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Simplified method of liquefaction hazard evaluation for subsurface layers

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ABSTRACT: A simplified method to evaluate the liquefaction hazard for subsurface layers is introduced. Method involves microtopographical mapping and in-situ tests such as the weight sounding test, groundwater level measurement and soil sampling for grain size analysis. A chart was prepared to discriminate between occurrence and non-occurrence of ground rupturing due to liquefaction based on the in-situ test data. The method was applied to an area which suffered from liquefaction-induced damages. Results of the evaluation showed reasonably good agreement with the damages of wooden houses which was assessed by interviewing the residents.

1 INTRODUCTION

In seismic active regions such as Japan strong earthquakes have occurred repeatedly causing heavy damages. Liquefaction is one of the hazards which causes damage of wooden houses. Methods of liquefaction potential evaluation which have been widely used (e.g. Seed & Idriss, 1971; Iwasaki et al., 1978; Tokimatsu & Yoshimi, 1983) incorporate boring data at levels 20 to 30 m below the ground level. They are not necessarily suitable for liquefaction hazard evaluation of housing sites. This is because in the case of housing, the main concern is the shallow part of subsurface layers and several points are needed to be investigated for better evaluation of the damage of each house. This paper reports a simplified method of liquefaction hazard evaluation and its applicability to subsurface layers with emphasis on damage of houses.

2 SITE INVESTIGATION

Liquefaction hazard of a residential quarter in Azuma village of Ibaraki Prefecture, which was damaged by the 1987 Chibaken-toho-oki earthquake, was evaluated by the simplified method as explained in the following. Azuma village is located on the left bank of the lower course of Tone river.

2.1 *Microtopographic map*

It is well known that the sites of some microtopographies such as former river channel are vulnerable to liquefaction (Wakamatsu, 1991). Hence the geomorphological classification map was used for the seismic microzonation (Kotoda et al., 1988). The standard of liquefaction vulnerability based on microtopography was proposed by NLDTC (1991) as summarized in Table 1.

The investigated area in Azuma village consists of natural levee etc. as shown in Figure 1 (Wakamatsu, 1991). According to the standard of NLDTC, the liquefaction potential is high in a former river channel and a sandy dry riverbed. It is medium in a natural levee and a delta.

Table 1. Liquefaction vulnerability classification based on microtopography (NLDTC, 1991)

Liquefaction vulnerability	Microtopographical units
high	former river channel or pond, reclaimed land, margin of natural levee, lowland between sand dune, riverbed with fine sand, fill with high water table
medium	delta, natural levee, back swamp, fan with gentle slope delta, valley plain, reclaimed land by drainage
low	sand dune, fan, gravelly riverbed

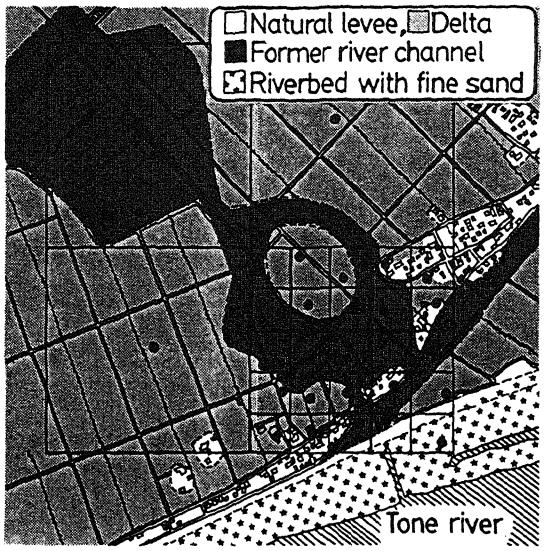

Fig.1 Microtopography of the investigated area in Azuma village (Wakamatsu, 1991)

2.2 *In-situ test*

The weight penetrometer (Broms & Bergdahl, 1982) consists of a screw shaped point, rods and weights (5, 10, 10, 25, 25 and 25 kg). The load on the penetrometer is gradually increased to 1 kN by increasing the number of weights. When the penetrometer does not penetrate any further with the load of 1 kN, it is rotated and the number of halfturns per every 0.25 m of penetration is recorded and reported as Nsw (halfturns/m). The main advantages of the weight sounding test are portability, easy operation and enough penetration ability.

The weight sounding tests were performed at 28 points indicated with black dots in Figure 1 where the size of small meshes is 100 m × 100 m. The groundwater levels were also measured at the respective points. The samples were taken from the sounding pits by using a plate spring sampler for the grain size analyses.

