A METHOD FOR ESTIMATING AND INCREASING THE STABILITY OF MAN-MADE HOUSING SITES DURING EARTHQUAKES

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SYNOPSIS

In this paper, authors present a method for estimating and increasing the stability of man-made housing sites during earthquakes. As a convenient and temporary method, at first, microtremor observations are carried out simultaneously on the cutting ground and housing site being concerned. As a closer investigation, the boring work and a standard penetration test is performed at the housing site to be considered in the convenient method. If the N value is smaller than 4, the inclinometers and pipe strain meters are installed to observe ground displacement most possibly happened. When a large variation is measured, steel pipe piles are driven into the ground or a retaining wall is constructed to make the ground stable.

INTRODUCTION

High growth in Japan since the 1960's has brought a rapid urban development and a redevelopment as well as a rapid construction of housing sites in the suburbs. Most housing sites were constructed by filling deep valleys with volcanic ash deposit, without using any controlled compaction methods. Due to this, the authors have been concerned that a disaster might happen in a housing area a few years after construction.

These housing sites, that had been carelessly constructed, in the Sendai area were severely shaken by the Miyagiken-oki Earthquake on June 12, 1978. The news of the earthquake damages to these housing sites gave a great shock to the inhabitants of cities in Japan. The public wants to know the reason why such terrible damages occurred to these housing sistes, and also how to protect their housing from such damages in the furture.

The authors have published a paper(1) on the causes of the damages to housing sites by the Miyagiken-oki Earthquake. In this paper, they present a method for estimating and increasing the stability of artificial housing site during earthquake.

A CONVENENIENT METHOD BY THE MICROTREMOR'R OBSERVATION FOR ESTIMATING STABILITY OF HOUSING SITES DURING EARTHQUAKE

Microtremor's observations were carried out at the 250 locations in Midorigaoka area of the housing site of A type and at the 230 locations in Nankodai area of the B type. The housing site of A type is defined as the site on a hillside which was constructed by filling a steep valley

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with volcanic ash deposit. On the other hand, the B type is given a definition to the site where the original form of hill was quite disappeared by a large scale of earth work and then the houses were built on the flattened land.

The relation between the mean value of microtremor's amplitude and the depth of fill in Midorigaoka and Nankodai is plotted in Fig.1(a) and Fig.1 (b). As the measured values seem to be scattered, the tripartite observations of microtremor were performed again to obatin a higher accuracy. Marks with a double circle in Fig.1 show the values obtained by the tripartite observation. It is clear from Fig.1(a) and 1(b) that the mean value of microtremor's amplitude is linearly related with the depth of fill in the housing sites. Therefore, the correlation is expressed by the following equation;

$$h = 235\,(df - dc)$$

where, h : depth of the fill (m)
df : mean value of microtremor's amplitude of the fill (μm).
dc : mean value of microtremor's amplitude of the cut (μm).

According to the investigation of damages to house, retaining wall, gas and water pipe by the 1978 Miyagiken-oki Earthquake, the relation between the earthquake damage ratio and the depth of fill are found as shown in Fig.2(a) and 2(b). It is clear from Fig.2 that the damage ratio of houses increases with the depth of fill in the housing site of A type, however the damage ratio of houses in the B type, and the damage ratio of retaining wall, gas and water pipe in both A and B type show a peak value on the border of the fill and the cutting ground.

If we eliminate the depth of fill from two relations, that is, one relation between the depth of fill and the mean value of amplitude in Fig.1, and other relation between the depth of fill and the damage ratio in Fig.2, the correlation between the damage ratio and the difference of mean value is deduced as shown in Fig.3. Then, the following conclusions are obtained in Fig.3.

(i) Earthquake damages to dwelling houses and gas pipes scarcely occurred in the housing sites where a difference of mean value of microtremor's amplitude between on the cutting ground and the fill was under 0.012μm.

(ii) The more a difference of mean value of microtremor's amplitude increased, the more damages to dwelling houses of A type increased, while the dwelling houses of B type were most severely damaged on the sites where a difference of mean value was from 0.012μm to 0.021μm.

(iii) And also, the pipe lines in the housing sites of both A and B type were most terribly damaged in the sites where a difference of mean value was from 0.012μm to 0.021μm.

Based on these conclusions, we can roughly estimate the stability of the housing site during earthquake by simultaneous observation of microtremor on the cutting ground and the fill.

A CLOSER METHOD FOR ESTIMATING STABILITY OF HOUSING SITES DURING EARTHQUAKE BY BORING, STANDARD PENETRATION TEST, PIPE STRAIN METER AND INCLINOMETER.

