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MODELING OF INHOMOGENEITY IN SEDIMENT LAYERS IN TOKYO METROPOLITAN AREA IN JAPAN FOR STRONG GROUND MOTION PREDICTION

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SUMMARY

In this study, we investigate the effect of gradual velocity increase with depth in sediment layers on strong ground motions. At Shimohsa, the deep well was excavated to 2300m depths and the detailed velocity structure was derived from VSP. Thickness of the sediment at Shimohsa is about 1500m. Sediment is consists of 2 geological layers. The upper sediment layer is Pleistocen and thickness of the layer is about 1300m.The lower sediment layer is Miocene. The gradual increase of velocity with depth is clearly seen in the sediment layers in depths from 100m to 1300m.

We make three 1D seismic velocity models of Shimohsa to investigate effect of the gradual velocity increase with depth in the sediment layers on strong ground motions. Difference between three 1D models is modeling of the sediment layers exisiting from 80m to 1300m in depth. In the first model, a constant velocity layer is modeled for the sediment layers (1layer model). In the second model, 16 layers are modeled for the sediment layers and the gradual increase of velocity with depth is well represented (16layer model). In third model, 2 layers are modeled for the sediment layers. This model is intermediate of the first and second models. Using these three models, we calculated S-wave amplification factors between bedrock and ground surface and compare with three amplification factors. We found that the gradual velocity increase affect amplification factors of S-wave for frequency less than 1Hz. We do simulation of seismograms at Shimohsa during a small earthquake (Mj4.7). The 16 layer model successfully reproduces wave reflected between bedrock and surface. We calculate amplitude response of fundamental modes of surface waves. We found that the gradual velocity increase also affect amplitude responses of surface-waves for frequency less than 1Hz. It is thought that modeling of gradual increase of velocity with depth in sediment layers is valid for improving existing velocity structure models.

INTRODUCTION

Recently several 3D seismic velocity models of Kanto basin are developed and are used in reproduction and/or prediction of strong ground motions. Kouketsu *et al.*(Koketsu [1]) developed 2 layered model from travel time of P waves obtained by seismic refraction survey. Sato *et al.* (Sato [2]) developed the model from geological data and by waveform modeling. In their model, sediment consists of about 5 layers.

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Yamanaka *et al.* (Yamanaka [3]) developed the model mainly from the inversion results of the phase velocities of surface waves in microtremors. In their model, sediment consists of 3 layers.

From the engineering point of view, we need to predict short period (about 1-2 sec) motions because such period ground motions is destructive to buildings. But the existing 3D models are not verified in short period. We need to develop more accurate 3D velocity model of Kanto basin to be able to predict short period strong ground motions.

Recently many deep well were excavated and vertical seismic velocity structures are revealed at these wells (NIED [4]). From these data, vertical velocity structure of the sediment consists of two kinds of structures. One of the structures is gradual increase of velocity with depth (call 'gradual increasing structure' hereafter) in a geological layer. The other is fluctuation of velocity. These two structures are not still well considered in existing 3D velocity model of Kanto basin although such structures have potential to affect the strong ground motions.

In this study, we investigated the effect of gradual increasing structure. We should examine the effect of such structure in a 3D velocity model. But in a 3D model, waves are affected by not only vertical velocity structure but also horizontal velocity structure. It is difficult to extract the effect of such vertical structure from waves in a 3D model. So we start to investigate with 1D velocity structure.

SEISMIC VELOCITY STRUCTURE AT SHIMOHSA DEEP OBSERVATION WELL

At Shimohsa, in Japan, the deep observation well was excavated to 2300m depths. Figure1 shows the location of the well. Accurate vertical velocity structure was derived by VSP. Figure 2 shows the velocity structure(Yamamizu [5]). Seismometers were set up at depths of 23m and 2300m. Thickness of the sediment at Shimohsa is about 1500m. Sediment is consists of 2 geological layer. The upper sediment layer is Pleistocene and thickness of the layer is about 1100m. The lower sediment layer is Miocene. The gradual increasing structure is clearly seen in the sediment until about 1300m depths.

