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Dynamic response characteristics of layered media on inclined basement

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ABSTRACT : In order to investigate quantitatively seismic behavior of a alluvial deposit on a inclined basement, two-dimensional equivalent linear analysis was implemented by using the dynamic finite element method. Short period components and vertical motion are generated due to the inclined basement. These effects are particularly notable in alluvial deposit on the inclined basement, and drop off with distance from this domain.

1. INTRODUCTION

Alluvial deposits on inclined basement are said to be affected in various ways during earthquake excitations, such as amplification of the earthquake motion, generation of large vertical earthquake motions, and other effects. These phenomena have been observed in Northern Italian earthquake[1] suffered on an alluvial fan on a hillside also in the case of Off-Miyagi Prefecture earthquake[2]. In this study, we carry out a response analysis using the two-dimensional finite element method in order to clarify quantitatively how Quaternary period layers are affected by irregular base structures.

2. TOPOGRAPHY AND GROUND STRUCTURE

Figure 1 shows the ground structure used in the analysis model, while Table 1 gives the properties of the ground. The model represents ancient ground of the Neocene period that has been eroded by the action of rivers to leave thick deposits of the Quaternary period. The section that remains as a terraced cliff unaffected by eroding action forms the inclined base. The deposited Quaternary layer has an alternating structure of gravel, sand and silt layers. The Tertiary period layer, which acts as the seismic basement, is assumed to be somewhat weathered at the surface part, but its shear wave velocity is assumed to be more than 400 m/s. For convenience in describing the results and indicating locations in the model, it is divided into three domains: the shallow basement portion (the old terraced cliff portion), the inclined basement portion, and the level basement portion. Also for convenience, the right-hand side of the model will be called the north side, and the left will be known as the south side.

3. ANALYSIS MODEL

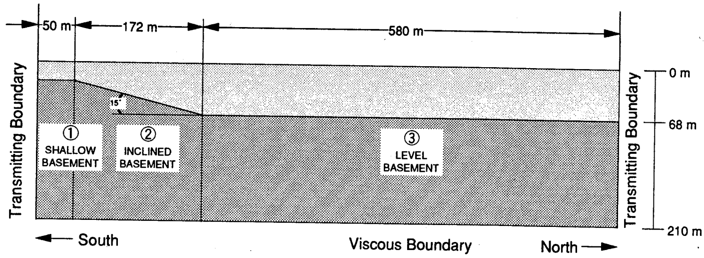


Fig-1 Ground Model

The analysis model is approximately 800 m wide in horizontal extent including from the shallow basement portion to the level basement portion. Depthwise, the model reaches down to GL-220 m.

The values shown in Table 1 were taken to be the initial stiffness, and two-dimensional equivalent linear analysis was implemented. G/Go ~ r, h ~ r curves were obtained by approximating the results of dynamic deformation tests conducted on reference soil samples.

The Tertiary layer bedrock was assumed to be of linear elasticity except weathered surface part. The frequency range used in the analysis was chosen to be up to 6 Hz, since this was determined based on the comparison of the response value obtained from the one-dimensional amplification theory (SHAKE) for the level basement portion. The minimum element height was determined from the Vs of the convergence stiffness of the one-dimensional amplification theory ; it was less than 1/5 of the shortest wavelength. Similarly, since the wave motion was assumed to propagate in the horizontal direction due tothe inclined base, the element width was also made less than 1/5 of the shortest wavelength. Consequently, the model became extremely large both in terms of the number of nodes and the elements. A transmitting boundary on the sides and a viscous boundary at the base of the model were applied.

