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ESTIMATION OF STRUCTURAL DAMAGE BASED ON THE EFFECT OF LOCAL SURFACE GEOLOGY

Yutaka OSAWA[1], Tadao MINAMI[1], Kahio OSADA[2], Gyoo-Sick JEON[3] and Satoshi OHGAKI[3]

[1]Professor, Earthquake Research Institute, University of Tokyo
[2]Research Associate, Earthquake Research Institute, University of Tokyo
[3]Graduate Student, University of Tokyo

SUMMARY

We made microtremor measurements on wooden houses and school buildings as well as on the ground in the Odawara valley in order to make damage assessment for the expected disastrous earthquake. The general ground condition of the valley is readable from a serial arrangement the Fourier spectra in a dense network of observation sites, although it is very difficult to figure the predominant period from a single Fourier spectrum. The effect of the surface geology on structural response can be roughly estimated by comparing the natural periods of building with a fixed and a flexible foundations. The dynamic character of wooden store houses differed from that of the ordinary houses due to the fact that the former has a wide open space in the first floor.

INTRODUCTION

We know that the earthquake damage strongly depends on the ground conditions from the past experience of destructive earthquakes. For example, some buildings are completely collapsed while another buildings of the similar structural type was not damaged even if they stand at a closed distance. The most economical and simple way to know the ground conditions and the dynamic characters of buildings is to measure the vibration due to microtremors. Estimation of bearing capacity of structures and the ground condition are very important for mitigating the earthquake disaster in a large and middle city.

According to the historical data, Odawara city has suffered earthquake damage at intervals of about 70 years during the recent 300 years (the last one occurred in 1923). To clarify the effects of local geology on the strong ground motion, the Strong Earthquake Motion Observation Center of the Earthquake Research Institute has started observation of earthquake motions by installing 15 observatories in and around the alluvial valley of Odawara (5x8 km).

MICROTREMOR MEASUREMENTS ON THE GROUND

At the center of the valley, a big river (Sakawa river) runs north-south and the ground surface is covered by the soft alluvial deposit. In order to make soil formation models, we conducted a series of microtremor measurements at 150 locations in and around Odawara valley. Measurements were made at night from 10 p.m. to 6 a.m., to avoid undesirable noises from traffic and machinery.

Fig-1 shows the location of measurement points (marked by black circle), strong ground motion observatories (marked by ✱) and 6 mesh lines(marked by the white circle) among the total 17 mesh lines. Observing the predominant periods in the Fourier spectra, the surface soils of the Odawara valley were classified into five categories depending on the depth of the alluvial soils above the bedrock :

Part A which locates in the right side of river consists of a various soil layers and has several kinds of predominant periods. The Fourier spectra in the mountain area (part B) which consists of the weathered rock has a flat and wide peak in a short period range. The left and upper side of river (part C) consists of sand and gravel layers and the predominant period is about 2.5 sec. The soil layers around the mesh line No.12 (part D) suddenly changed their thickness and in some cases the soil layer formation became completely different. It can be explained by the predominant period being changed from 0.3 sec to 0.9 sec. The predominant period of the seaside area (part E) is generally shorter than the adjacent area.

Fig-2 shows wave forms, Fourier spectra and boring profiles of 6 measurement points on the NO.12 mesh line (the length about 1 km). The dotted line in the figure indicates variations in the predominant periods of the ground. The predominant periods of point 1 and point 2 on the No.13 mesh line changed markedly although the distance between the points is so short as 200 m. In generally, when the soil layers are composed by the soft soil, the wave form has the component of long periods as point 1 (N value of standard penetration test reached to the about 50 at the depth of 10 m). In contrast, the soft soil layers has the component of short periods in the wave form as point 2 (N value was still about 10 at the underground 30 m). The relationship of soft-hard ground conditions and long-short periods can be explained by the wave records and layer formation of the ground as shown in fig 2-b and fig 2-c.

The ground formations could be figured out to some degree by comparing the microtremor records even if the boring data of the ground is not available.

