SEISMIC WAVE-PROPAGATION IN A LAYER OVER A HALF-SPACE

by

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Abstract

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Seismic wave propagation in the near field of a point source is studied theoretically. Barker (1970) formulation is extended to include the horizontally polarized shear (SH) waves for the case of a layer over a half-space. Synthetic seismograms are then calculated for P, SV and SH sources using an approximation in the Cagniard-deHoop technique. Seismograms are displayed to show the effects of the variations of source type, source depth, range and structure on the wave-forms so obtained. Near surface P or SV sources are efficient generators of Rayleigh waves. Dispersion of Love waves become more prominent as the contrast between layer and half-space parameters increase.

Thesis Supervisor: M. Nafi Toksöz

Title: Professor of Geophysics

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Chapter I

INTRODUCTION

With the advent of high-speed computers there has been an upsurge of interest in theoretical seismology. The extensive computations needed in this field seem to be less formidable now than in the past. Further, with the accumulation of large amounts of data, obtaining better and more accurate seismograms has become almost essential. Here in this thesis an attempt has been made in this direction.

Helmberger (1967) has shown how to compute seismic records in the high frequency range for long distances. He was mainly interested in the refractions of P and SV waves from the oceanic Mohorovicic discontinuity, well known as head waves. Harkrider (1964) also calculates theoretical seismograms for long ranges. Filson (1970), utilizing the technique developed by Pekeris et. al. (1963) computes long period SH_n records for long ranges.

Here in this thesis, an attempt has been made to compute synthetic seismograms for a simple case of a layer over a half-space. We consider a point source responsible for generating P, SV or SH wave types to be embedded in the layer. Barker (1970) has solved this problem using Helmberger's (1967) approach for the case of P and SV sources. The author here incorporates an SH source into this problem and then computes seismograms for different models which could be synthesized by the use of the above sources. The Cagniard-deHoop method has been utilized to put the solution into operational form.

In order to compare synthetic seismograms with the observed ones we require a double convolution process with the response of the model. The source-function, a function describing the behavior of the source, is first convolved with the response of the model which in turn is again convolved with the instrument response to give us the synthetic seismograms. However, in this thesis we have only convolved the impulse response of the model with a source time function, a triangle of base 0.4 and area unity. This would allow us to see the effects of source type, source depth, range and structure on the wave forms thus obtained which is the main aim of this study.

The technique exposed in Barker (1970) and here requires less computer time and the results obtained are accurate for both high and low frequency ranges. Near field P, SV and SH wave seismograms computed in this thesis show the accuracy of our results. It should be remarked, however, that in order to obtain a more exact seismogram at a distance of about 50 or 100 km for P, SV case a greater number of rays have to be incorporated, which increases the computation time considerably. As a further test, comparisons have been made with the results of Pekeris et. al. (1963,65) for P, SV and SH sources.

Chapter II deals with the statement and the formulation of the problem. Here we solve the inhomogeneous wave equation by the Laplace Transform technique, which is simple and straightforward. Chapter III deals with the computation of seismograms. Finally in Chapter IV we outline the conclusions reached by undertaking this study.

Chapter II

THEORETICAL FORMULATION OF THE PROBLEM

Let us consider a homogeneous, linearly isotropic, elastic half-space overlain by a homogeneous, linearly isotropic elastic layer. Further, let there be a point source of P, SV and SH waves in the layer. The geometry of the assumed model is shown in Figure 1. We would like to formulate the problem in circular cylindrical coordinates (r,θ,z). The angle θ would not appear in the final form of the expression for the displacement because of the axial symmetry of the source. Let λ and μ define Lamé's constants, ρ be density, α and β denote compressional and shear (SV and SH both) wave velocities.

The response at the observation point A can be calculated by solving the inhomogeneous wave equation, e.g., for SH waves

$$\mu_1 \nabla^2 u_\theta(r,z,t) - \rho \frac{\partial^2}{\partial t^2} u_\theta(r,z,t) = -\frac{H(t)\,\delta(r)\,\delta(z-h)}{2\pi r} \qquad (1)$$

where $u_\theta(r,z,t)$ denotes the component of the displacement in the θ direction. $H(t)$ is the Heaviside unit step-function defined as

$$H(t) = \begin{cases} 0 & t < 0 \\ 1 & t > 0 \end{cases}$$

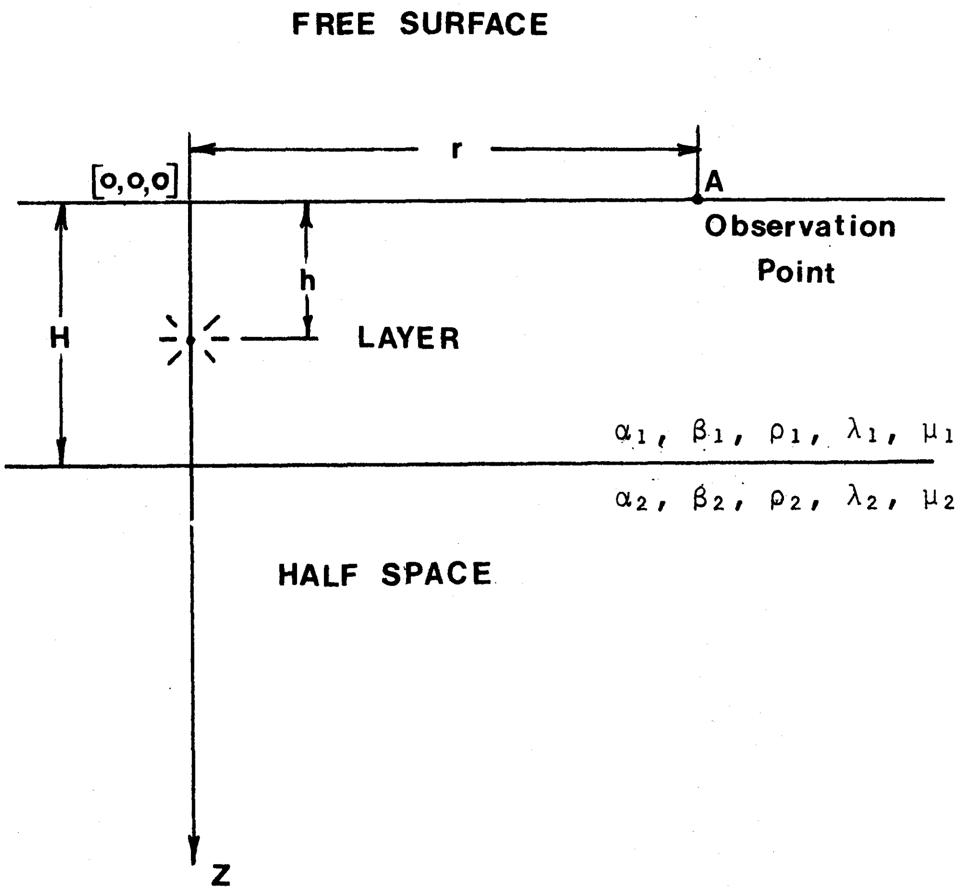

FREE SURFACE
r
[o,o,o]
A
Observation Point
H
h
LAYER
$\alpha_1, \beta_1, \rho_1, \lambda_1, \mu_1$
$\alpha_2, \beta_2, \rho_2, \lambda_2, \mu_2$
HALF SPACE
Z

FIG. 1

and δ denotes the Dirac-delta function. The quantity on the right-hand side of Equation 1 represents the force produced by the point source of torque about the z-axis in the layer. We then exploit Laplace Transform technique to solve Equation 1, as done by Helmberger (1967). The details have been given in Appendix A.

The once-transformed in time deplacement due to the nth generalized ray can be written [Barker(1970)] as

$$\bar{u}_{z,n}(r,0,s) = s \ \mathrm{Im} \int_0^{i\infty} pF_{n,z}(p) K_0(spr) \ e^{-sg_n(p)} dp \qquad (2)$$

$$\bar{u}_{r,n}(r,0,s) = s \ \mathrm{Im} \int_0^{i\infty} pF_{n,r}(p) K_1(spr) \ e^{-sg_n(p)} dp \qquad (3)$$

and

$$\bar{u}_{\theta,n}(r,0,s) = s \ \mathrm{Im} \int_0^{i\infty} pF_n(p) K_0(spr) \ e^{-sj_n(p)} dp \qquad (4)$$

where a bar has been placed over the quantity whose Laplace transform has been taken. In the above equations, s denotes the transform variable in complex frequency, p is the complex integration variable, and the Im symbol means that only the imaginary part of the complex function is considered. Further, $K_0(spr)$ and $K_1(spr)$ are the modified Bessel functions of zero and first order respectively. The notation $u_{z,n}(r,z,t)$ and

$u_{r,n}(r,z,t)$ represent the vertical and the radial components of displacement for P or SV source and similarly $u_{\theta,n}(r,z,t)$ is the component of the displacement in the θ direction for an SH source. However, in Equations 2, 3 and 4 these displacements have been Laplace transformed in time. The functions $F_{n,z}(p)$, $F_{n,r}(p)$ and $F_n(p)$ are

$$F_{n,z}(p) = S\ R_z(p)\zeta_n(p)$$

$$F_{n,r}(p) = S\ R_r(p)\zeta_n(p)$$

and

$$F_n(p) = S\ R\ \zeta_n'(p)$$

where

$$\begin{cases} S = 1/2\pi^2\eta_1(\lambda_1+2\mu_1) & \text{for P source} \\ S = 1/2\pi^2\eta_2\mu_1 & \text{for SV \& SH source} \end{cases}$$

and

$$\eta_1 = (\frac{1}{\alpha_1^2}-p^2)^{1/2} \qquad \eta_2 = (\frac{1}{\beta_1^2}-p^2)^{1/2}$$

where α_1 and β_1 are the compressional and shear (SV and SH) wave velocities in the layer. The functions $R_z(p)$, $R_r(p)$ and R are the responses due to the presence of the free surface for an upgoing P or SV and SH wave. $\zeta_n(p)$ and $\zeta_n'(p)$ are the reflection coefficient for the nth generalized ray for P or SV and SH sources. These functions have been written out explicitly in the Appendix B. Finally, the function $g_n(p)$ and $j_n(p)$ are given by

For P and SV waves:

$$g_n(p) = (1-HK_{ud}-h)[(1-K_{sp})\eta_i' + K_{sp}\eta_i] + l_s^{(n)}\eta_i' H + l_p^{(n)}\eta_i H$$

and for SH waves

$$j_n(p) = [2h-H]K_{ud}\eta_i' + [H-h]\eta_i' + l_s^{(n)}\eta_i' H$$

where

$$K_{ud} = \begin{cases} 1 & \text{if, at the source, the ray is directed upward} \\ 0 & \text{if, at the source, the ray is directed downward} \end{cases}$$

and

$$K_{sp} = \begin{cases} 1 & \text{if the source emits P waves} \\ 0 & \text{if the source emits SV waves} \end{cases}$$

$l_s^{(n)}$ denotes the number of traverses made by the nth ray as an SV or SH wave. Similarly, $l_p^{(n)}$ is the number of traverses as a P wave.

We choose to approximate $K_0(spr)$ and $K_1(spr)$ by its asymptotic expansion for large arguments and making use of the Laplace inversion formulae [See Barker (1970)] to get

$$u_{z,n}(r,0,t) = \mathrm{Im}\,\frac{\partial}{\partial t}\left\{\frac{1}{\sqrt{t}} * \left[\sqrt{\frac{p}{2r}}F_{n,z}(p)\frac{dp}{dt} - \frac{1}{8}H(t) * \left(\frac{1}{\sqrt{2pr^3}}F_{n,z}(p)\frac{dp}{dt}\right) + \frac{9}{128}t * \left(\frac{1}{\sqrt{2p^3r^5}}F_{n,z}(p)\frac{dp}{dt}\right)\right]\right\} \tag{5}$$

$$u_{r,n}(r,0,t) = \mathrm{Im}\,\frac{\partial}{\partial t}\left\{\frac{1}{\sqrt{t}} * \left[-\sqrt{\frac{p}{2r}}F_{n,r}(p)\frac{dp}{dt} - \frac{3}{8}H(t) * \left(\frac{1}{\sqrt{2pr^3}}F_{n,r}(p)\frac{dp}{dt}\right) + \frac{3}{128}t * \left(\frac{1}{\sqrt{2p^3r^5}}F_{n,r}(p)\frac{dp}{dt}\right)\right]\right\} \tag{6}$$

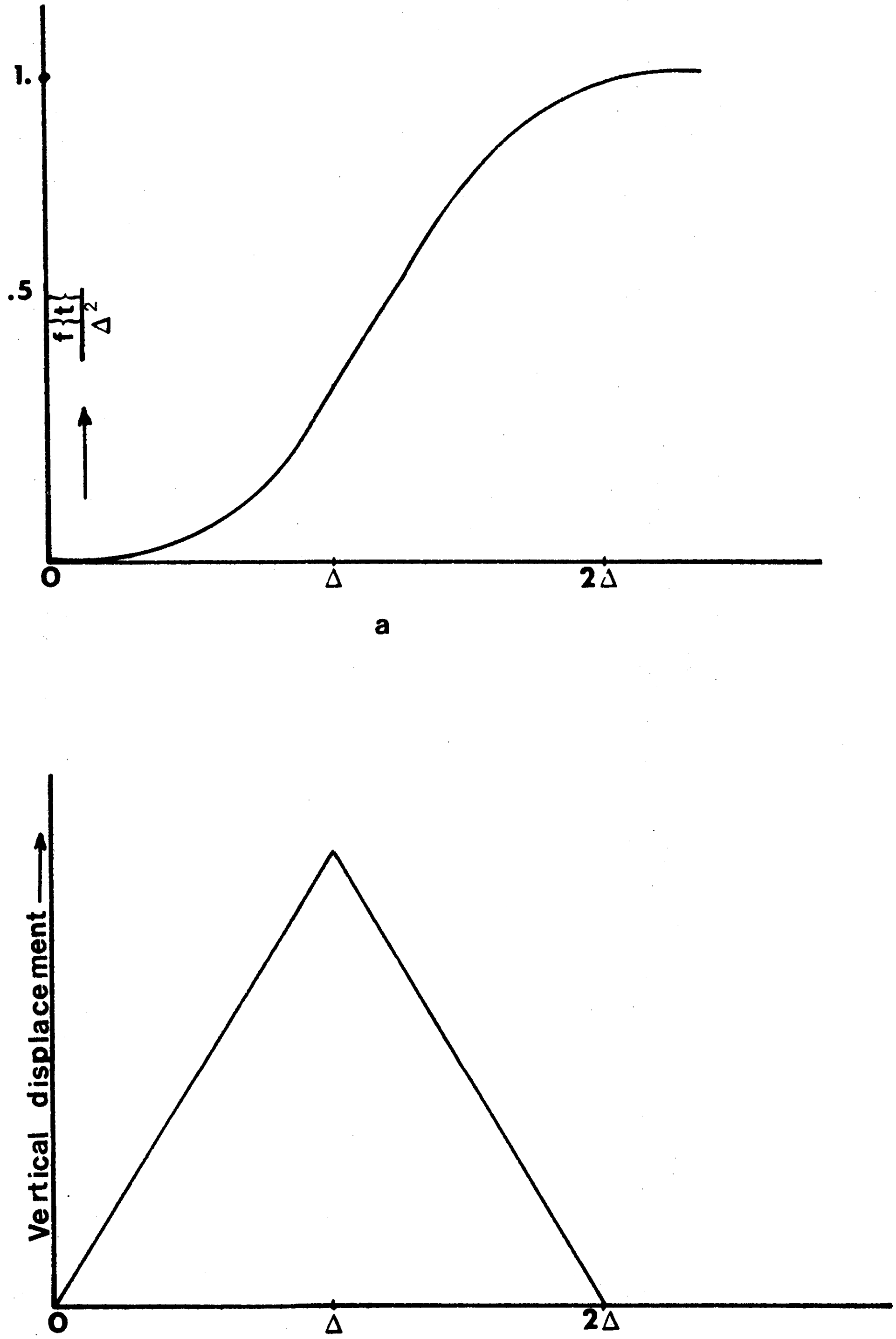
$$\bar{u}_{\theta,n}(r,0,t) = \mathrm{Im}\,\frac{\partial}{\partial t}\left\{\frac{1}{\sqrt{t}} * \left[\sqrt{\frac{p}{2r}}F_n(p)\frac{dp}{dt} - \frac{1}{8}H(t) * \left(\frac{1}{\sqrt{2pr^3}}F_n(p)\frac{dp}{dt}\right) + \frac{9}{128}t * \left(\frac{1}{\sqrt{2p^3r^5}}F_n(p)\frac{dp}{dt}\right)\right]\right\} \tag{7}$$

where * denotes convolution. We have done calculations based on Equations 5, 6 and 7. We use only the first two terms in the modified Bessel function which holds good for large arguments, i.e. for long ranges. It seems that for long ranges we get most of the contribution in Bessel function's asymptotic expansion from the first term as it should be. A computer program for evaluating Equations 5, 6 and 7 has been given in Appendix C with a detailed listing. However, we would like to add that the computations for all cases discussed in this thesis, we have taken 64 generalized rays. Pekeris et al. (1963,65) have used almost as much as 5 times the number of rays we have used.

In order to get synthetic seismograms the impulse response obtained from evaluating Equations 5, 6 and 7 is convolved with a suitable source-time-function. (Figure 2a).

The step-function with rounded shoulders defined by Figure 2a is mathematically equivalent to (where Δ is the digitization interval)

$$\begin{aligned} f(t) &= 0 && t < 0 \\ &= \frac{1}{2}t^2 && 0 < t < \Delta \end{aligned} \tag{8}$$



a

b

FIG. 2

$$\begin{aligned} f(t) &= \tfrac{1}{2}t^2 - (t-\Delta)^2 & \Delta < t < 2\Delta \\ &= \tfrac{1}{2}t^2 - (t-\Delta)^2 + \tfrac{1}{2}(t-2\Delta)^2 = \Delta^2 & 2\Delta < t \end{aligned} \qquad (8)$$

At long distances Equation 8 produces saw-tooth-like displacements, as shown in Figure 2b. The impulse response obtained by evaluating Equations 5, 6 and 7 was convolved with a triangle of base·4, and an area of unity. This is true of all the plots shown in this thesis.

We should be careful in using equations 5, 6 and 7 because they hold good for sufficiently long ranges and large times, otherwise we cannot justify the use of asymptotic expansion for the modified Bessel functions $K_o(spr)$ and $K_1(spr)$.

Chapter III

COMPUTATION OF SEISMOGRAMS

Synthetic seismograms for a layer over a half-space have been computed in the distance range zero to 100 km using the numerical technique described in the previous chapter. Barker (1970) computer program was modified to take into consideration SH wave option. Seismograms have been calculated to investigate the effects of structure, source-type, source-depth and distance range. In all the synthetic seismograms presented in this thesis, the impulse response is convolved with a triangle of base 0.4 sec and area unity. For structure we chose two separate crustal models listed in Table I. Model I represents a 10 km thick granitic layer over a gabbroic half-space. Model II represents a sedimentary basin with a 2 km thick sedimentary layer overlying hard basement rock. To see the effect of source-type, we computed theoretical seismograms for P, SV and SH wave sources. We embedded each of these sources in case of Model I at .5, 2.and 5. km, while in Model II the source-depth was 1 km. We have made computations for 50 and 100 km distance range and in one case for 20 km.

Now let us examine each of the above-mentioned factors in detail. We start our discussion with source effects beginning with a P source at different depths in the Model I (Figures 3, 4). The seismograms show that the record begins with P wave refractions, which is later followed by reflections and Rayleigh waves. Here it is very clear that shallow P sources generate Rayleigh waves quite efficiently. As we increase the source depth we see a change in the surface wave amplitude and spectral characteristics. Now to determine the range effect we use a P source and Model II. In Figures 5 and 6 we see that as we increase the range, we get well-defined P reflections arriving at t = 25.3 sec. and also at later times.

To illustrate the effect of source type we go back to Model I but this time use an SV source at different depths for range 50 km. This is shown in Figures 7 and 8. Here we see that Rayleigh wave is an outstanding feature. In Figures 9 and 10 we consider the same model as has been used above, but now at the 100 km range. The first of these figures represents the early part of the seismogram showing the refracted and reflected arrivals. We did this just to show the similarity in body wave-forms for different source depths. Later in Figure 10 we display the generation of Rayleigh waves. These are so strong and large in amplitude that on a scale such as the one used in Figure 10, we could not see any other type of waveforms. In the real world, when we are actually recording the events, the response of the instrument can be controlled, which enables us to see different sorts of waveforms, though they differ greatly in amplitudes. We computed for an SV source, Model II and a range of 50 km, both the early part and the later part of the seismograms (Figure 11a,b).