Table-1 Properties of the ground

0	Geologic Feature	GO (tf/cm²)	Vs (m/s)	ρ (t/m³)	Poison Ratio.
-4	fill	5600	170	1.9	0.35
-10	sand	8900	220	1.8	0.45
-12	gravel	11500	250	1.8	0.49
-24	silt	4400	160	1.7	0.49
-28	sand	16300	290	1.9	0.46
-38	silt	4400	160	1.7	0.49
-53	silt	8400	220	1.7	0.49
-58	gravel	11500	250	1.8	0.49
-63	silt	7300	200	1.8	0.49
-68	gravel	33000	400	2.0	0.47
-78	mud stone	28000	400	1.7	0.47
	mud ston	33000 ~ 73000	440 ~ 630	1.7 ~ 1.8	0.4

4. EARTHQUAKE RESPONSE ANALYSIS

With a model of this size, in usual cases linear calculations using convergence stiffness obtained from SHAKE's results at various point of the model will be carried out due to the restriction of the capacities of computers. Consequently, given that there is a need to grasp the effects of the inclined basement as accurately as possible, equivalent linear analysis with a two-dimensional model was implemented.

4.1 *Input Earthqukake motion*

Figure 2 shows the waveform of the incident wave, and Fig. 3 represents the response spectrum.The input wave was established taking into account the seismic activity and other factors of the area under consideration. The incident S wave is assumed to enter from the base of the model.

4.2 *Results of analysis*

In Figs. 4 to 6, the contours represent the maximum values resulting from earthquake response analysis. Figure 4 is the distribution of maximum acceleration in the horizontal direction. The response of the alluvial layer has quite a variable distribution on the ground surface.

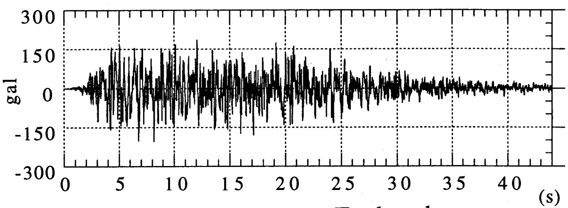


Fig-2 Input Earthquake

However, at depth in the shallow basement portion, as well as in the portion with a level basement, the distribution is layered. In the base bedrock, although the distribution differed somewhat in the shallow basement area and in the area of the inclined basement , it was generally similar in the area of level basement. Figure 5 shows the maximum vertical acceleration. In spite of the fact that only horizontal motion was input into the analysis, accelerations in vertical direction occurred.

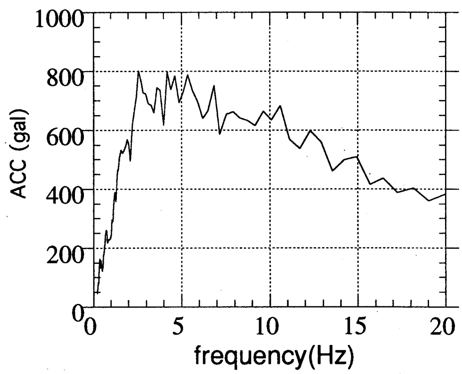


Fig-3 Response spectrum of input earthquake

The region where notable acceleration occurred in the vertical direction was mainly in the Quaternary layer in the inclined basement portion, and it decreases rapidly with distance from the area of the inclined basement. Figure 6 shows the distribution of maximum shear strain. Overall, a distribution similar to that in the level basement portion is predominant, and it is clear that the inclined basement has less effect than the case of response acceleration.

Figure 7 shows the distribution of maximum acceleration in the horizontal and vertical directions on the ground surface. Figures 8 to 11 show the acceleration waveform and spectrum in both the horizontal and vertical directions at several locations on the ground surface. The greatest horizontal acceleration occurred at a point above the shallow basement, and it decreased toward the north. The minimum value was at a location immediately before the toe of the inclined basement. Although there was some degree of variability, the value decreased with distance from the inclined basement.

The maximum value obtained in the one-dimensional response analysis of the level basement portion was at the edge on the north side, and the response shown in Figure 7 is approximately the same at this location. It can be seen from these waveforms and spectra that the frequency characteristics differ depending on the quantities of the short-period component in each portion. However, in the level basement portion, the waveform and period characteristics are similar and the effects of the inclined basement are small regardless of distance from the inclined basement. As regards the subsurface, the variations are clearly not as large as they are at the ground surface, and the maximum response at a depth of GL-24m was approximately the same regardless of location.

