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NUMERICAL SIMULATION ON MAGNIFICATION OF THE GROUND MOTION IN THE IRREGULAR SURFACE LAYER

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ABSTRACT

In Kobe Earthquake(1995) the heaviest damages were centered at some area which has the soft surface layers and the irregular topographical conditions. We focused on the embedded valley, which are assumed from boring data in Kobe City. Making two finite element models like a brick, we did three dimensional wave propagation simulation. From the numerical simulations, seismic motion on the embedded valley is magnified because of the predominant vibration of shearing wave and the wave components which apparently move horizontally from shallow to deep alluvium. Superimposing these components can make large earthquake motion and cause heavy damages.

KEYWORDS : 3D wave simulation, embedded valley, magnification of ground motion, severely damaged zone, Kobe earthquake

1. Introduction

It is popularly known that the surface layers of ground make seismic motion amplify because of multiple reflections. From some experiences of earthquakes damages, there have been heavily damaged zones. In the case of horizontal regular layers, seismic wave propagates in the vertical direction and the ground motion is simulated from one dimensional wave equation. Although in the case of irregular layers, seismic plane wave towards ground surface propagates in multi-directions, and some amplification's factors are combined as to increase ground motion more larger than one dimensional equation. The special condition in which earthquake's disaster happens severely, is flat alluvium locating near mountains. In Kobe Earthquake which occurred on January 17,1995, severely damaged zones are in the narrow band too. These zones were mainly spread between Rokko Mountains and sea. Complicated geological conditions might magnify ground motions, hence many houses and other structures might be destroyed.

We analyze magnification's factors and characteristics of strong motion in these area by numerical simulation on wave propagation. Inputting the strong shock wave into the FEM model, the wave propagates in the model. Irregular conditions such as the rigidity and the depth of the layers influence on magnification of the motion. We observed the earthquake motions in the model on computer graphic system. From calculated results, in narrow area with the special conditions of magnification, seismic motions are amplified more largely, and large vertical motions are induced with response to horizontal inputting. The seismic motion on the embedded valley is magnified because of the predominant vibration of shearing wave and the wave components which apparently move horizontally from shallow to deep alluvium. Superimposing these components can make large earthquake motion and cause heavy damages.

2. Geological Conditions in Daikai District

Kobe City which suffered from severe damages is laid on alluvium fans or alluvium layers in the South of Rokko mountains. Comparing the distribution of houses damages and the depth of a hard layer (N value>50), severely damaged areas have been rather coincided with the gradient part of hard layer and embedded valley. From the comparing results, we focused on Daikai District in Kobe City, where subway tunnel was collapsed. Figure 1 shows the depth of surface layer and the distribution of houses damages near Daikai Station. In this figure the dark gray areas indicate that the damage ratio of houses was over 50 %, and the gray area indicates over 30%. The contour lines of depth of surface layer change from 4 meters to 16 meters, and severely damaged area which is indicated as dark gray exists in the deeper part of the surface layer along the shallow embedded valley. This fact suggests that the three dimensional irregularity of surface layers could magnify seismic motion.

Then we do numerical simulation by finite element method so as to know characteristics of seismic motion on these layers. We use two models, one is the shallow cone-shaped surface layer of which the diameter is 900 meters, and the other is the real model made from boring data in Daikai District shown in figure 1. These models are shown in Figure 2(a) and 2(b), which have only surface layer and base layer, and each shear wave velocity is 100m/s or 300m/s. Both of two models have flat surface for simple condition.