Further, we also compare records obtained for different ranges using Model II. This is shown in Figure 12, for body waves. Then we compare the z component of the seismogram for Model II for SV and P sources for a range of 50 km (Figure 13). We see a resemblance between the two waveforms which we should expect. We can also see that the Rayleigh wave generated by an SV source has a larger amplitude than for a P source. It is clear than an SV source is a more efficient generator of Rayleigh waves than a P source, for the simple reason that the integration contour comes closer to the real axis in the case of the SV source.

Following our earlier procedure we examine the source-depth effect on the computed model seismograms for an SH source. To begin with, we look at Model I and range 50 km. This is shown in Figure 14. There is a very close resemblance in waveform shape for source-depths 0.5, 2 and 5 kms. We can clearly see the SH_n arrival (in Figure 14 b,c), which is followed by SH reflections. There is no indication of dispersed Love waves. We again consider the same model but increase the range to 100 km (Figure 15). We see a long quiet period beginning with refracted SH arrivals followed by SH reflections. Finally we consider Model II and here we investigate the range effect. Figure 16 shows the synthetic seismograms for the ranges 20, 50 and 100 km. In all of these seismograms we can see the generation of Love waves, which clearly stand out with their relatively larger amplitudes than the body waves.

Chapter IV

CONCLUSION

In this thesis, we investigated the effects of source type, source depth, range and structure or seismic wave propagation in a layer over a half-space. We considered compressional sources, vertical torque (SV) and horizontal torque (SH) as point source models. A close examination of the synthetic seismograms discussed in the last chapter revealed the following

(a) A relatively thin high-contrast layer accentuates the surface waves on the seismogram by increasing the dispersive effects in near-fields.

(b) Source-depth plays a very important role in determining the relative amplitude of the surface waves. Frequency content of these waves are also affected by the source-depth.

(c) For a given structure and source depth, SV type sources generate Rayleigh waves more efficiently than purely compressional (P type) sources.

(d) Body wave response (early portion of the seismogram) changes more rapidly with distance than the surface wave response.

(e) An extension of this work is to compare the theoretical seismograms with those of field data and to investigate earthquake source characteristics. However, before this can be done we need to incorporate the instrument response and realistic source-time function in the calculation of synthetic seismograms.

Table I

MODELS FOR COMPUTATION

Model I

Layer Thickness H = 10 km.

	α (km/sec)	β (km/sec)	ρ (gm/cc)	σ
Layer	5.	2.9	2.7	.25
Half-Space	7.2	4.2	2.9	.25

Model II

Layer Thickness H = 2 km.

	α (km/sec)	β (km/sec)	ρ (gm/cc)	σ
Layer	4.0	2.9	2.2	.25
Half-Space	6.0	3.46	2.4	.25

In both Models I and II α denotes a compressional wave velocity. β denotes shear wave velocity, ρ denotes density and σ denotes Poisson's ratio. Unless otherwise stated, source-depth is one-half the layer thickness.

COMPUTER PLOTS

In the figure captions, the first entry refers to the source type (P, SV, SH and C_0, where the last symbol means simultaneous comparison of two source types), second to component (Z and R for P and SV cases, otherwise omitted in SH case where only radial component can be plotted), third to the model (I or II) and finally fourth, to the range (20, 50 or 100 km. or C, in which case the seismograms are simultaneously compared at two ranges for the same model). Unless otherwise stated, source-depth is one-half the layer thickness. However, while examining the plots we should note the variation of the amplitude scale. It should also be emphasized that the horizontal (time) scale is not always uniform in all the plots.

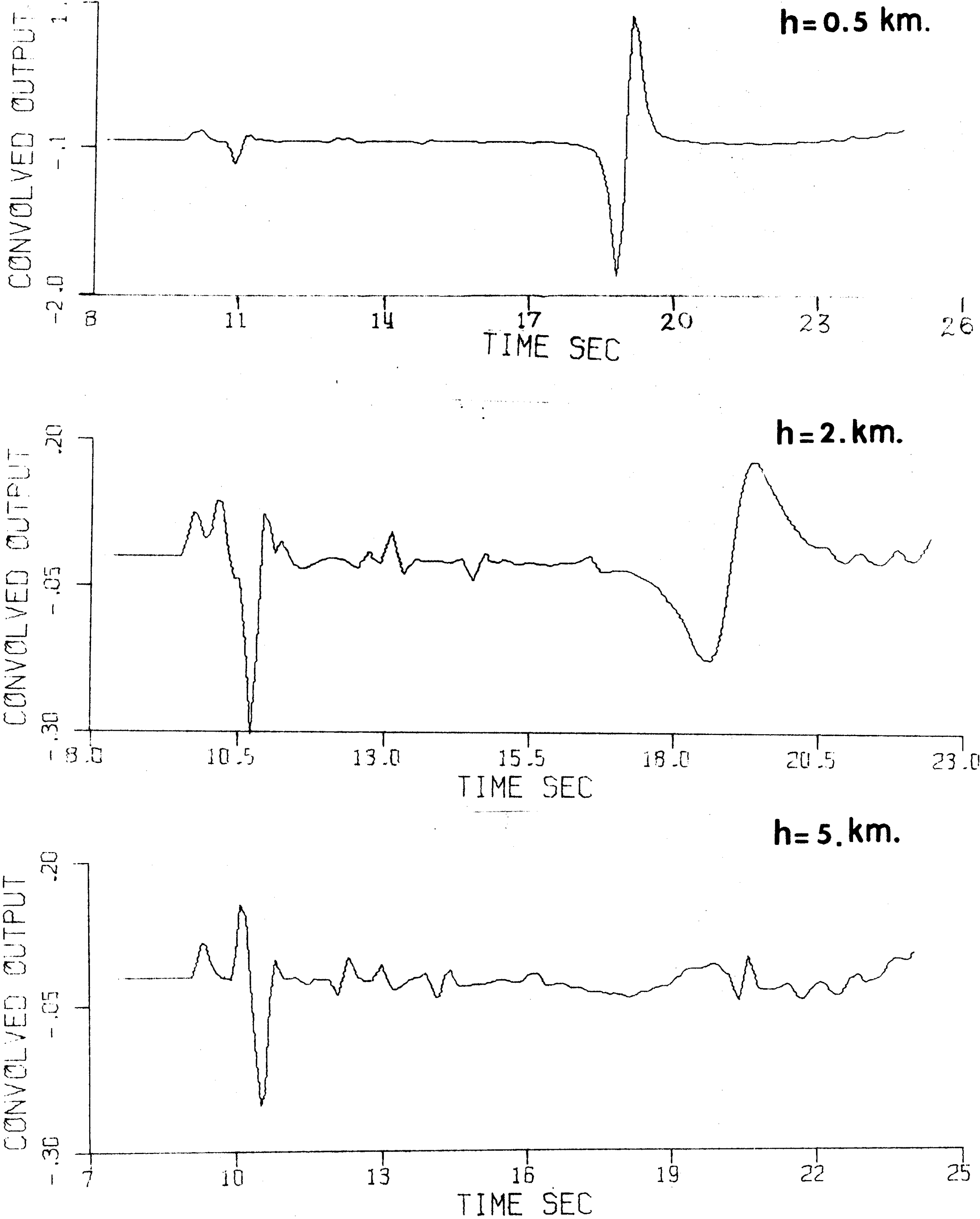
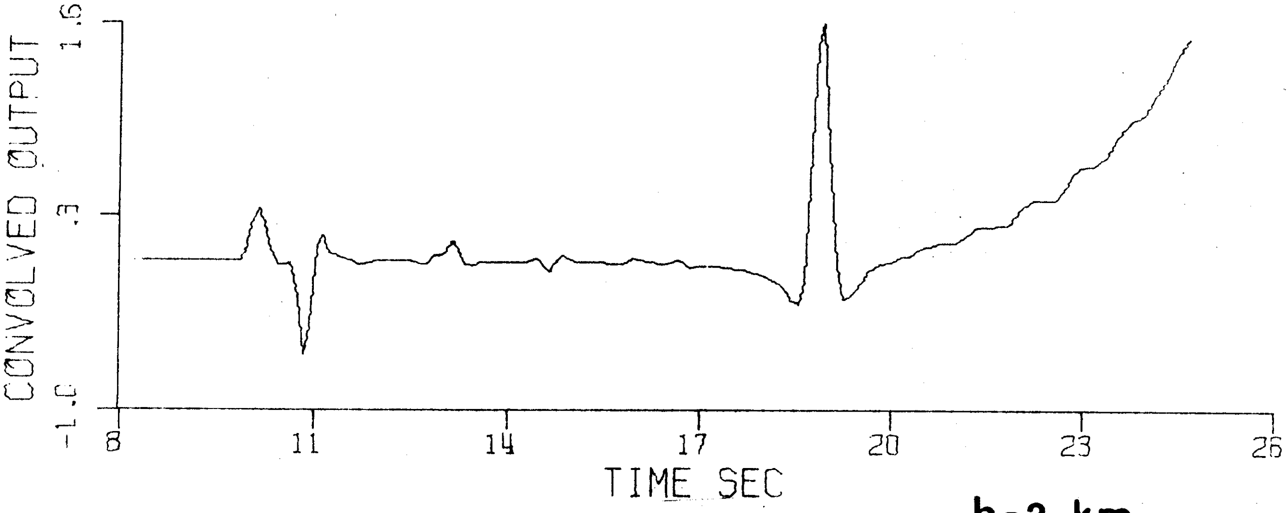
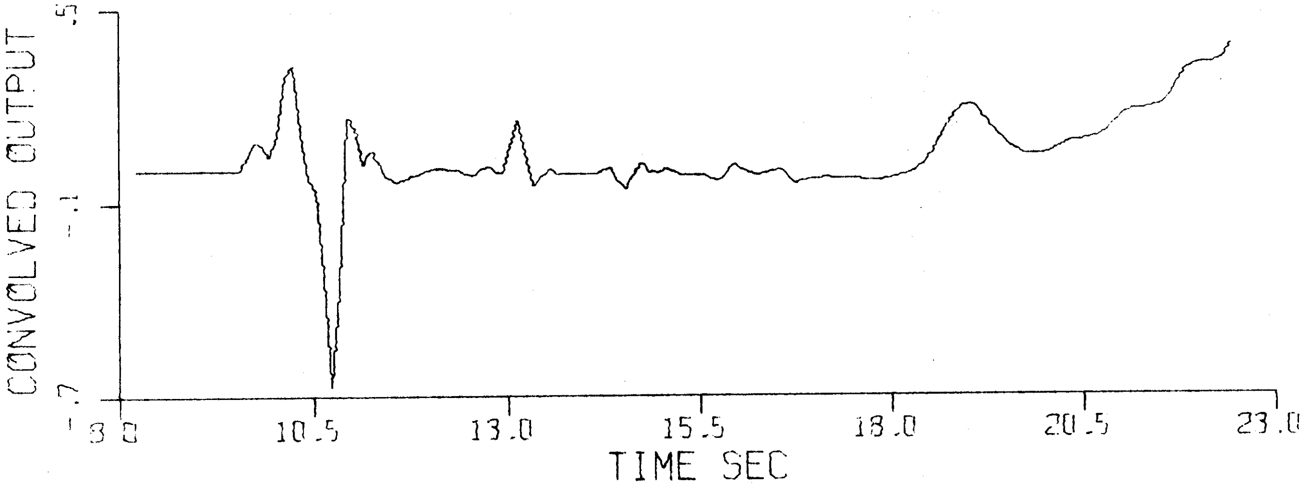

h=0.5 km.
CONVOLVED OUTPUT
1.8
-.1
-2.0
8
11
14
17
20
23
26
TIME SEC
h=2.km.
CONVOLVED OUTPUT
.20
-.05
-.30
8.0
10.5
13.0
15.5
18.0
20.5
23.0
TIME SEC
h=5.km.
CONVOLVED OUTPUT
.20
-.05
-.30
7
10
13
16
19
22
25
TIME SEC

FIG. 3. P,Z,1,50

h=0.5 km.



h=2. km.



h=5. km.

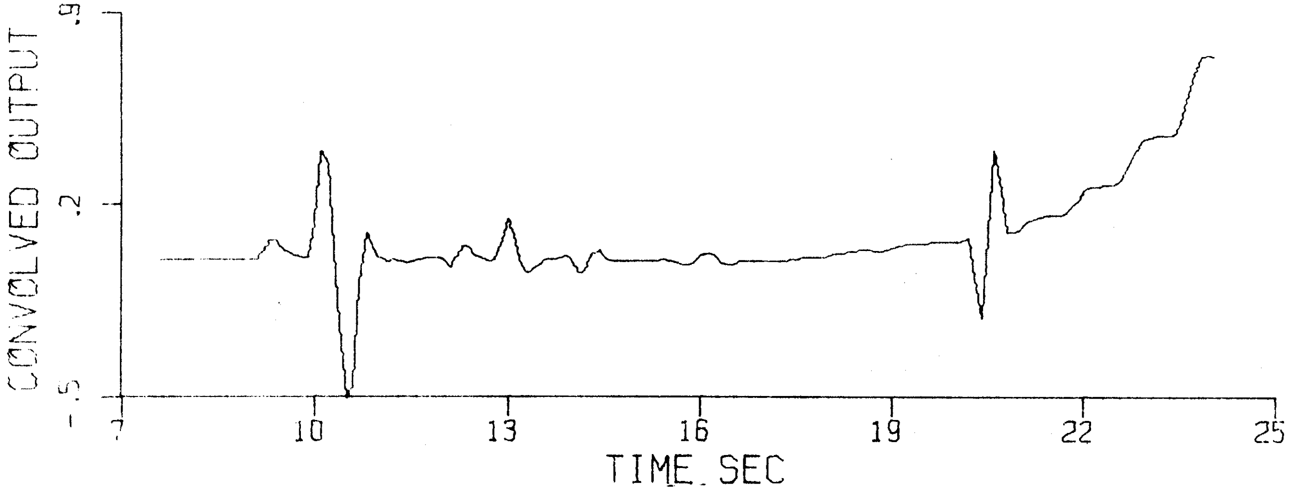


FIG. 4. P,R,1,50

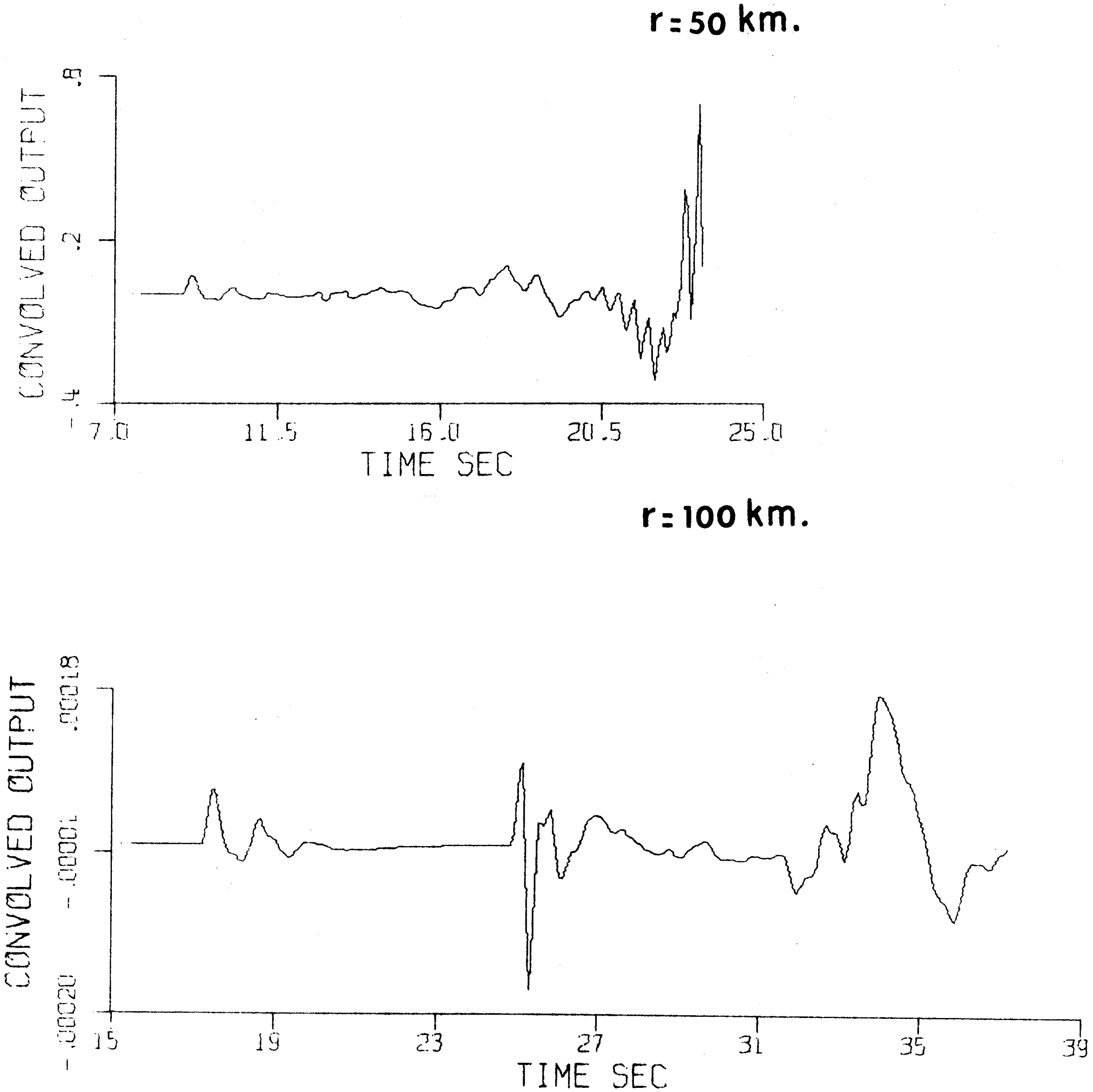
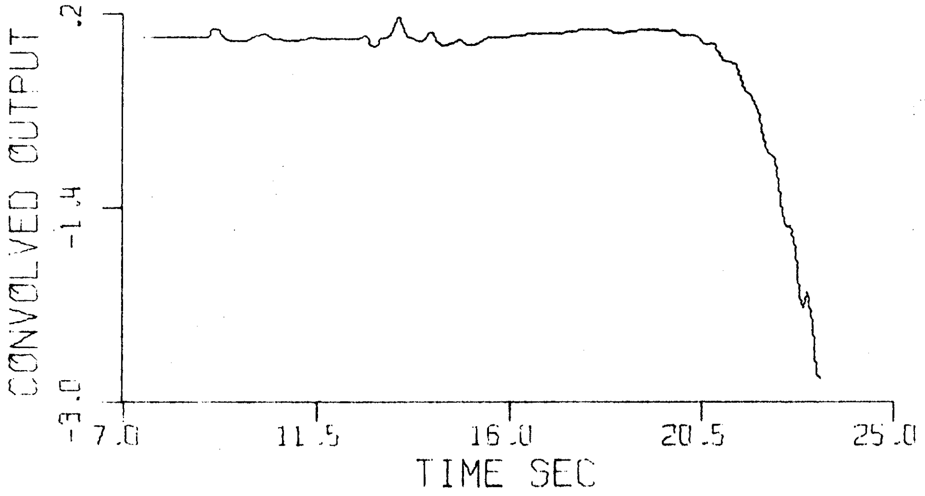

r = 50 km.
CONVOLVED OUTPUT
.8
.2
-.4
7.0
11.5
16.0
20.5
25.0
TIME SEC
r = 100 km.
CONVOLVED OUTPUT
.00018
-.00001
-.00020
15
19
23
27
31
35
39
TIME SEC

FIG. 5. P, Z, II, C

r=50 km.



r=100 km.