The maximum vertical acceleration occurred on the surface above the top of the slope of the inclined basement. In the inclined basement portion, the long-period component (below 1 Hz) was relatively small and components centered on 2~ 3 Hz were predominant. However, with distance from this area, they were rapidly attenuated along with the acceleration. To the north, waves with a frequency of 0.7 Hz were predominant. These large variations in frequency characteristics allow us to infer that the effects of wave dispersion due to the inclined basement are large. This can also be inferred from the fact that similar behavior is seen at a depth of GL-24 m, while at a depth of GL-68 m in the bedrock it was not notable and can only be discerned in the alluvial layer.

Figure 12 shows the distribution of maximum acceleration (both horizontal and vertical) in the vertical direction at several locations in the level basement area. Figure 13 gives the distribution of shear strain in the vertical direction. Although there are some variations depending on depth, it is generally the case that the maximum value falls with distance from the location of the inclined basement.

5. CONCLUSIONS

- The presence of the inclined basement had an effect on acceleration and ground strain, which were considerably different from the case when a horizontal layered structure was assumed.
- The effect on acceleration arises in two forms: the appearance of a short-period component in the horizontal response, and the occurrence of vertical acceleration in spite of the purely horizontal excitation. However, significant effects are limited to the area immediate above and in the vicinity of the inclined basement portion.
- The shear strain, which has a dominant effect on ground stability, is affected by the occurrence of acceleration in the vertical direction, but the effect in the level basement portion other than the inclined base portion, gave similar results as the one dimensional analysis.