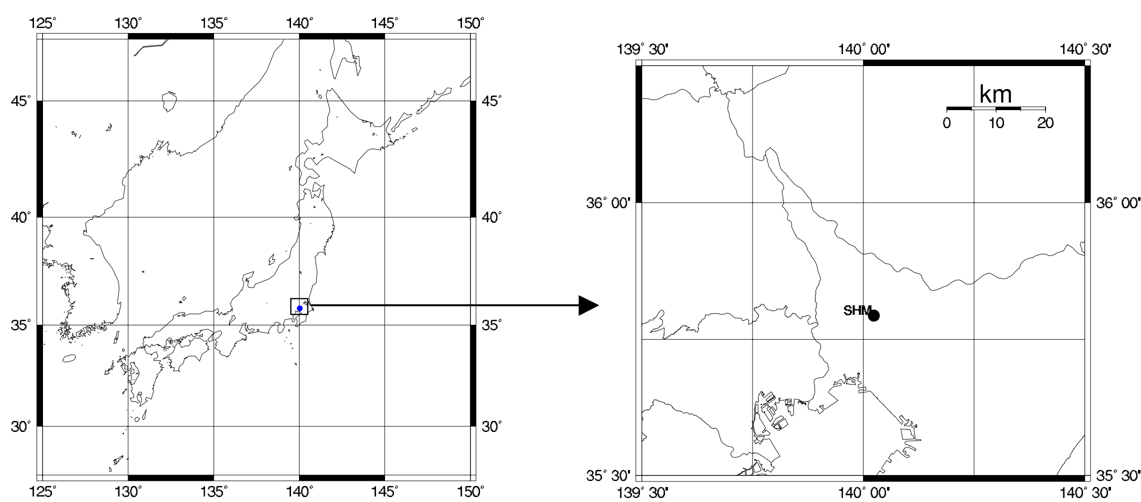
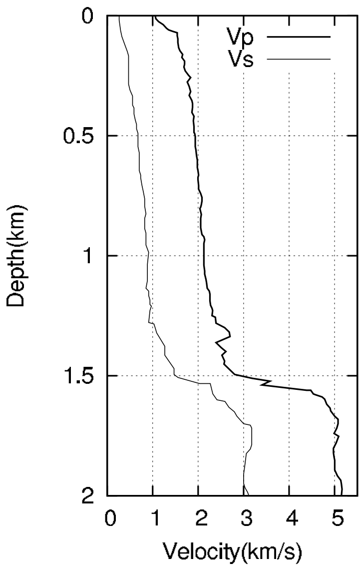


Figure 1 Location of the deep well at Shimohsa (SHM)



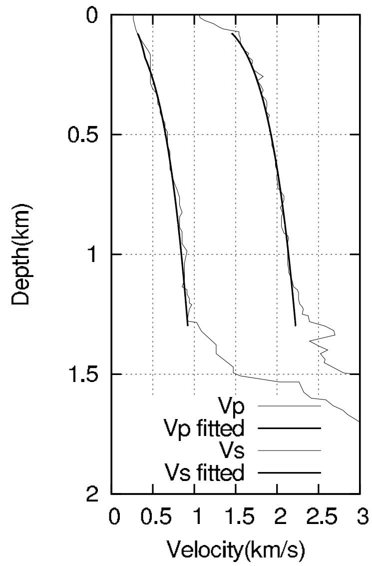


Figure 2 Velocity structure by VSP at Shimohsa

Figure 3 Gradual increasing structure

EFFECT OF GRDUAL INCREASE OF VELOCITY IN THE SEDIMENT

Modeling gradual increasing structure

We extracted the gradual increasing structure from velocities by VSP shown in figure 2. In the range from 80m to 1300m in depth, gradual increasing structure can be recognized in both P-wave and S-wave. We fitted the relation $Vp=a*Z^b$ to the P-wave velocities in that range. We obtain following relationship for gradual increasing structure of P-wave,

$$Vp=756Z^{0.151} \quad (80m < Z < 1300m) \qquad 1)$$

where Z is depth in m and Vp is P-wave velocity in m/s.

