LATERAL HETEROGENEITIES AND SOURCE LOCATION EFFECTS ON SH WAVE FIELD USING FINITE DIFFERENCE METHOD AND DOUBLE COUPLE SOURCE

Pitarka,A.

Seismological Centre, Tirana, Albania

A B S T R A C T

We perform a numerical simulation to investigate 2D SH wave propagation in sediment - filled valleys, generated by a double couple point source. The amplitude of direct waves and the secondary surface waves greatly depend on the geometry of the basement and source location. We try to simulate the velocity seismogram recorded at Ashigara valley test site, Japan by using two-dimensional SH-wave propagation modelling. Peak velocity is very well predicted. The early part of the observed seismogram is well modelled, however the later arrivals are not. This is probably due to the simplified underground structure model we used, derived from seismic refraction survey.

ΕΠΙΔΡΑΣΗ ΤΗΣ ΘΕΣΗΣ ΤΗΣ ΠΗΓΗΣ ΚΑΙ ΤΩΝ ΠΛΕΥΡΙΚΩΝ ΑΣΥΝΕΧΕΙΩΝ ΣΤΑ ΚΥΜΑΤΑ SH ΜΕ ΕΦΑΡΜΟΓΗ ΤΩΝ ΠΕΠΕΡΑΣΜΕΩΝ ΔΙΑΦΟΡΩΝ ΓΙΑ ΔΙΠΛΟΥ ΖΕΥΓΟΥΣ ΠΗΓΗ

Pitarka,Α.

Π Ε Ρ Ι Λ Η Ψ Η

Η αριθμητική προσομοίωση χρησιμοποιείται για τη μελέτη της διάδοσης SH κυμάτων που προήλθαν από διπλού ζεύγους σημειακή πηγή σε λεκάνες ιζημάτων. Το πλάτος των απ' ευθείας κυμάτων και των δευτερευουσών επιφανειακών εξαρτάται από τη γεωμετρία της λεκάνης και τη θέση της πηγής. Γίνεται προσπάθεια για την προσομοίωση μιας αναγραφής εδαφικής ταχύτητας στη λεκάνης Ashigara της Ιαπωνίας με μοντέλο διάδοσης SH κυμάτων. Το συνθετικό σεισμόγραμμα βρίσκεται σε συμφωνία με το πραγματικό στην αρχή της καταγραφής όχι όμως και στο τέλος, ενώ τα σημεία των κορυφών βρίσκονται σε συμφωνία. Αυτό δείχνει ότι οι διαφορές των σεισμογραμμάτων τους διαφόρους σταθμούς της λεκάνης Ashigara οφείλονται στο μηχανισμό γένεσης και όχι στη δομή της λεκάνης.

INTRODUCTION

Observations during strong earthquakes and numerical simulations of strong ground motion have shown that the amplification of seismic motion is affected not only by local soil conditions but also from the deep underground geological structure, known as "wave propagation effect" and source location

(Bard and Bouchon, 1980; Gaffet and Bouchon, 1991; Zahradnik and Hron, 1987). This effect might be quite strong at some areas.

Our main purpose is to investigate the effects of lateral strong heterogeneities and source location on SH waves propagation for a double couple seismic source. Usually 2D modelling is used for line source seismograms calculation too, which is not realistic. In the present study we extend the theoretical investigation to the case of point source seismograms by using a procedure whereby two-dimensional Finite-Difference line source seismograms can be mapped into point source seismograms. The advantage of this method is that point source seismograms are calculated by a simple transformation of 2D line source seismograms with the proper point source dislocation characteristics.

Strong motion synthetics calculated with this method are compared with seismograms recorded at Ashigara Valley blind test site during an earthquake of magnitude M=5.1.