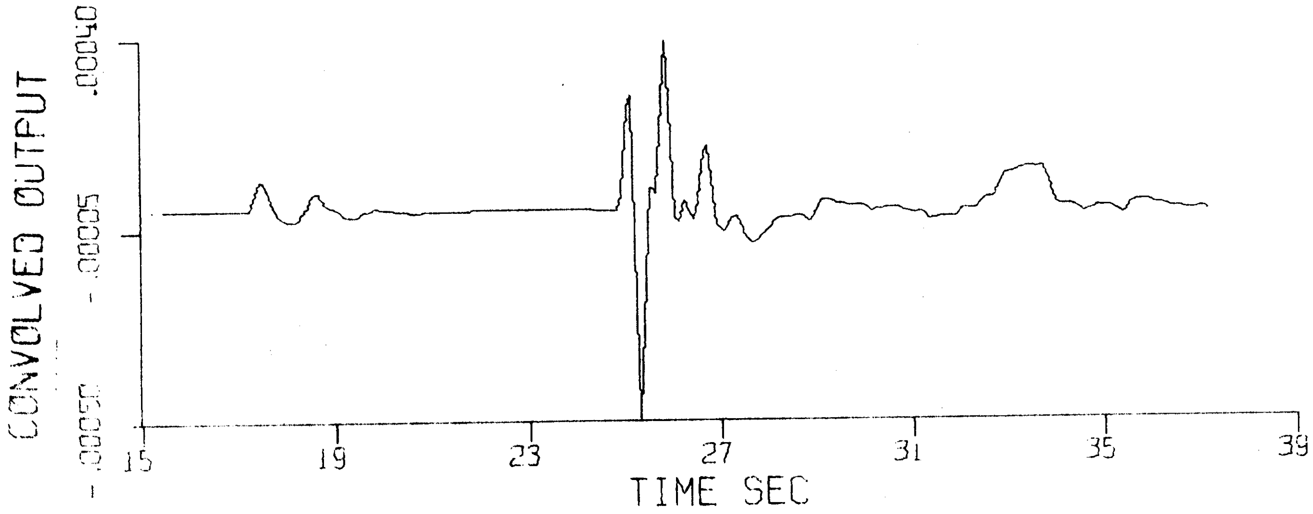


FIG. 6. P, R, II, C

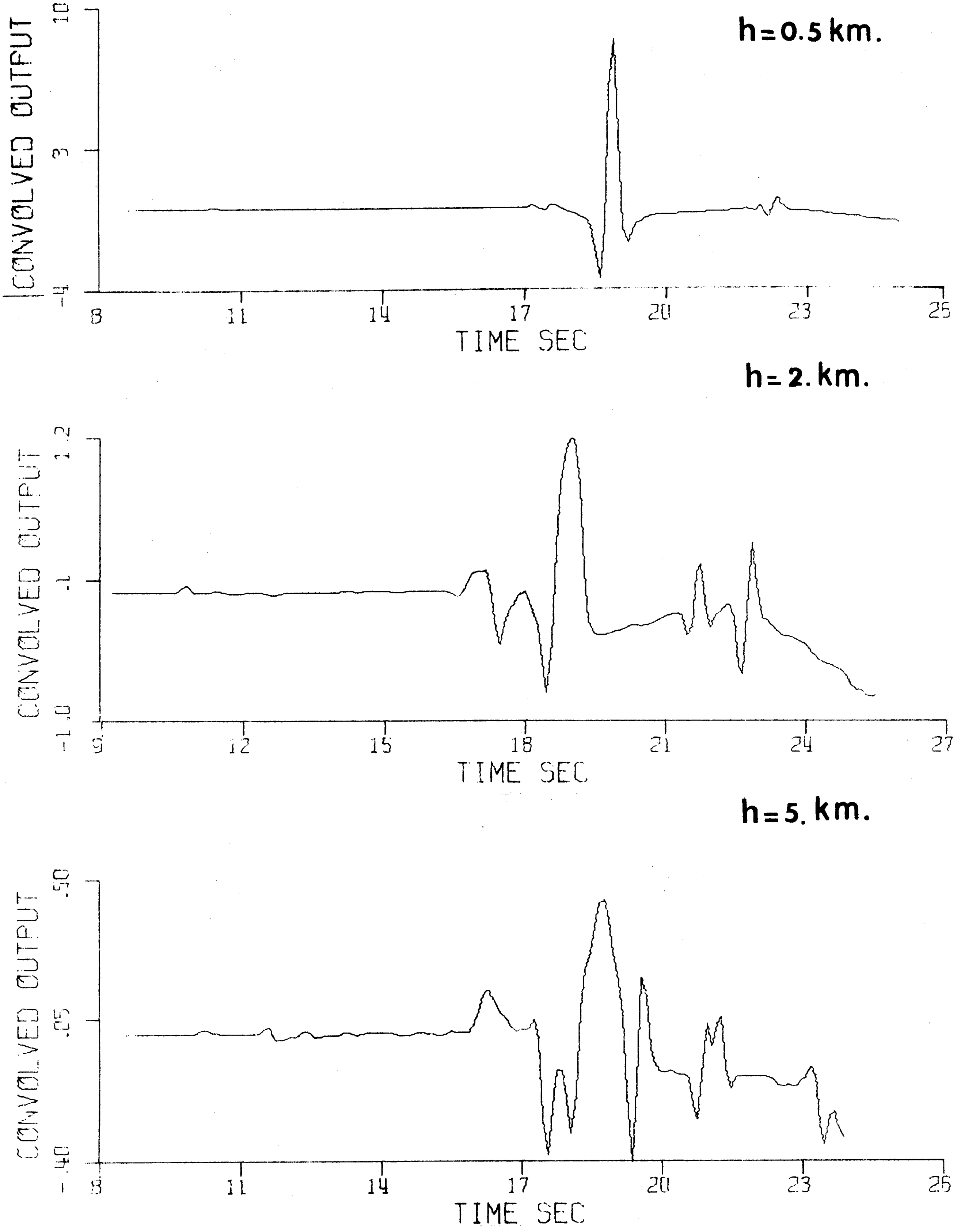

h=0.5 km.
CONVOLVED OUTPUT
10
3
-4
8
11
14
17
20
23
25
TIME SEC
h= 2. km.
CONVOLVED OUTPUT
1.2
.1
-1.0
9
12
15
18
21
24
27
TIME SEC
h=5. km.
CONVOLVED OUTPUT
.50
.05
-.40
8
11
14
17
20
23
25
TIME SEC

FIG. 7. SV, Z, I, 50

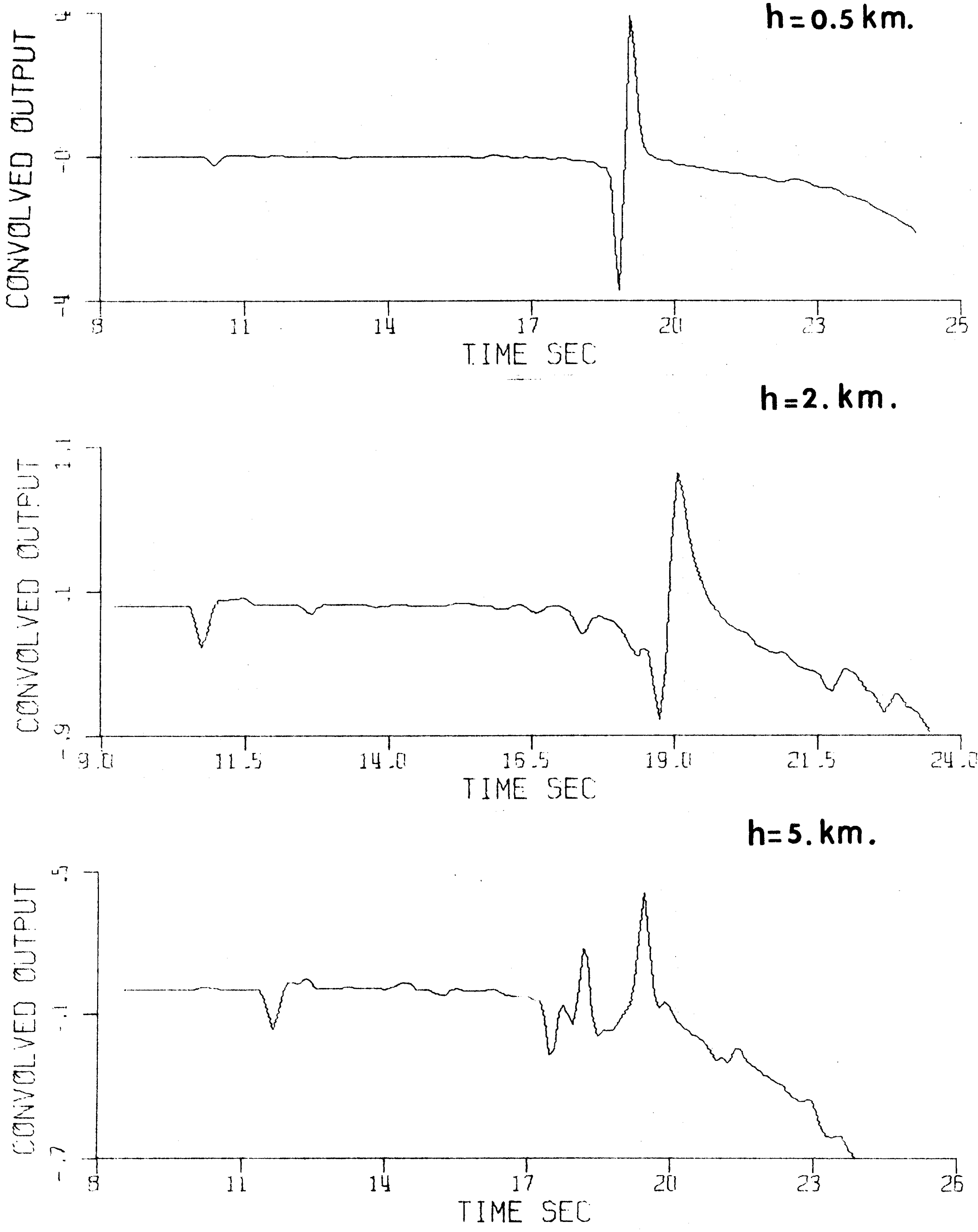
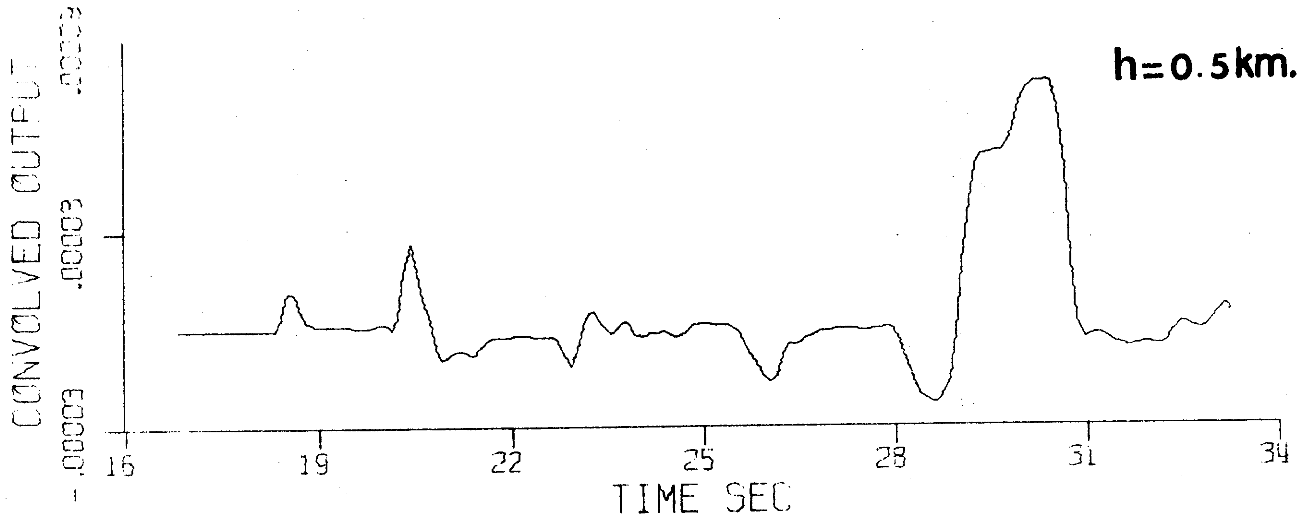
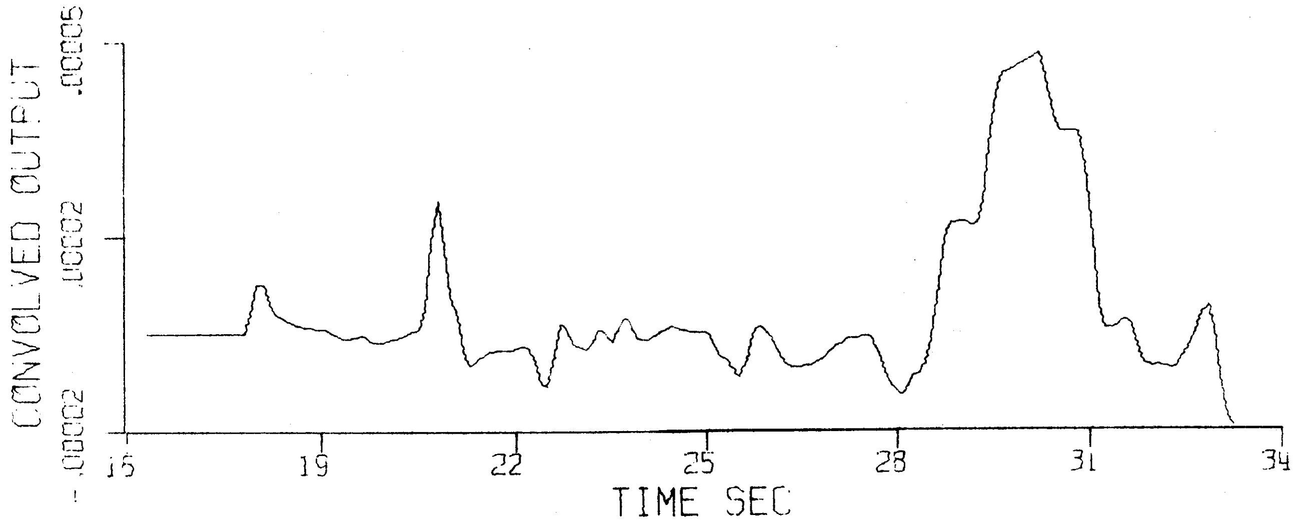

h=0.5 km.
CONVOLVED OUTPUT
4
-0
-4
8
11
14
17
20
23
25
TIME SEC
h=2. km.
CONVOLVED OUTPUT
1.1
.1
-.9
9.0
11.5
14.0
16.5
19.0
21.5
24.0
TIME SEC
h=5. km.
CONVOLVED OUTPUT
.5
-.1
-.7
8
11
14
17
20
23
26
TIME SEC

Fig. 8. SV, R, I, 50

h=0.5km.



h=2.km.



h=5.km.

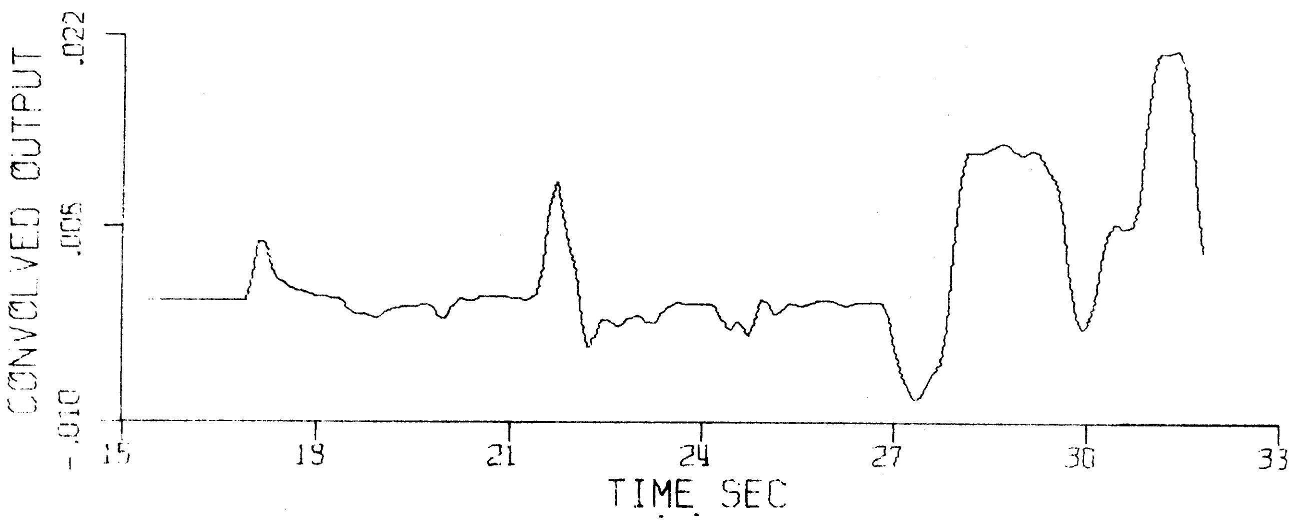
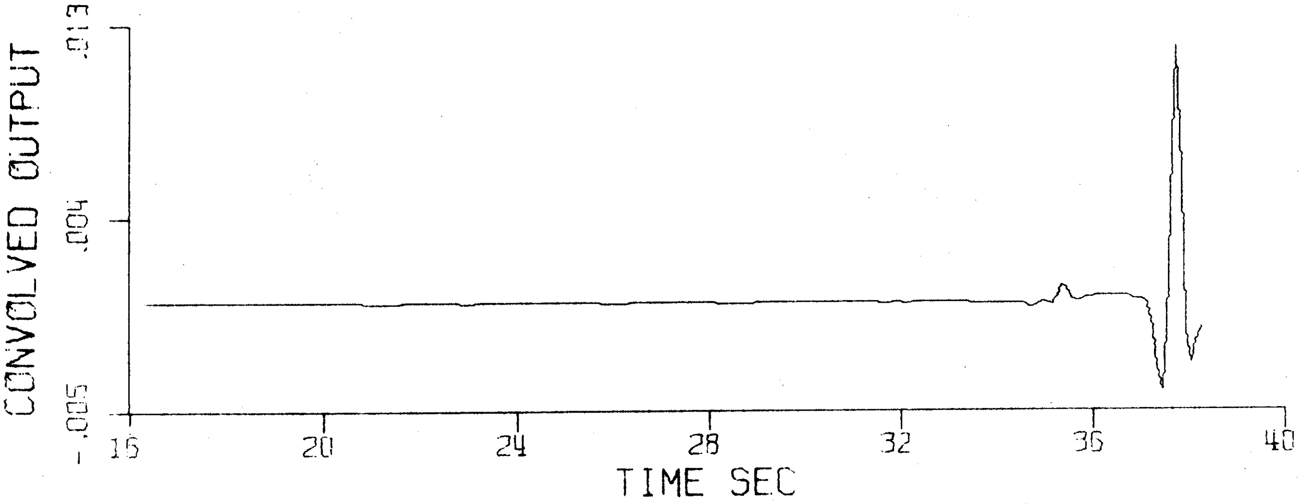
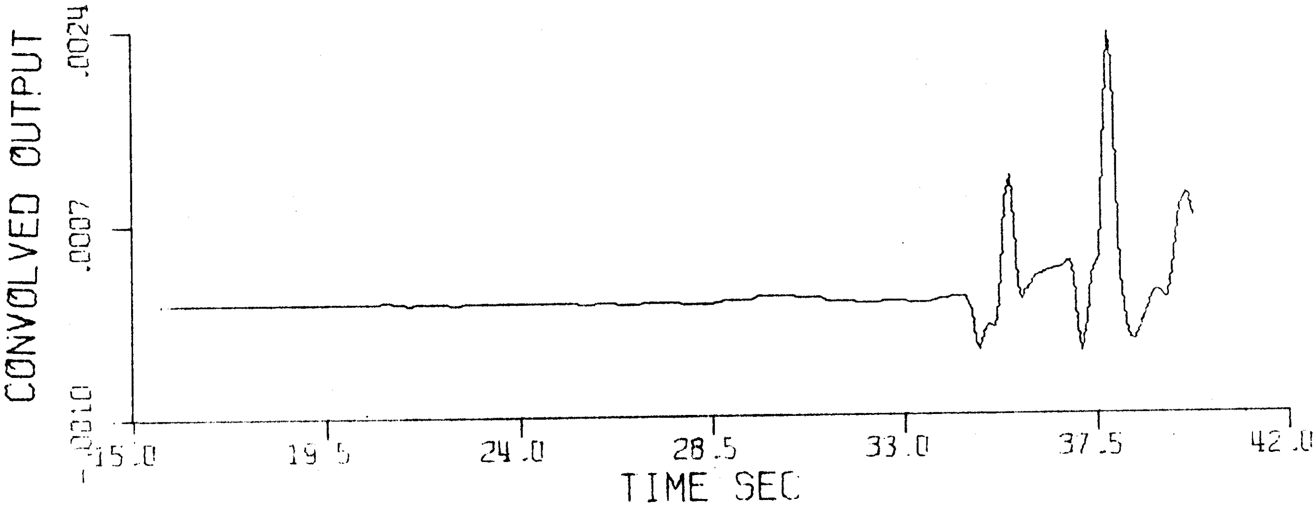


FIG. 9. SV, Z, 1, 100

h=0.5 km.



h= 2. km.



h=5. km.