Gradual increasing structure for S-wave is calculated from Vp by the relation (Kanagawa city[6])

$$Vs=0.8Vp-800 \quad 2)$$

where Vs is S-wave velocity in m/s.

Figure 3 is comparison of the gradual increasing velocity structure and velocities derived by VSP. The gradual increasing structure is well fitted to the velocities by VSP. To investigate effect of gradual increasing structure, we make following three 1D models.

1. 1 layer model

A constant velocity layer is modeled for gradual increasing structure. Vp of a constant velocity layer is decided so that travel time of P-wave coincides with the one of the gradual increasing structure. S-wave velocity is also decided in a same manner. The surface structure shallower than 80m was derived by PS logging (Yamamizu [7]) and we adopt it. From 1300m to 1584m in depth, thickness of the layers is set at 71m. Vp and Vs of each layer is averages of gradual increasing structure at same depth. This model is a representative model that does not have gradual increasing structure in the sediment.

2. 16 layers model

16 layers are modeled for the gradual increasing structure. Except 16 layers, 16 layers model is same as other two models. Total travel time of 16 layers coincides with the travel time of the

gradual increasing structure. Each layer has same travel time of P-wave and S-wave. This model has gradual increasing structure in the sediment.

3. 2 layers model

2 layers are modeled for the gradual increasing structure. Except gradual increasing structure, 2 layers model is same as other two models. Procedure of calculating velocities and thickness of each layer is same as 16 layers model. This model has intermediate velocity structure between 1 layer and 16 layers model.

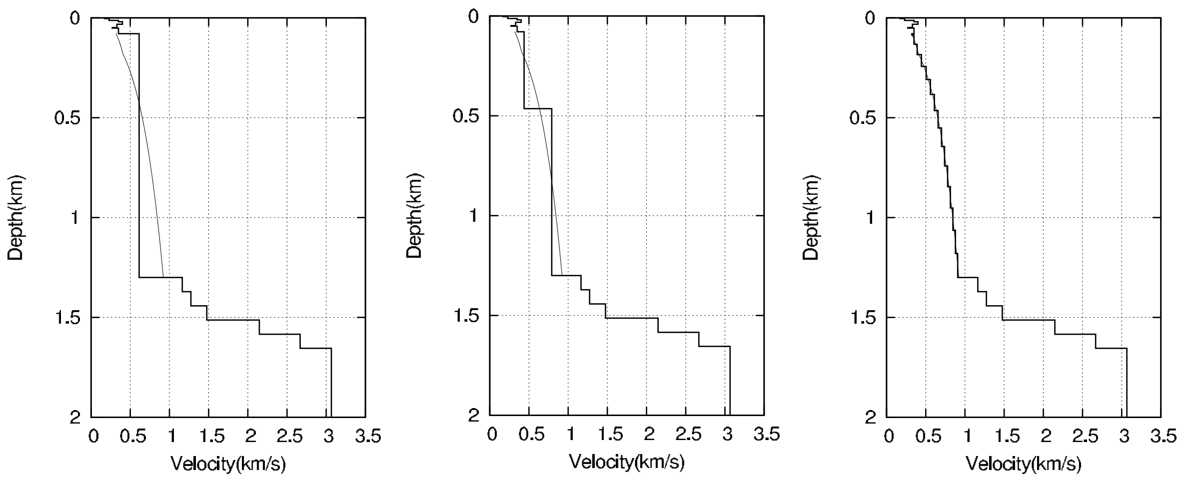
Vs structures of the three models are shown in Figure 4.