DESCRIPTION OF THE COMPUTATIONAL METHOD

We employ a 2D Finite Difference method for solving the SH-wave equation in a heterogeneous medium (Boore 1972):

$$\rho \frac{\partial^2 u}{\partial t^2} = \frac{\partial}{\partial x}\left(\mu \frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial z}\left(\mu \frac{\partial u}{\partial z}\right) \qquad (1)$$

where:

$u(x,z)$ - displacement
$\mu(x,z)$ - rigidity
$\rho(x,z)$ - density

The second-order finite difference approximation is applied for calculation of partial derivatives in eq.(1). For taking into account detailed variation of soil rigidity, we use the approach proposed by Tikhonov and Samarski (Mittchell, 1969):

$$\frac{\partial}{\partial x}\left(\mu \frac{\partial u}{\partial x}\right) \approx \frac{H_m u_{m-1} - (H_m - H_{m+1})\, u_m + H_{m+1} u_{m+1}}{(\Delta x)^2} \qquad (2)$$

where:

$$H_m = \Delta x \left[\int_{x_{m-1}}^{x_m} \frac{dx}{\mu}\right]^{-1} \qquad (3)$$

H - equivalent "horizontal" rigidity
Δx - grid step

Similar formula is used for calculation of the second partial derivative in the equation (1). Nonreflecting boundary conditions are imposed on the sides and the bottom of the FD grid, as described by Reynolds (1978) and free surface conditions are applied at the surface of the model.

Because the effect of seismic source location is one of our major interests, we use a reasonable point source dislocation model based on the method proposed by Vidale et al. (1985) and Bolt (1987). This method allows for mapping line source seismograms computed by 2D-FD scheme, to point source seismograms. The implementation of the seismic point source into the FD grid is realised by inserting wavefield due to a point source into the source region: a small region surrounding the point source. The use of the source region rather than a source point can avoid the singularities in the displacement field. In order to minimise the undesirable reflections of scattered waves at the border of the source region we used a two stage method as described by Alterman and Karal (1968). Following this method the wave propagation equation is solved twice in the source region, once imposing the source and once without a source. Combining the two results the source region becomes transparent to the scattered waves.

TEST OF THE METHOD

We tested our FD code comparing with other computation schemes (Aki and Richards, 1980) for vertical incidence of plane SH waves. The agreement is excellent. We also tested the method by including the seismic source, in the case of a two layer model given in Fig.1. A cosine shape function with a period To=0.5 sec is adopted as source time function. The synthetic seismograms generated by a strike slip point source mechanism and those obtained using the Reflectivity Method (H. Takenaka personal communication, 1992) are shown in Fig.1 The agreement between the two methods is rather good.

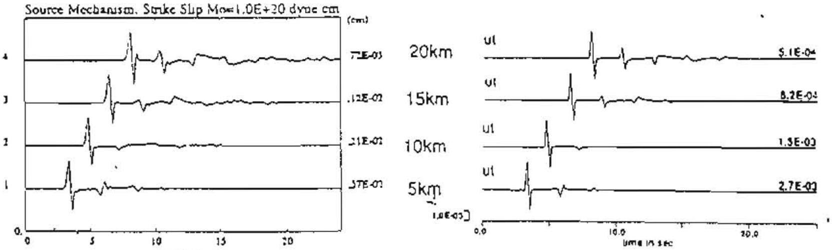
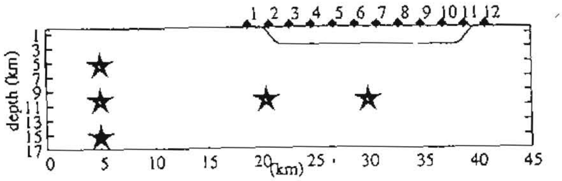


Fig.1. Synthetic SH seismograms computed using FD Method in the present study (Left) and Reflectivity Method (Right) along the surface of a flat two layer model. Source mechanism is Strike Slip. The epicentral distance of each receiver is indicated at the center of the figure and absolute amplitudes are at the right of the traces.