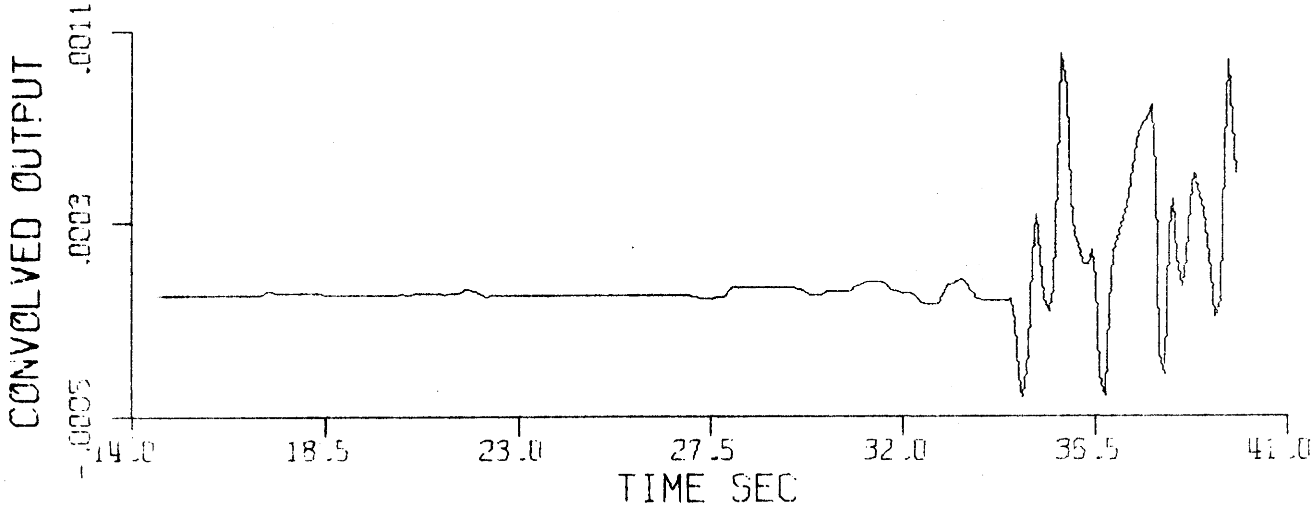
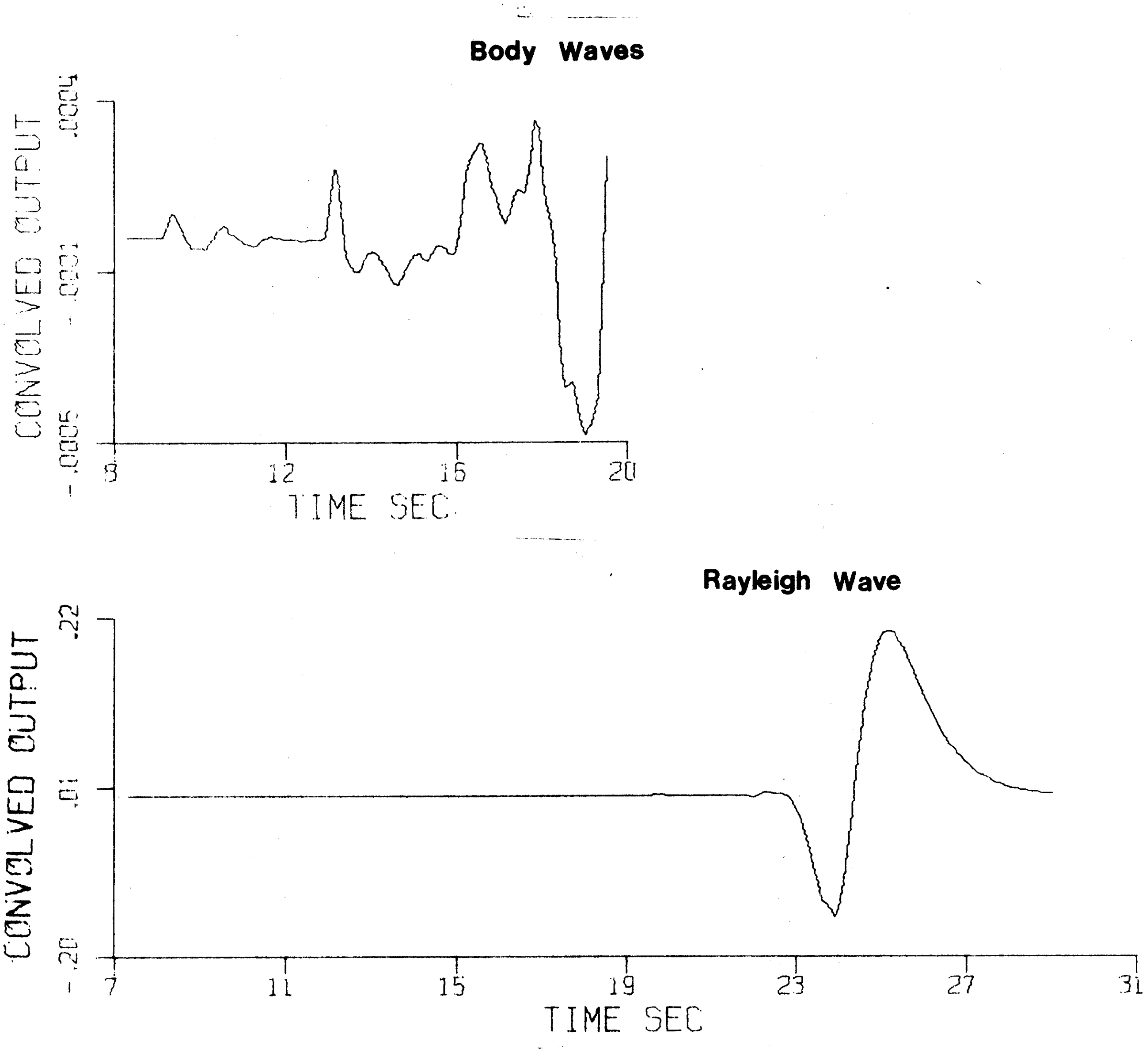


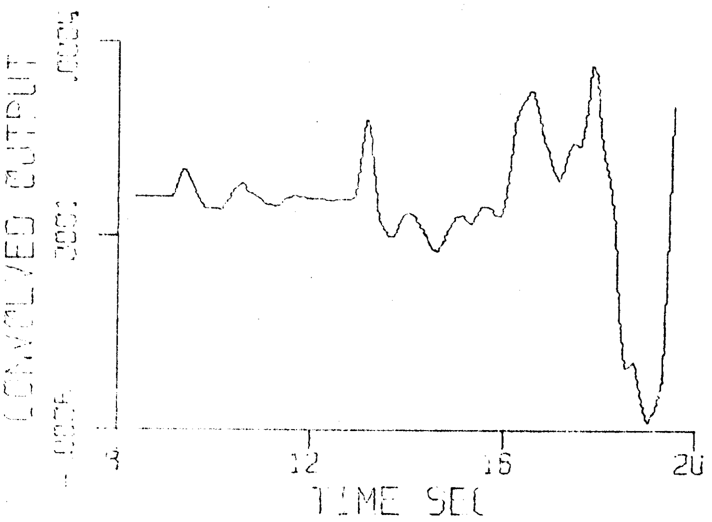
FIG. 10 SV, Z, 1, 100


Body Waves

Rayleigh Wave

FIG. 11. SV, Z, II, 50

r = 50 km.



r = 100 km

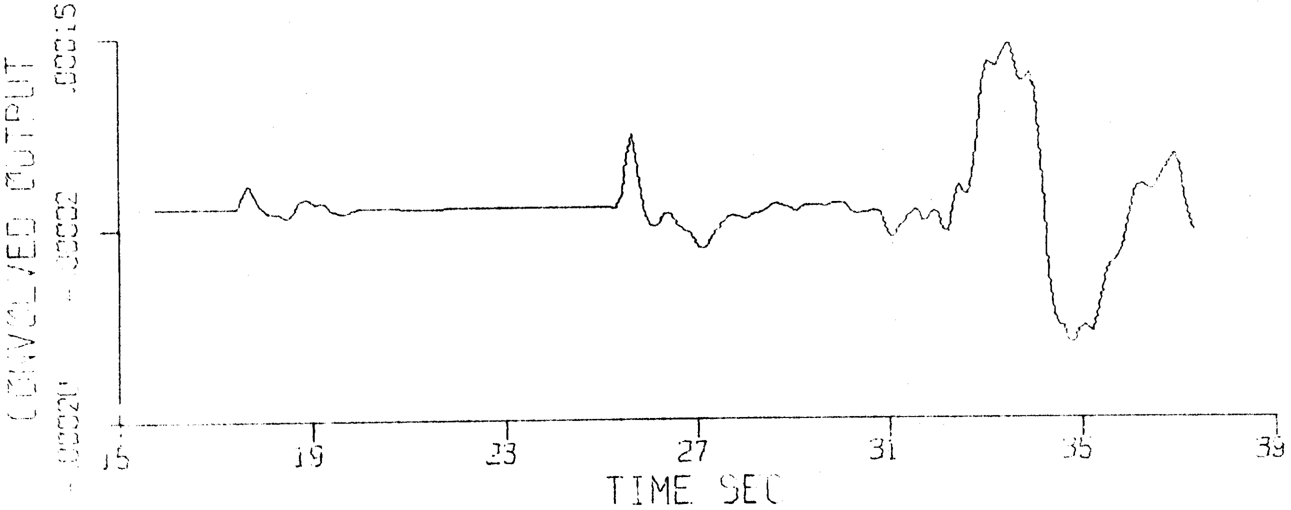
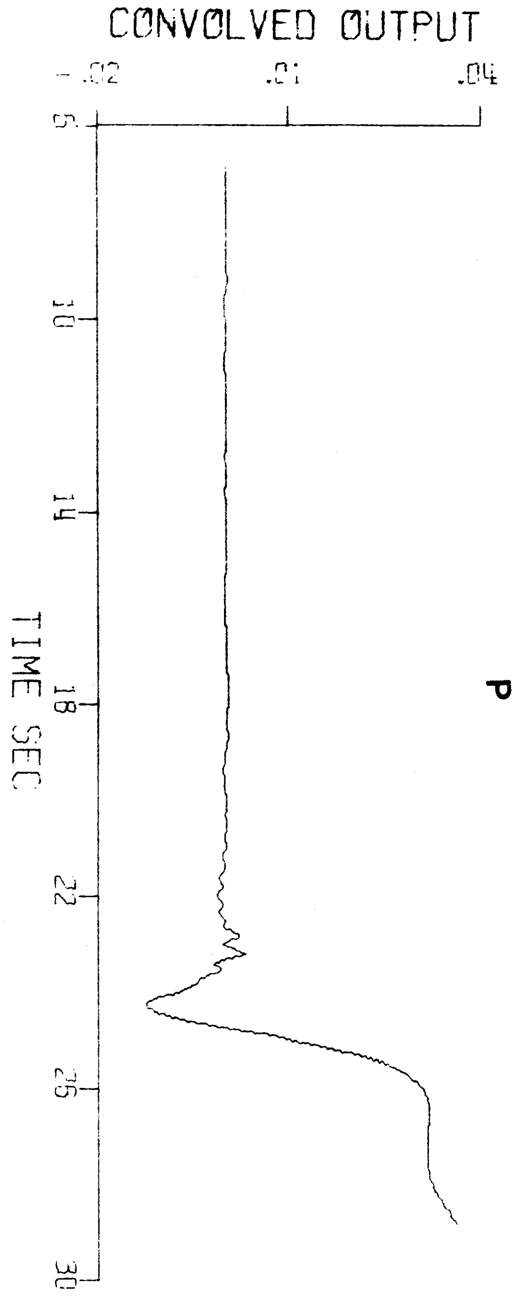
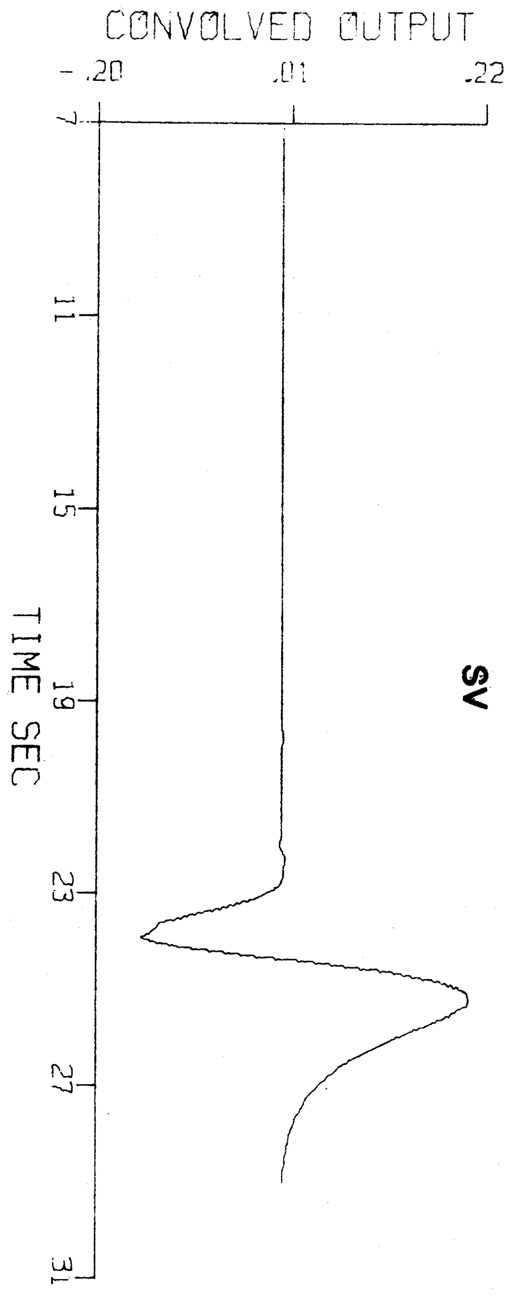
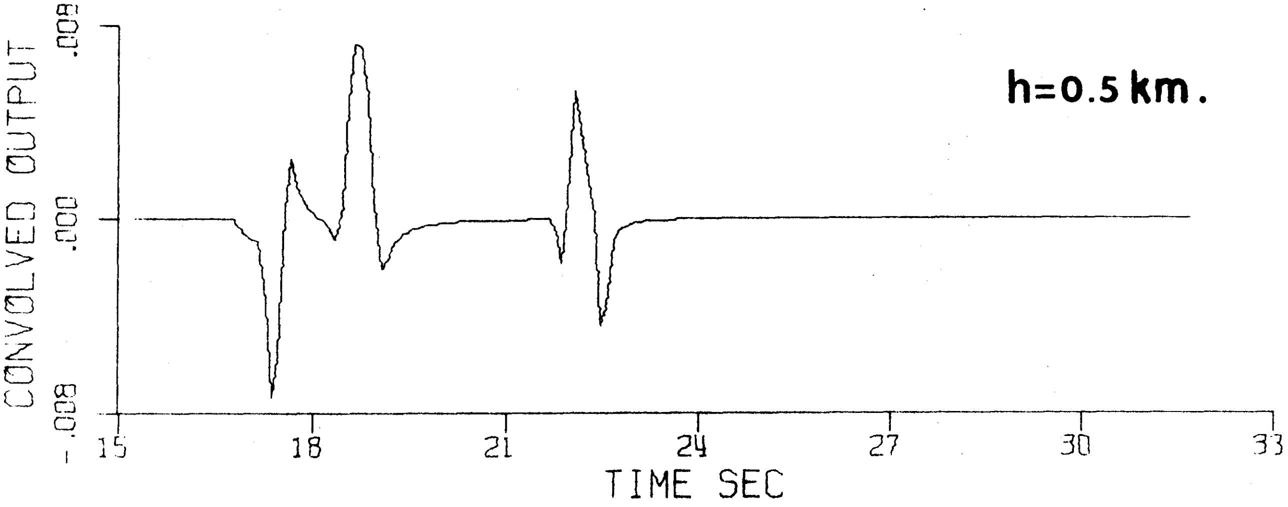


Fig. 12. SV, Z, II, C

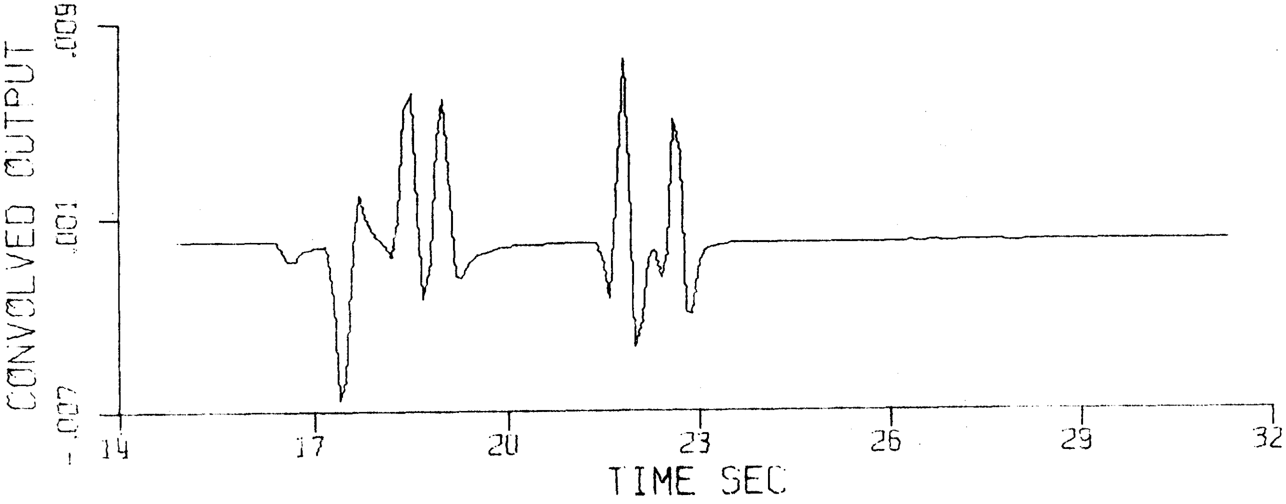

CONVOLVED OUTPUT
-.02
.01
.04
6
10
14
18
22
26
30
TIME SEC
P


CONVOLVED OUTPUT
-.20
.01
.22
7
11
15
19
23
27
31
TIME SEC
SV

h=0.5 km.



h=2. km.



h=5. km.