For the layers above 1584m depth., we adopt Q value measured in the well at Shimohsa (Kinoshita [8]).

$$Qs=50f$$

where Qs is Q value of S-wave and f is frequency(Hz).

For the layers below 1584m depths, Qs is set at 100. For P-wave, Qp of all layers are set at 2Qs.



(a) 1 layer model (b) 2 layers model (c) 16 layers model

Figure 4 Vs structures of 1D models

Comparison of S-wave amplifications and simulations between three models

1D vertical S-wave amplification

We calculate S-wave amplifications between ground surface and 2300m in depth. Figure 5 shows S-wave amplifications of 1 layer, 2 layers, and 16layers models. Effect of gradual increasing structure on amplification is seen for frequency less than 1 Hz. For frequency higher than 0.2Hz, frequencies of the peaks of amplifications are almost same between three models. But amplification factor at peaks are different. It is thought that gradual increasing structure affect amplification factor rather than frequencies of peaks.

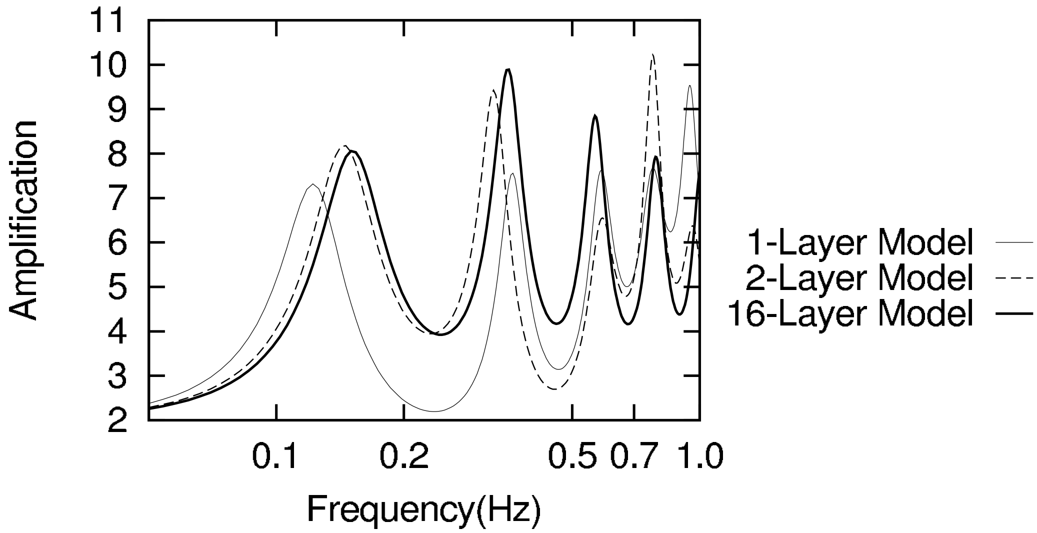


Figure 4 Theoretical S-wave amplifications between surface and 2300m in depth

Simulation of seismograms during a small earthquake(Mj 4.7)

To investigate the effect of gradual increasing structure on seismograms, we do simulation of ground motions by f-k method (Hisada [9]) during the north-west Chiba prefecture earthquake (Mj4.7) of August 18, 2003 and compare with synthetic seismographs of each models and observed seismographs. We added crust model below the three models in calculation of f-k method.

The north-west Chiba prefecture earthquake (Mj4.7) of August 18, 2003

Hypocenter and mechanism estimated by NIED is shown in figure 5. We adopt focal mechanism, location of Hypocenter and depth estimated by NIED(http://www.fnet.bosai.go.jp/freesia/index-j.html). Moment of the fault was estimated 1.92E+16Nm by NIED. But we change moment to 1.59E+16Nm to match amplitude of direct S-wave of seismogram at a depth of 2033m between record and synthesis. We modeled this fault for a point source. We assume that shape of slip velocity function is triangle. Duration of the slip velocity function is read from duration of direct S-wave of seismogram at a depth of 2300m.