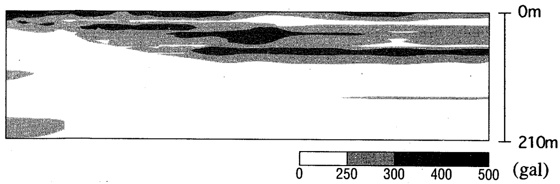


Fig-4 Distribution of maximum acceleration in horizontal direction

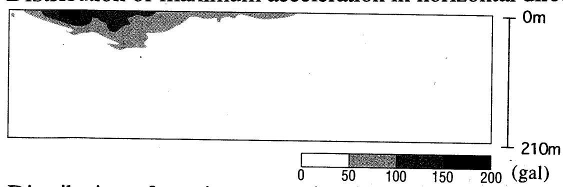


Fig-5 Distribution of maximum acceleration in vertical direction

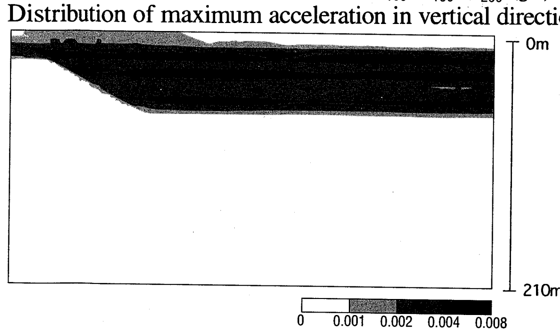


Fig-6 Distribution of maximum shear strain

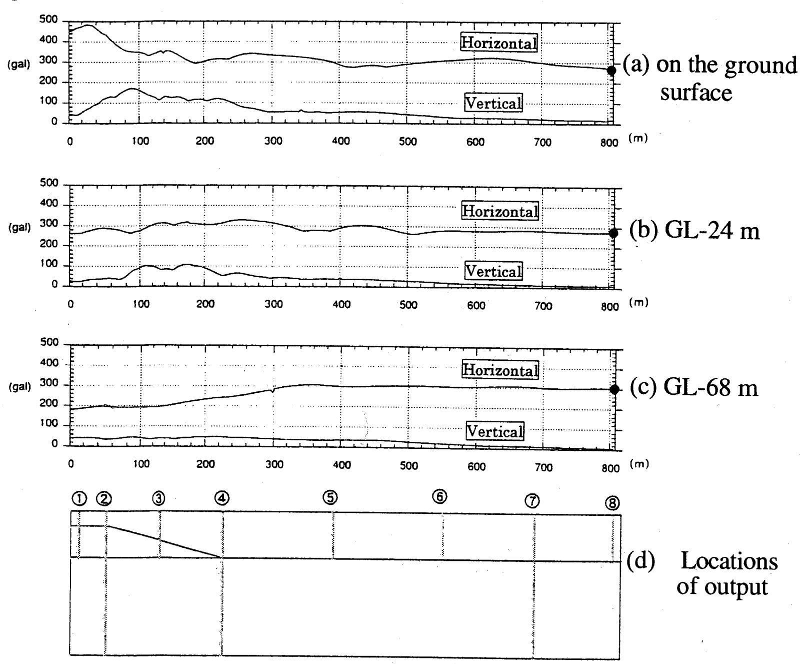
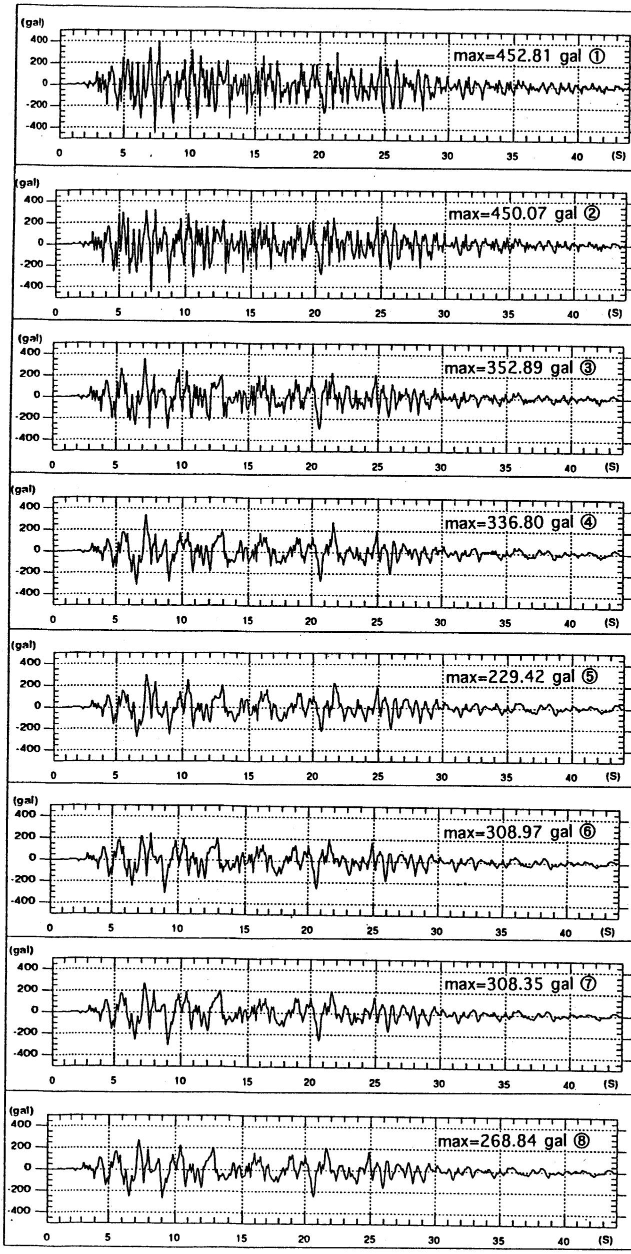


Fig-7 Horizontal distribution of acceleration in the horizontal and vertical directions

