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Determination of the Hypocentral Parameters Outside The Seismic Array Using a Single Station of Three-Component

지진관측망 밖의 진원결정과 3-성분 단일 지진관측에 관해서

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요약/Abstract

HYPO71PC 프로그램을 이용하여 지진 관측망안에서 일어난 지진의 진원인자 결정은 잘알려져 있다. 그러나 이 지진 관측망이 일정하게 진원주위로 분포 되지 않거나 지진 관측망 밖의 진원 결정은 이 프로그램의 사용시에 문제가 있다. 더우기 남, 북한 지진 자료 교환이 없기 때문에 북한의 소규모 지진을 결정하는 것은 매우 어렵다.

우리는 지진 관측망 밖의 천발지진을 결정하기 위하여 3 성분의 단일 지진관측시 편광 방법을 사용한다. 우선 1991. 4. 14. 의성 지진, 1994. 2. 12. 계룡산 지진 등 지진관측망의 내부지진과 1992. 11. 12. 서평양지진, 1994. 7. 26. 황해 지진등 외부지진을 예로 사용하였다. 지진 관측망 안의 진원은 곧 수렴하는데 관측망 밖의 지진은 수렴이 되지 않았다. 따라서 관측망 밖의 진원을 3 성분의 단일 지진관측을 이용한 Polarization 방법으로 쉽게 진원의 방위각을 결정하고 위상 차이에 의한 진앙거리를 결정할 수 있었다. Polarization 방법을 모델링에 의해서 만들어진 이론지진 기록지의 방위각과 입사각을 결정함으로 이방법의 유용성을 증명하였다.

It is well known that the hypocentral parameters inside the seismic array are well determined using HYPO71PC Programs. These programs, however, do not work well for the non-evenly distribution of the seismic stations and/or the seismic events outside the seismic array. Furthermore it is very difficult to determine the exact locations of small events in North Korea since there is no seismological data exchange between South and North Koreas.

We used the polarization method of the single-station with 3-component in addition to HYPO71PC(IASPEI's Program) in order to determine the source parameters of shallow-focus earthquakes outside the seismic array. First of all, we tested the interior events of the Uisung earthquake, April 14, 1991 and the Mt. Keyryong earthquakes, February 12, 1994, and two exterior events of W. Pyoungyang earthquake, November 12, 1992, and Yellow Sea earthquake, July 26, 1994 to investigate the convergence and divergence to calculate the source parameters. We have found that the source determination outside the seismic array never converges to the exact location whereas the any events inside the array quickly converge to the exact location. The seismic events outside the array such as two events Vladivostok and East Sea, and the Yellow Sea event are more accurately determined using the polarization method. Estimating the source azimuth is carried out by estimating the polarization direction of the interesting phases and the range estimate is made from the relative timing of different phases. The polarization method is verified by finding that the estimates of azimuths and incidence angles by the polarization method are identical with those of the synthetic seismograms of the modellings using the generator program.

INTRODUCTION

Most of the seismic events within seismic array are well determined using HYPO71PC which is the hypocenter determination program released by IASPEI(International Association of Seismological and Physics of the Earth's Interior, 1989). The small seismic sources, however, outside the seismic array in the Korean Peninsula must be difficult to determine hypocentral parameters with high accuracy. For the sake of comparison between the interior and exterior events of the seismic array, we took W. Pyongyang earthquake of November 12, 1992, Yellow Sea earthquake July 26, 1994 Vladivostok and East Sea earthquakes July 22, 1994 for the exterior events, and Uisung earthquake of April 14, 1991 and Mt. Keyryong earthquake of February 12, 1994 for the interior events. The exterior earthquakes outside the Korean seismic array are determined by USGS using many world-wide seismic network. Uisung earthquake and Mt. Keyryong earthquake are inside the seismic array. The official array of Korea Meteological Administration that runs 12 seismic stations covers all over the Korea. The another important array is a microseismic array of the Seismological Institute of Hanyang University that consists of six seismic stations and located in the central part of Korean Peninsula(See Fig. 1).

A polarization method using the single station with three components is a kind of powerful schemes to estimate hypocentral parameters of the seismic events. Magotra et al.(1987) used this technique to monitor a low-yield or comprehensive nuclear test ban. Jurkevics(1988) computed the polarization ellipse within sliding time windows by solving the eigen problem for the covariance matrix. The significant results of the data analysis are the well-defined polarization of Pn and Sn waves cross entire short-period band. The source azimuth estimates are obtained from Pn and Lg motion, and the range estimates are then obtained from the relative timing of different phases.

THEORETICAL BACKGROUND

A more quantitative approach involves processing the signal and extracting or enhancing their polarization content(Vidale, 1986; Menke et. al., 1990; Menke and Lerner-Lam, 1991). There are two basic procedures which can be used for analyzing three-component data. The first involves applying some type of non-linear filter to the data bound on their polarization content and outputing modified seismogram. The record involves estimating parameters of some a priori model filtered to the data in a time-variging manner (Magotra et. al., 1987; Jurkevics, 1988; Roberts and Christofferson, 1990; Sutean-Hensen,1991). The polarization within a time window, let $X[\ xij]\ ; i=1,2,3,\cdots,N,$ $j=1,2,3$ be the data matrix in one window, where X_{ij} is the ith sample of component j and N is the number of samples. The covariance S is represented as follows;

$$S_{xy} = cov(x,y) = \frac{1}{n-1}\sum_{i=1}^{n}(x_1 - \bar{x})(y_i - \bar{y})$$

$$= E[\ xy\ ]\ - E[\ x\ ]\ E[\ y\ ] \quad (1)$$

Where x_i, y_i and $\bar{x}$, $\bar{y}$ denote the observed values and mean values of x and y, respectively. E is expectation.