EFFECT OF THE GEOMETRY OF SEDIMENTARY BASIN AND SOURCE LOCATION ON SH WAVE PROPAGATION

The basin model we use in this study is described in Fig.2. It corresponds to a thin flat sedimentary valley overlying the bedrock with a large velocity contrast. The receivers are distributed on the surface of the basin. In order to clearly understand the effect of lateral heterogeneities on wave propagation, we do not include low velocity surface layers to the model, neither take into account absorbing properties of soils. A strike slip point source is implemented with a cosine source time function having a period of 1.0 sec and $M_0=1.0*10^{24}$ dyne cm. A grid with 750x200 points was used for FD calculations. The accuracy of the calculations is maintained up to 1 Hz.



	VS	RO
SEDIMENTS	1.0 KM/S	2.0 G/CM**3
BED ROCK	3.0 KM/S	2.5 G/CM**3

Fig.2. Basin geometry and source (star)-receiver (diamond) configuration in the calculations.

Effect of Depth

In this section we change the depth of sedimentary basin to understand the effect of the depth on wave propagation.

The synthetic seismograms calculated at the surface of the basin (Fig.3a) show that wave propagation is sensitive to the structure. In both three basin models four different phases can be well distinguished : direct waves, multiple reflections from the bottom of the basin, surface waves L1, generated at the left edge and their reflection L2 from the right edge of the basin. The amplitude of L1 waves slightly increases when the depth increases. This may be attributed to the increasing slope area due to the increasing basin depth, since the edge slope acts as a secondary source for surface wave excitation. It can be seen that the depth affect not only the amplitude but also the period and the phase velocity of secondary surface waves.

Effect of Slope

To study the slope effects we use three models having different slope angle and constant depth 2.5 km (Fig.3b).

The large amplitudes obtained at the receivers 2 and 3 near the slope, are due to the multiple reflections from the basin basement. The strong reflections due to the flat interface of the basin became smaller when the angle of slope decreased. The constructive interference of L1 waves, with the multiple reflections from the bottom of the basin exists independently of the slope angle. This interference amplify the ground motion at

