden houses suffered there. As surface acceleration increased, there was a tendency for damage rate to increase. In areas where liquefaction may be thought to have occurred, there is a clear difference in damage rate. In villages where liquefaction did not occur, damage rates are 0.1-8%, on the contrary in the villages where liquefaction is thought to have occurred, the damage rate extends widely, from 5 to 40%. It should bo noted that, the villages for which liquefaction was assumed to have occurred, only those villages where liquefaction occurred around the houses at the time, according to the Ministry of Construction, Public Works Research Institute (1974) and Kotohda, et al (1978), were selected.

EXAMPLE 2: INVESTIGATION OF 1944 TONANKAI EARTHQUAKE (M=8.0) DAMAGE TO WOODEN HOUSES

Ooba (1957) and Iida (1976) have reported on the damage to wooden houses as a result of the Tonankai Earthquake. In this instance, we have an epicentral distance near that in Example 1. The authors study included an evaluation of 28 villages around Hamamatsu City (see Fig. 1) that were assumed to have experienced liquefaction. Figure 5 shows the distribution of damage rate to wooden houses for each village. This rate ranges from 0 to 24%, however, villages with a damage rate of over 10% are almost restricted to those found along the banks of the Tenryu River.

Subsurface soil layer distribution and points where liquefaction occurred

Figure 6 shows the types of ground found on the surface of the area of investigation, and the points where liquefaction are assumed to have occurred. In the east, deposits from the Tenryu and Magome rivers form natural levee. In the south, there is an area of sand dunes, made by the coast flow of the Sea of Enshu. In both of these areas, the ground consists mainly of alluvial sand and gravel layers, while a part of the back marsh area has clayey soil layers. From the north to the west, terraced hills and fans are found, forming a tableland consisting mainly of diluvial gravel layers. At the time of the Tonankai Earthquake, the areas where liquefaction occurred were almost exclusively limited to the natural embankments at the lowest reachs of the Tenryu River. The areas where liquefaction were assumed to have occurred were determined using a variety of reference material, as a questionnaire survey of residents in the region, taken at the time of the earthquake.

Evaluation of seismic motion

The same evaluation method as for Example 1 was used. Because epicentral distance were 90-110 km, incidental acceleration was set at uniform 90 gal. As a result, surface acceleration values for 28 villages ranged from 181 to 267 gal.