The covariance matrix is 3×3 real and asymmetric. The symmetrical function of observation is normally correlated. the terms of S are the auto- and cross-variance of the three components of motion(Jurkevics, 1988).

$$S = \begin{bmatrix} S_{zz} & S_{zn} & S_{ze} \\ S_{nz} & S_{nn} & S_{ne} \\ S_{ez} & S_{en} & S_{ee} \end{bmatrix} \qquad (2)$$

Where subscripts z, n and e indicate the vertical(up-down), northsouth(radial), and east-west(transverse) components, respectively. S is the matrix of coefficient for a quadritic focus which is an ellipsoid. The principal axes of the ellipsoid are found by solving the eigen problem for S. This involves finding the eigen values $(\lambda_1 \lambda_2 \lambda_3)$ and eigenvectors $(\overline{u_1}\ \ \overline{u_2}\ \ \overline{u_3})$ which are nontrivial solution to

$$(\overline{S} - \lambda^2 \overline{I})\,\overline{u} = 0 \qquad (3)$$

Where I is the 3×3 identity matrix and 0 is a column vector of zeros. The eigen values and corresponding eigen vectors are determined solving the characteristic determinant.

$$\det\ (\overline{S} - \lambda^2 \overline{I}) = 0$$

The eigen vectors are chosen to be orthogonal and unit length. The three principal axes of the polarization ellipsoid are given by λ_j, u_j, j = 1, ... ,3, where the eigen vectors are the axis orientation and their length are λ_j in amplitude units. The eigen values are ordered such that $\lambda_j \geq \lambda_k$ for $j<k$. Purely rectilinear ground motion has only one nonzero eigenvalue; $\lambda_j = 0$, $j \neq 1$ Purely elliptical polarization has two nonzero eigenvalues, $\lambda_1 \geq \lambda_2$, $\lambda_3 = 0$. Information describing the characteristics of ground motion is extracted using attributes computed from the principal axes. The degree of rectilinearity is given by $1-(\lambda_2+\lambda_3)/2\lambda_1$ which is 1 when there is only one nonzero eigenvalue as for pure body waves. Pure Rayleigh- and/or S-wave motions are elliptical and the particle motion is confined to a plane. A measure of the degree of planarity is $1-2\lambda_3/(\lambda_1+\lambda_2)$. The azimuth of P-wave propagation can be estimated from the horizontal orientation of the rectilinear motion.

$$P_{AZ} = \arctan\left(u_{21}\,sign(u_{11}) / u_{31}sign(u_{11})\right) \quad (4)$$

where $\overline{u_{j1}}$, $j = 1, 2, 3$ are the three direction cosines of eigenvector $\overline{u_1}$. The apparent incidence angle of rectilinear motion as measured from vertical may be obtained:

$$P_{INC} = \arccos|u_{11}| \quad (5)$$

The range estimation is performed via the phase detection of interesting phases. The seismic signal propagating from the source of the event has several distinct phases associated with it which propagates at varying velocities, Pn, Pg, Sn, Sg and Lg/Rg are the most prominent and constant arrivals on the short-period records. Using these phases and Omori formula, it is very possible to estimate the epicentral distance from the source to the station. From the local data, some seismic phases related to crustal conversion are observed using the polarization that requires strong lateral variations(Bataille and Chiu, 1991).

DATA ANALYSIS AND INTERPRETATION

In order to prove the availability of HYPO71PC, we have tested four Korean seismic events, which are Uisung earthquake of April 14, 1991, West Pyongyang earthquake of November 12, 1992, Mt. Keyryong earthquake of February 12, 1994 and Yellow Sea earhquake of July 26, 1994. W. Pyongyang and Yellow Sea earthquakes are outside the Korean seismic array, but their epicenters are determined by USGS using WWSSN (World-Wide Standardized Seismic Network).

Uisung and Mt. Keyryong earthquakes are inside the Korean seismic array.(See Fig. 1 and Table 1.). We tried to test convergence and divergence using HYPO71PC with initial conditions, epicenters and focal depths. As you see on Figs. 2 and 4, the parameters of the seismic events within the seismic array are well determined and converge to one point, whereas those of the seismic events outside the seismic array like W. Pyongyang and Yellow Sea earthquakes are not well determined (See Figs. 3 and 5) using the Korean seismic array unless South and North Koreas have agreement of data