• : Max. acc.obrained from SHAKE



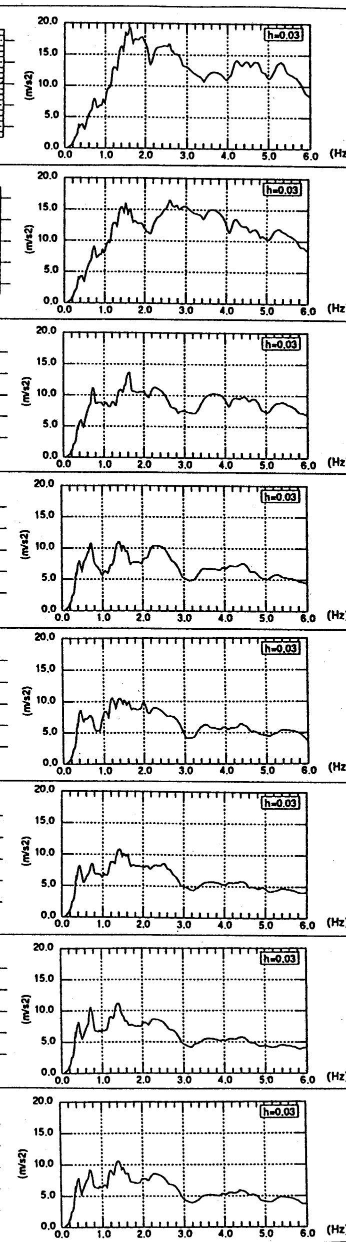
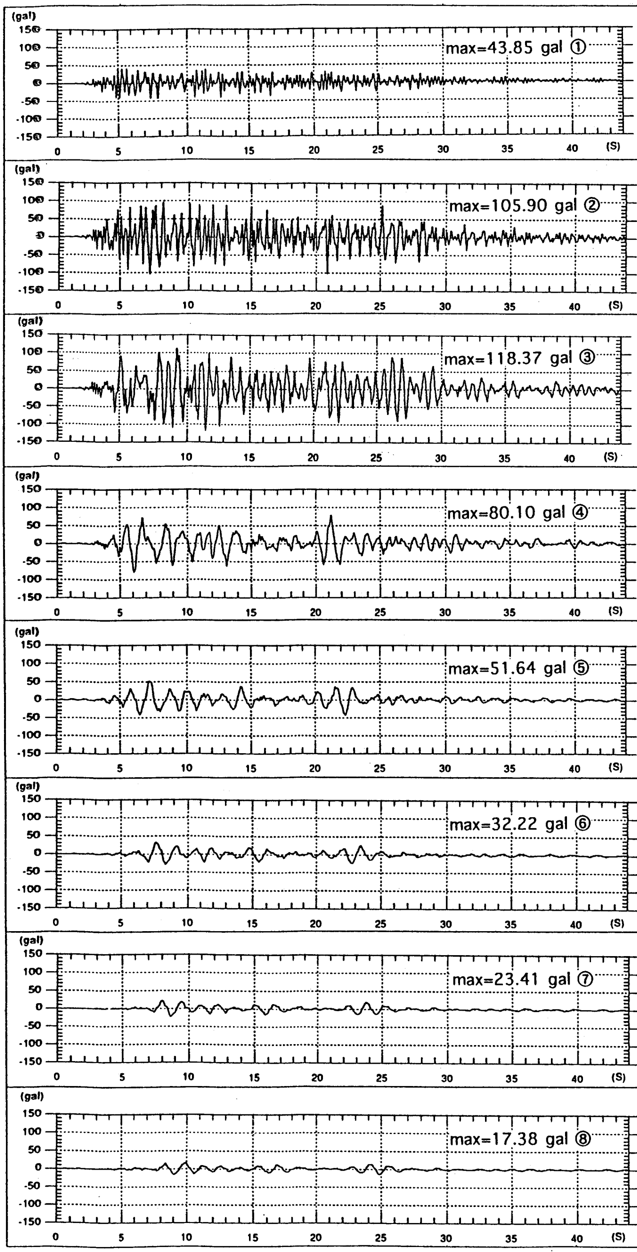


Fig-8 Wave of acceleration in the horizontal direction on the ground surface

Fig-9 Fourier spectrum of acceleration in the horizontal direction on the ground surface