Immediately after the 1978 Miyagiken-oki Earthquake, a large number of boring and standard penetration test were carried out in seven damaged housing districts. Frequency-distribution diagrams of N values obtained at each district are shown in Fig.4(a). And also, variation of peak and mean value of N value in Fig.4(a) with the lapse of time after construction are shown in Fig.4(b). It is evident in Fig.4(b) that both peak value and mean value of N are moving from a large value to a small value with a lapse of time after construction of housing sites. From the result of penetration test described above, the authors gave a geotechnical comment as follows.

In process of construction of the housing sites, a large size of soft rocks such as sand stone, mud stone or tuff were kicked down in the valley and just placed without sufficient compaction, therefore large voids existed among the fill. According to previous investigation, it is already confirmed that the porosity in the housing ground immediately after construction was about 30 to 40%. Over a long time after filling, rain and ground water could easily flow through the voids, and rocks thus came to be deterorated by water and consequently converted into clay. The more the rocks changed in to clay, the more difficult water permeated through the voids, therefore, the voids came to be saturated with water and the ground thus softened.

A closer method by a boring and a standard penetration test should be applied as follows. The boring work and standard penetration test should be carried out in the housing site where a difference of mean value of microtremor's amplitude is largest in the site of A type and 0.012μm to 0.021μm in the site of B type. If a value of porosity in the housing ground is over 30 to 40%, a grouting by vent-mortar should be performed in the voids. For the housing ground in which an averaged N value is over 10, any measures don't need for the present, because no damaged to the housing ground have suffered during the 1978 Miyagiken-oki Earthquake. It seems to be the most probable, however, that an averaged N value will decrease with the lapse of time, therefore it had better to be carried out again the penetration test about ten years away. If the averaged value is from 5 to 9, it is concerned a slight damage to be happened based on the experience of the 1978 Miyagiken-oki Earthquake. In this case, a penetration test will be tried to reexamine the ground condition after several years elapsed. On the other hand, when the N value is under 4, the observation of ground movement by inclinometer and pipe strain meter should be carried out immediately on the housing ground, because a severe damage might be occurred during earthquake. When a strain is over 5×10^2μm for a month and an inclination is over 1.0 second for a day, the housing ground will be unstable during earthquake. In this case, it is better to make the ground stable by the methods as described in next section. On the other hand, when a strain is above 5×10^3μm for a month and an inclination is over 10 sec. for a day, it is considered that stability of the housing ground is very low. In this case, steel pipe piles should be driven into the ground or retaining wall constructed immediately to make the ground stable.

DESIGN AND CONSTRUCTION OF A STEEL PILE WALL

Immediately after the Miyagiken-oki Earthquake, considerable ground movements were observed at the depth of 5.0m and 18.5m in Midorigaoka housing site. Then, steel pile wall design was tried to be performed there. Two circular slip surface passed through at the depth of 5.0m and 18.5m were prepared for a static analysis of stability of the slope. The strength parameters of $\tan\phi = 0.18$ and $c = 0$ were obtained from c-ϕ diagram. Then, the factor of safety of 1.2, which means a ratio of the shearing strength to the shearing stress, was estimated based on a conventional method of stability analysis. From the result of stability analysis, a retaining wall of buttress type with a steel pipe pile foundation was adopted to be constructed at the site of B.P 36, and also a steel pipe pile wall to be driven into the site of B-1 and B.P 13 as shown in Fig.5. A steel pipe pile with a diameter of 318.5mm was put into the hole to the depth of one and one third length of a surface layer. And then, a H type steel pile was inserted into the pipe pile and concrete milk was injected into the pipe pile. Such a pile foundation work was carried out at the interval of two meters in two lines with a zigzag style.

In order to observe ground displacement after construction of the wall, strain meters were put into the ground at B-1 location and then observation had been continued for a year immediately after the construction. According to the result of observation, an accumulated value of strain for a month had kept showing under 10^2μm at the depth of 5.0 and 18.5m, in which considerable movements had been observed before the wall construction. Therefore, it is confirmed that high stability to the ground movement was obtained owing to the wall construction.

In order to know ground behavior during earthquake after construction of the wall, authors tried to observe earthquake motions of the housing site. The accelero-seismographs of three component with a frequency of 3.0 HZ. were installed on the natural ground, on the fill of 7m and 15m thickness as shown in Fig.5. Eighteen moderate seismic records were obtained for three years from 1980 to 1982. In the direction of slope, seismic amplitude of the fill of 7m and 15m thickness is almost similar to the natural ground. However, in the direction perpendicular to slope, seismic amplitude of the fill of 7m thickness is little larger than the fill of 15m thickness. Therefore, further investigation to reduct the seismic amplitude in the direction of perpendicular to slope is necessary.