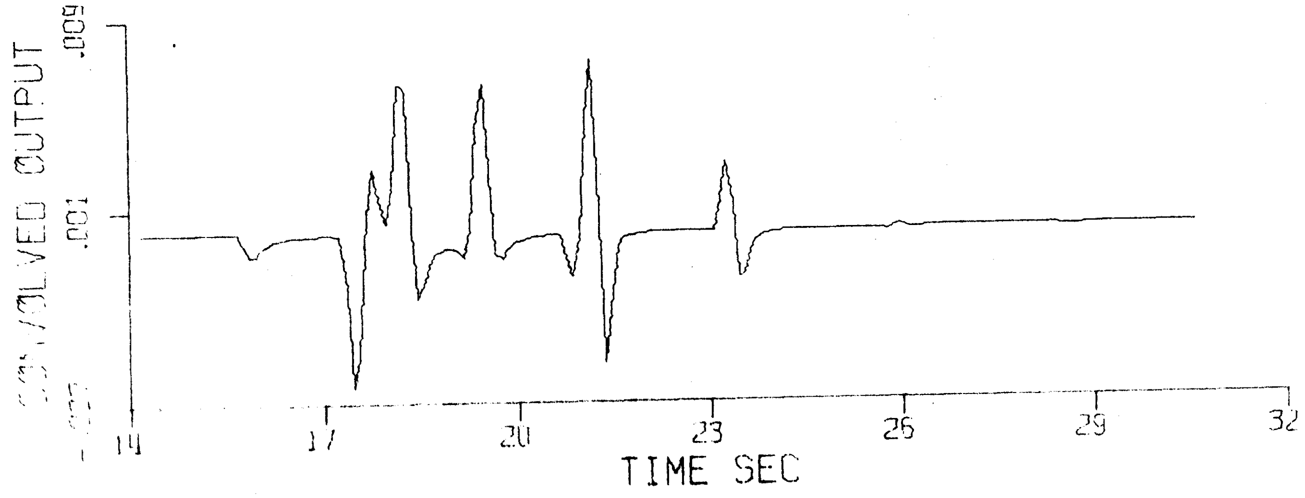


FIG. 14. SH, 1, 50

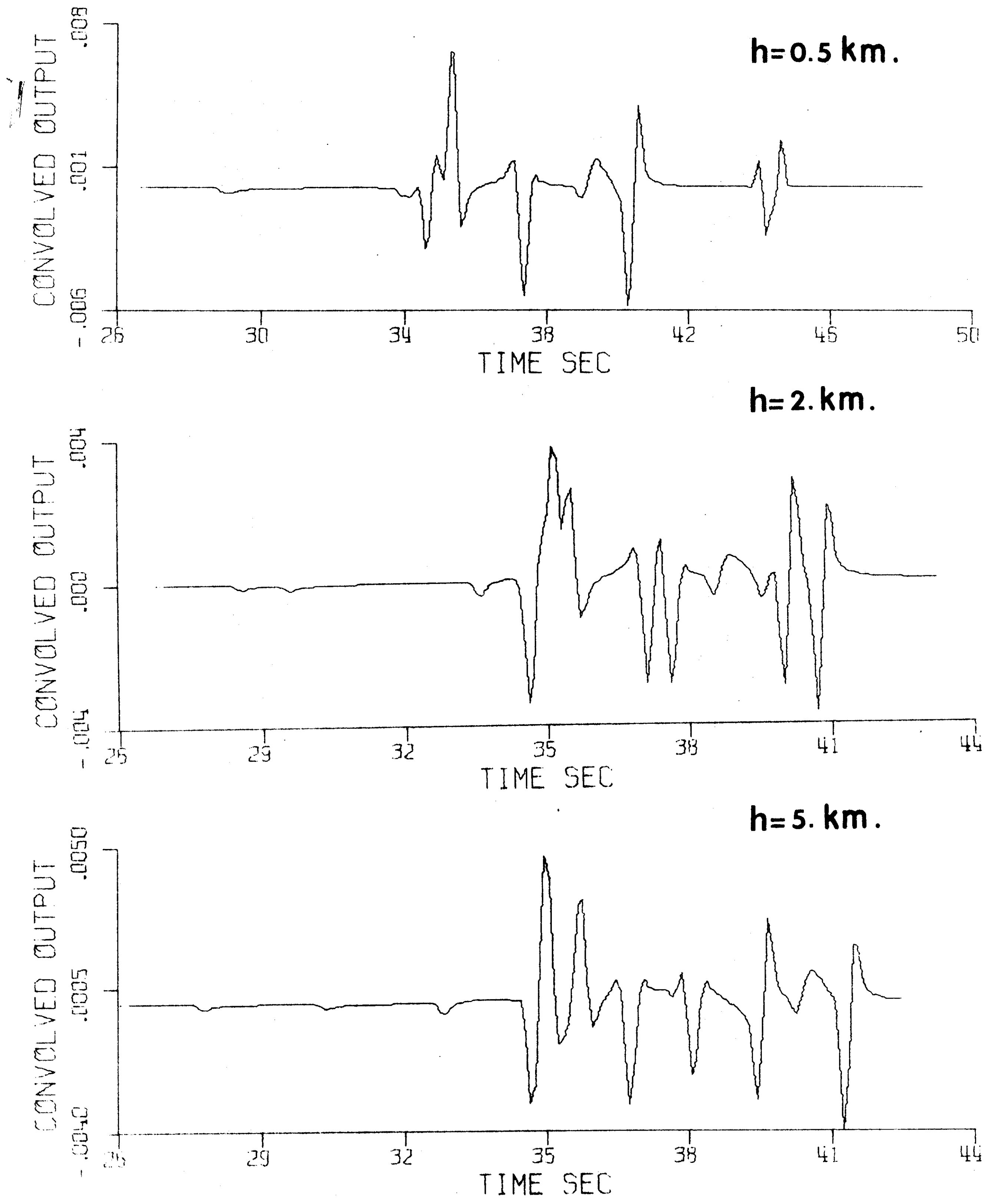


FIG. 15. SH, 1, 100

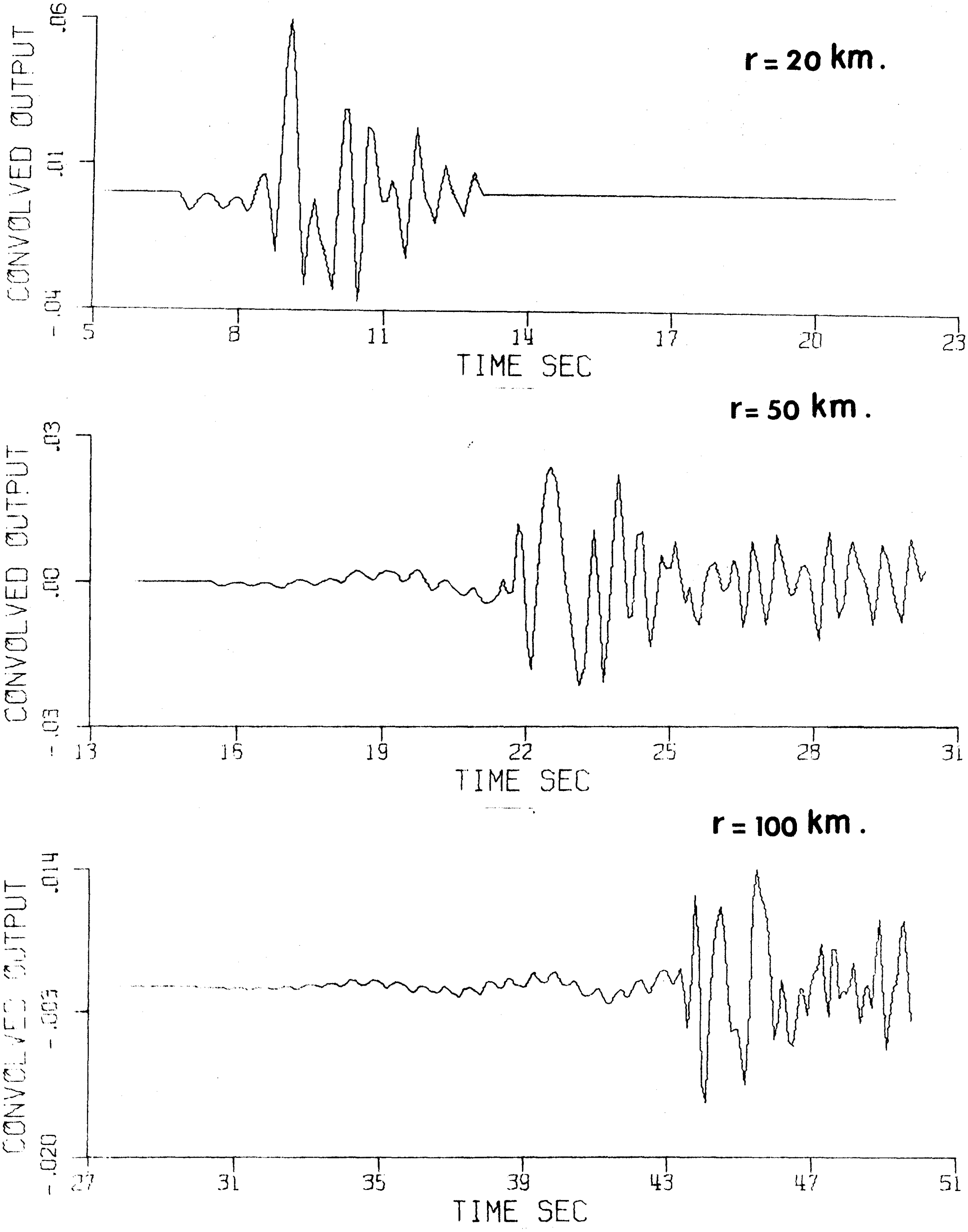

r = 20 km.
CONVOLVED OUTPUT
.06
.01
-.04
5
8
11
14
17
20
23
TIME SEC
r = 50 km.
CONVOLVED OUTPUT
.03
.00
-.03
13
16
19
22
25
28
31
TIME SEC
r = 100 km.
CONVOLVED OUTPUT
.014
-.003
-.020
27
31
35
39
43
47
51
TIME SEC

Fig. 16. SH, II, C

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Appendix A

SOLUTION OF THE INHOMOGENEOUS WAVE EQUATION

Here we would like to solve the inhomogeneous wave equation (1)

$$\mu\nabla^2 u_\theta(r,z,t) - \rho\frac{\partial^2}{\partial t^2}u_\theta(r,z,t) = \frac{-H(t)\,\delta(r)\,\delta(z-h)}{2\pi r} \qquad \text{(A1)}$$

The Laplace transform of (A1) in time domain is

$$\nabla^2\bar{u}_\theta(r,z,s) - \frac{s^2}{\beta^2}\,\bar{u}_\theta(r,z,s) = -\frac{\delta(r)\,\delta(z-h)}{2\pi\mu r} \qquad \text{(A2)}$$

Note that

$$\nabla^2 \equiv \frac{1}{r}\frac{d}{dr}\,r\,\frac{d}{dr} + \frac{d^2}{dz^2} \equiv \nabla_r^2 + \frac{d^2}{dz^2}$$

And now let us define the bilaterial Laplace transform as

$$\bar{\bar{u}}_\theta(r,\nu,s) = \int_{-\infty}^{+\infty} \bar{u}_\theta(r,z,s)\,e^{\nu z}\,dz$$

When this is applied to (A2) we get as a consequence

$$\nabla_r^2\bar{\bar{u}}_\theta(r,\nu,s) - (K^2-\nu^2)\,\bar{\bar{u}}_\theta(r,\nu,s) = -\frac{\delta(r)\,e^{-\nu h}}{2\pi\mu r} \qquad \text{(A3)}$$

Define $\zeta^2 = K^2-\nu^2$, where $K^2 = s^2/\beta^2$, radiation condition becomes Re $\zeta \geq 0$ which has to be satisfied. Consider the equation

$$\nabla_r^2 V - \zeta^2 V = - \frac{\delta(r-r_0)}{r} \qquad \text{(A4)}$$

which has as its homogeneous solutions

$$V_1 = I_0(\zeta,r) \qquad V_2 = K_0(\zeta,r)$$

which for large r behaves as

$$V_1 \simeq \frac{e^{\zeta r}}{\sqrt{2\pi\zeta r}} \qquad V_2 \simeq \sqrt{\frac{\pi}{2\zeta r}}\, e^{-\zeta r}$$

$$V = cI_0(\zeta r_<)K_0(\zeta r_>) \qquad \text{(A5)}$$

where $r_> \equiv \max(r,r_0)$, $r_< \equiv \min(r,r_0)$ and c, a constant, to be determined from the continuity condition of V at $r = r_0$.

Multiplying (A4) by r and integrating from $r_0-\epsilon$ to $r_0+\epsilon$ we get

$$\lim_{\epsilon\to 0} \left[r\frac{dV}{dr} \right]_{r_0-\epsilon}^{r_0+\epsilon} = -1 \qquad \text{(A6)}$$

Put (A5) into (A6) to get

$$c\zeta r_0 [I_0(\zeta r_0)K_0'(\zeta r_0) - I_0'(\zeta r_0)K_0(\zeta r_0)] = -1 \qquad \text{(A7)}$$

where the prime (') denotes differentiation with respect to r_0. The quantity in parenthesis in (A7) denotes the Wronskian of (I_0,K_0) and is found to be $-1/\zeta r_0$. Hence c = 1, giving the particular solution as

$$V = I_0(\zeta r_<)K_0(\zeta r_>) \tag{A8}$$

From (A3) we get $r_0 = 0$ which gives us

$$u_\theta = K_0(\zeta r) \qquad I_0(0) = 1$$

and therefore the particular solution of (A3) is

$$\bar{u}_\theta(r,\nu,s) = K_0(\zeta r)e^{-\nu h}/2\pi\mu$$

The inversion from ν to z gives us

$$\bar{u}_\theta(r,z,s) = \frac{1}{2\pi i}\,\frac{1}{2\pi\mu}\int_{-i\infty}^{+i\infty} K_0(\zeta r)e^{+\nu(z-h)}d\nu \tag{A9}$$

Alternatively we can write (A9) as

$$\bar{u}_\theta(r,z,s) = \frac{1}{2\pi^2\mu}\,\mathrm{Im}\int_0^{i\infty} K_0(\zeta r)e^{\nu(z-h)}d\nu \tag{A10}$$

or

$$\bar{u}_\theta(r,z,s) = -\frac{1}{2\pi^2\mu}\,\mathrm{Im}\int_0^{i\infty} K_0(\zeta r)e^{\nu(z-h)}d\nu \tag{A11}$$

Keeping in mind the condition Re $\zeta \geq 0$ has to be satisfied, we cut the ν plane as shown in Figure A1.

Shifting the path of integration in Equation A10 to the tip of the cut in the left half of the ν plane for $z > h$, we get

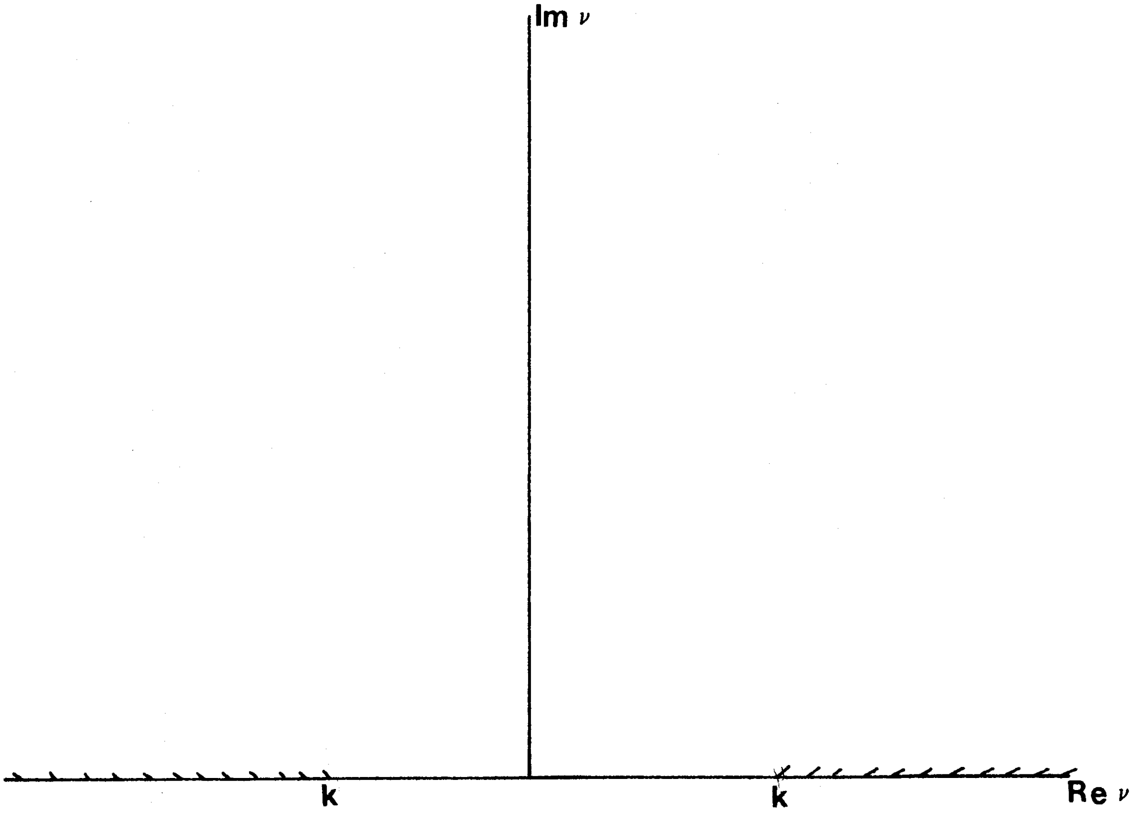

FIG. A1

$$\bar{u}_\theta(r,z,s) = \frac{1}{2\pi^2\mu} \operatorname{Im} \int_{-K}^{\infty} K_0(\zeta r) e^{\nu|z-h|} d\nu \tag{A12}$$

or making a change in the variable of integration gives us

$$\bar{u}_\theta(r,z,s) = -\frac{1}{2\pi^2\mu} \operatorname{Im} \int_{0}^{i\infty} K_0(\zeta r) \frac{\zeta}{\nu}\, e^{+\nu|z-h|} d\zeta \tag{A13}$$

for Re $\nu \le 0$.

If we put $\nu = -\nu$ in (A12) we get

$$\bar{u}_\theta(r,z,s) \quad \frac{1}{2\pi^2\mu} \operatorname{Im} \int_{0}^{i\infty} K_0(\zeta r) \frac{\zeta}{\nu}\, e^{-\nu|z-h|}\, d\zeta \tag{A14}$$

for Re $\nu \ge 0$. If we again consider for $z > h$ an appropriate equation corresponding to (A10), i.e. (A11), we would see that we get (A14). This shows that (A14) holds true for all z. Let $\zeta = sp$, $\nu = s\eta$ in (A14) to get

$$\bar{u}_\theta(r,z,s) = \frac{s}{2\pi^2\mu} \operatorname{Im} \int_{0}^{i\infty} \frac{p}{\eta} K_0(spr) e^{-s\eta|z-h|} dp \tag{A15}$$

which is the solution for the homogeneous half-space. This formulation can easily be extended for layered media if we introduce a function $F_n(p)$ in (A15) which takes into consideration the reflection coefficient at the interface, the receiver directivity function and the source radiation function to get

$$\bar{u}_{\theta,n}(r,0,s) = s \ \mathrm{Im}\int_0^{i\infty} pF_n(p)\ K_0(spr)\ e^{-sj_n(p)}\,dp \qquad \text{(A16)}$$

where $j_n(p)$ describes the time taken by the nth generalized ray to traverse the layer. This is Equation 4 in the main text of this thesis. Proceeding in exactly the same way, we can obtain Equations 2 and 3 for P and/or SV sources.

Appendix B

CALCULATION OF REFLECTION COEFFICIENTS AND RECEIVER FUNCTIONS

P and SV Waves. The reflection function $\zeta_n(p)$ is a measure of the attenuation of energy due to internal reflections and is given by

$$\zeta_n(p) = R_{DPP}^{l_{DPP}^{(n)}} \; R_{DPS}^{l_{DPS}^{(n)}} \; R_{DSP}^{l_{DSP}^{(n)}} \; R_{DSS}^{l_{DSS}^{(n)}} \; R_{UPP}^{l_{UPP}^{(n)}} \; R_{UPS}^{l_{UPS}^{(n)}} \; R_{USP}^{l_{USP}^{(n)}} \; R_{USS}^{l_{USS}^{(n)}}$$

where $l_{DPP}^{(n)}$ denotes the number of P to P reflections off the lower boundary and similarly, $l_{UPP}^{(n)}$ is the number of P to P reflections off the free surface. The functions R_{DPP}, R_{DPS}, etc. denote the reflection coefficients and are given by [See for details Helmberger (1967), Barker (1970)]

$$R_{DPP} = (-[1] + [2] + [3] - [4] - [5] + [6])/D_1$$

$$R_{DPS} = 2p\eta_1[(K_2-p^2)(K_3-p^2) - \eta_2\eta_2'(K_1-p^2)]/D_1$$

$$R_{DSP} = 2p\eta_1'[(K_2-p^2)(K_3-p^2) - \eta_2\eta_2'(K_1-p^2)]/D_1$$

$$R_{DSS} = (-[1] + [2] + [3] - [4] + [5] - [6])/D_1$$

where

$$D_1 = [1] + [2] + [3] + [4] - [5] - [6]$$

$$[1] = p^2(K_3-p^2)^2 \qquad [2] = \eta_1\eta_2\eta_1'\eta_2' p^2$$

$[3] = \eta_1\eta_1'(K_3-p^2)^2$ $\qquad$ $[4] = \eta_2\eta_2'(K_1-p^2)^2$

$[5] = \eta_1\eta_2'K_1K_2$ $\qquad$ $[6] = \eta_2\eta_1'K_1K_2$

and

$$K_1 = -\frac{1}{2}\left(\frac{\rho_1}{\mu_2-\mu_1}\right) \qquad K_2 = \frac{1}{2}\left(\frac{\rho_2}{\mu_2-\mu_1}\right)$$

$$K_3 = K_1 + K_2$$

Also

$$R_{UPP} = R_{USS} = [4\beta_1^4p^2\eta_1\eta_1' - (1-2\beta_1^2p^2)^2]/D_2$$

$$R_{UPS} = 4p\eta_1(1-2\beta_1^2p^2)/D_2$$

$$R_{USP} = -4p\eta_1'(1-2\beta_1^2p^2)/D_2$$

$$D_2 = 4\beta_1^4p^2\eta_1\eta_1' + (1-2\beta_1^2p^2)^2$$

where

$$\eta_1 = \sqrt{\frac{1}{\alpha_1^2} - p^2} \qquad \eta_1' = \sqrt{\frac{1}{\beta_1^2} - p^2}$$

$$\eta_2 = \sqrt{\frac{1}{\alpha_2^2} - p^2} \qquad \eta_2' = \sqrt{\frac{1}{\beta_2^2} - p^2}$$

where α_1 and β_1 are velocities of compressional and shear waves in the layer, and α_2 and β_2 that in the half-space. ρ and μ denote density and rigidity respectively and p is complex integration variable which has dimensions of sec/km.