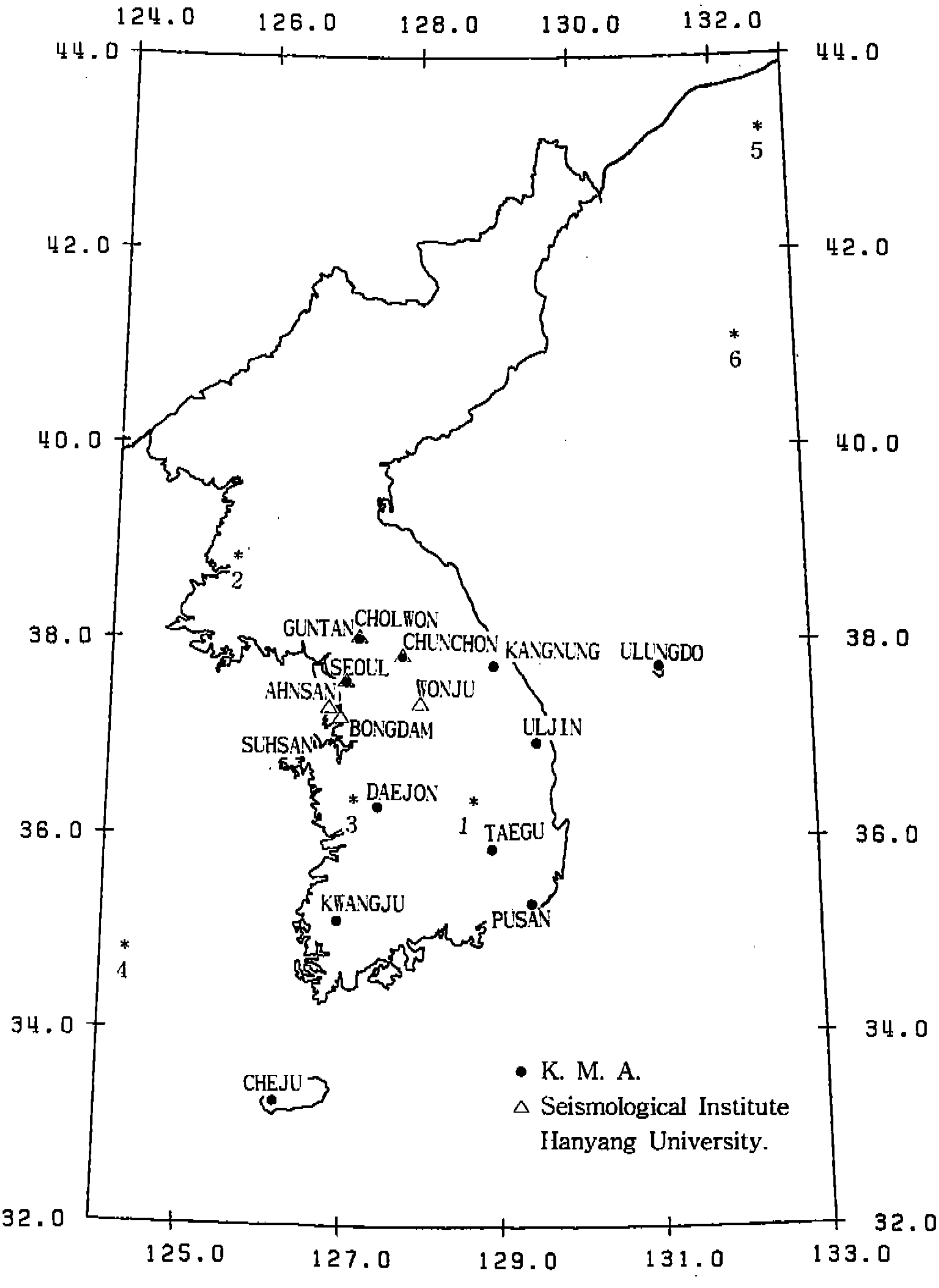

Fig. 1 The location of seismic stations and seismic events for the present studies.

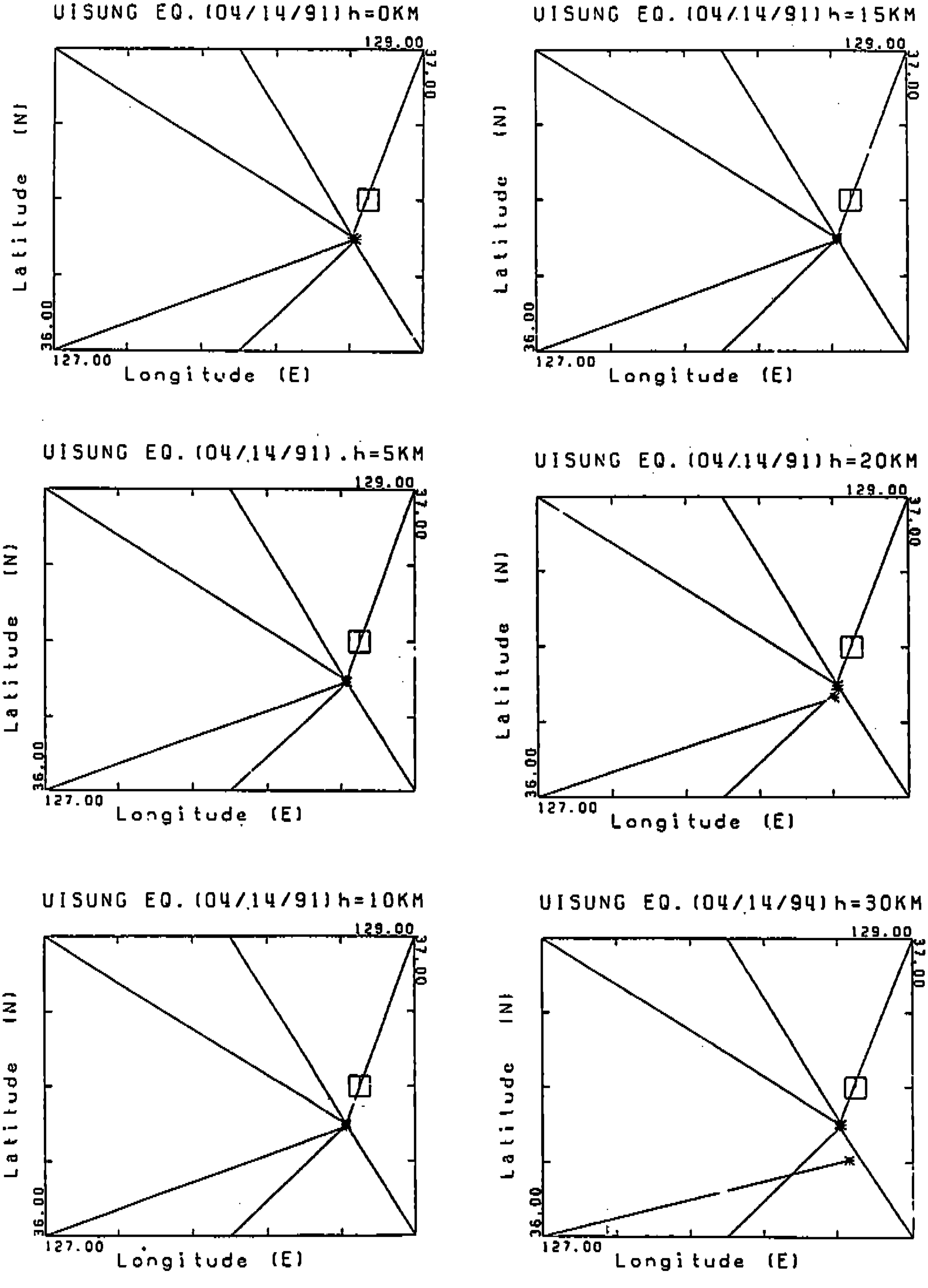

Fig. 2 The convergence of the seismic source determination for the Uisung Earthquake.