2.3 *Damage of houses caused by liquefaction*

Damage of wooden houses in this area was investigated through interviews with the residents in terms of settlement, tilting, damage of building. The extent of damage of the house due to liquefaction was assessed based on the information thus obtained. Remedial works were also recorded.

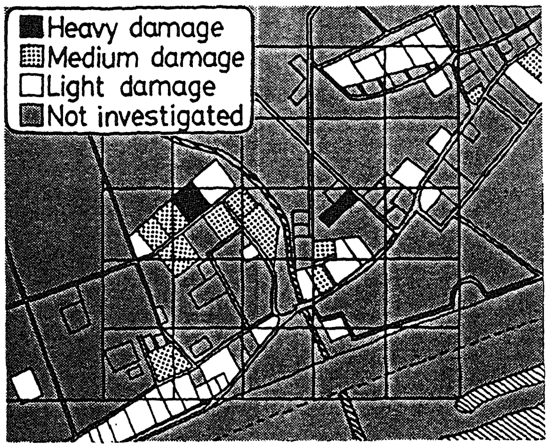

Fig.2 Damage of houses due to liquefaction assessed through interviews

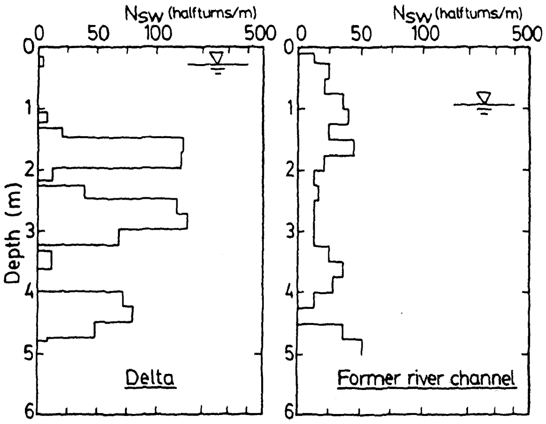

Fig.3 Examples of the weight sounding test results

3 RESULTS AND DISCUSSIONS

Figure 2 shows the extent of damage of houses assessed through interviews. It is seen that the damage is light at houses on the natural levee and it is heavy in the former river channel or pond.

Examples of the weight sounding test results are shown in Figure 3 where the groundwater levels are also indicated. Though the value of Nsw increased with depth in the uniform clean sand deposits which were investigated elsewhere, the similar behavior was not always observed here. The penetrometer sometimes penetrated without rotation (Nsw=0) at certain depths. Cohesive soil was often found to be attached along

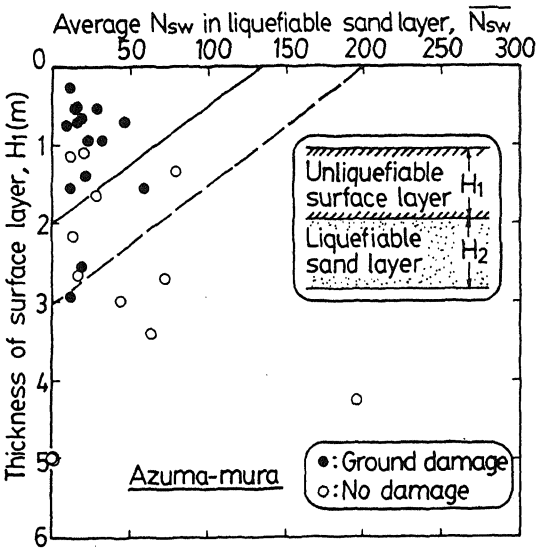

Fig.4 Conditions of subsurface soil stratification discriminating between occurrence and non-occurrence of ground damage due to liquefaction

the depth of the rod. It was also found that the soil samples obtained from the depths where Nsw=0 mostly contained fines ($<75\mu m$) more than 30 to 35 %. Therefore, the ground which gave Nsw=0 was estimated to be composed of cohesive soils, even if the gradation of the soil was not obtained from the procured sample.

From the groundwater level, the gradation of soil and the penetration resistance, Nsw, thus obtained, the thickness of the surface unliquefiable layer H_1 was then defined as being equal to the depth of the ground water table if it was located within the sand deposit. If an unliquefiable cohesive soil existed to a depth below the ground water table, H_1 was chosen as the thickness of the surface layer itself. The average of Nsw, $\overline{Nsw}$, was taken in the liquefiable sand layer underlying the unliquefiable surface layer down to 5 m, which was considered to be the depth that might be most responsible for the damage of small buildings such as wooden houses.