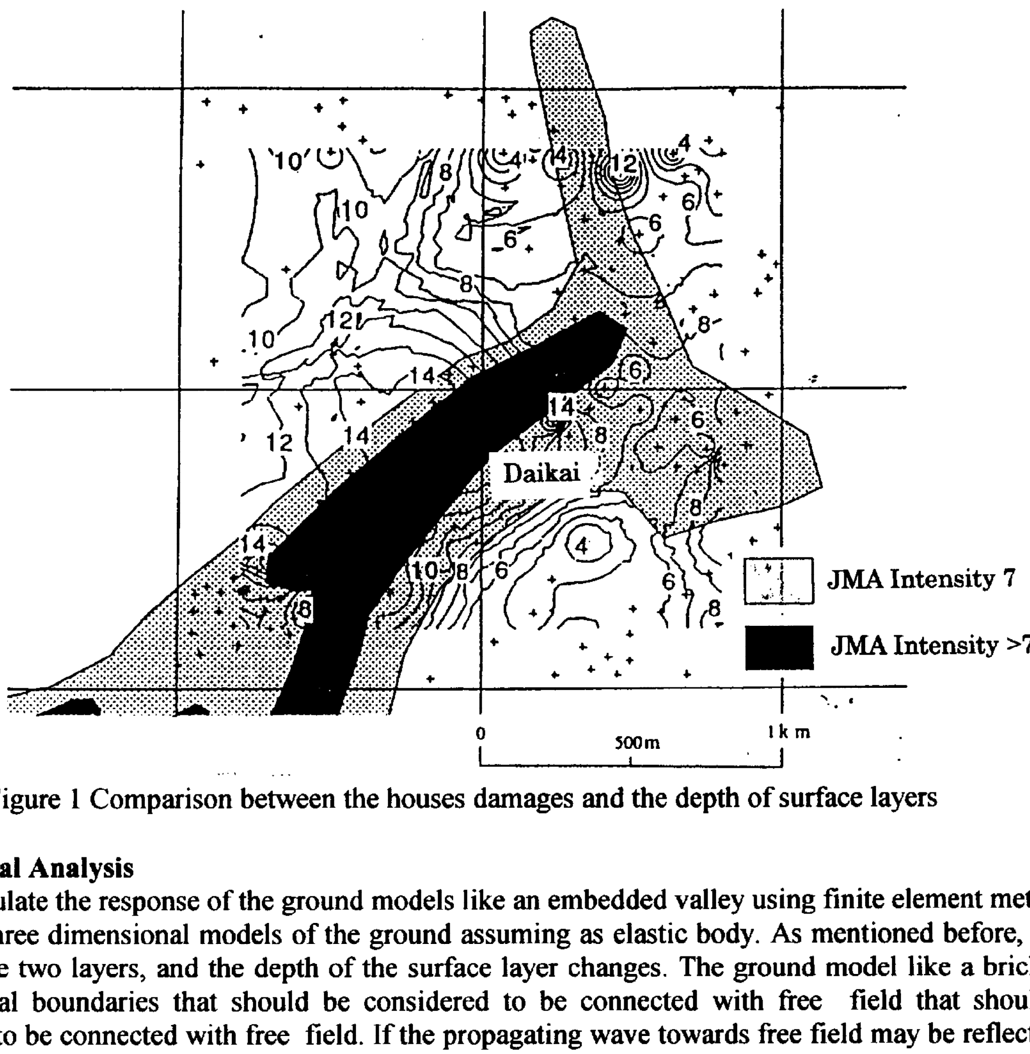
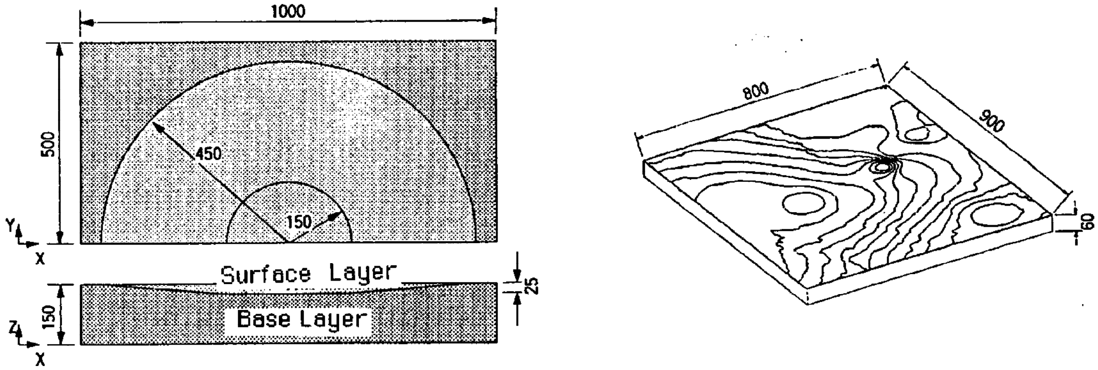


Figure 1 Comparison between the houses damages and the depth of surface layers

3. Numerical Analysis

We calculate the response of the ground models like an embedded valley using finite element method. We make three dimensional models of the ground assuming as elastic body. As mentioned before, these models have two layers, and the depth of the surface layer changes. The ground model like a brick has five artificial boundaries that should be considered to be connected with free field that should be considered to be connected with free field. If the propagating wave towards free field may be reflected at these artificial boundaries, calculation results include the effect of reflection wave which should not exist. So the special boundary conditions are necessary for canceling the reflection wave. We adopt the