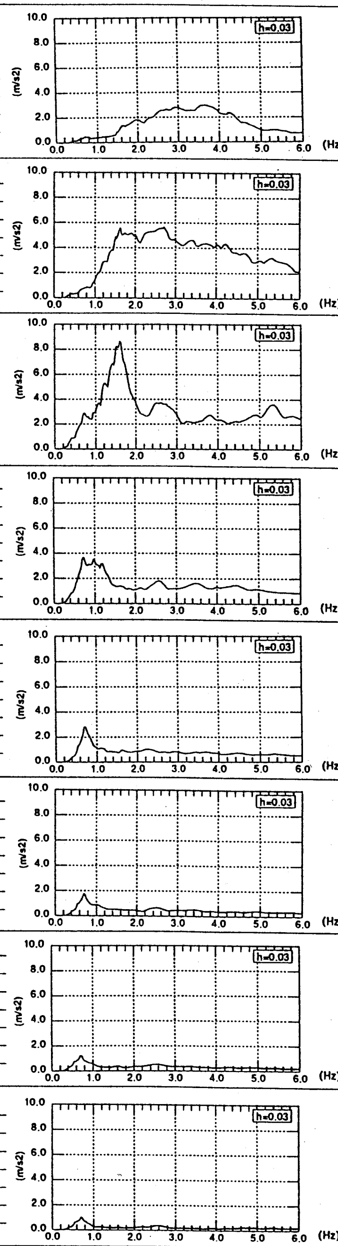


Fig-10 Wave of acceleration in the vertical direction on the ground surface

Fig-11 Fourier spectrum of acceleration in the vertical direction on the ground surface

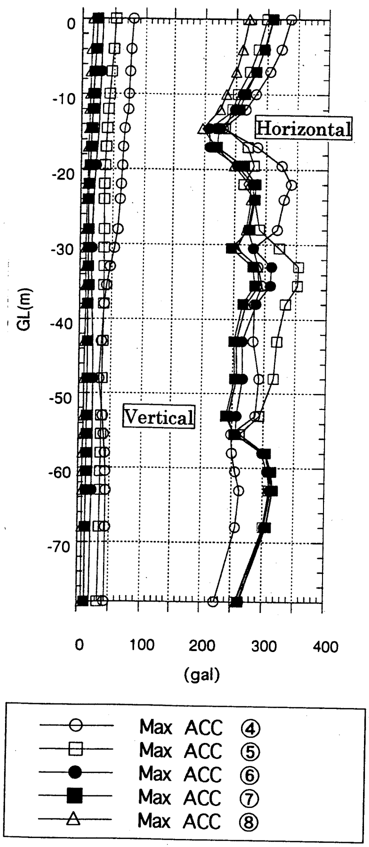


Fig-12 Vertical distribution of acceleration in the horizontal and vertical direction

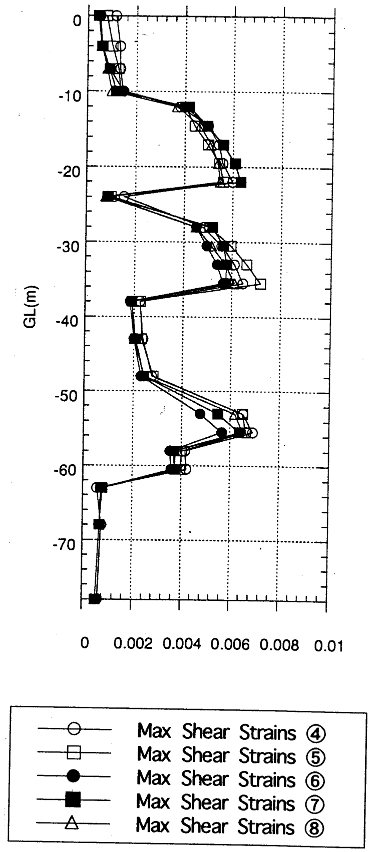


Fig-13 Distribution in vertical direction of maximum shear strains

REFERENCES

1. Architectural Institute of Japan 1979 Damage assessment report for Guatemala and Northern Italy Earthquake
2. Asano, Nishio, and Tsukamoto 1982 Observation of behavior of conduit buried in large-scale housing site reclamation area during an earthquake: 601-602. Japan Society of Civil Engineers, 37th Annual Lecture Meeting, First Section,