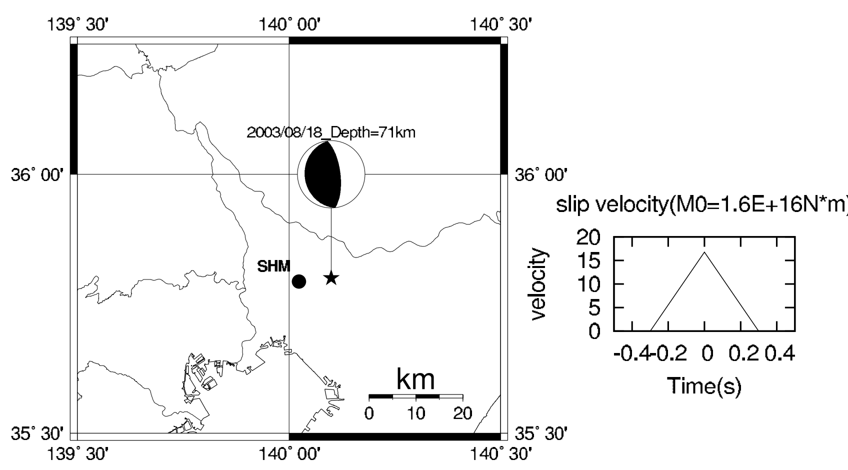


Figure 5 Simulated fault and it’s slip velocity function

Effect of gradual increasing structure on seismograms

Synthetic and observed 0.1-1.0Hz EW-component velocity waveforms at surface and a depth of 2300m are shown in figure 6. In case of this earthquake, EW motion predominated among three directions. In the observed seismogram at ground surface, wave reflected between bedrock and ground surface is clearly recognized. All of the synthetic seismograms in three models reproduce such reflected waves. But amplitudes and shape of reflected wave are different among three models. In case of 2 layers model, reflected wave is not clear. It is thought that this is due to reflected waves generated at velocity step at 0.5km(see figure 3(b)). In case of 1 layer model, reflected wave is clear but it's amplitude is small compared to observed seismogram. 16 layers model is best for agreement with observed and synthetic seismograms.