MICROTREMOR MEASUREMENTS OF SCHOOL BUILDING

Fig-3 shows locations of 41 R.C school buildings having 2-4 stories in Odawara city, on which the microtremor measurements were made. The left side and right side in fig-4 show the Fourier spectra of the records obtained on the roof, and the spectral ratio between the roof and the base of buildings. They are classified into three types according to the spectra types and their mode shapes :

The first type (A school) which was built in the relatively solid ground condition has a single sharp peak in the spectrum (0.2 sec) and in the spectrum ratio (0.18 sec). The second type (B school) which was built in a deep soft ground surface has two peaks (0.34 sec, 0.22 sec) which can be consider as the natural periods of first mode and second mode in fig 5-b. In contrast, the third type (C school) which stands in a shallow soft layers does not show any clear peak. The soil-structure interaction effects can be clarified by the mode shape in fig-5 as follows. A school has only 10% swaying ratio while C school has almost 80% swaying ratio, and C school has the medium value of two schools. In generally, the soil-structure interaction effect can not be neglected in the cases where the stiffness of building is much stiffer than the soil stiffness.

The fundamental periods of 36 school buildings among the 41 school buildings were plotted in Fig-6 (soft soils to the left and hard soils to the right), in which the solid and open circles indicate the apparent natural period, T, measured on the top of the building and the period, T, as the effects of swaying motion being excluded. While T takes nearly constant values among all the building, T decreases to the right, the discrepancies becoming greater to the left (soft soils). This discrepancy, which is due to the soil-building interaction effects, suggests large differences in structural damage to school buildings on various soil conditions although they have similar construction types.

MICROTREMOR MEASUREMENTS OF WOODEN HOUSE

Two-storied wooden houses having a shopping space in the first story is much more flexible in the first story as compared to the second story. Also, the direction (NS) which is faced to the street needs a wide opening like the entrance door for customer while the opposite direction (EW) has a wall to separate the adjacent houses. Therefore, the relative displacement of first floor has a quietly large value comparing with that of the second floor. The swaying ratio in EW direction is larger than that in NS direction due to the difference of stiffness in each directions. To have large damage in this type of houses is explained by this reason based on the experience of past earthquake damage.

Fig-7 shows mode shapes in the longitudinal and transverse directions for the L-wooden house. Fig-8 shows the Fourier spectra of the first floor and the second floor, and their ratios. The Fourier spectrum on the second floor in EW direction has two predominant periods (0.19sec and 0.26sec), only one predominant period exists in NS direction. The second peak (0.26 sec) is considered to be the predominant period of the ground, because no peak is observed in the spectrum on the first floor.

To find the damping coefficient, free vibration tests were made by human power excitation. An example of displacement record of the free vibration test and the calculated damping coefficient were shown in fig-9. As shown in fig-10, damping coefficients decrease according to the natural periods increase. The relationship between swaying ratios and the relative amount of wall is shown in Fig-11. Apparently, the wall area ratio (the length of wall divided by the area of wall : m/m^2) induces the swaying ratio. The sway ratio depends on the ratio between the building stiffness and ground stiffness. Also, according as the swaying ratio increases, the natural period elongates as shown in fig-12.

Therefore, the greater building stiffness which is compared with the ground stiffness becomes, the larger becomes the amount of swaying and period elongation, hence the effects of soil-structure interaction being increased.

CONCLUSION

The microtremor measurement on the ground showed a good agreement with soil layer models made from the boring data. Therefore, the microtremor measurement can be a practical and economical way of knowing the ground conditions without boring test. Also, the effects of soil-structure interaction is very important in estimating earthquake damages to various types of structures. All the information in this paper will be utilized in establishing the overall damage assessment of buildings in Odawara, a typical medium size city on alluvial soils in Japan.