APPLICATION OF THE METHOD TO PRACTICAL PROBLEM

The concerned housing site has been constructed on a hill side by filling a deep valley with volcanic ash soil. First, a convenient method by microtremor's observation was applied. Mean values of microtremor's amplitude obtained by simultaneous observation are shown in Fig.6(a). Using a relation between the difference of mean value and depth of the fill, distributions of depth of the fill was obtained as shown in Fig.6(b). From a soil profile in Fig.7, it was proved that depth of the fill was obtained with a high accuracy by microtremor's observation. As shown in soil profile, the average of N value to a depth of 3.5m is under 3. According to experience of Miyagiken-oki Earthquake, extreme damages occurred to housing ground with N value under 4. Based on this experience, authors desigened a retaining wall of L type with a pile foundation. Two circular slip surface passed through shallow and deep zone were prepared for a stability analysis as shown in Fig.8. The factor of safety of 1.2 was estimated based on conventional method of stability of analysis. Comparison on dynamic behaviour of housing ground before and after the wall construction is made by a mean value of microtremor's amplitude. Mean value of microtremor's amplitude before wall construction was 0.15μm, however a mean value on the fill immediately after construction decreased to a value of 0.12μm. It is thus considered that dynamic stability of housing site was increased due to the retaining wall.

REFERENCE

(1) F. Kawakami, A. Asada and E. Yanagisawa : On Damages to Housing Sites by the Off-Miyagi Earthquake of June 12, 1978, Journal of Natural Disaster Science, Volume 1, No.2, 1979, pp81-97.

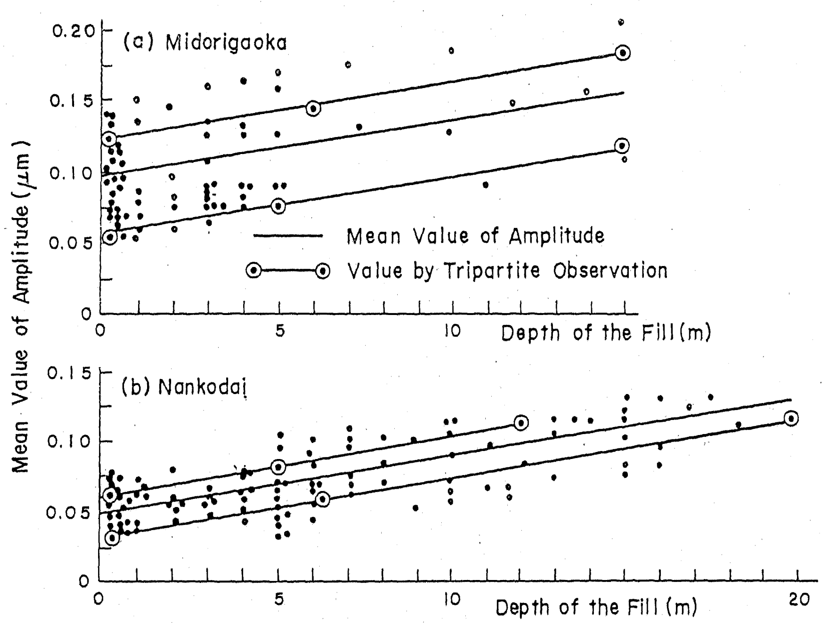

Fig-1 Relation between Mean Value of Amplitude and Depth of the Fill

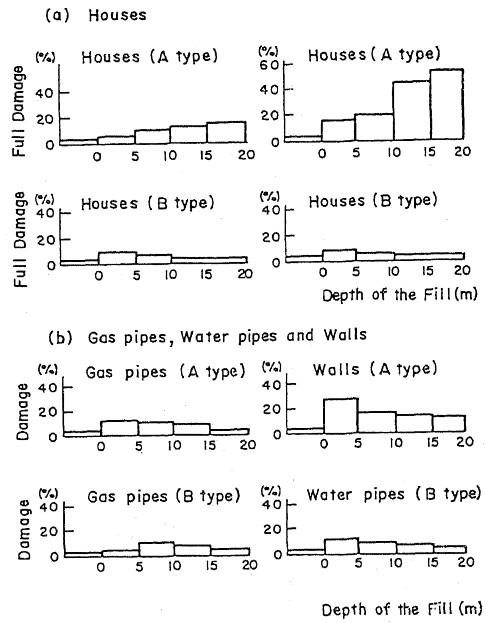

Fig-2 Variation of Housing Damage Ratio with Depth of the Fill

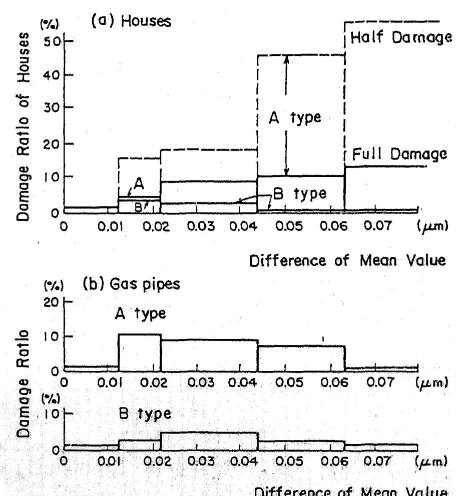

Fig-3 Relation between Hoasing Damage Ratio and Difference of Mean Value of Amplitude