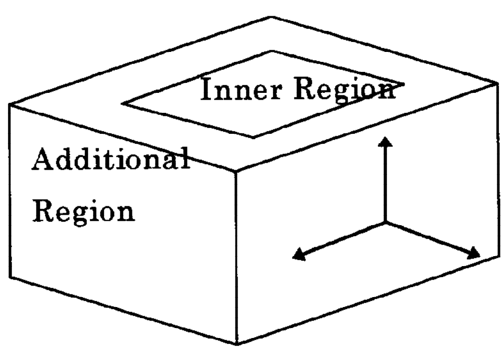
(a) cone-shaped surface layer (b) Daikai District

Figure 2 Models for numerical simulation

superimposing boundary proposed by P.A. Cundall, which is averaging two solutions of constant stress and constant velocity.

Figure 3 shows the calculation model on the artificial boundaries, which is modified by Suzuki et. al. to deal with three dimensional elastic body. The inner region is surrounded by additional boundary region and the reflection wave exists only in these additional areas. In the boundary region eight paterns of solution are calculated with some combinations of boundary conditions.

Along the lateral artificial boundaries, free field's motion is necessary to identify the incident wave component to be reflected. Free field's motion is independently calculated from two dimensional analysis such as SH wave problem and SV wave problem. Acting forces on a plane of nodes near bottom boundary, time step iterations have been done using Runge-Kutta Method. The forces are in proportion to velocity of seismic incident wave, which generate a sine type wavelet propagating both upwards and downwards. This upwards wavelet transfers on FEM models and time series of displacement or velocity on whole nodes in the model are calculated. We use computer animation to trace the ground motion.



Combination of constant stress and constant velocity conditions in normal and tangential directions

Figure 3 Illustration of calculation model with additional region

4. Calculation Results and Remarks

(1) Idealized model with like a cone-shaped surface layer

The ground model in this case has the surface layer like shallow bowl of which diameter is 900 meters, considering symmetric condition, a half size model is adopted. The gradient of boundaries strata between hard and soft layers is 8.3 %, and the maximum of the depth is 25 meters. Inputting two shock wave with 4 Hz sine type in x direction, the propagating wave towards the ground surface changes its form and the amplitude.

Figure 4(a) and 4(b) show the animation of the ground motion which are the results of different time steps. Traveling wave from base layer into soft layer becomes short wave length, and reflects both at the ground surface and at the boundary strata. The period of predominant vibration is determined with the formula, Vs/4H, in which Vs is shearing wave velocity and H is depth of surface layer. In this case, the amplitude of wave becomes large in the zone of about 6 meters depth like a donut. This large motion transfers towards deep surface layer or the center of the model, because of the irregular boundary strata. This wave has also vertical component.

In the center area of the model, transferring waves from different directions superimpose complicatedly, so the ground motion of the surface becomes larger too. This area corresponds to the center of embedded valley.

(2) Model of Daikai District

Next case is the model of Daikai District. This model is made from boring data in Kobe City, but the condition of ground surface is simply flat. Comparing with the former model, this model is less irregular layers. Inputting 4 Hz sine type force, wave propagation simulation has be done same as the former model.

Figure 5(a) and 5(b) shows the animation results. Large ground motions has occurred at the zones with 6 meters depth of surface layer, and these motions transfer towards deeper alluvium. When these components of wave superimpose, large ground motion has occurred too. Two factors which are predominant vibration and superimposition of transferring waves could make large ground motion on the irregular layers.