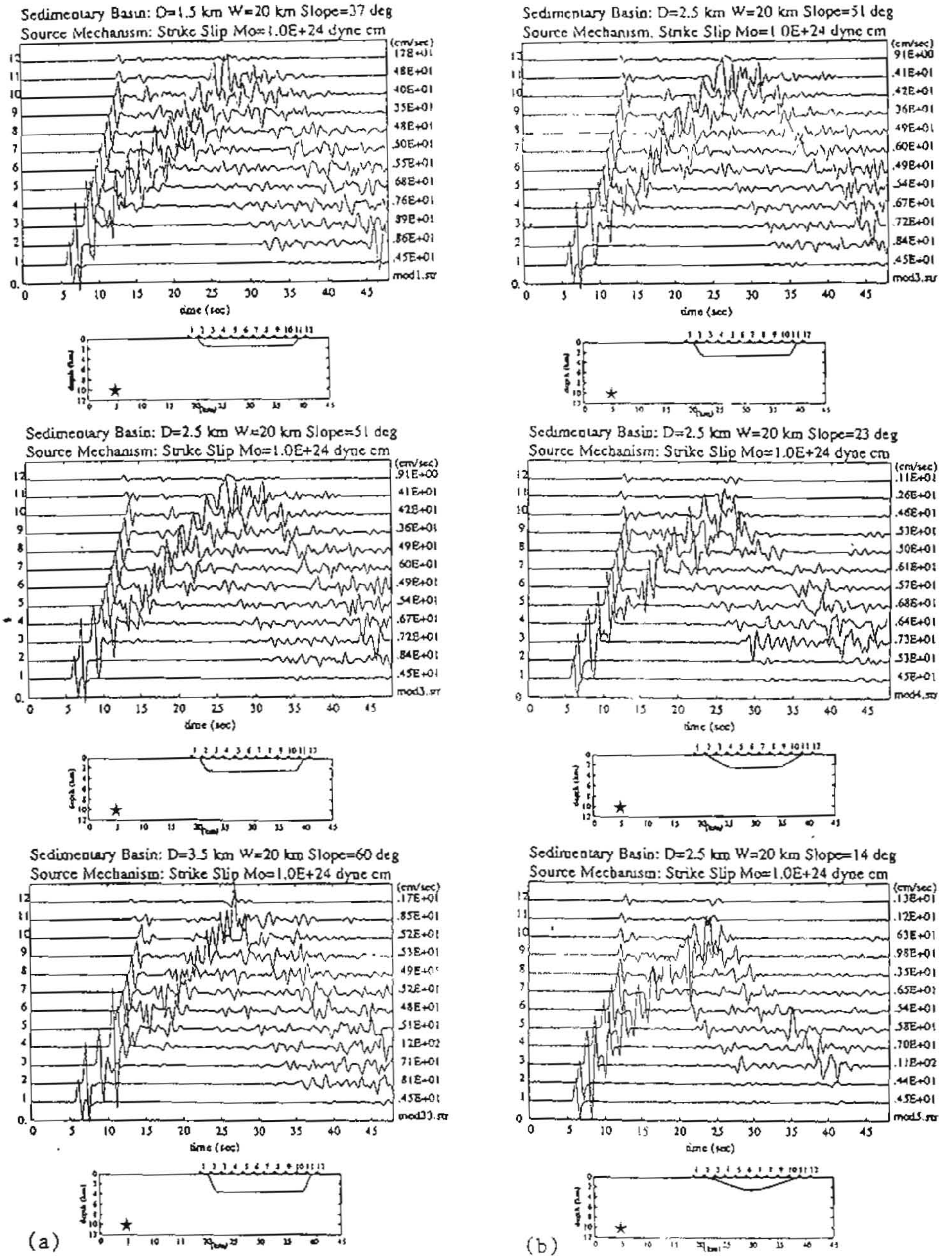


Fig.3. Computed SH seismograms. Receiver numbers are shown at the left and maximum velocity is shown at the right of each trace a) different basin depth D. (top - D=1.5 Km, middle - D=2.5 Km, bottom -D=3.5 Km) b) different slope angle (top: slope=51 deg., middle: slope=23 deg., bottom: slope-14deg.

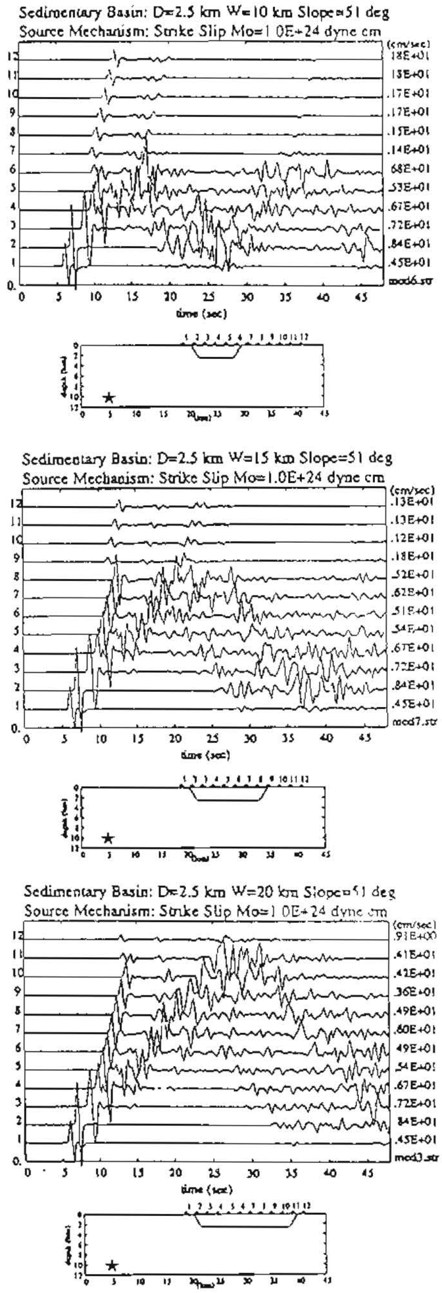


Fig.4. Computed SH siesmograms. Receiver numbers are shown at the left and maximum velocity is shown at the right of each trace top - W=10Km, middle - W=15Km, bottom - W=20 Km.

the receivers near the edges. The angle of slope affects not only the amplitude of multiple reflections near the edges but also the amplitude of surface waves. It can be pointed out that the amplitude of surface wave generated from the right slope of the basin increases as the angle of slope decreases.