In this context, $\overline{Nsw}$ is regarded as an index for the liquefaction potential of the ground. The smaller $\overline{Nsw}$ is, the higher the liquefaction potential would be. On the other hand, H_1 is considered to be an index of the resistance of the unliquefiable surface layer to prevent the damage coming from the underlying liquefied layer.

The thickness of the surface layer H_1, and the average of Nsw, $\overline{Nsw}$, were obtained according to the above rule, and plotted in Figure 4. The data from sites of known liquefaction damage are indicated by black circles and those from sites without damage are marked by white circles. It may be seen in Figure 4 that the data points with known liquefaction damage fall in the upper left zone, while the white circles fall in the lower right zone. Referring to Ishihara (1985), two lines were drawn on the figure to separate the chart into three zones, i.e. possibility of liquefaction-induced damage high, medium or low.

As shown in Figure 5, liquefaction vulnerability was then evaluated for each mesh in Figure 1 by using the liquefaction classification chart determined as Figure 4. Although Figure 5 was drawn only from the information of in-situ tests, susceptibility to liquefaction is much affected by the microtopography of the site as mentioned before. Referring to Table 1, liquefaction vulnerability of this area was estimated to be moderate in the natural levee and the delta, and high in the former river channel and the riverbed of fine sand. Therefore, Figure 5 was modified by incorporating the microtopography and is shown in Figure 6.

The result of this evaluation showed reasonably good agreement with the damage of wooden houses which was assessed through interviews to the residents.

4 CONCLUSIONS

Geomorphological units included in the investigated area were found to be a natural levee, a delta, a former river channel and a riverbed with fine sand. Susceptibility for liquefaction of these units was estimated to be moderate in the natural levee and the delta, and high in the former river channel and the riverbed of fine sand. Results of field investigation at the sites where the liquefaction occurred or did not occur were compiled and plotted in the figure indicating $\overline{Nsw}$ versus H_1. The figure was divided into three areas of high, moderate and low liquefaction potential by two straight lines. A microzoning map on possibility of liquefaction-induced damage was drawn by combining the liquefaction classification chart with the geomorphological land classification map. It showed reasonably good agreement with the damage of houses evaluated through the interviews with residents.

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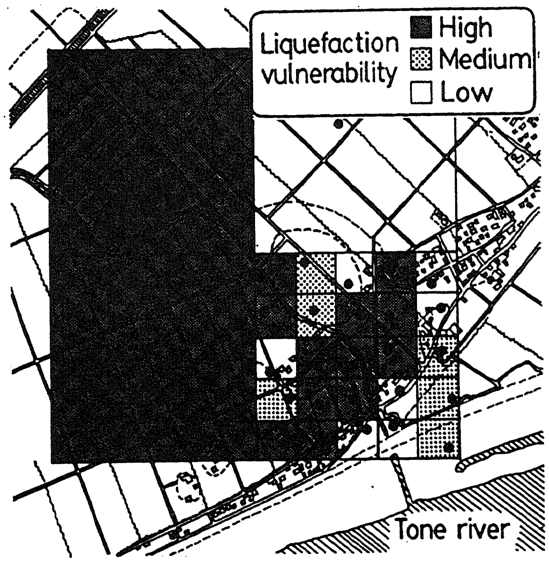

Fig.5 Possibility of liquefaction-induced damage evaluated by using the liquefaction classification chart

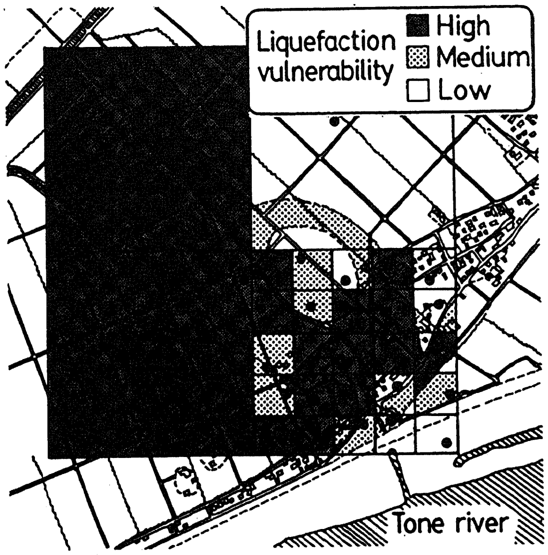

Fig.6 Possibility of liquefaction-induced damage modified by incorporating the microtopography

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