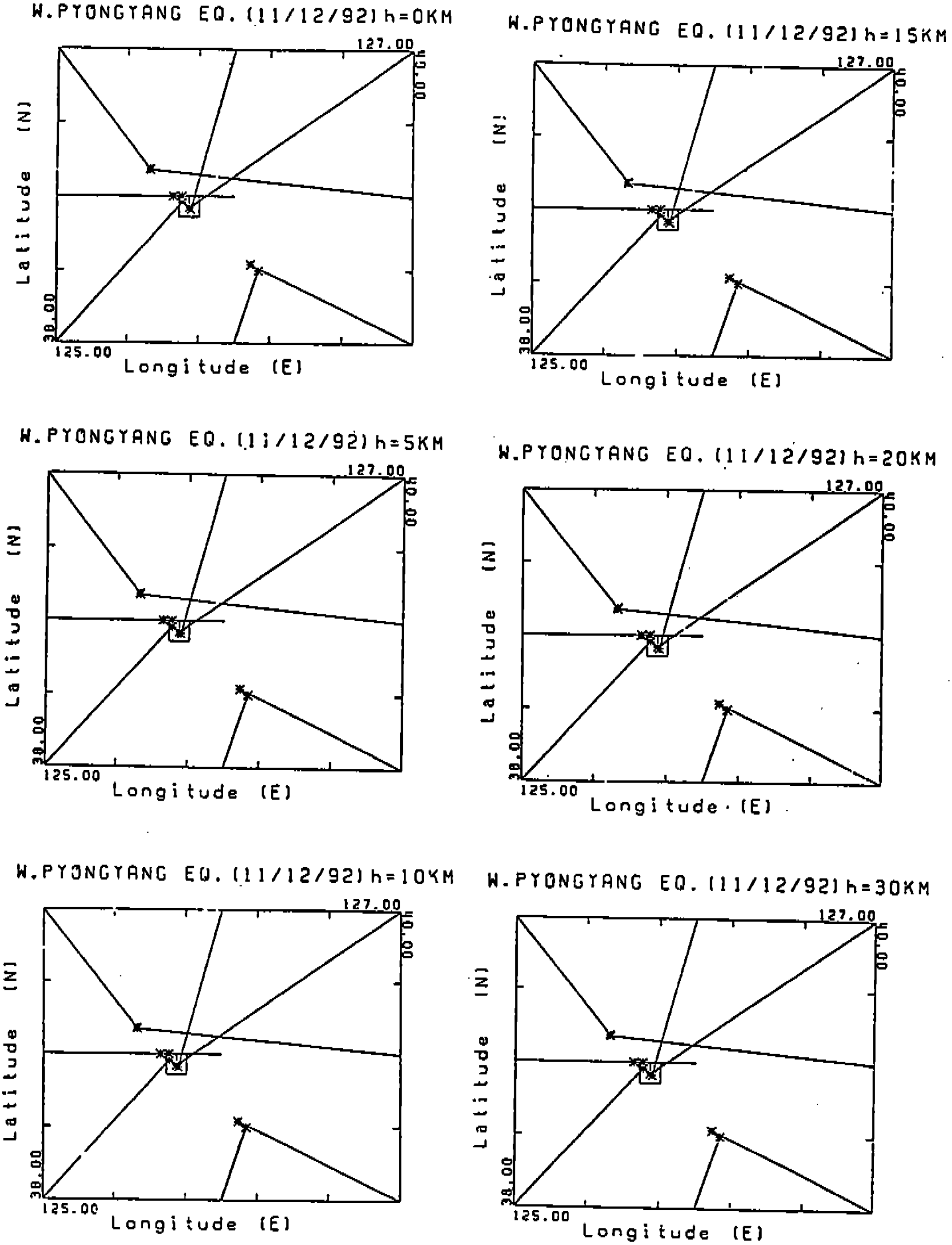

Fig. 3 The divergence of the seismic source determination for the W. Pyongyang Earthquake.