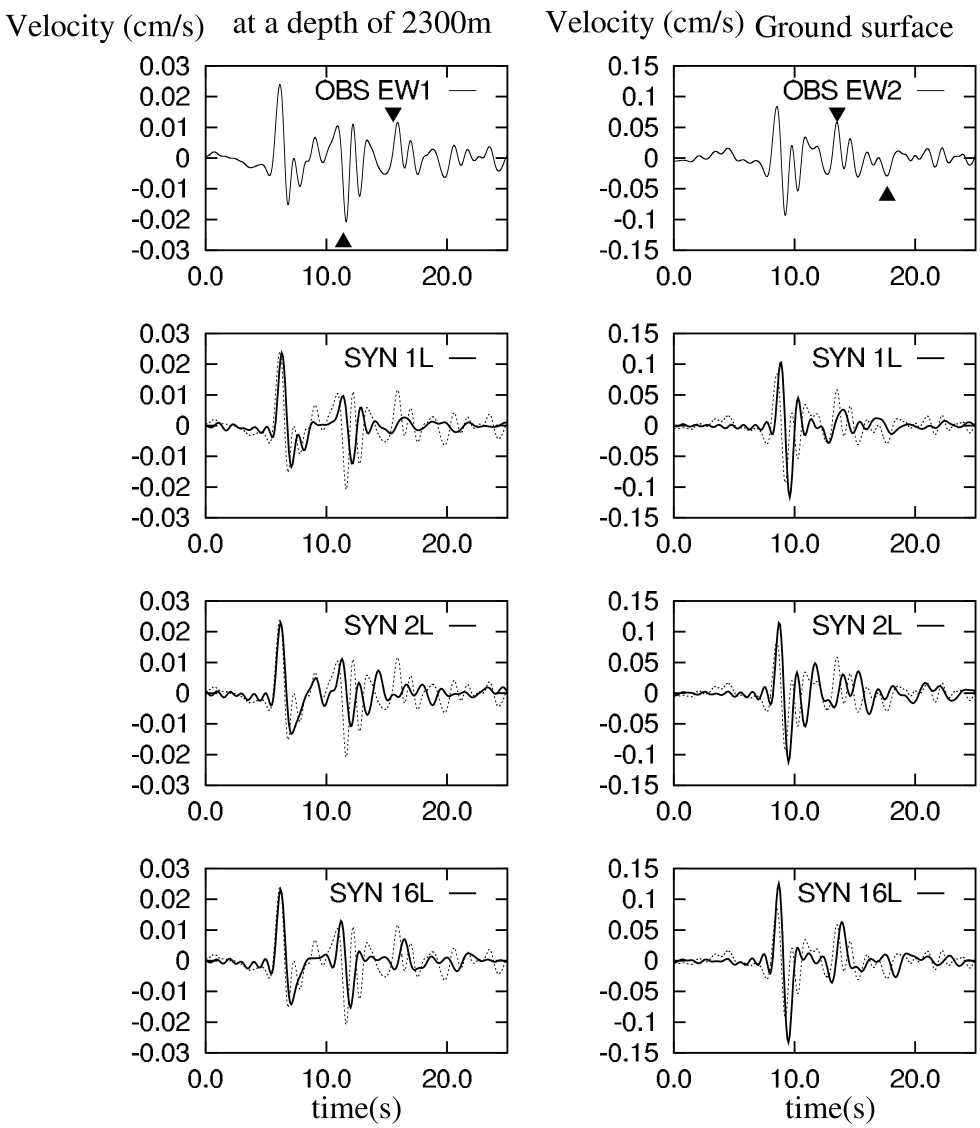


Figure 6 Observed and synthetic 0.1-1.0Hz EW-component velocity waveforms at ground surface and a depth of 2300m(▼indicates reflected wave)

Comparison of surface-wave amplitude responses between three models

Theoretical surface-wave amplitude response

Figure 6 shows surface-wave amplitude response (D. G. Harkrider [10]) of fundamental mode of Love and Rayleigh waves. Effect of gradual increasing structure on amplitude response is obvious for frequency higher than 0.2 Hz. Ratio of amplitude response (1 layer model / 16 layers model) is about 2 at about 0.5Hz. Compared to S-wave amplification factor, gradual increasing structure has more effect on surface-wave.