Effect of Width

The models depicted in Fig.4 are used to study the effects of width of the basin. The seismic source is located at the right side of the basin at a depth of 10 km. The seismograms are calculated at the same location as in the previous models.

As it is seen on the Fig.4, in all trial models surface waves remain trapped inside the basin and constructive interferences of surface waves generated by the two sides may occur depending on the width of basin and receiver location.

Effect of Source Location

In order to investigate the relationship between relative source location and excitation of the secondary surface wave, we calculated synthetics changing source location as shown in Fig.5

Relative amplitudes of the secondary surface wave and direct SH wave depend on the relative location of the sources and receivers. In the case of Fig. 5a, the amplitude of direct SH waves at receivers near the left edge, is larger than that of secondary surface waves. At the central zone of the basin the amplitude of direct waves is smaller (Fig. 5a,b,c). This conclusion does not hold in the cases of Fig.5d,e. When the source is situated just beneath the edge, direct waves and multiple reflections at the basement are relatively large and the secondary surface waves is very small. In Fig.5e, maximum amplifications is found near the edges of the basin. This is not only due to the surface waves but also due to the strike slip mechanism of the source which generates small direct waves at the central part.

NUMERICAL MODELING OF SH WAVE PROPAGATION IN THE ASHIGARA VALLEY

By applying the computation method presented in this study we tried to model the strong motion recorded at the rock site at Ashigara Valley during the earthquake of August 5,1990 with magnitude M=5.1.

Figure 6 displays a geological map of the Ashigara valley. A seismic refraction study has been carried out to know the underground structures in that valley (JESG, 1991). Based on this study we delineate a simplified 2D model (Fig.7) of the cross section corresponding to a N60 direction. The focal mechanism of the earthquake is mainly strike slip with a small component of dip slip. The direction of one of the nodal planes is perpendicular to the cross section. Based on the focal mechanism of this earthquake we adopted the following source parameters for the calculation of the synthetics (JESG, 1991): strike = 90°, dip=80°, slip = 15° and seismic moment $M_o=3.5*10^{25}$ dyne cm. A cosine shape function was used as source time function with time duration $T_o=0.5$ sec. We rotate the observed accelerogram in order to obtain transverse seismogram and compare with the synthetics

