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VIBRATION AND WAVE PROPAGATION EXPERIMENTS OF GROUND MODEL ON INCLINED RIGID BASEMENT

Aritoshi HASUMI[1], Takumi TOSHINAWA[2], and Tatsuo OHMACHI[3]

[1]Graduate Student, The Graduate School at Nagatsuta,
Tokyo Institute of Technology, Midori-ku, Yokohama, Japan
[2]Research Associate, Ditto
[3]Professor, Ditto

SUMMARY

Presented in this paper is characteristics of vibration and wave propagation in an inclined ground layer. The harmonic vibration experiment was conducted on ground model with inclined rigid basement, and a cut-off thickness was newly defined for a prescribed period. In wave propagation experiment there is a remarkable difference in a changing of spectrum between propagations of two directions, and this is simply explained by that a component traveling beyond the cut-off thickness vanishes.

INTRODUCTION

Many metropolises in Japan are lying on thick sedimentary layers. Earthquake ground motions with rather-long period are often observed in these areas. These motions are probably induced by surface waves traveling the layers. Nowadays, period range for earthquake-resistant design is extending to longer in accordance with a increasing number of huge structures, such as long-span bridge and skyscraper. Seismic reliability of underground structures and life-line systems are much associated with ground strain produced by the surface waves. For these reasons the importance of surface waves on earthquake engineering is increasing.

Although surface waves are defined theoretically only in parallel layers, existing ground layers have more or less inclinations due to topographical irregularity. Hence, three experiments on ground models with inclined rigid basement were conducted with a main focus on propagation of Love waves in order to check applicability of theories in parallel layers experimentally.

SHEAR VIBRATION OF AN INCLINED GROUND MODEL

It is well-known that vibration and wave propagation are equivalent to each other. Shear vibration of horizontally layered ground of finite-length can be regarded as standing Love waves propagated in opposite directions. So first of all we dealt with shear vibration of finite-length ground model with inclined rigid basement to study influence of inclination.

Vibration Experiment The harmonic vibration experiment of ground model (Photo) with inclined rigid basement was performed. Acryl-amide gel was used for surface layer. For both basement and side boundaries, wood was used. Soft rubber strings were placed in the gel in both horizontal and vertical directions for easy inspection of displacement patterns. Dimension of the model and S-wave velocity are shown in Fig.1. The angle of inclination is 9.5 degree. At each resonant period, various modal shapes would be observed. The higher vibration mode is, the shallower the point with the maximum amplitude becomes. The displacement patterns along a vertical axis are less influenced by the inclination of the basement. At about 0.08sec the shallower portion was vibrating in a fundamental mode while the deeper portion was vibrating in the next higher mode along a vertical axis.

F.E.M. Analysis Eigenvalue analysis by F.E.M. was conducted for ground model with the same dimension and S-wave velocity as was used in the vibration experiment. The natural periods and vibration shapes of several modes are shown in Fig.2. The displacement pattern observed at 0.08sec in the experiment is seemingly made by superposition of mode 7 and mode 8.

At each mode there is practically no displacement in the shallower side of a limit with certain thickness. This can be explained by the modal response factor of Love wave shown in Fig.3 (Ref.1). When the shear modulus ratio is infinite, the period which satisfies the quater wave-length law is a cut-off period and amplitude vanishes for a component of dimensionless period over 4. In a inclined layer, though vibrating in a period seemingly, dimensionless period differ at points with different thickness. The thickness which satisfies dimensionless period is equal to 4, might be called a cut-off thickness. The cut-off thickness H for a prescribed period T is defined by

$$H = TVs/4$$

where Vs is S-wave velocity. Each cut-off thickness for the natural periods are shown in Fig.2. In a portion with a thickness more than the cut-off thickness, displacement patterns along a horizontal axis is regarded as a sine curve approximately. But in a portion with less thickness than cut off thickness, displacement decreases asymptotically. The thickness of maximum amplitude is larger than the cut off thickness. In other words, the predominant period of ground with inclined rigid basement is shorter than 4H/Vs.

For each mode of vibration, if phase velocity Ci is calculated from the natural period T and a distance Li between two neighboring nodes by Ci=2*Li/Ti, the velocities fall on the dispersion curve of Love waves in parallel layer.

According to the experiment and F.E.M. analysis described here, the inclined layer dose not differ from the parallel layer regarding Love waves except for existence of the cut-off thickness.

WAVE PROPAGATION IN AN INCLINED GROUND MODEL

Wave Propagation Experiment The profile and the S-wave velocity of the ground model are shown in Fig.4. The angle of inclination is 3.5 degree. The material for the surface layer was also the acryl-amide gel in this wave propagation experiment. The impulsive excitation was generated by the plate-hitting method and the induced Love waves were observed at several points on the surface by small and light pick-ups. The excitation was applied at either a deeper or shallower portion of the model, intending to produce either upslope or downslope propagation of Love waves. The former is called the upslope case and the latter is called the downslope case. Special attention was paid to changes in wave forms and in spectral characteristics during such the wave propagations.