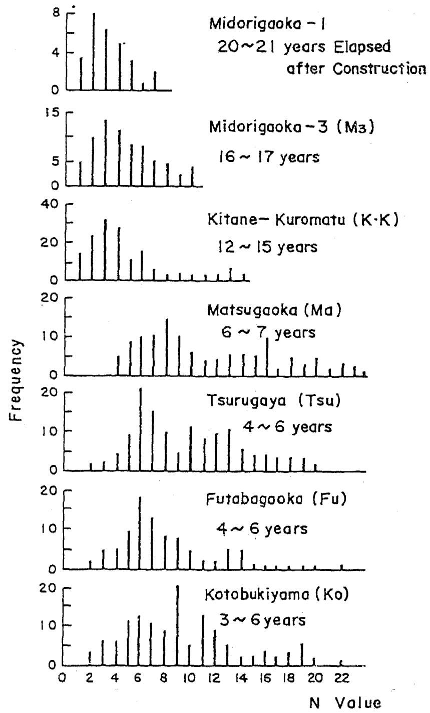

Fig-4(a) Frequency Distribution of N Value

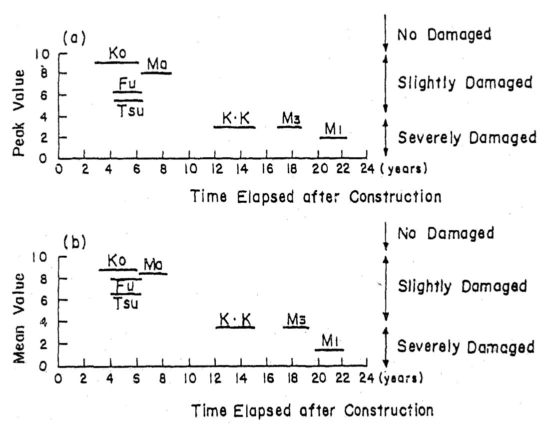

Fig-4 (b) Variation of N value with Time Elapsed after Construction

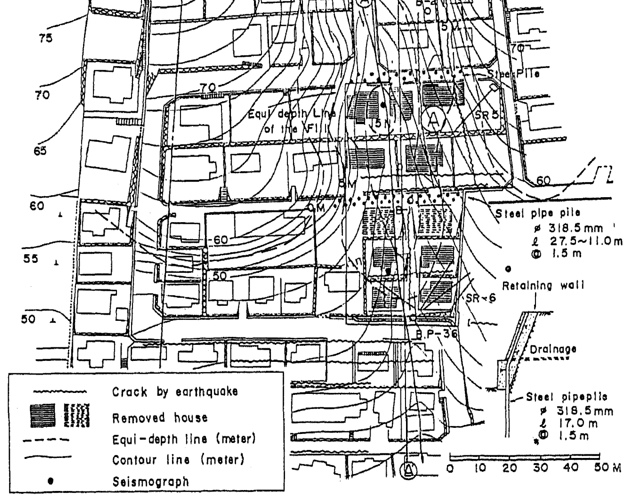

Fig 5 Plan View of extremely damaged housing block in Mi

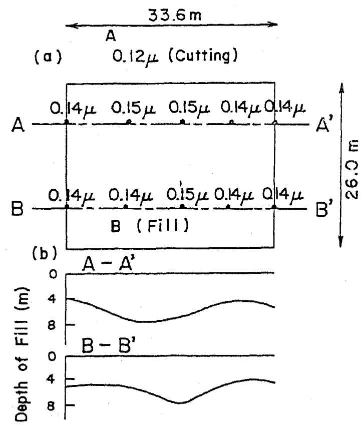

Fig-6 Mean Value of Amplitude and Depth of the Fill

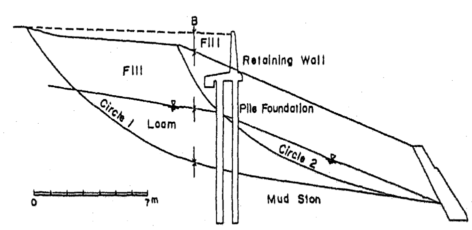

Fig-8 Cross Section after Wall Construction

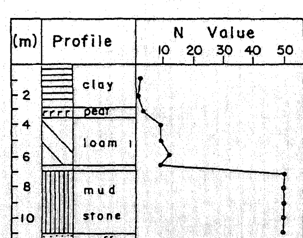

Fig-7 Soil Profile at B