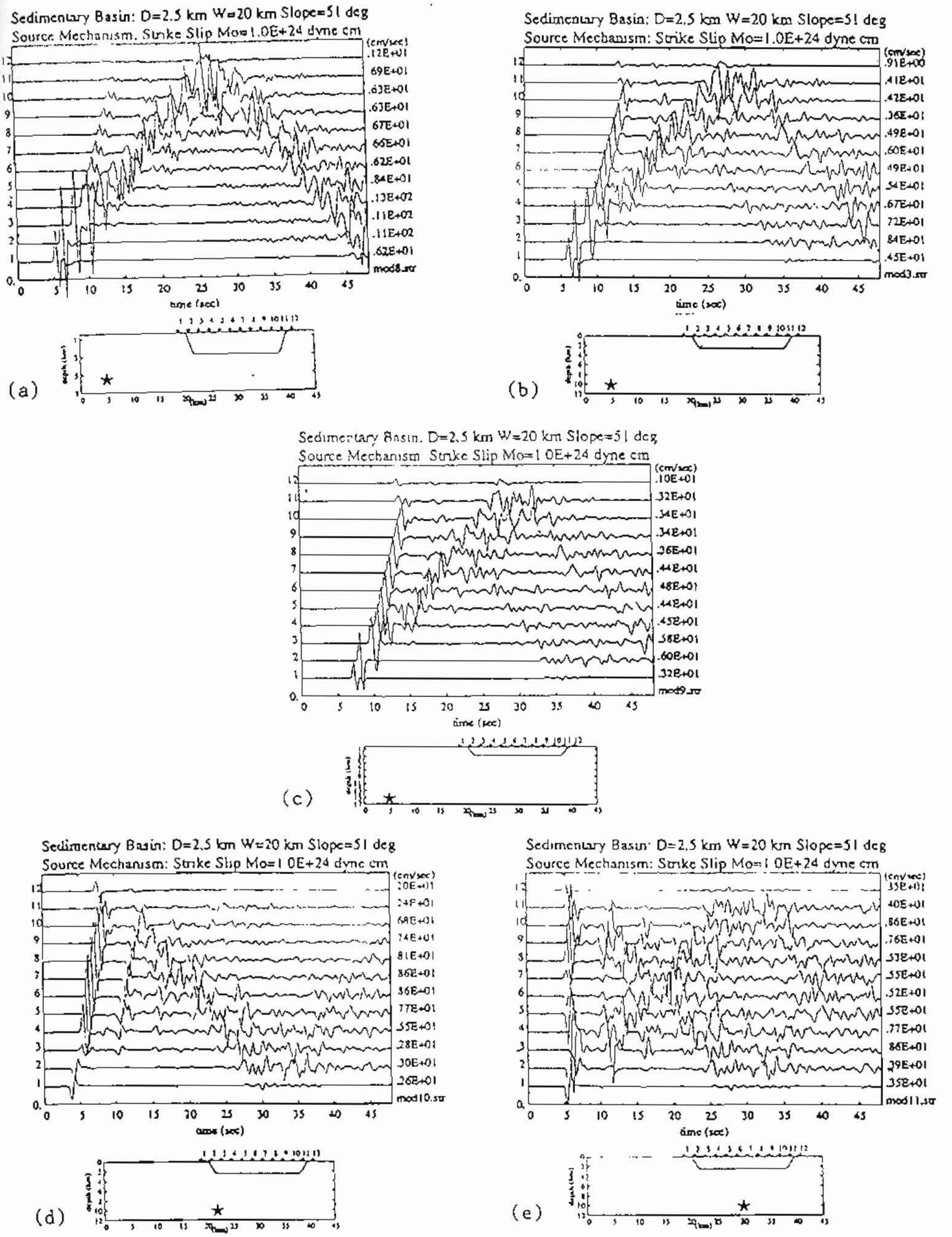


Fig.5. Computed SH seismograms. Receiver numbers are shown at the left and maximum amplitudes are shown at the right of each trace seismic source is located at a depth H=10Km beneath the edge (a) - H=5Km, (b) - H=10Km, (c) - H=15Km, (d) source benearth the right edge (e) source beneath the center of the basin.

(Fig.8). Both the observed and calculated seismograms are filtered with pass band 0.4-10.0 sec. The filtering has not changed the major features of the record.

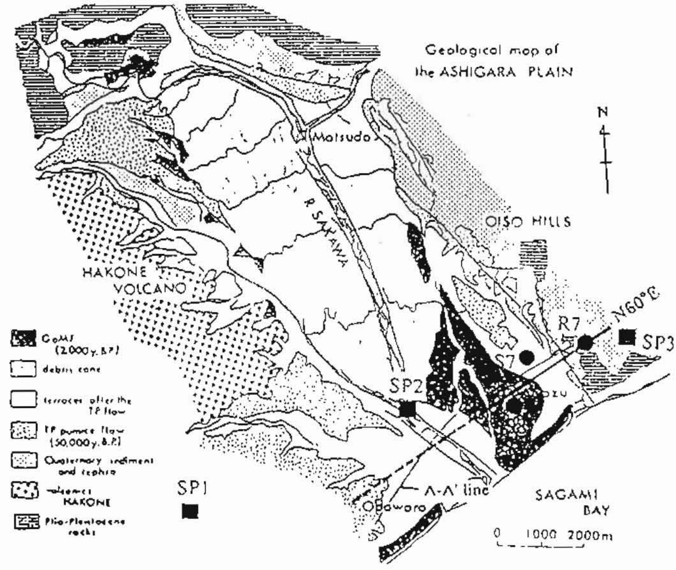


Fig.6. Geological map of the Ashigara Valley and the locations of shot points of an refraction survey (squares). The thin line denoted as A-A' represents the cross section used in the present study.