For SH Waves. Taking Figure 1 of the main text into consideration, we have the following wave equations

$$\nabla^2\chi_1(x,z,t) - \frac{1}{\beta_1^2}\frac{\partial^2\chi_1}{\partial t^2} = -\delta(t)\delta(x)\delta(z-h) \tag{B1}$$

and

$$\nabla^2\chi_2(x,z,t) - \frac{1}{\beta_2^2}\frac{\partial^2\chi_2}{\partial t^2} = 0 \tag{B2}$$

where χ_1 and χ_2 are SH-potentials in the layer and half-space respectively.

We define unilateral and bilateral Laplace Transforms with respect to t for the function g(t) and similarly with respect to x for g(x) as follows

$$\bar{g}(s) = \int_0^{\infty} g(t)e^{st}dt \quad \text{where } s \text{ is positive real} \tag{B3}$$

and

$$\hat{g}(\zeta) = \int_{-\infty}^{+\infty} g(x)e^{-\zeta x}dx \quad \text{where } \zeta \text{ is complex} \tag{B4}$$

After transforming (B1) and (B2) with respect to s and ζ, the solutions for SH wave displacements after Gilbert and Knopoff (1961) in the layer and the half-space respectively are given by

$$\chi_1 = \frac{1}{2\nu_1}\left[e^{-\nu_1|z-h|} + Ae^{-\nu_1 z}\right] \tag{B5}$$

$$\chi_2 = \frac{B}{2\nu_1}e^{\nu_2 z} \tag{B6}$$

where

$$\nu_1 = \sqrt{\frac{1}{\beta_1^2} - p^2} \qquad \nu_2 = \sqrt{\frac{1}{\beta_2^2} - p^2}$$

Boundary conditions at the interface require continuity of displacement and stress, viz.

$$\chi_2 = \chi_2 \tag{B7}$$

$$p_{zy}\big|_1 = \mu_1 \frac{\partial \chi_1}{\partial z}\Big|_2 = p_{zy}\big|_2 = \mu_2 \frac{\partial \chi_2}{\partial z}\Big|_2 \tag{B8}$$

in order to determine A and B in (B5) and (B6). If we change the origin of the coordinate system to the top of the interface we get

$$e^{-\nu_1 h} + A = B$$

$$\nu_1 \mu_1 e^{-\nu_1 h} - \mu_1 \nu_1 A = \mu_2 \nu_2 B \tag{B9}$$

$$A = R_{DSH} = \frac{\mu_1 \nu_1 - \mu_2 \nu_2}{\mu_1 \nu_1 + \mu_2 \nu_2} e^{-\nu_1 h}$$

If we put $\nu_1 = s\eta_1$ $\nu_2 = s\eta_2$

$$A = \frac{b\eta_1 - \eta_2}{b\eta_1 + \eta_2} e^{-s\eta_1 h} \quad \text{where } b = \frac{\mu_1}{\mu_2} \tag{B10}$$

and

$$B = \frac{2\nu_1 \mu_1}{\mu_1 \nu_1 \;\; \mu_2 \nu_2} e^{-\nu_1 h} = \frac{2\nu_1 \mu_1}{\mu_1 \eta_1 \;\; \mu_2 \eta} e^{-s\eta_1 h} \tag{B11}$$

The reflection coefficient given by (B10) turns out to be of the same form as given by Pekeris et. al. (1963) and Mitra (1963). Similarly, we can find out the reflection coefficient (c) for the free surface by requiring stress $\bar{p}_{z\theta}$ to vanish at that surface.

$$C = R_{USH} = 1 \qquad \text{(B12)}$$

The reflection function $\zeta_n(p)$ is, therefore given by

$$\zeta_n'(p) = R_{USH}^{l_{USH}^{(n)}} R_{DSH}^{l_{DSH}^{(n)}} \qquad \text{(B13)}$$

where R_{USH} and R_{DSH} are given by (B12) and (B10) respectively. $l_{USH}^{(n)}$ is the number of SH to SH reflections off the free surface and similarly $l_{DSH}^{(n)}$ is the number of SH to SH reflections off the lower boundary.

The receiver function is calculated from stress-free boundary condition at the free surface (Phinney, 1967). The once transformed in time displacement due to an upgoing SH wave is

$$\bar{u}_{\theta,n}(r,o,s) = \frac{1}{2\pi^2\mu} \mathrm{Im} \int_0^{i\infty} \frac{sp}{\eta_1'} K_o(spr)\{1+R_{USH}\}e^{-\eta_1' h}\, dp \qquad \text{(B14)}$$

The function in braces is our receiver function R which can be easily seen to be identical to

$$R = 2 \qquad \text{(B15)}$$

Appendix C

COMPUTER PROGRAM

Here we give a printout of the program that we have used in evaluating Equations 5, 6 and 7. We have incorporated into this listing a detailed explanation of various features of the program. It was originally written by Don Helmberger. Barker (1970) extended it for the P-SV problem valid for both high and low frequency ranges. We included the SH wave option in it. The main program produces the impulse response. A secondary program then convolves this with a suitable source-function to give the final results.

```
C         MAIN
      IMPLICIT REAL*8 (A-H,O-Z)
C*********INTRODUCTION**************************************************
C
C   BRUCE GORDON AND CHANDRA M. NAUTIYAL ,54-524, M. I. T.
C
C   MAY 12, 1972
C
C THIS PROGRAM FOR DETERMINING THE THEORETICAL RESPONSE TO A POINT
C SOURCE OF AN ELASTIC LAYER OVER AN ELASTIC HALF SPACE IS UNDER
C REVISION TO EXTEND THE ORIGINAL MODEL OF TERRY BARKER TO INCLUDE
C AN SH SOURCE.
C
C THIS PROGRAM IS IN A FORM SUITED TO AN N-LAYER MODEL. THERE IS ALSO
C PROVISION FOR MODELING A HALF-SPACE ALONE(THE KPEK OPTION) WHICH I
C HAVE REMOVED FROM THIS PROGRAM FOR SIMPLICITY). SOME OF THESE
C UNNECESSARY FEATURES HAVE BEEN REMOVED,BUT FURTHER CLEANING UP IS
C REQUIRED TO OBTAIN  A GOOD WORKING PROGRAM. WHERE POSSIBLE I HAVE
C NOTED THE NECESSARY CHANGES.
C AT PRESENT ALL COMMON STATEMENTS ARE NOT OF THE SAME LENGTH IN EACH
C SUBPROGRAM NOR THE VARIABLES INTERFACED PROPERLY(I.E. IN ORDER OF
C DECREASING LENGTH).CLEANING UP THE COMMON STATEMENTS WILL IMPROVE
C THE EFFICIENCY OF THE PROGRAM.
C
C ALL CALCULATIONS ARE DOUBLE PRECISION UNLESS OTHERWISE NOTED
C
C*********SUBPROGRAMS***************************************************
C
C THE PROGRAM IS DIVIDED INTO MAIN AND THE FOLLOWING SUBPROGRAMS IN
C ALPHABETICAL  ORDER:      ADJUST,CONTOR,CR,CURAY,DELPS,FA,FIND2,
C HELP,HIGH,INTERP,PLN1,PLN2,PSICO,PTIM,RAYDEF,RECVR,REFFT,SETUP,SF2,
C TIME2,TS
C THE FUNCTION OF EACH SUBPROGRAM WILL BE MADE CLEAR IN THE BODY OF THE
C PROGRAM AND IN THE COMMENTS INCLUDED IN EACH.
C
C
```

```
C THE  SUBPROGRAMS SETUP,CONTOR,TIME2,PSICO,REFFT, AND RECVR HAVE BEEN
C REVISED SINCE THE LIBRARY WAS CREATED AND ARE NOW RUN AS SOURCE DECKS.
C
C**********ADDITIONAL PROGRAMS*******************************************
C
C CONVOLUTION WITH A SPECIFIED SOURCE  FUNCTION AND PLOTTING ON CALCOMP
C ARE PERFORMED IN ANOTHER PROGRAM.
C
C**********INPUT*********************************************************
C
C  THE INPUTS TO THIS PROGRAM ARE AS FOLLOWS: THE NUMBER OF LAYERS,NMOD,
C  IN FORMAT (I10) ON THE FIRST CARD. IN THIS CASE NMOD IS ALWAYS 3,
C  INCLUDING THE HALF SPACE ABOVE THE LAYER,WHICH IS A VACUUM.
C  THE NEXT CARDS CONTAIN IN SUCCESSION: THE COMPRESSIONAL AND  SHEAR
C  VELOCITIES IN EACH  LAYER (KM/SEC), THE DENSITY (GM/CC),AND THE
C  THICKNESS (KM). THE UPPER HALF SPACE PARAMETERS AND THE THICKNESS
C  OF THE SOLID HALF SPACE MAY BE ASSIGNED ANY VALUES.EACH CARD CONTAINS
C  THE VALUES FOR ONE LAYER IN FORMAT (4F10.0) .
C  THE NEXT CARD CONTAINS THE RANGE IN FORMAT(F10.0) .
C  THE NEXT CARD CONTAINS THE DESIRED INTERVAL BETWEEN RECORD POINTS(DP)
C  IN SEC,THE LENGTH OF RECORD CALCULATED FOR EACH RAY(TMX, IN SEC), AND
C  THE NUMBER OF RECORD POINTS(NN) IN THE FINAL OUTPUT IN FORMAT(2F10.0,
C  I10). THIS COMPLETES THE DATA READ-IN IN THE MAIN PROGRAM.
C
C  IN THE SUBROUTINE RAYDEF,THE PARAMETERS DESCRIBING THE PARTICULAR
C  MODEL ENTER THE PROGRAM.ON THE FIRST CARD THE LAYER THICKNESS IN
C  METERS,THE SOURCE DEPTH IN METERS,AND THE KIND OF SOURCE(KSSP=0 DESIGN
C  -ATES SHEAR SOURCE, AND KSSP=1 DESIGNATES COMPRESSIONAL SOURCE) ALL IN
C  FORMAT(2F10.0,I10). NOTE THAT IN PUTTING THE PROGRAM IN FINAL FORM A
C  SEPERATE DESIGNATION FOR SH SOURCE MIGHT BE CONVENIENT.
C  THE NEXT CARDS CONTAIN THE RAY PARAMETERS FOR (19,LAST RAY USED), THE
C  FIRST EIFHTEEN RAYS ARE CURRENTLY DEFINED IN RAYDEF. AS THE SUBROUTINE
C  RAYDEF HAS NO OTHER FUNCTION,IT WOULD BE CONVENIENT TO READ IN ALL THE
C  RAY PARAMETERS AND ELIMINATE THIS SUBROUTINE. THE FIRST SET OF
C  PARAMETER CARDS CONTAIN THE FOLLOWING IN FORMAT(4I1): KUD(J) (~~0~~ 1 FOR
C  UPGOING RAY,~~1~~ FOR DOWNGOING); LTS(J),THE NUMBER OF S-S REFLECTIONS;
                0
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REVERSED

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C LTP(J), THE NUMBER OF P-P REFLECTIONS,KRSP(J), THE MODE OF THE         00000720 MAIN0073
C RECEIVER(=0 FOR  S AND 1 FOR P)                                        00000730 MAIN0074
C THE NEXT SET OF CARDS CONTAIN THE VALUES OF THE TWO DIMENSIONAL ARRAY 00000740 MAIN0075
C LREF(I,J) WHICH DEFINE THE NATURE OF THE REFLECTIONS AT THE TOP        00000750 MAIN0076
C AND THE BOTTOM OF THE LAYER,EIGHT VALUES FOR EACH RAY DEFINING GIVING 00000760 MAIN0077
C FIRST THE NUMBER OF P TO P, S TO P, P TO S, AND S TO S INTERACTIONS   00000770 MAIN0078
C AT THE BOTTOM INTERFACE, NEXT THE SAME VALUES FOR THE FREE SURFACE.    00000780 MAIN0079
C THE SH PROGRAM SETS LTP AND KRSP ALWAYS EQUAL ZERO AND HAS NO PP,PS,  00000790 MAIN0080
C OR SP INTERACTIONS                                                     00000800 MAIN0081
C                                                                        00000810 MAIN0082
C**********OUTPUT*******************************************************00000820 MAIN0083
C                                                                        00000830 MAIN0084
C THIS PROGRAM GENERATES PUNCHED OUTPUT FOR THE THEORETICAL RESPONSE     00000840 MAIN0085
C UNCONVOLVED WITH ANY SOURCE FUNCTION, PRINTING FIRST THE STARTING TIME00000850 MAIN0086
C FOR THE RECORD IN SECONDS,TT(1), THE TIME INTERVAL BETWEEN DATA POINTS00000860 MAIN0087
C IN SECONDS,DP, AND THE NUMBER OF DATA POINTS IN THE RECORD,NN IN THE   00000870 MAIN0088
C FORMAT(2E15.6,I10). THIS HEADING CARD IS FOLLOWED BY THE SURFACE       00000880 MAIN0089
C RESPONSE IN FORMAT(5E15.6).                                            00000890 MAIN0090
C                                                                        00000900 MAIN0091
C THERE IS ALSO PRINTED OUTPUT,SOME OPTIONAL SOME NOT: FIRST A LISTING   00000910 MAIN0092
C OF MODEL PARAMETERS; THEN FOR EACH RAY, THE VALUES OF P AT THE POINT   00000920 MAIN0093
C OF REFLECTION(AN INTEGRATION PARAMETER) AND DP/DT AS COMPLEX NUMBERS; 00000930 MAIN0094
C THEN THE TIME(IN SEC) OF THE REFLECTION ARRIVAL OF THE SURFACE RESPONS00000940 MAIN0095
C -S,FOLLOWED BY THE SURFACE RESPONSE AT EVERY FIFTH CALCULATED VALUE.  00000950 MAIN0096
C NOTE THE DESIRED RESPONSE IS HERE GIVEN BY PHIZ, THE VERTICAL COMPONEN00000960 MAIN0097
C -T,AS THAT COMPONENT INVOLVES  THE KO BESSEL FUNCTION REQUIRED FOR AN 00000970 MAIN0098
C SH SOURCE. THE  PHIR(RADIAL) COMPONENT USES THE K1 BESSEL FUNCTION.    00000980 MAIN0099
C IN THIS APPROXIMATION ONLY THE FIRST TWO TERMS IN THE EXPANSION OF     00000990 MAIN0100
C THESE FUNCTIONS ARE RETAINED. THEREFORE THE TWO ITEMS DIFFER ONLY IN   00001000 MAIN0101
C THE SECOND TERM,AND IN THE FIRST-ORDER NOT AT ALL.                     00001010 MAIN0102
C THE RAY OUTPUT IS FOLLOWED BY A LISTING OF THE TIME SERIES OF THE      00001020 MAIN0103
C OUTPUT SURFACE RESPONSE. NOTE THAT THIS PRINTED RECORD IS PADDED WITH 00001030 MAIN0104
C ZEROES AT THE BEGINNING TC 10% OF ITS LENGTH                           00001040 MAIN0105
C                                                                        00001050 MAIN0106
C**********THE ORDER OF EXECUTION**************************************00001060 MAIN0107
C                                                                        00001070 MAIN0108
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C THE PROGRAM IS EXECUTED APPROXIMATELY AS FOLLOWS:
C MODEL PARAMETERS ARE READ IN OR OTHERWISE SPECIFIED IN MAIN. CONTROL
C IS THEN PASSED TO SUBROUTINE SETUP.
C IF THIS CALL IS FIRST TO SETUP,THE SUBROUTINE RAYDEF IS CALLED TO READ
C IN OR OTHERWISE ESTABLISH THE RAY PARAMETERS, THE ARRAYS WHICH CONTAIN
C THE OUTPUT ARE INITIALIZED, AND THE FUNCTION TS IS USED TO DETERMINE
C THE TIME OF FIRSTARRIVAL,THE BEGINNING OF THE RECORD. THE PROGRAM THEN
C ITERATES OVER EACH RAY .FOR EACH RAY THE FIRST SUBROUTINE CALLED IS
C HIGH. IN HIGH WE EMPLOY THE SUBROUTINE FIND2 TO DETERMINE THE VALUES
C OF PO AND TO,THAT IS THE VALUE OF THE INTEGRATION PARAMETER P AND THE
C TIME T AT THE REFLECTION ARRIVAL FOR THIS RAY.IN GENERAL EACH RAY
C RESPONSE IS DIVIDED INTO TWO PARTS, AN INTEGRATION ALONG THE REAL
C AXIS FOR THE REFRACTED RESPONSE, AND AN INTEGRATION ALONG THE COMPLEX
C CONTOUR FOR THE RESPONSE AFTER REFLECTION. FOR A DISCUSSION OF THE
C METHOD SEE THE REFERENCES. THE POINT OF REFLECTION IS FOUND WHERE THE
C CONTOUR LEAVES THE REAL AXIS AND DP/DT HAS A POLE.
C BEFORE THE REFRACTION ARRIVAL,THAT IS BEFORE THE FIRST BRANCH POINT
C AS GIVENBY P=1/(LARGEST VELOCITY OF PROPAGATION IN THE HALF SPACE),
C THE INTEGRAL IS ZERO. THE FIRST BRANCH CUT MAY NOT OCCUR UNTIL AFTER
C THE REFLECTION ARRIVAL .IF THIS IS SO THERE IS NO REFRACTED SIGNAL
C THE SUBROUTINE HELP IS NOW CALLED TO FIND THE TIME OF ARRIVAL OF THE
C REFRACTED SIGNAL AND THE VALUE OF DP/DT THERE. WE NOW COMPARE THIS
C REFRACTED ARRIVAL TIME WITH THE REFLECTED  ARRIVAL TIME AND CALCULATE
C THE INTEGRATION INTERVAL DELP FOR THE REFRACTED RECORD,THAT IS UP TO
C BUT NOT INCLUDING THE POINT OF REFLECTION. DEPENDING ON THE SEPERATION
C BETWEEN THE BRANCH CUT (REFRACTION ARRIVALS) AND THE POLE (REFLECTION
C ARRIVAL) THE INTERVAL SIZE MAY BE CONSTANT OR CALCULATED IN SUBROUTINE
C DELPS USING A SINE RELATIONSHIP. IF THERE IS A REFRACTED ARRIVAL
C CONTROL IS TRANSFERRED TO SUBROUTINE PLN1 TO PERFORM THIS PART OF THE
C INTEGRATION.NOTE THAT IF THERE IS A REFRACTED ARRIVAL THE FIRST VALUE
C OF THE TIME SERIES OF SURFACE RESPONSE IS ALWAYS SET TO ZERO. IN PLN1
C WE USE THE ALREADY CALCULATED INTERVALS DELP AND THE SUBROUTINE HELP
C TO CALCULATE THE TIME AND DP/DT FOR EACH VALUE OF THE INTEGRATION
C PARAMETER P.FOR EACH P WE THEN CALL THE SUBROUITNE PSICO.IN PSICO
C WE PERFORM THE INTEGRATION,CALCULATING THE TWO COMPLEX TERMS IN THE
C EXPANSION USED BY TERRY BARKER TO APPROXIMATE THE INTEGRAL.FIRST WE
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C CALL THE SUBROUTINE REFFT TO DETERMINE THE VALUE OF THE REFLECTION    00001440 MAIN0145
C FUNCTION, THEN THE SUBROUTINE RECVR TO DETERMINE THE RECEIVER FUNCTION00001450 MAIN0146
C WE THEN MULTIPLY THE REFLECTION FUNCTION BY ITSELF ACCORDING TO THE   00001460 MAIN0147
C NUMBER OF REFLECTIONS SPECIFIED IN ARRAY LREF.THE TWO COMPLEX TERMS   00001470 MAIN0148
C IN THE EXPANSION FOR THE RADIAL AND THE VERTICAL SURFACE RESPONSE ARE 00001480 MAIN0149
C THEN CALCULATED CONTROL RETURNS TO PLN1. WE THEN COMPLETE SIMILAR     00001490 MAIN0150
C CALCULATIONS FOR GRADUALLY DECREASING INTERVALS APPROACHING BUT NOT   00001500 MAIN0151
C INCLUDING THE POINT OF REFLECTION.CONTROL IS RETURNED TO HIGH.THE     00001510 MAIN0152
C SUBROUTINE CONTOR IS NOW CALLED TO DEFINE THE COMPLEX CONTOR OF INTE  00001520 MAIN0153
C -GRATION  FOR THE SIGNAL AFTER THE REFLECTION ARRIVAL.FIRST A SERIES  00001530 MAIN0154
C OF DECREASING INTERVALS IS CALCULATED ABOUT THE POINT OF REFLECTION.  00001540 MAIN0155
C THE INTEGRATION PARAMETER P IS NOW COMPLEX AND THIS COMPLEX CONTOUR   00001550 MAIN0156
C IS DEFINED BY REQUIRING THAT ANOTHER PARAMETER,THE TIME,BE REAL.      00001560 MAIN0157
C THEREFORE T THE CONTOUR IS DEFINED BY MINIMIZING THE IMAGINARY PART OF00001570 MAIN0158
C THE TIME PARAMETER IN SUBROUTINE TIME2. THE INTEGRATION INTERVALS     00001580 MAIN0159
C ABOUT THE SEVERAL BRANCH POINTS ARE DEFINED USING THE SUBROUTINE DELPS00001590 MAIN0160
C FOR A VARYING INTERVAL SIZE.AFTER THE LAST BRANCH POINT THE INTERVALS 00001600 MAIN0161
C INCREASE IN SIZE UNTIL THE END OF THE RECORD.CONTROL IS RETURNED TO   00001610 MAIN0162
C HIGH.                                                                 00001620 MAIN0163
C THE SUBROUTINE PLN2 IS THEN CALLED TO COMPLETE THE INTEGRATION FOR    00001630 MAIN0164
C THE REST OF THE CONTOUR.PLN2 USES PSICO TO CALCULATE THE TWO COMPLEX  00001640 MAIN0165
C TERMS FOR THE RADIAL AND THE VERTICAL  SURFACE RESPONSE FOR THE VALUES00001650 MAIN0166
C OF P DETERMINED IN CONTOUR. THIS NOW COMPLETE SET OF VALUES IS        00001660 MAIN0167
C CONVOLVED WITH THE APPROPRIATE TIME FUNCTIONS FOR THE ENTIRE CONTOUR. 00001670 MAIN0168
C NOTE THAT THE POINT OF REFLECTION IS SPECIALLY TREATED,USING THE      00001680 MAIN0169
C SUBROUTINE INTERP FOR INTERPOLATION AS NEEDED.CONTROL IS RETURNED TO  00001690 MAIN0170
C HIGH. THE OUTPUT IS PRINTED FOR EVERY FIFTH VALUE OF THE TIME SERIES  00001700 MAIN0171
C AND THE CONTROL IS RETURNED TO SETUP.WE NOW CALL USE THE SUBROUTINE   00001710 MAIN0172
C ADJUST.ORIGINALLY WE SPECIFIED A DESIRED OUTPUT,DESIGNATING LENGTH OF 00001720 MAIN0173
C RECORD FOR EACH  RAY,TMX,THE TIME INTERVAL,DP,AND THE NUMBER OF POINTS00001730 MAIN0174
C IN THE SERIES,NN.WE NOW ADJUST THIS DESIRED SERIES SO THAT ONE POINT  00001740 MAIN0175
C OF IT COINCIDES WITH THE REFLECTION ARRIVAL AT TO. WE NOW USE THE     00001750 MAIN0176
C SUBROUTINE INTERP TO INTERPOLATE THE OUTPUT TO THE DESIRED TIME SERIES00001760 MAIN0177
C THE SUBROUTINE DDGT3 IS THEN USED TO TAKE THE TIME DERIVETIVE ,AND    00001770 MAIN0178
C THE OUTPUT IS PRINTED AND PUNCHED ON CARDS.CONTROL RETURNS TO MAIN    00001780 MAIN0179
C AND PROGRAM ENDS.                                                     00001790 MAIN0180
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C
C***********************************************************************
C THE MAIN PROGRAM
C
C THE MAIN PROGRAM SERVES THREE FUNCTIONS,READ-IN OF PARAMETERS DESCRI
C -BING THE MODEL,SETTING THE VALUES OF CONSTANTS, AND CALLING ONCE THE
C SUBROUTINE SETUP WHICH CONTROLS ALL ACTUAL CALCULATIONS.IT IS
C SUGGESTED THAT ALL THE PARAMETER READ-INS BE INCLUDED IN MAIN ELIMINAT
C -ING ,THE SUBROUTINE RAYDEF,WHICH DEFINES RAY PARAMETERS,AND THAT THE
C CONSTANTS MIGHT BE SET IN A BLOCK DATA SUBPROGRAM FOR CONVENIENCE,
C SO THAT THE MAIN SIMPLY READS IN PARAMETERS AND CALLS SETUP. THUS ALL
C THE SUBROUTINES MAY BE PLACED IN A DISC LIBRARY AND THE LENGTH OF THE
C MAIN PROGRAM MINIMIZED.
C
C THE MAIN PROGRAM CALLS THE SUBPROGRAMS CURAY AND SETUP
C***********************************************************************
      COMMON/ORSTF/C(100),S(100),D(100),TH(100),X
      COMMON/CONFIX/DEL,NN,NDP,TMX,XDIM,YDIM,DP,KD
      COMMON/STUFF/CC(100),SS(100),DD(100),TTH(100),XX,RCSQ(100),
     1             RSSQ(100)
      COMMON/THY/T(1000),PP(1000),RP(600)
      COMMON/PLOTC/CON,NNF,NPT,NSYN
      COMMON/FIXP/DDN(100),ARN(100),FLAT
      COMMON/STOR/P(1000),TD(1000)
      COMMON/THZ/TT(1000),PPZ(1000),PPR(1000)
      COMMON/TINP/DELTM,DLTM,NDA,MTD,DLTP,NDB,JO,NDIRT
      COMMON/LPRINT/PRNT,PRNTS,KST,KEND,PRNTC,NDC,DET
      COMMON/CTRSTF/NCASE,NPRAY,NYT,NDUM,VRL2,VRL3
      COMMON/MYER/ DTIM
      DIMENSION R(10)
      LOGICAL PRNT,PRNTS,PRNTC,FLAT
      FLAT=.TRUE.
      PRNT = .FALSE.
      PRNTS = .FALSE.
      PRNTC=.FALSE.
C FLAT IS USED IN CURAY AND FOR THIS PROGRAM IS ALWAYS TRUE,INDICATING
```