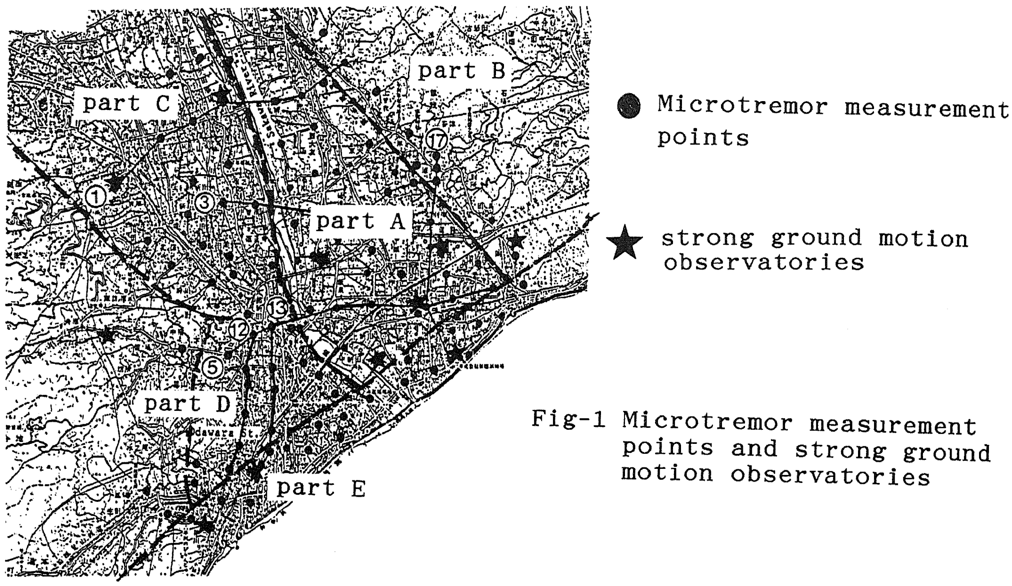
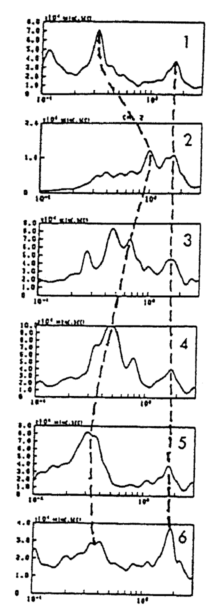
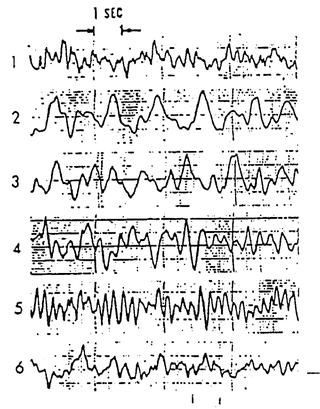


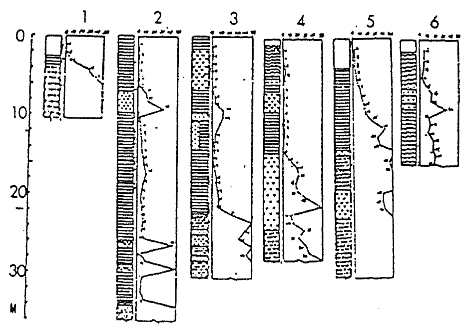
Fig-1 Microtremor measurement points and strong ground motion observatories



a) Fourier spectra



b) Wave forms



c) soil profiles

Fig-2 Microtremor of 6 points on the mesh line No.12

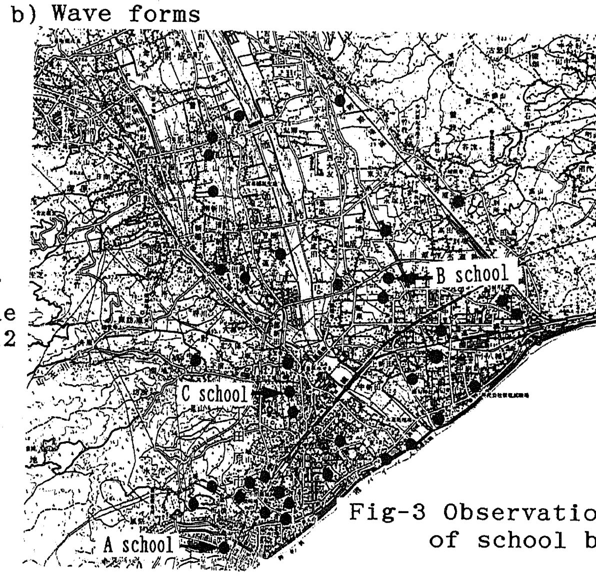
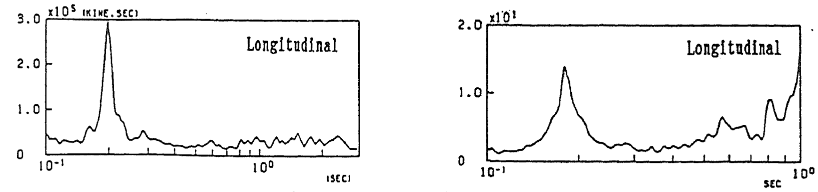
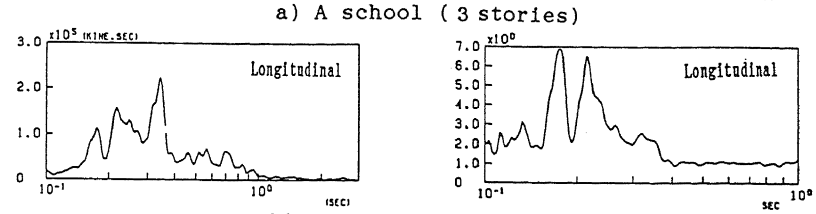