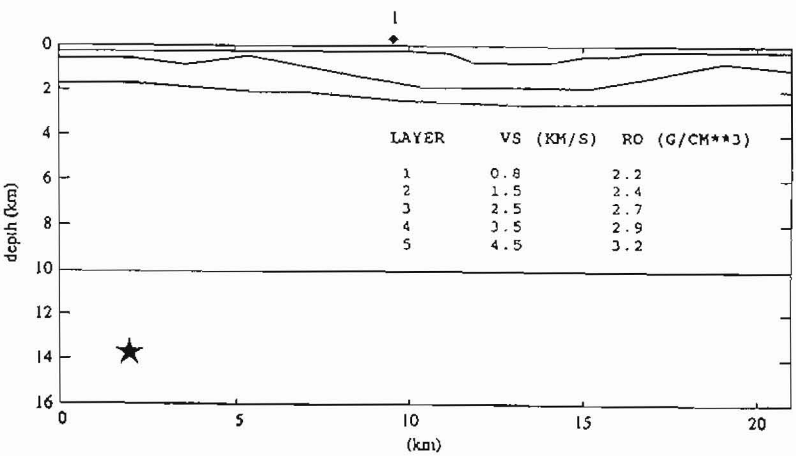


Fig.7. Comparison of the observed (solid line) and synthetic siesmogram (dashed line).

As it can be seen in Fig.8, the maximum amplitudes are the same. We obtain a rather good agreement between the early portion of synthetic seismogram with the low pass filtered observed one. This part of the seismogram includes the direct wave and multiple reflections at the shallowest interface. The later phases are not well reproduced by the calculations. This is probably due to the simple shape of the deeper layers adopted in the model, which as it is pointed out in the above numerical simulations, affects the observed later phases. The good agreement between the long period recorded and synthetic seismogram, in the case of Ashigara site, shows that the moderate shallow earthquake of August 5, 1990 can be modelled by a single point dislocation source.

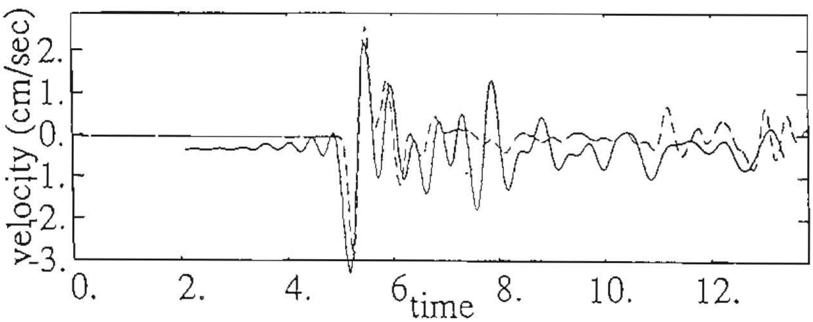


Fig.8. Comparison of the observed (solid line) and synthetic seismogram (dashed line).

In the future, detailed numerical simulation should be carried out in Ashigara Valley in order to understand the velocity amplitude variation observed on soft soil conditions depending on soil heterogeneities and focal mechanism for near earthquakes.

CONCLUSIONS

1- Sedimentary basin and source location strongly affect SH wave propagation. Relative location of seismic source to the slopes of the basin is the most important factor for the excitation of secondary surface waves.
2- Constructive interferences of primary SH waves and their reflections at the basement produce the maximum amplitude at the edges of the basin
3- By applying the computation method presented in this study for simulating the recorded seismogram at the rock site of Ashigara Valley we obtain a good agreement between the early portion of long period synthetic seismogram with the observed one.

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