(3) Remarks

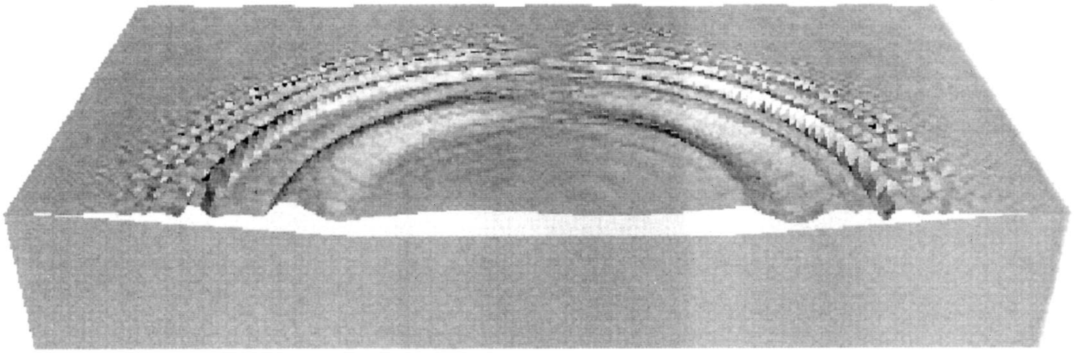
From the results of numerical simulations, we assume the magnification factors of an embedded valley. Though inputting wave is simplified in these calculations, earthquake motion incident from base layer has some frequency characteristics. Based on one dimensional multiple reflection theory, ground motion has been magnified by predominant vibration. So in some zones which have predominant period same with the peak period of inputting motion, large ground motion has occurred. This is the first factor of magnification.

Considering two boundaries of ground surface and strata between soft and hard layer, two boundaries are not parallel in an embedded valley. Plane wave incident from hard layer changes the traveling direction from vertical to horizontal when reflecting at some boundary. We know there is a critical angle of total reflection of shear wave. In this condition, shear wave energy does not decrease because of no transmitting into hard layer. This shear wave generated by predominant vibration propagates in horizontal direction from shallow to deep surface layer. This shear wave with total reflection is the second factor. When coupling the first factor and the second factor, special conditions for large ground motion could be satisfied at some zone. Figure 6 shows the illustration of wave traveling in the irregular surface layer. In an embedded valley, two components of wave could superimpose near the center of the valley, so making large earthquake motion and causing heavy damages.

5. Conclusion

In this report, some case studies are tried by FEM calculation, and features of amplification of the ground that has irregular layers are known. On the alluvial layers, seismic ground's motions are amplified because of predominant vibration and superimposition of shear waves. In narrow area with the special conditions of magnification, seismic motion could be amplified more largely, and large vertical motions are induced with response to horizontal inputting. Especially in the case of an embedded valley, the wave components which apparently travel horizontally from shallow to deep alluvium superimpose near the center of the valley. This could make large ground motion and cause severe damages of structures. So irregular boundaries of underground layers are related with amplification of seismic motions, and these could be concerned with the locality of the damage's distribution.

(a)



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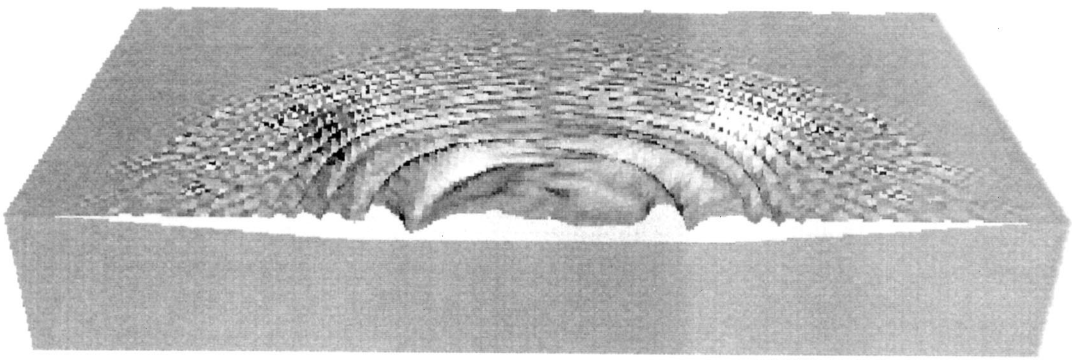
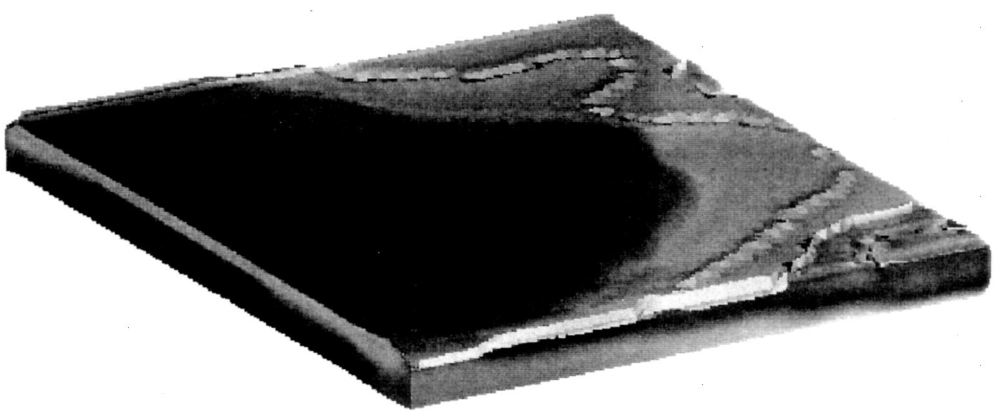