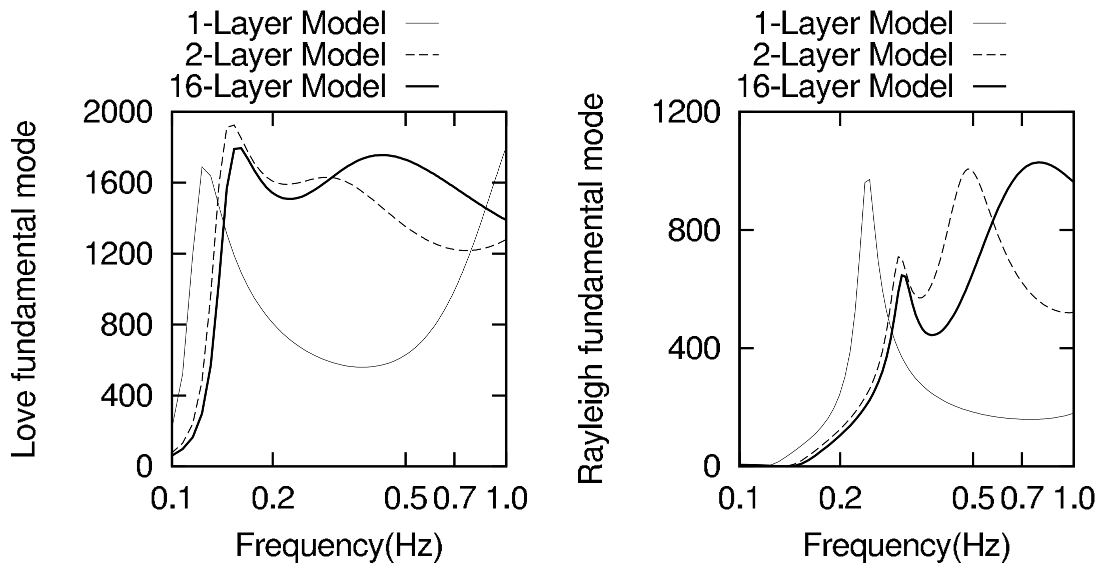


Figure 6 Theoretical surface-wave amplitude response

CONCLUSION

We investigate the effect of gradual velocity increase with depth in sediment layers on strong ground motions at Shimohsa. As result, following things are revealed.

1) The gradual velocity increase with depth in sediment layers affects S-wave amplification factor and surface-wave amplitude response for frequency less than 1Hz.

2) Agreement with Observed and synthetic seismograms are improved by modeling gradual velocity increase in sediment layers.

It is thought that modeling of gradual increase of velocity with depth in sediment is valid to improve existing 3D velocity structure model.

* We used the records in KiK-net (http://www.kik.bosai.go.jp/kik/). We would like to thank NIED.

REFERENCES

1. Koketsu, K. and S. Higashi "Three-dimensional topography of the sediment/basement interface in the Tokyo metropolitan area, central Japan" Bull. Seism. Soc. Am. 1992; 82: 2328-2349.
2. T. Sato, Robert W. Graves, and Paul G. Somerville “Three-dimensional finite-difference simulations of long-period strong motions in th Tokyo metropolitan area during the 1990 Odawara Earthquake (Kj5.1) and the Great 1923 Kanto Earthquake(Ms8.2) in Japan” Bull. Seism. Soc. Am. 1999; 89(3): 579-607.

3. H. Yamanaka, and N. Yamada "Estimation of 3D S-wave velocity model of deep sedimentary layers in Kanto plain, Japan, using microtremor array measurements" BUTURI-TANSA 2002; 55(1):53-65(in Japanese)
4. National Research Institute For Earth Science and Disaster Prevention "Geological and logging data of the deep observation wells in the Kanto region, Japan" Technical Note Of The Natl. Res. Inst. Earth Sci. Disaster Prevention 1999; 192
5. Yamamizu,F. ":S-wave velocity structure as revealed by the deep well VSP" Programme and Abstracts, Seism. Soc. Japan 2001; 63-63(in Japanese)
6. Kawasaki city "Underground structure survey in Kawasaki city" (http://www.hp1039.jishin.go.jp/kozo/Kawasaki3frm.htm) 1998 (in Japanese)
7. Yamamizu,F. "Down-hole measurements of seismic wave velocities in deep soil deposits beneath the TOKYO Metropolitan area" Rept. Natl. Res. Inst. Earth Sci. Disaster Prvention 1996; 56: 1-32
8. S. Kinoshita "Attenuation Characteristics of S-waves in a sedimentary layer-basement system in the Kanto region, Japan, for a frequency range of 0.5 to 16Hz" Zishin(J. Seism. Soc.Japan) 2002; 55: 19-31
9. Y. Hisada "An efficient method for computing Green's functions for a layered half-space with sources and receivers at close depths (Part2)" Bull. Seism. Soc. Am. 1999; 89(3): 579-607.
10. D. G. Harkrider "Surface waves in multilayered elastic media. PartII." Bull. Seism. Soc. Am. 1970; 60(6): 1937-1987.