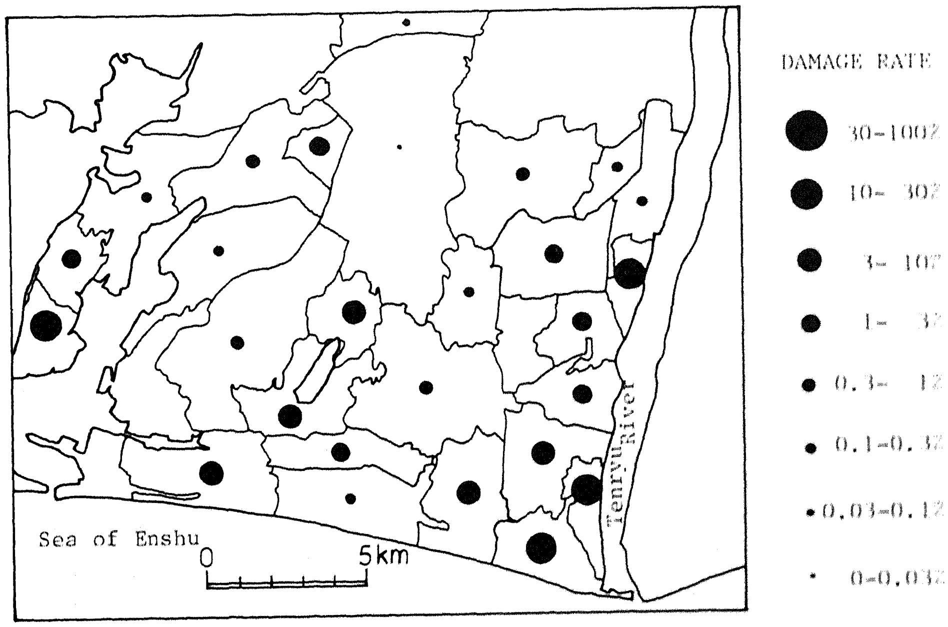

Fig. 5 Distribution of Damage Rate to Wooden Houses during Tonankai Earthquake

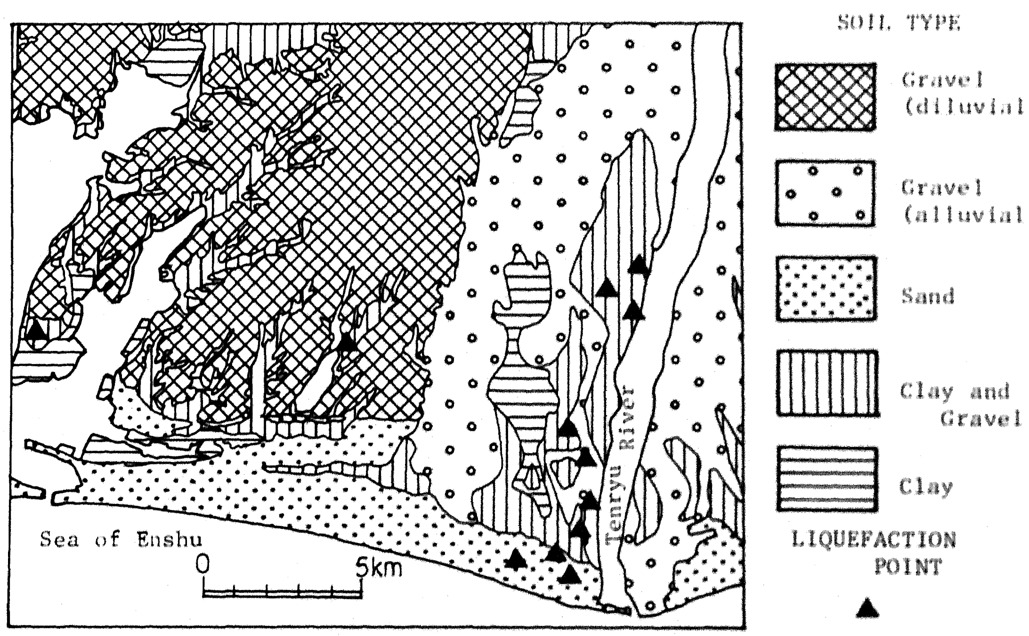

Fig.6 Subsurface Soil Distribution and Liquefaction Point during Tonankai Earthquake

Relationship between surface acceleration and damage rate of wooden houses

Figure 7 shows the relationship between surface acceleration in the 28 villages and the damage rate to wooden houses. The same tendencies were shown as in Example 1, with damage rates of 6% or less in villages where liquefaction did not occur. In the villages where liquefaction did occur, damage rate extends widely from 4 to 24%.

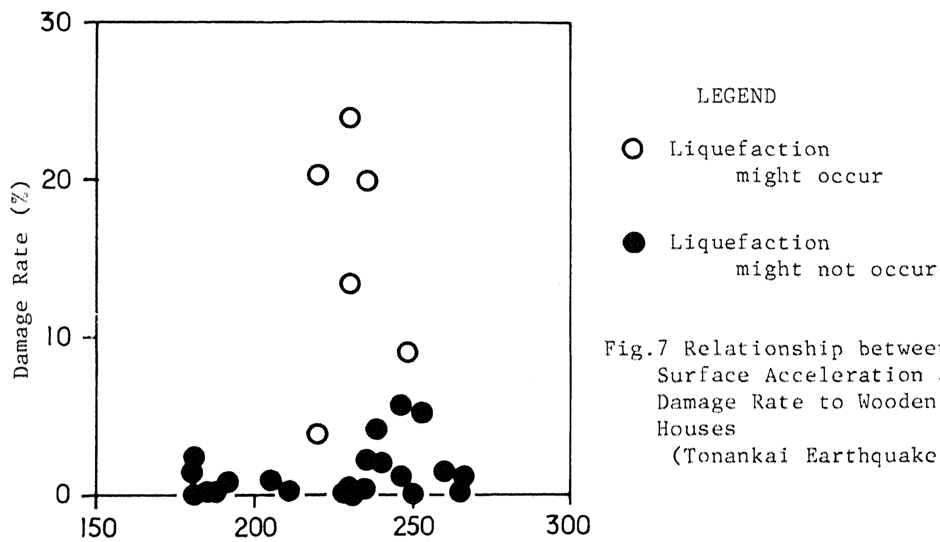

Fig.7 Relationship between Surface Acceleration and Damage Rate to Wooden Houses (Tonankai Earthquake)

DISCUSSION

The above examples showed that damage rate increases with surface acceleration from 0 to 8% when liquefaction does not occur. Where liquefaction does occur, the correlation with surface acceleration is somewhat unclear, but damage rate is 4 to 40%, a considerably higher than the case where liquefaction does not occur.

Because there are few differences in degree of strength of wooden houses, which are commonly found everywhere in Japan, damage rate to wooden houses is often used as a index for estimateing seismic forces. However,this method of evaluating seismic forces has heretofore not taken the factor of liquefaction into account. Figure 8 is a graphic representation of the process by which the relationship between damage rate to wooden houses and seismic force may be determined by taking liquefaction into account. When liquefaction does not occur, the relationship between the two is straightforward

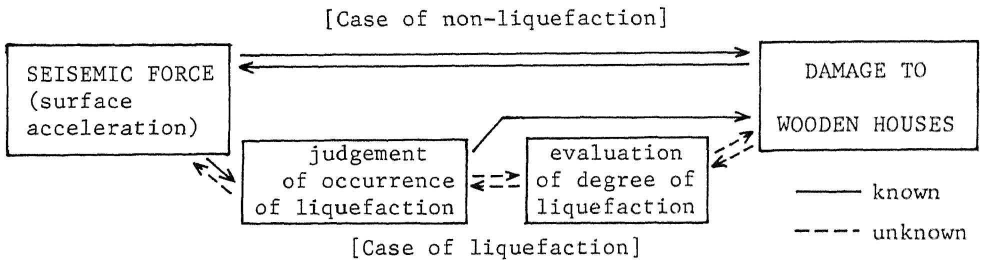

Fig.8 A View of Relationship between Seismic Force and Damage to Wooden Houses

enough, but when the above findings are considered, we see that little is known as yet about the effects of the degree of liquefaction. As study of this phenomenon continues, it should become possible to estsblish the relationship of degree of liquefaction to damage rate to wooden houses as a means of more accurately estimating seismic force.

As mentioned above, it becomes clear that we should take into account the damages to wooden houses in the case of liquefaction and non-liquefaction separately. In order to evaluate quantitatively the relationship between damage to wooden houses and seismic force, the investigation of the degree of liquefaction will be needed and also become the problem in the future.

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