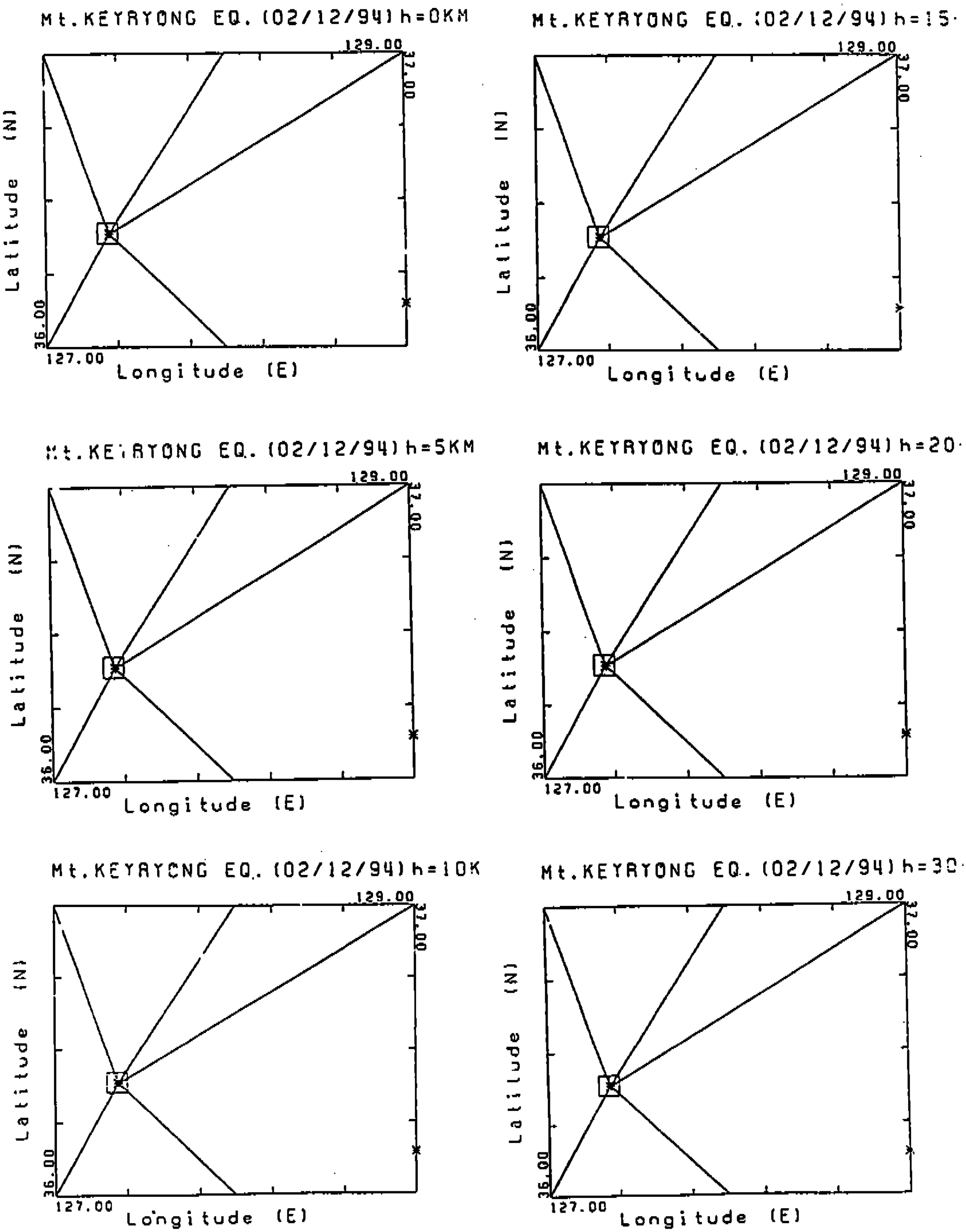

Fig. 4 The convergence of the seismic source determination for the Mt. Keyryong Earthquake.

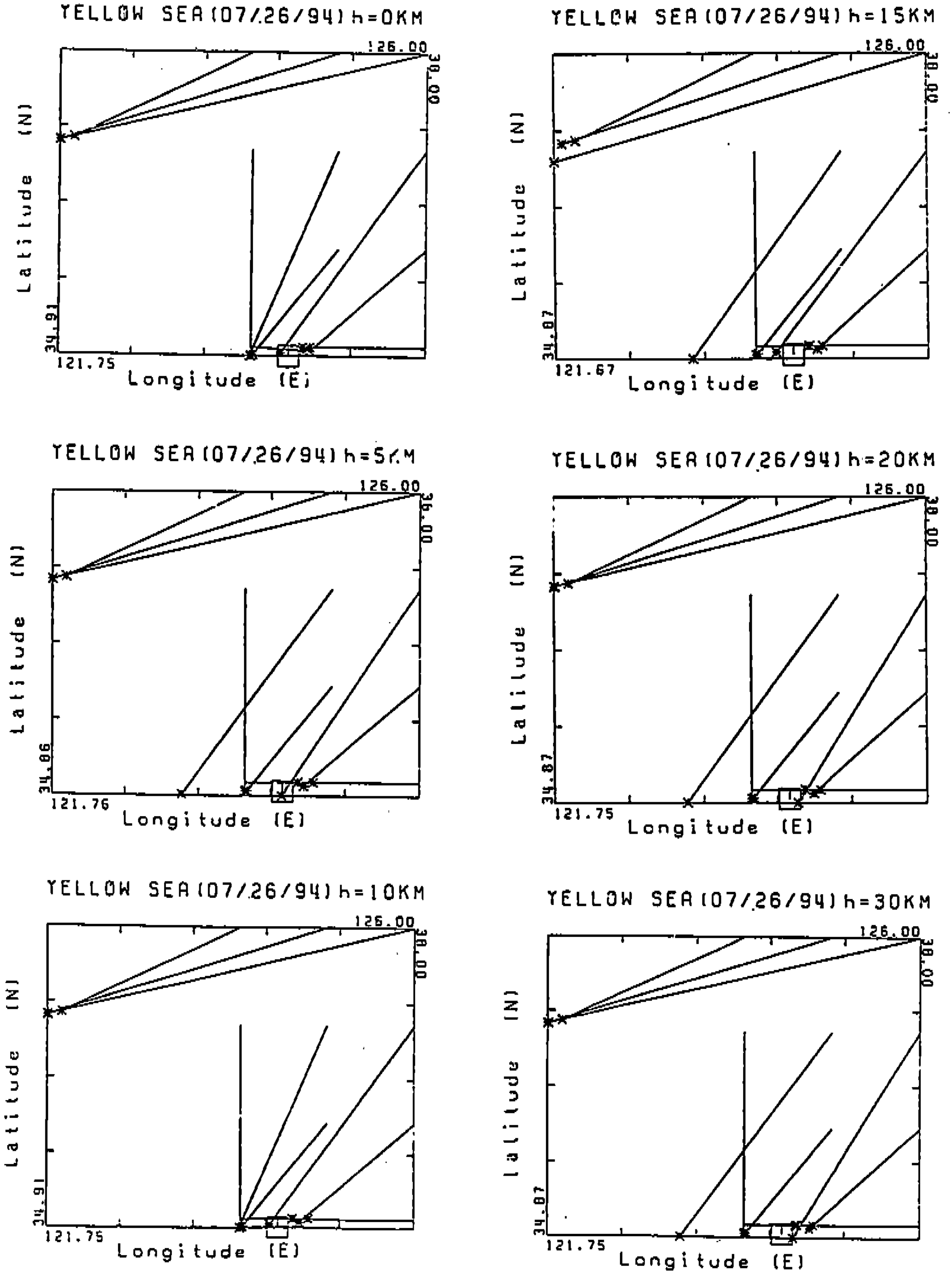

Fig. 5 The divergece of the seismic source determination for the Yellow Sea Earthquake.