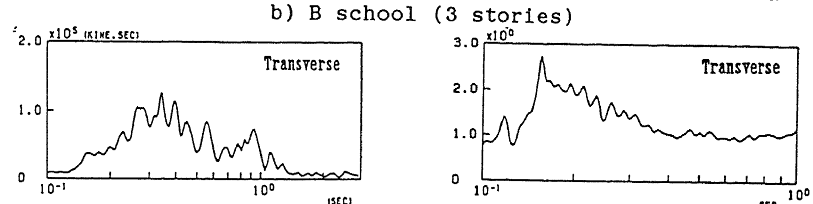
Fig-3 Observation points of school buildings



a) A school (3 stories)

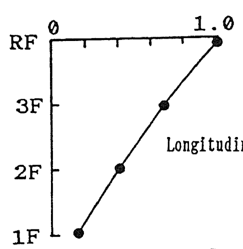


b) B school (3 stories)

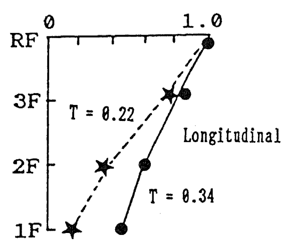


c) C school (2 stories)

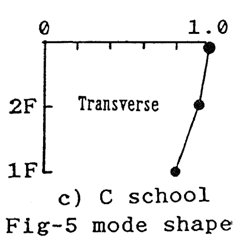
Fig-4 Fourier spectra and spectral ratio