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C THAT THE MODEL USES A FLAT SECTION RATHER THAN AN ACTURAL SPHERICAL   00002160 MAIN0217
C MODEL OF THE EARTH                                                    00002170 MAIN0218
C THESE THREE VARIABLES CONTROLS THE PRINTING OF INTERMEDIATE RESULTS   00002180 MAIN0219
C OF SOME DIAGNOSTIC IMPORTANCE. IN PARTICULAR PRNTC=TRUE.PRINTS ALL THE00002190 MAIN0220
C ITERATION STEPS IN SUBROUTINE TIME2 FOR DETERMINING THE IMAGINARY     00002200 MAIN0221
C PART OF THE INTEGRATION VARIABLE T,THAT IS TIME ALONG THE COMPLEX     00002210 MAIN0222
C CONTOUR AFTER REFLECTION.DO NOT USE THIS OPTION IF RUNNING FOR MORE   00002220 MAIN0223
C THAN ONE RAY AS A PROHIBITIVE VOLUME OF OUTPUT IS PRODUCED.           00002230 MAIN0224
C IN GENERAL IT IS BEST NOT TO SET THESE OPTIONS TO TRUE FOR A RUN      00002240 MAIN0225
C INVOLVING MORE THAN A FEW RAYS                                        00002250 MAIN0226
C                                                                       00002260 MAIN0227
C INPUT MODEL PARAMETERS                                                00002270 MAIN0228
C                                                                       00002280 MAIN0229
      READ (5,100) NMOD                                                 00002290 MAIN0230
      DO 200 J=1,NMOD                                                   00002300 MAIN0231
200   READ (5,300) C(J),S(J),D(J),TH(J)                                 00002310 MAIN0232
100   FORMAT (I10)                                                      00002320 MAIN0233
300   FORMAT (4F10.0)                                                   00002330 MAIN0234
600   READ(5,500) X,IGO,KPEK                                            00002340 MAIN0235
500   FORMAT (F10.0,2I10)                                               00002350 MAIN0236
      READ (5,501)  DP,TMX,NN                                           00002360 MAIN0237
501   FORMAT (2F10.0,I10)                                               00002370 MAIN0238
C                                                                       00002380 MAIN0239
C ASSIGN VALUES TO CONSTANTS                                            00002390 MAIN0240
C                                                                       00002400 MAIN0241
      NNF=1                                                             00002410 MAIN0242
      NPT=0                                                             00002420 MAIN0243
      JO=3                                                              00002430 MAIN0244
C DESIGNATES A THREE LAYER MODEL                                        00002440 MAIN0245
      CALL CURAY (JO)                                                   00002450 MAIN0246
C CURAY IS APPARENTLY DESIGNED TO ALLOW FOR USE OF A SPHERICAL SECTION  00002460 MAIN0247
C OF THE EARTH AND IS REALLY UNNECESSARY HERE,IT CALCULATES A FEW       00002470 MAIN0248
C CONSTANTS SUCH AS THE SQUARES OF THE VELOCITIES. THESE CALCULATIONS   00002480 MAIN0249
C COULD EASILY BE INTEGRATED INTO THE MAIN PROGRAM                      00002490 MAIN0250
      CON =1.0/(2.*(3.14159**2)*D(2)*S(2)**2)                           00002500 MAIN0251
C CON IS A FACTOR USED IN PSICO TO CALCULATE THE TERMS OF THE SURFACE   00002510 MAIN0252
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C RESPONSE.
      XX=X
C XX IS THE RANGE
      MTD=2
C MTD IS USED IN CONTOR TO INCREASE THE INTERVAL SIZE BETWEEN THE LAST
C BRANCHPOINT AND THE END OF THE RECORD
      DELTM=.0025
C DELTM IS THE MINIMUM SIZE P(INTEGRATION VARIABLE) STEP,SEE CONTOR
C SUBROUTINE
      DMAX=1.E-4
      DLTM=.1
      NDP=30
C NDP IS A PARAMETER USED IN SUBROUTINE DELPS IN CALCULATING INTEGRATION
C INTERVALS USING A SINE RELATIONSHIP
      DET=1.E-5
      DTIM=DP
C IN CALCULATING INTEGRATION INTERVALS ON THE COMPLEX CONTOUR SIDE OF
C REFLECTION POINT ,THE CALCULATION IS TERMINATED WHEN IT IS WITHIN
C DTIM OF TO,THE TIME OF REFLECTION
      DEL=DP
C DEL IS USED AS THE DELTA INTERVAL FOR THE TIME SERIES OF SURFACE
C RESPONSE
      DLTP=DP
      NYT=3
      VRL2=.92*S(2)
      VRL3=.92*S(3)
      NPRAY=40
      K=NN/2
      NCASE = 0
C NCASE REFERS TO THE SOURCE AND MODEL COMBINATION,NCASE=0 DESIGNATES
C SH SOURCE AND THREE LAYER MODEL AS HERE,=1 P,SV,SOURCE AND SAME MODEL
C ,=2 IS APPARENTLY USED FOR SOLID HALF SPACE RUNS,NOT RELEVENT HERE
C SETUP EXECUTES THE PROGRAM AND GENERATES OUTPUT
      CALL SETUP(1,0,01,36,0,MPLOT,1)
         END
ADJT
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      SUBROUTINE ADJUST(NN,NFIX)                                          00002870 MAIN0289
      IMPLICIT REAL*8  (A-H,O-Z)                                          00002880 MAIN0290
      COMMON/EXACT/PHIZ(1000),PHIR(1000),TD(1000),NEND,NM                 00002890 MAIN0291
      COMMON/THZ/  T(1000),PPZ(1000),PPR(1000)                            00002900 MAIN0292
      M          = NM+1                                                   00002910 MAIN0293
      TR         = TD(M)                                                  00002920 MAIN0294
      I          = 0                                                      00002930 MAIN0295
 80    I         = I+1                                                    00002940 MAIN0296
      IF(I.GT.NN) GO TO 70                                                00002950 MAIN0297
      IF(T(I).GT.TR) GO TO 81                                             00002960 MAIN0298
      GO TO 80                                                            00002970 MAIN0299
 81    DNE       = TR-T(I-1)                                              00002980 MAIN0300
      DPL        = T(I)-TR                                                00002990 MAIN0301
      IF (DABS(DNE) .GT. DABS(DPL))  GOT O 83                             00003000 MAIN0302
      DELTA      = -DNE                                                   00003010 MAIN0303
      NFIX       = I-1                                                    00003020 MAIN0304
      GO TO 85                                                            00003030 MAIN0305
 83     DELTA    = DPL                                                    00003040 MAIN0306
      NFIX       = I                                                      00003050 MAIN0307
 85    DO 84 J=1,NEND                                                     00003060 MAIN0308
      TD(J)      = TD(J)+DELTA                                            00003070 MAIN0309
 84     CONTINUE                                                          00003080 MAIN0310
      RETURN                                                              00003090 MAIN0311
 70     NFIX     = 0                                                      00003100 MAIN0312
      RETURN                                                              00003110 MAIN0313
      END                                                                 00003120 MAIN0314
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      SUBROUTINE CONTOR(TMX,M,KN,N,MO)                                  00003130 CONT0001
C***********************************************************************00003140 CONT0002
C THIS SUBROUTINE SPECIFIES THE COMPLEX CONTOUR OF INTEGRATION FOR THE  00003150 CONT0003
C REFLECTED ARRIVAL                                                     00003160 CONT0004
C THE SUBRPOGRAMS TIME2 AND DELPS ARE CALLED                            00003170 CONT0005
C                                                                       00003180 CONT0006
C CALL LIST: TMX IS THE LENGTH OF RECORD(IN SEC) TO BE CALCULATED AFTER 00003190 CONT0007
C THE REFLECTED ARRIVAL,M HAS NO APPARENT FUNCTION,NCR DOES KN,N IS THE 00003200 CONT0008
C RAY NUMBER ,AND MO TNE NUMBER OF POINTS FIRST FOLLOWING THE REFLECTION00003210 CONT0009
C ARRIVAL.                                                              00003220 CONT0010
C***********************************************************************00003230 CONT0011
      IMPLICIT REAL*8  (A-H,O-Z)                                        00003240 CONT0012
      COMMON/MAGIC/PP(1200),DDPT(1200),TT(1200)                         00003250 CONT0013
      COMMON/SPE/DELP(800),DD1,DD2,DD3,DD4,NU                           00003260 CONT0014
      COMMON/PATHC/PO,TO,K                                              00003270 CONT0015
      COMMON/TINP/DELTM,DLTM,NDA,MTD,DLTP,NDB,JO,NDIRT                  00003280 CONT0016
      COMMON/TFIX/TN1,TN2,TN3,TN4,JN1,JN2,JN3,JN4                       00003290 CONT0017
      COMMON/CTRSTF/NCASE,NPRAY,NYT,NDUM,VRL2,VRL3                      00003300 CONT0018
      DIMENSION DER(400)                                                00003310 CONT0019
      LOGICAL PRNT,PRNTS,PRNTC                                          00003320 CONT0020
      COMMON/LPRINT/PRNT,PRNTS,KST,KEND,PRNTC,NDC,DET                   00003330 CONT0021
      COMMON/MYER/ DTIM                                                 00003340 CONT0022
      COMPLEX*16  PP,DDPT,P,CT,DEV                                      00003350 CONT0023
      DET = 1.D-5                                                       00003360 CONT0024
      JN        = 10                                                    00003370 CONT0025
 1    Q         = PO                                                    00003380 CONT0026
      I         = MO-1                                                  00003390 CONT0027
      PIL       = 1.E-6                                                 00003400 CONT0028
      PP(I)     = PO                                                    00003410 CONT0029
      TT(I)     = TO                                                    00003420 CONT0030
      KM        = 100                                                   00003430 CONT0031
      IF(DELP(1).LE.DELTM) DELP(1)=DELTM                                00003440 CONT0032
 33    I        = KM-1                                                  00003450 CONT0033
      L         = 0                                                     00003460 CONT0034
      DO 10 J=1,JN                                                      00003470 CONT0035
      L         = L+1                                                   00003480 CONT0036
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      I          = I+1                                                  00003490 CONT0037
 9    Q          = Q+DELP(J)                                            00003500 CONT0038
      PI         = PO*.2                                                00003510 CONT0039
      DL         = PI*.45                                               00003520 CONT0040
      CALL TIME2(Q,PI,DL,P,DEV,CT,KN,N,PIL)                             00003530 CONT0041
      RTIME      = CT                                                   00003540 CONT0042
      TIMEI      = CT*(0.,-1.)                                          00003550 CONT0043
      DR         = DEV                                                  00003560 CONT0044
      DDPT(I)    = DEV                                                  00003570 CONT0045
      TT(I)      = RTIME                                                00003580 CONT0046
      PP(I)      = P                                                    00003590 CONT0047
      IF(TT(I)-TO.LE.DTIM) GO TO 32                                     00003600 CONT0048
      IF(DR.LE.0.) GO TO 30                                             00003610 CONT0049
      IF(DABS(TIMEI).GT.1.E-3) GO TO 30                                 00003620 CONT0050
      IF(RTIME-TO.LT..001) GO TO 30                                     00003630 CONT0051
      JJ         = J+1                                                  00003640 CONT0052
      DELP(JJ) =      ((PO-PP(I))/2.)                                   00003650 CONT0053
10      CONTINUE                                                        00003660 CONT0054
30     IF(I.LE.KM) DELP(1)=5.*DELP(1)                                   00003670 CONT0055
      IF(I.LE.KM) GO TO 33                                              00003680 CONT0056
      PRINT 101                                                         00003690 CONT0057
  101 FORMAT(//' EXIT LOOP CONDITION IN CONTOR: I.GT.KM- STATEMENT 30'/)00003700 CONT0058
      I          = I-1                                                  00003710 CONT0059
32     JJ        = I-KM+1                                               00003720 CONT0060
      DO 31 J=1,JJ                                                      00003730 CONT0061
      LL         = MO+J-1                                               00003740 CONT0062
      NN         = I-J+1                                                00003750 CONT0063
      TT(LL)     = TT(NN)                                               00003760 CONT0064
      PP(LL)     = PP(NN)                                               00003770 CONT0065
      DDPT(LL) = DDPT(NN)                                               00003780 CONT0066
31     CONTINUE                                                         00003790 CONT0067
      I          = LL                                                   00003800 CONT0068
      DELP(JN) =      (PP(LL)-PP(LL-1))                                 00003810 CONT0069
      J          = JN                                                   00003820 CONT0070
      MM         = 1                                                    00003830 CONT0071
      TM         = TMX+TO                                               00003840 CONT0072
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      PI         = PP(LL)*(0.,-1.)                                       00003850 CONT0073
      Q          = PP(LL)                                                00003860 CONT0074
      JF = LL                                                            00003870 CONT0075
      DER(JF) = PP(LL) - PP(LL-1)                                        00003880 CONT0076
      IF(NCASE.EQ.0) GO TO 12                                            00003890 CONT0077
      IF(NCASE.EQ.1)RG=DABS(1./VRL2-Q)                                   00003900 CONT0078
      IF(NCASE.EQ.2)RG=DABS(1./VRL3-Q)                                   00003910 CONT0079
      CALL DELPS(NPRAY,RG,1,NYT)                                         00003920 CONT0080
      J1         = LL                                                    00003930 CONT0081
      J2         = J1+NO                                                 00003940 CONT0082
      IJ         = 0                                                     00003950 CONT0083
      DO 21 J=J1,J2                                                      00003960 CONT0084
      IJ         = IJ+1                                                  00003970 CONT0085
21     DER(J)    = DELP(IJ)                                              00003980 CONT0086
      JF         = J2                                                    00003990 CONT0087
      IF(NCASE.EQ.1) GO TO 23                                            00004000 CONT0088
      RG         =DABS(1./VRL2-1./VRL3)                                  00004010 CONT0089
      CALL DELPS(NPRAY,RG,1,NYT)                                         00004020 CONT0090
      J1         = J2+1                                                  00004030 CONT0091
      J2         = J1+NO                                                 00004040 CONT0092
      IJ         = 0                                                     00004050 CONT0093
      DO 24 J=J1,J2                                                      00004060 CONT0094
      IJ         = IJ+1                                                  00004070 CONT0095
24     DER(J)    = DELP(IJ)                                              00004080 CONT0096
      JF         = J2                                                    00004090 CONT0097
23     IF(PRNTC)  WRITE(6,100) (DER(J),J=J1,J2)                          00004100 CONT0098
100      FORMAT(6E12.4)                                                  00004110 CONT0099
      DO 25 J=LL,JF                                                      00004120 CONT0100
      Q          = Q+DER(J)                                              00004130 CONT0101
      I          = I+1                                                   00004140 CONT0102
      DELPR      =      (PP(I-1)-PP(I-2))                                00004150 CONT0103
      DELPI      =        (PP(I-1)-PP(I-2))   *(0.,-1.)                  00004160 CONT0104
      PI         = (DELPI*DER(J)     )/DELPR  +PI                        00004170 CONT0105
      DL         = PI*.5                                                 00004180 CONT0106
      CALL TIME2(Q,PI,DL,P,DEV,CT,KN,N,PIL)                              00004190 CONT0107
      PP(I)      = P                                                     00004200 CONT0108
```