Table 1. Hypocenter parameters of seismic events in this study.

No.	Events	Hypocenter			Origin Time		M	h(Km)
		Lat.(N)	Long.(E)		M/D/Y	H-M-S		
1	Uisung EQ.	36.5	128.7	**	04/14/91	01-48-32.5	3.1	
2	W. Pyongyang EQ.	38.93	125.75	*	11/12/92	08-02-26.8	3.8	10
3	Mt. Keyryong EQ.	36.4	127.3	**	02/12/94	11-58-14.3	3.5	10
4	Yellow Sea EQ.	34.91	124.43	*	07/26/94	02-41-50.41	4.9	10
5	Vladivostok EQ.	42.30	132.89	*	07/22/94	03-36-31.71	6.4	473.0
6	N. East Sea EQ.	41.18	132.35	*	07/22/94	03-55-58.73	5.7	515.1

* USGS(United States Geological Survey), NEIC(National Earthquake Information Center), Boulder, Co. U.S.A.

** KMA(Korea Meteorological Administration)

exchange in the near future. Furthermore some local small size of events($M \leq 4.0$) can be hardly detected by WWSSN operation. In order to resolve this problem, we prefer to use the polarization method for the single station of three-components.

Recent studies of large deep-focus earthquakes proved that there are some multiple events with a main event(Kikuchi and Kanamori,1994). We can also read same multiple events(arrows) after the first arrival of the event 1 at 3h 38m 13.4s and the first arrival of the event 2 at 3h 57m 32.3s in Fig. 6a and Fig. 6b. This indicates that these are strong superposition of P-wave particle motions in the vertical(CH1) and radial components(CH2) in Figs. 6a and 6b. We cannot see any new phase change due to the interface within these short intervals of the deep events 1 and 2. We can see the waveforms as well as the first motions of the vertical component(CH1) are the same as the radial component(CH2). We can see only the superposed P-wave particle motion for there two events within these sliding time windows. In Fig. 6a and Fig. 6b, we can find that the polarization method to determine azimuths of the earthquake epicenters is not fit for the deep-focus earthquakes since two horizontal components(radial and transverse) can not constitute a vector sum. Therefore the polarization method for these two deep-focus large events are only valid on the condition that time window should be very short(less than 0.8 second).

As shown on Figs. 6a, 6b, and 6c, we can see azimuth(station to epicenter) vs time and azimuth vs incident angle for Vladivostok, the N. East Sea and the Yellow Sea earthquakes at Guntan station. The azimuth estimates of Vladivostok and the N. East Sea earthquakes are not reliable since one of the horizontal component(radial) is coincident with the vertical component due to the deep-focus earthquake of the regional seismics. At Guntan station, estimated the azimuth as 342.50° and 348.28° for Vladivostok and N. East Sea events, whereas the estimates of azimuth for the Yellow Sea event are 243.15° at Guntan station and 257.41° at Daejon station. Especially, the waveforms of Fig. 6d which are clipped after 55 seconds at Daejon station have no physical meaning after 55 seconds. We can also find correlation between incidence angles and azimuths for shallow-focus and deepfocus earthquakes for Yellow Sea and Vladivostok and N. East Sea earthquakes. The phase identifications are performed using polarization attributes as predictions. Therefore the location of the epicenter can be easily determined by using the azimuth of source and S-P method. We could not use the polarization method to determine the locations of Vladivostok and East Sea earthquakes because we did not obtain the larger time window of the threechannel recorder at that time. The focal mechanism of the Vladivostok earthquake was estimated as the down-dip compression reverse fault with 5.52×10^{26} dyne·cm in moment by Irie et al.(1994). We could, however, determine the epicenter of the Yellow Sea earthquake using the three-channel recorder at Guntan and Daejon stations. Furthermore the azimuth and apparent incidence angle of the Yellow Sea earthquake at Daejon(see Fig. 6d) are well determined for body waves, whereas those for surface waves are sporadic due to the clipped waveforms. We estimated the location of the Yellow Sea earthquake as (S_n-P_n = 46.0s, Az = 243.25°) at the Guntan station and as (S_n-P_n = 40.2s, Az = 252.38°) at Daejon station, indicating that the epicenter of the Yellow Sea earthquake is at 35.33° N, 123.5° E. The incidence angles for the two deep-focus earthquakes of Vladivostok and N. East Sea and the shallow-focus earthquake of the Yellow Sea are estimated as 33-37° and 76.40° at Daejon and 56.33° at Guntan respectively. This estimated epicenter is very close to the epicenter given by NEIC(National Earthquake Information Center), USGS in Table 1. This is also verified that the generated modelling with the given azimuth and incidence angle is identical with azimuth and the incidence angle determined by the polarization method (Chiu, 1994). Furthermore the polarization method gives not only hypocenter parameters but also the characteristics of waveforms developing on the filter frequency band. Therefore the polarization method is the most powerful technique to detect and identify the ambigoous signals such as the decoupled explosions and/or multiple explosions as well as to locate the source as long as we have enough samples per second and take short time window, picking up a new phase on the seismogram.