a) A school

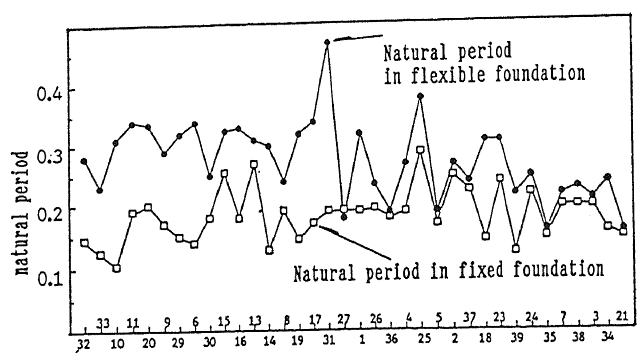


b) B school

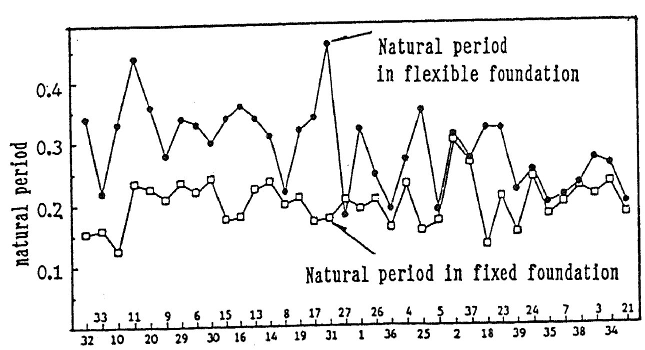


c) C school

Fig-5 mode shape



a) Transverse direction



b) Longitudinal direction

Fig-6 Natural periods in fixed and flexible foundation

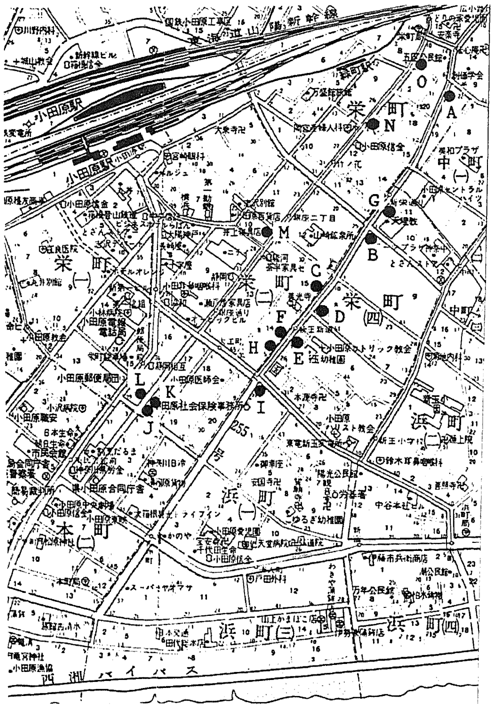


Fig-13 Observation points of wooden houses

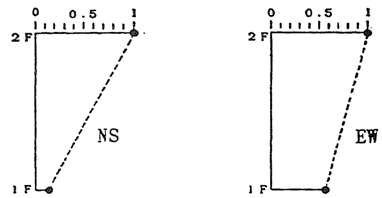


Fig-7 Mode shape

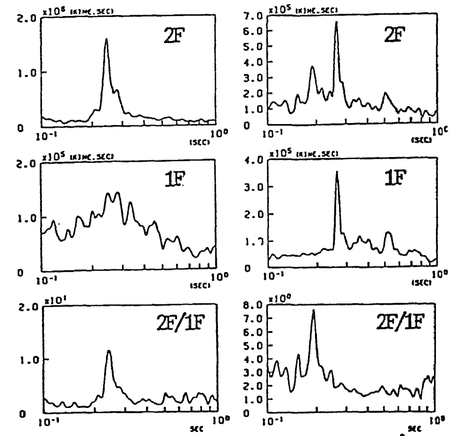


Fig-8 Fourier spectra and spectral ratio

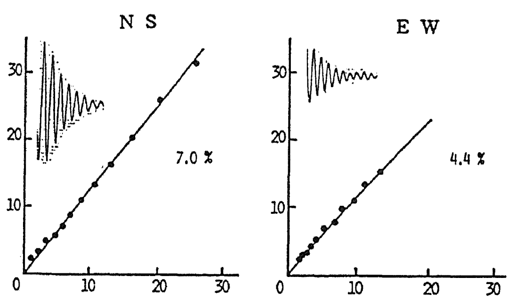


Fig-9 Free vibration wave and damping coefficient

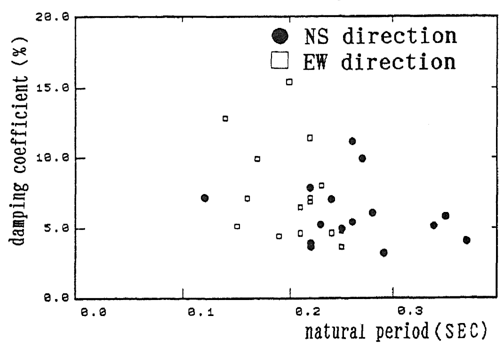


Fig-10 Natural period and damping coefficient

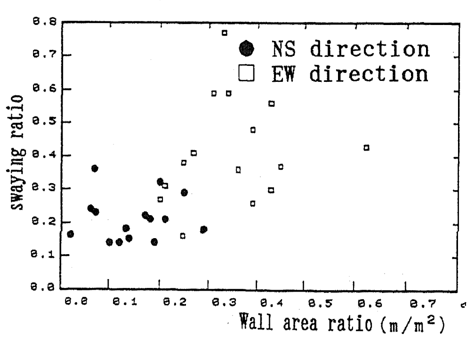


Fig-11 Wall area ratio and swaying ratio

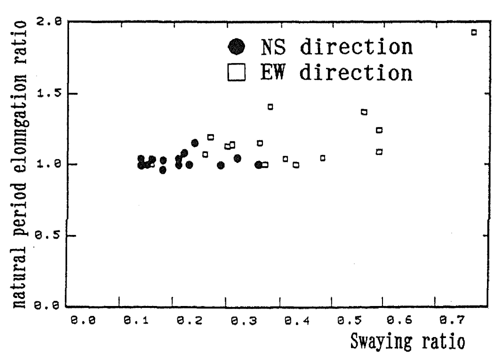


Fig-12 Swaying ratio and natural period elonngation ratio