Observed displacement wave forms at 7.5, 15.0, 22.5cm distant from hitting point with their Fourier spectra in the upslope case and the downslope case are shown in Fig.5(a) and (b) respectively. There are two peaks of spectral amplitude which correspond to the predominant periods of the fundamental mode and the first mode of Love waves. In the upslope case the spectral amplitude decays from the longer period side and the predominant period becomes shorter as the wave propagates. This is due to the fact that a component traveling beyond the cut-off thickness vanishes. The predominant period of each point is related with the thickness of each point, but it is a little shorter than 4H/Vs.

In the downslope case the predominant periods do not change, and only depends the thickness of the hit point. This period almost corresponds to the predominant period of the hit point that is a little shorter than 4H/Vs. These characteristics can be easily explained by the result of the vibration experiment. Love waves are not influenced by the cut-off thickness in the downslope propagation.

Love wave is superposition of SH-waves repeated reflection in a surface layer. Examples of the wave rays of the upslope and downslope case are shown in Fig.6(a) and (b). From this point of view, in the upslope case SH-waves generated at the hit point reflect many times under the observed points until they reach the points. This is why the spectrum is much influenced by the thickness of the observed point. In the downslope case, on the other hand, SH-waves repeat reflection near the hit point with a less frequency of reflection around the observation points. Therefore the spectrum depends on the thickness of the hit point rather than that of the observed point.

CONCLUSIONS

From the vibration and wave propagation experiments on the ground model with an inclined layer, the following conclusions were obtained:

1) As for displacement patterns along a vertical axis, Love waves induce the same patterns regardless of inclination of the rigid basement.

2) A cut-off thickness for a prescribed period was newly defined for an inclined layer. In a portion with a thickness more than cut off thickness, phase velocities of Love waves correspond to that of parallel layers.

3) The spectrum and their predominant period show a change with a travel distance of the wave propagation. There is a remarkable difference in the change between the upslope or downslope propagations, but this difference can be easily explained by the cut-off thickness.

REFERENCES

1. T. Ohmachi : An Approach to Reformulation of Love Wave by Means of Vibration Technique, Technical Report No.33, Tokyo Institute of Technology, Department of Civil Engineering, (1984).

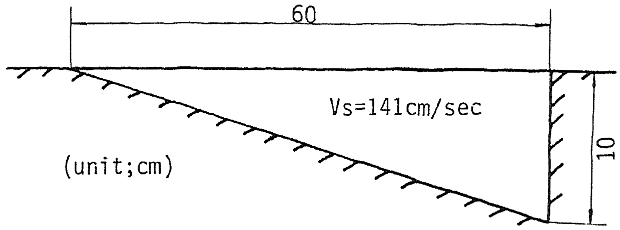

Fig.1 Profile and S-wave Velocity of Ground Model

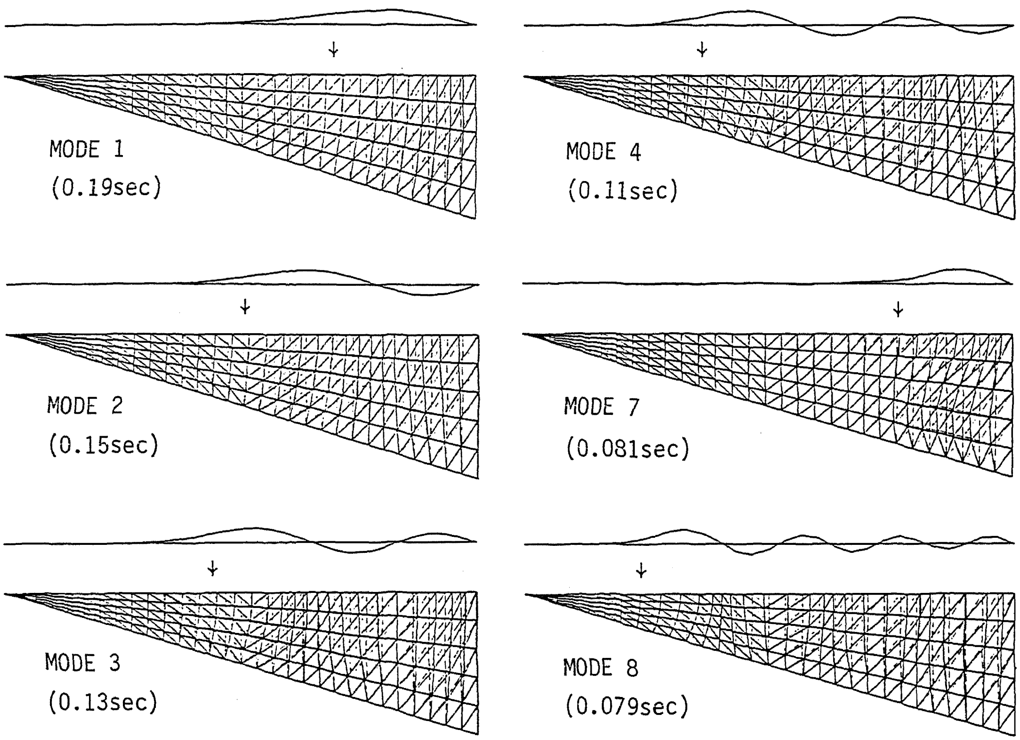

Fig.2 Vibration Shapes with Their Natural Periods (↓ : cut-off thickness)
The displacement in a transverse direction is shown in a radial direction in these profiles.