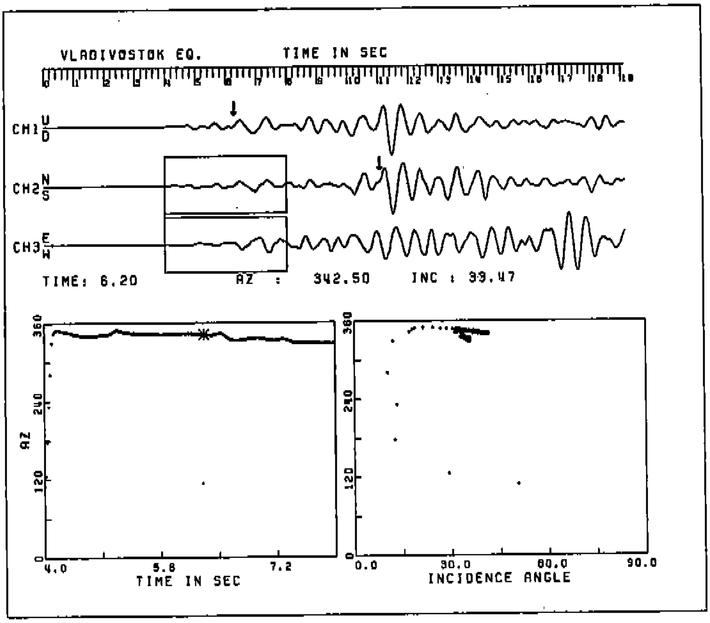

Fig. 6a Determination of azimuths and incidence angles for Vladivostok earthquake 7/22/94 using the polarization method at Guntan. Arrows indicate the arrivals of the multiple events.

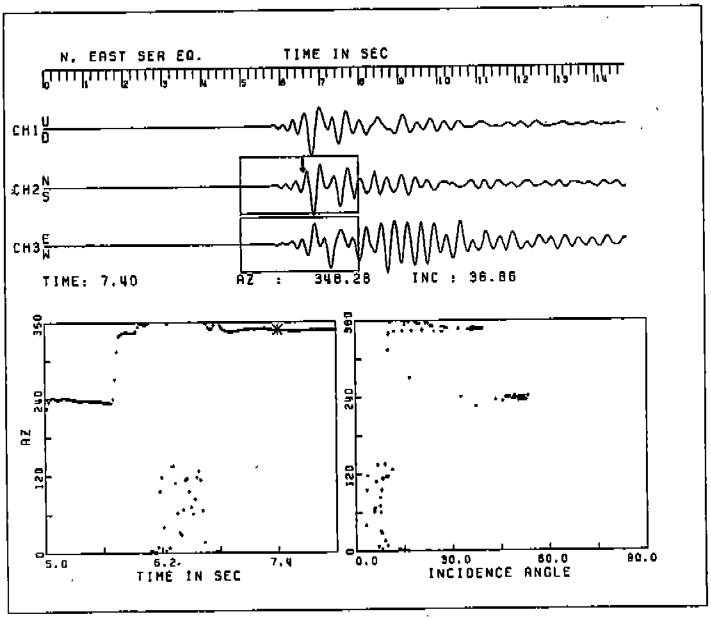

Fig. 6b Determination of azimuths and incidence angles for East Sea earthquake 7/22/94 using the polarization method at Guntan. Arrows indicate the arrivals of the multiple events.

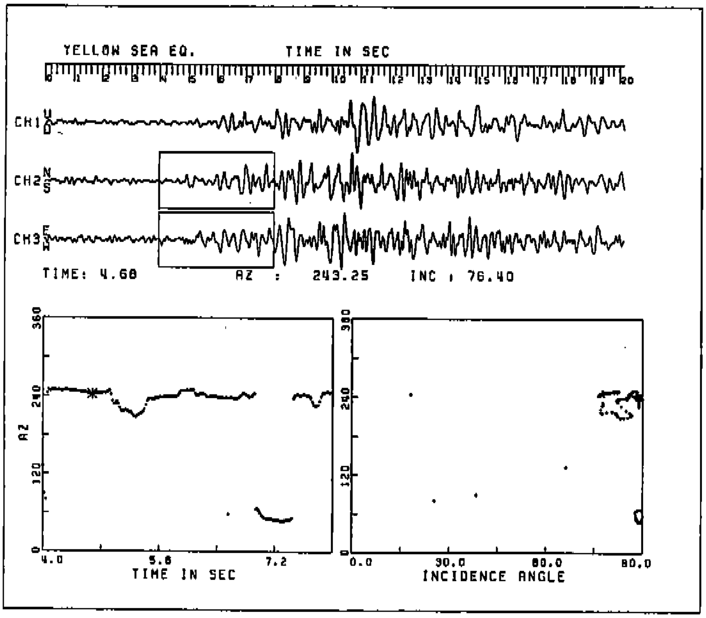

Fig. 6c Determination of azimuths and incidence angles for Yellow Sea earthquake 7/26/94 using the polarization method at Guntan

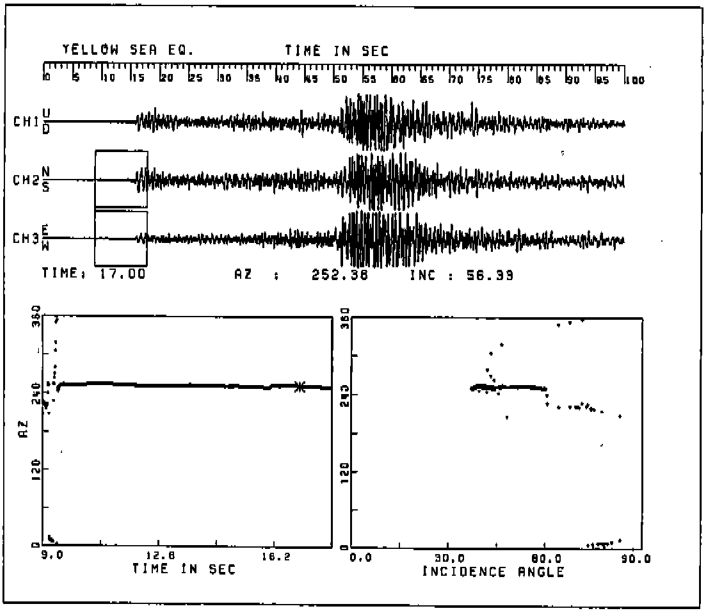

Fig. 6d Determination of azimuths and incidence angles for Yellow Sea earthquake 7/26/94 using the P-wave polarization method at Daejon