Figure 4 Animation of ground motion in the case of cone-shaped surface layer

(a)



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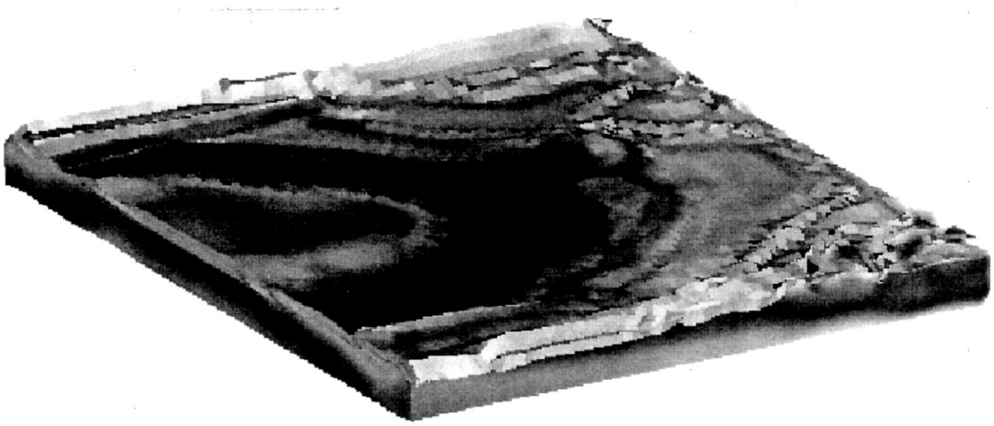

Figure 5 Animation of ground motion in the case of Daikai District model

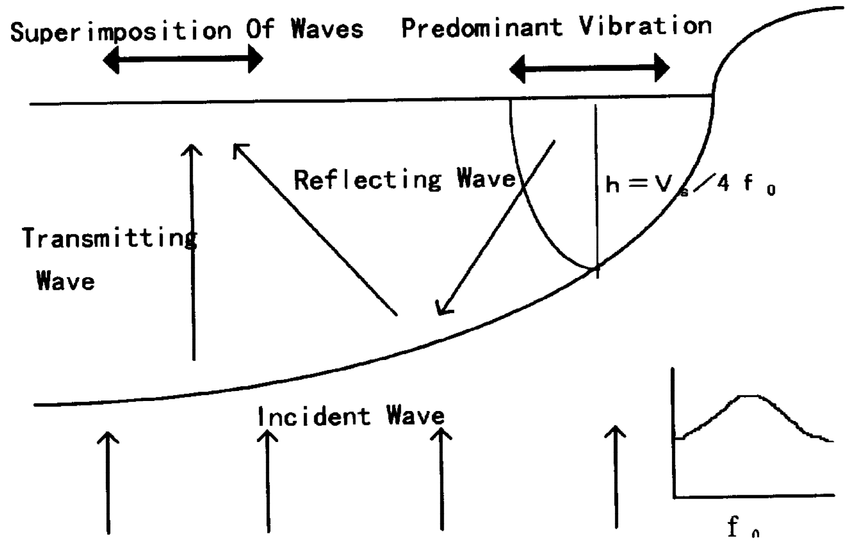

Figure 6 Illustration of ground motion in the irregular layer

References

1) Igarashi, S. et. al. :Vertical ground motion generated by irregular layers of ground and damages of structures, Proc. of 23rd JSCE Earthquake Engineering Symposium-1995

2) Suzuki, T. et. al. :Numerical simulation on ground motion of irregular surface layers, Proc. of 23rd JSCE Earthquake Engineering Symposium-1995

3)Cundall P.A. et. al.:Solution of infinite dynamic problems by finite modeling in the time domain, Proc. 2nd Int. Conf. Appl. Num. Modeling, Madrid (1978)

4) Suzuki. T. and Hakuno, M. : 3-D dynamic analysis of ground motion by FEM with non-reflecting boundary, Proc. of JSCE Structural Eng./Earthquake Eng. Vol.2 No.1 (1985)