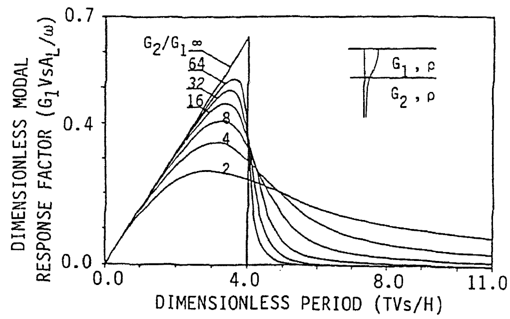

Fig.3 Modal Response Factor Plotted Against Period

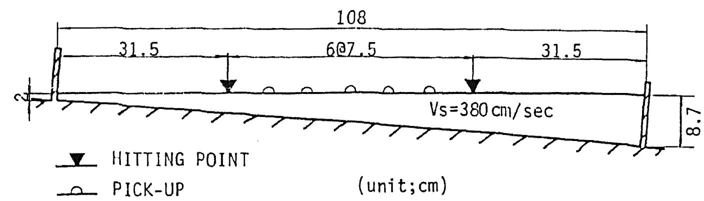

Fig.4 Profile and S-wave Velocity of Ground Model

(a) The Upslope Case

(b) The Downslope Case

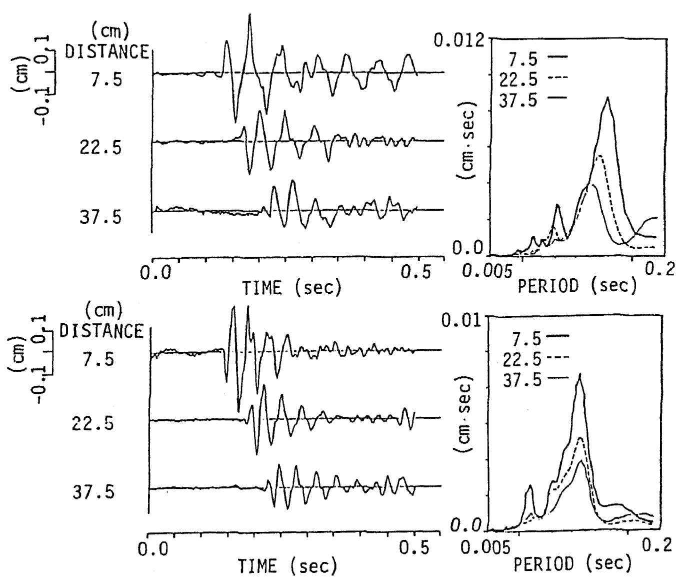

Fig.5 Observed Displacement Wave Forms with Their Fourier Spectra

(a) The Upslope Case

(b) The Downslope Case

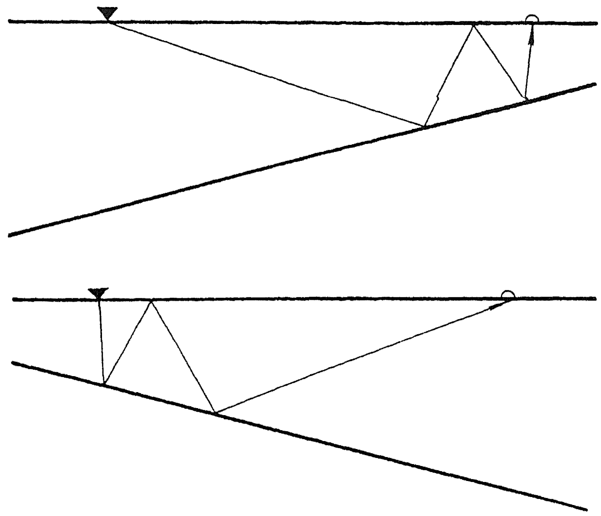

Fig.6 Example of SH-wave Rays

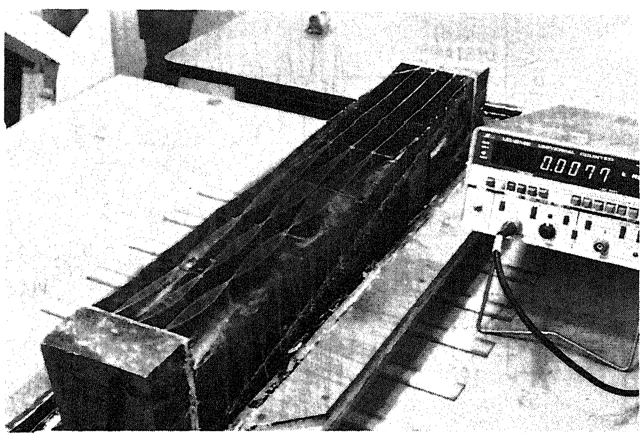

Photo Vibration Experiment