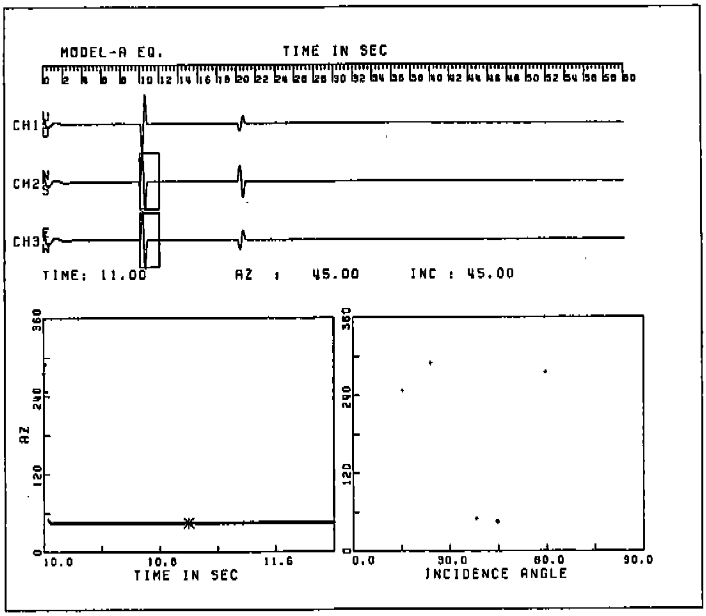

Fig. 6e The synthetic seismograms of the generator program modelling(Chiu,1994). spc(sampling/second) = 100 sec, azimuth = 45.0°, incidence angle = 45.0°, period = 0.8 sec, time window = 2 seconds.

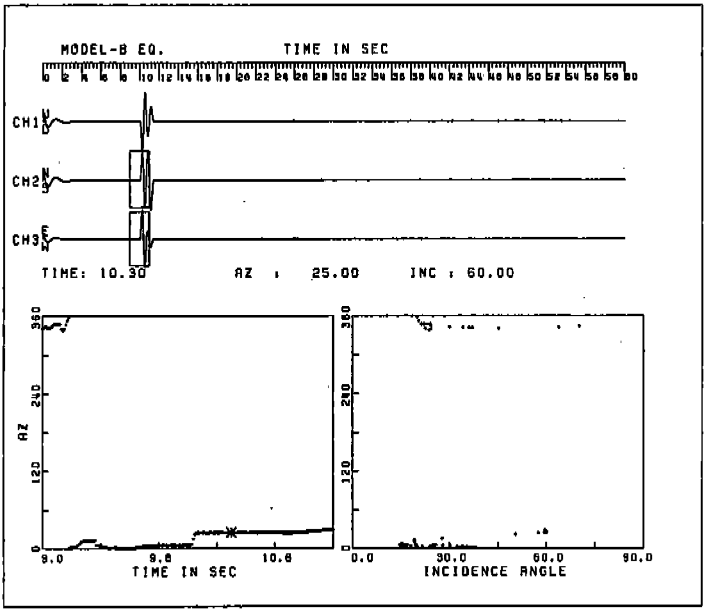

Fig. 6f The synthetic seismograms of the multiple events first event : azimuth = 25.0°, incidence angle = 60.0°, period = 0.8 sec, amp. = 0.8, sps = 100sec, time window = 2 seconds.

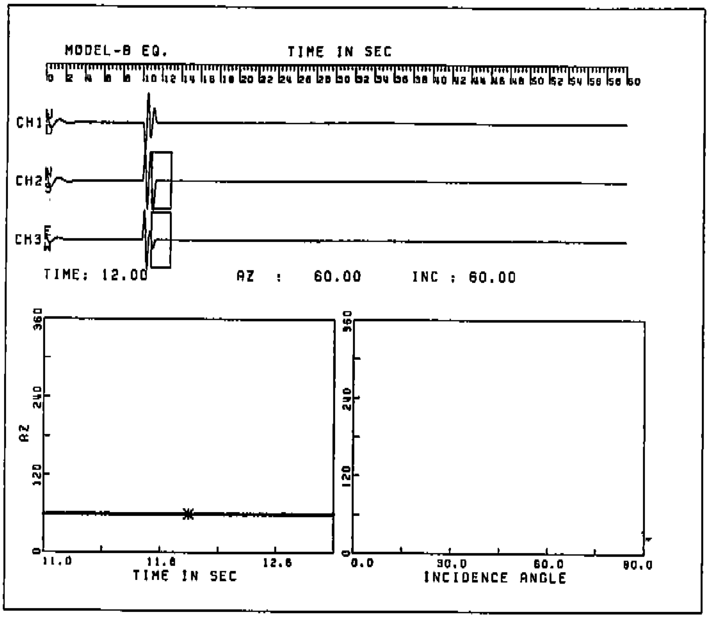

Fig.6g The synthetic seismograms of the multiple events second event : azimuth=60.0°, incidence angle =60.0°, period = 1.0 sec, amp.=0.5, sps=100sec, time win dow=2 seconds.

CONCLUSIONS

The polarization method works very well in determining the polarization of incoming waves and composing the signal into waves of desired direction of polarizations therefore we can determine the azimuth of the seismic source as well as the incidence angle of incomming waves, and can be extended to location the epicenter. In addition to identifying P and S waves for accurately locating source, the possibility of determining the polarization in small time windows is important for the study of crustal surface waves and scattering process within the code.(Bataille and Chiu, 1991). The source location and azimuth estimations can be improved by using small-aparature seismic array with at least three stations and apparent velocity passing through the seismic array. The polarization method is verified by knowing that the azimuths and incidence angles for the synthetic seismograms of the modellings using the generator program are found to be identical with those by the computation of the polarization as shown on Figs. 6e , 6f and 6g.

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