```
      RTIME     = CT                                                     00004210 CONT0109
      DDPT(I)   = DEV                                                    00004220 CONT0110
      TT(I)     = RTIME                                                  00004230 CONT0111
      IF(TT(I).GT.TM) GO TO 13                                           00004240 CONT0112
   25   CONTINUE                                                         00004250 CONT0113
   12   Q       = Q+MM*DER(JF)                                           00004260 CONT0114
      I         = I+1                                                    00004270 CONT0115
      DELPR     =      (PP(I-1)-PP(I-2))                                 00004280 CONT0116
      DELPI     =        (PP(I-1)-PP(I-2)) *(0.,-1.)                     00004290 CONT0117
      PI        = (DELPI*MM*DER(JF))/DELPR +PI                           00004300 CONT0118
      DL        = PI*.5                                                  00004310 CONT0119
      CALL TIME2(Q,PI,DL,P,DEV,CT,KN,N,PIL)                              00004320 CONT0120
      PP(I)     = P                                                      00004330 CONT0121
      RTIME     = CT                                                     00004340 CONT0122
      DDPT(I)   = DEV                                                    00004350 CONT0123
      TT(I)     = RTIME                                                  00004360 CONT0124
      IF(TT(I).GT.TM) GO TO 13                                           00004370 CONT0125
   14  IF(TT(I)-TT(I-1).LE.DLTM) MM=MTD*MM                               00004380 CONT0126
      GO TO 12                                                           00004390 CONT0127
   13   CONTINUE                                                         00004400 CONT0128
      M         = I                                                      00004410 CONT0129
      RETURN                                                             00004420 CONT0130
      END                                                                00004430 CONT0131
```

```
      COMPLEX FUNCTION CR*16 (P,C)                                      00004440 CRFN0001
      IMPLICIT REAL*8  (A-H,O-Z)                                        00004450 CRFN0002
      COMPLEX*16  P,CZ                                                  00004460 CRFN0003
      CZ=1./C**2-P*P                                                    00004470 CRFN0004
      U=CZ                                                              00004480 CRFN0005
      X=CZ*(0.,-1.)                                                     00004490 CRFN0006
      R=DSQRT(X*X + U*U)                                                00004500 CRFN0007
      W1= DABS(R+U)/2.                                                  00004510 CRFN0008
      W2= DABS(R-U)/2.                                                  00004520 CRFN0009
      R1=DSQRT(W1)                                                      00004530 CRFN0010
      R2=DSQRT(W2)                                                      00004540 CRFN0011
      CR=R1-R2*(0.,1.)                                                  00004550 CRFN0012
      RETURN                                                            00004560 CRFN0013
      END                                                               00004570 CRFN0014
```

```
      SUBROUTINE CURAY(JO)                                              00004580 CURY0001
      IMPLICIT REAL*8  (A-H,O-Z)                                        00004590 CURY0002
      COMMON /SENSE/ DRCSQ(100) ,DRSSQ(100)                             00004600 CURY0003
      COMMON/STUFF/C(100),S(100),D(100),TH(100),X,RCSQ(100),RSSQ(100)   00004610 CURY0004
      COMMON/DRSTF/CC(100),SS(100),DD(100),TTH(100),XX                  00004620 CURY0005
      COMMON/FIXP/DDN(100),ARN(100),FLAT                                00004630 CURY0006
      LOGICAL FLAT                                                      00004640 CURY0007
      DIMENSION DEPTH(100)                                              00004650 CURY0008
       DIMENSION DT(100)                                                00004660 CURY0009
       X        = XX                                                    00004670 CURY0010
      PRINT 2, X                                                        00004680 CURY0011
    2 FORMAT (1H1,10X,'CURAY' /11X,'RANGE',F10.0/16X,'THICKNESS',9X,'   00004690 CURY0012
     +DEPTH',5X,'P-VELOCITY',5X,'S-VELOCITY',8X,'DENSITY')              00004700 CURY0013
      DEPTH(1) = TTH(1)/2.0                                             00004710 CURY0014
      DO 10 J = 2,JO                                                    00004720 CURY0015
   10  DEPTH(J)= DEPTH(J-1)+(TTH(J)+TTH(J-1))/2.                        00004730 CURY0016
      DO 5 J = 1,JO                                                     00004740 CURY0017
      Q        = 6371.0 / (6371.0-DEPTH(J))                             00004750 CURY0018
      IF(FLAT) Q     = 1.                                               00004760 CURY0019
      ARN(J)   = 1./Q                                                   00004770 CURY0020
      C(J)     = CC(J)*Q                                                00004780 CURY0021
       S(J)    = SS(J)*Q                                                00004790 CURY0022
      D(J)     = DD(J)*Q                                                00004800 CURY0023
       TH(J)   = TTH(J)*Q                                               00004810 CURY0024
      DRCSQ(J) = 1.0 / C(J) **2                                         00004820 CURY0025
      DRSSQ(J) = 1.0 / S(J)**2                                          00004830 CURY0026
      RCSQ(J)  = DRCSQ(J)                                               00004840 CURY0027
      RSSQ(J)  = DRSSQ(J)                                               00004850 CURY0028
    5   CONTINUE                                                        00004860 CURY0029
      DT(1)    = TTH(1)                                                 00004870 CURY0030
      DO 20 J=2,JO                                                      00004880 CURY0031
      DT(J)    = DT(J-1) +TTH(J)                                        00004890 CURY0032
   20   CONTINUE                                                        00004900 CURY0033
      DO 25 J=1,JO                                                      00004910 CURY0034
      IF(FLAT) DT(J) = 0.0                                              00004920 CURY0035
      DDN(J)   = (6371.-DT(J))/6371.                                    00004930 CURY0036
```

```
25      CONTINUE                                                          00004940 CURY0037
      PRINT 1, (J,TH(J),DEPTH(J),C(J),S(J),D(J),ARN(J),DDN(J),J=1,JO)    00004950 CURY0038
1     FORMAT (I5,5X,7G15.4)                                              00004960 CURY0039
      RETURN                                                             00004970 CURY0040
      END                                                                00004980 CURY0041
```

```
      SUBROUTINE DELPS (NNN,RG,NN,N)                                            00004990 DELP0001
      IMPLICIT REAL*8  (A-H,O-Z)                                                00005000 DELP0002
      DIMENSION PP(200)                                                         00005010 DELP0003
      COMMON/SPE/DELP(800),DD1,DD2,DD3,DD4,NO                                   00005020 DELP0004
      RG        = RG-1.E-08                                                     00005030 DELP0005
      PI        = 3.141593                                                      00005040 DELP0006
      AN        = PI/(NNN*2.)                                                   00005050 DELP0007
      J         = NN                                                            00005060 DELP0008
      A         = AN                                                            00005070 DELP0009
      DELP(J)   = RG*(DSIN(A)**N)                                               00005080 DELP0010
      TO        = DELP(J)                                                       00005090 DELP0011
      A         = A+AN                                                          00005100 DELP0012
       K        = 1                                                             00005110 DELP0013
      PP(1)     = DELP(1)                                                       00005120 DELP0014
1       J       = J+1                                                           00005130 DELP0015
      K         = K+1                                                           00005140 DELP0016
      PP(K)     = RG*DSIN(A)**N                                                 00005150 DELP0017
      DELP(J)   = PP(K)-PP(K-1)                                                 00005160 DELP0018
      DELP(J)   =DABS (DELP(J))                                                 00005170 DELP0019
      TO        = TO+DELP(J)                                                    00005180 DELP0020
      A         = A+AN                                                          00005190 DELP0021
      IF(TO.LT.RG) GO TO 1                                                      00005200 DELP0022
2       NO      = J-1                                                           00005210 DELP0023
      RETURN                                                                    00005220 DELP0024
      END                                                                       00005230 DELP0025
```

```
      SUBROUTINE FIND2 (Q,K,DEL,DET,PQ,TQ,NRY)                          00005240 FND20001
      IMPLICIT REAL*8  (A-H,O-Z)                                        00005250 FND20002
      DIMENSION E(100)                                                  00005260 FND20003
      COMMON/RAYPAR/KUD(100),KRSP(100),LTS(100),LTP(100),LREF(100,4)    00005270 FND20004
      COMMON/PLACE/THIC,H,KSSP                                          00005280 FND20005
      COMMON/STUFF/C(100),S(100),D(100),TH(100),X                       00005290 FND20006
      COMMON /SENSE/ RCSQ(100),RSSQ(100)                                00005300 FND20007
      COMMON / LPRINT/ PRNT,PRNTS                                       00005310 FND20008
      LOGICAL PRNT,PRNTS                                                00005320 FND20009
      TH(1)     = (1.-KUD(NRY))*(THIC-H) + KUD(NRY)*H                   00005330 FND20010
      TH(3)     = 0.                                                    00005340 FND20011
      TH(4)     = 0.                                                    00005350 FND20012
      IF (KSSP .EQ. 1)  TH(4)=TH(1)                                     00005360 FND20013
      IF (KSSP .EQ. 0)  TH(3)=TH(1)                                     00005370 FND20014
      KF        = 1                                                     00005380 FND20015
      KOUNT     = 0                                                     00005390 FND20016
      TDE       = DEL                                                   00005400 FND20017
8     P         = Q                                                     00005410 FND20018
      KOUNT     = KCUNT + 1                                             00005420 FND20019
5       P       = P+DEL                                                 00005430 FND20020
      PSQ       = P ** 2                                                00005440 FND20021
      E(2)      = DSQRT(DABS(RCSQ(2)-PSQ))                              00005450 FND20022
      E(3)      = DSQRT(DABS(RSSQ(2)-PSQ))                              00005460 FND20023
      BLTEM     = -TH(2)*LTP(NRY)/E(2) -TH(2)*LTS(NRY)/E(3)             00005470 FND20024
      BLTEM     = BLTEM-TH(4)/E(2)                                      00005480 FND20025
      BLTEM     = BLTEM-TH(3)/E(3)                                      00005490 FND20026
      BL        = X + BLTEM*P                                           00005500 FND20027
      IF(DABS (DEL).LE.1.E-18) GO TO 1                                  00005510 FND20028
6     IF (DABS(BL).LE.X/DET) GO TO 1                                    00005520 FND20029
2      IF(BL)3,1,4                                                      00005530 FND20030
3      DEL      =-DABS (DEL*.5)                                         00005540 FND20031
      GO TO 5                                                           00005550 FND20032
4      DEL      =DABS(DEL*.5)                                           00005560 FND20033
       GO TO 5                                                          00005570 FND20034
1     IF(DABS(BL).LT.1.E-8) GO TO 7                                     00005580 FND20035
      IF (KOUNT.GE.5) GO TO 7                                           00005590 FND20036
```

```
      Q          = Q/10.0                                                    00005600 FND20037
      DEL        = TDE                                                       00005610 FND20038
      GO TO 8                                                                00005620 FND20039
 7    PO         = P                                                         00005630 FND20040
      TOTEM      = E(2)*TH(4)+E(2)*LTP(NRY)*TH(2)+E(3)*LTS(NRY)*TH(2)       00005640 FND20041
     1       +E(3)*TH(3)                                                     00005650 FND20042
      TO         = P*X + TOTEM                                               00005660 FND20043
      PQ         = PO                                                        00005670 FND20044
      TQ         = TO                                                        00005680 FND20045
      IF (DABS(BL).LT.1.0E-6) RETURN                                         00005690 FND20046
      IF (.NOT.PRNT) RETURN                                                  00005700 FND20047
      WRITE (6,17) PO,TO,BL                                                  00005710 FND20048
 17   FORMAT (1H0,4X,'PO  ',E18.6,10X,'TO  ',E18.6,10X,'BL  ',E18.6)        00005720 FND20049
      RETURN                                                                 00005730 FND20050
      END                                                                    00005740 FND20051
```

```
      SUBROUTINE HELP(K,N,P,TTP,DTP,NRY)                                 00005750 HELP0001
      IMPLICIT REAL*8  (A-H,O-Z)                                         00005760 HELP0002
      COMMON/STUFF/C(100),S(100),D(100),TH(100),X,RCSQ(100),RSSQ(100)    00005770 HELP0003
      COMMON/RAYPAP/KUD(100),KRSP(100),LTS(100),LTP(100),LREF(100,4)     00005780 HELP0004
      COMMON/LPRINT/PRNT,PRNTS,KST,KEND,PRNTC,NDC,DET                    00005790 HELP0005
      LOGICAL PRNT,PRNTS,PRNTC,FLAT                                      00005800 HELP0006
  100 FORMAT(10X,'SUB. HELP,P,E,TOTEM,BLTEM,DTP,TTP',/,6(E16.6))         00005810 HELP0007
      PSQ        = P**2                                                  00005820 HELP0008
      J          = 2                                                     00005830 HELP0009
      E          =DSQRT(DABS(RCSQ(J)-PSQ))                               00005840 HELP0010
      TOTEM      = E*(TH(4)+TH(2)*LTP(NRY))                              00005850 HELP0011
      BLTEM      = -(TH(4)+TH(2)*LTP(NRY))/E                             00005860 HELP0012
      IF(PRNTC) WRITE(6,100) P,E,TOTEM,BLTEM,DTP,TTP                     00005870 HELP0013
      E          =DSQRT(DABS(RSSQ(J)-PSQ))                               00005880 HELP0014
      TOTEM      = TOTEM+TH(2)*LTS(NRY)*E +TH(3)*E                       00005890 HELP0015
      BLTEM      = BLTEM-TH(2)*LTS(NRY)/E -TH(3)/E                       00005900 HELP0016
      BL         = X + P*BLTEM                                           00005910 HELP0017
      TO         = P*X + TOTEM                                           00005920 HELP0018
      DTP        = 1./BL                                                 00005930 HELP0019
      TTP        = TO                                                    00005940 HELP0020
      IF(PRNTC) WRITE(6,100) P,E,TOTEM,BLTEM,DTP,TTP                     00005950 HELP0021
      RETURN                                                             00005960 HELP0022
      END                                                                00005970 HELP0023
```

```
      SUBROUTINE HIGH(NDP,TMX,K,KI,N)                                   00005980 HIGH0001
C***********************************************************************00005990 HIGH0002
C THE SUBPROGRAM HIGH CALCULATES THE SURFACE RESPONSE FOR EACH RAY      00006000 HIGH0003
C NDP IS USED IN CALCULATING THE INTEGRATION STEPS ABOUT REFLECTION ,   00006010 HIGH0004
C TMX IS THE LENGTH OF THE RECORD READ IN MAIN,K AND KI DO NOT SEEM TO  00006020 HIGH0005
C BE USED, N IS THE RAY NUMBER                                          00006030 HIGH0006
C THE SUBPROGRAM FIND2,HELP,DELPS,PLN1,CONTOR,AND PLN2 ARE CALLED       00006040 HIGH0007
C THE SURFACE RESPONSE IS PRINTED FOR EVERY FIFTH RAY                   00006050 HIGH0008
C***********************************************************************00006060 HIGH0009
      IMPLICIT REAL*8  (A-H,O-Z)                                        00006070 HIGH0010
      COMMON/RAYPAR/KUD(100),KRSP(100),LTS(100),LTP(100),LREF(100,4)    00006080 HIGH0011
      COMMON/PLACE/THIC,H,KSSP                                          00006090 HIGH0012
      COMMON/EXACT/PHIZ(1000),PHIR(1000),TD(1000),NEND,NM               00006100 HIGH0013
      COMMON/MAGIC/PP(1200),DDPT(1200),TT(1200)                         00006110 HIGH0014
      COMMON/SPE/DELP(800),DD1,DD2,DD3,DD4,ND                           00006120 HIGH0015
       COMMON/PATHC/PO,TO,KK                                            00006130 HIGH0016
      COMMON/TINP/DELTM,DLTM,NDA,MTD,DLTP,NDB,JO,NDIRT                  00006140 HIGH0017
      COMMON/ORSTF/CC(100),SS(100),DD(100),TTH(100),XX                  00006150 HIGH0018
      COMMON / LPRINT/ PRNT,PRNTS                                       00006160 HIGH0019
      LOGICAL PRNT,PRNTS                                                00006170 HIGH0020
      COMPLEX*16  PP,DDPT                                               00006180 HIGH0021
      JN1      = 12                                                     00006190 HIGH0022
      JN2      = 10                                                     00006200 HIGH0023
      JN3      = 8                                                      00006210 HIGH0024
      JN4      = 100                                                    00006220 HIGH0025
      TN1      = .8                                                     00006230 HIGH0026
      TN2      = .2                                                     00006240 HIGH0027
      TN3      = .1                                                     00006250 HIGH0028
      TN4      = .001                                                   00006260 HIGH0029
C THESE EIGHT PARAMETERS ARE USED IN CALCULATING THE INTEGRATION        00006270 HIGH0030
C INTERVAL ABOUT PO ,THE POINT OF REFLECTION                            00006280 HIGH0031
      V2 = SS(3)                                                        00006290 HIGH0032
C V2 SHOULD BE THE LARGEST PROPAGATION VELOCITY USED IN THE MODEL,      00006300 HIGH0033
C FOR P,SV MODEL ,CC(3)                                                 00006310 HIGH0034
      NRY      = N                                                      00006320 HIGH0035
C NRY BECOMES THE RAY NUMBER                                            00006330 HIGH0036
```

```
C DEL IS THE INITIAL ITERATION STEP INP,THE INTEGRATION PARAMETER,FOR
C USE IN FIND2 IN DETERMINING THE VALUES OF P AND TIME AT THE REFLECTION
C ARRIVAL IF THE SIGNAL IS AT ANY TIME IN P OR COMPRESSIONAL MODE DEL =
C 1./CC(I),IF NOT DEL =1./SS(2)
      KNRY      = NRY*KSSP
      DEL       = 1./SS(2)
      IF(LTP(NRY).GT.0) GO TO 82
      IF(KSSP.EQ.0) GO TO 81
 82   DEL       = 1./CC(2)
 81    P        = -1.E-9
      DAT       = 1.E+12
       CALL FIND2(P,KK,DEL,DAT,PO,TO,N)
      NNN       = NDP
      NK        = 2
       IF(NRY.EQ.1) V2=.9*SS(2)
      P         = 1./V2
      RG        =DABS(PO-P)
      CALL HELP(K,N,P,TTP,DTP,N)
      TC        = TTP
      TG        = TO-TTP
      IF(PO.LE.1./V2) GO TO 6
      IF(TG.GT.TN1) GO TO 6
      JN        = JN1
      IF(TG.GT.TN2) GO TO18
      JN        = JN2
      IF(TG.GT.TN3) GO TO18
      JN        = JN3
 18   QZ        = RG/(JN+1)
      DO 15 J = 1,JN
      DELP(J)   = QZ
 15     CONTINUE
      NO        = JN
      IF(TG.LT.TN4) GO TO 2
      GO TO 19
 6     CALL DELPS(NNN,RG,1,NK)
      IF (.NOT.PRNT) GO TO 19
```

```
      PRINT 7, V2, XM, PO, RG, TC, TO, (DELP(J),J=1,NO)                 00006700 HIGH0073
 7    FORMAT (1H0,4X,'V2= ',G13.6,5X,'XM= ',G13.6,5X,'PO= ',            00006710 HIGH0074
     1G13.6/5X,'RG= ',G13.6,5X,'TC= ',G13.6,5X,'TO= ',G13.6/5X,'DELP'/  00006720 HIGH0075
     2(G15.6))                                                          00006730 HIGH0076
19      IF(PO.LE.1./V2) GO TO 2                                         00006740 HIGH0077
      CALL PLN1(PO,TO,K,N,TC,N,V2)                                      00006750 HIGH0078
 2     MO       = NO+2                                                  00006760 HIGH0079
      IF(TG.LT.TN4) MO=2                                                00006770 HIGH0080
      IF(PO.LT.1./V2) MO=2                                              00006780 HIGH0081
      CALL CONTOR(TMX,M,KN,N,MO)                                        00006790 HIGH0082
      IF (.NOT.PRNT) GO TO 620                                          00006800 HIGH0083
      WRITE (6,5)                                                       00006810 HIGH0084
 5    FORMAT (1H0,13X,'PP',27X,'DDPT',24X,'TT')                         00006820 HIGH0085
      JJ        = MO                                                    00006830 HIGH0086
      WRITE(6,200) (PP(J),DDPT(J),TT(J),J=JJ,M)                         00006840 HIGH0087
200    FORMAT(5E15.4)                                                   00006850 HIGH0088
620   CALL PLN2(PO,TO,K,MO,M,N)                                         00006860 HIGH0089
      NEND      = M                                                     00006870 HIGH0090
      NM        = NO                                                    00006880 HIGH0091
      IF(PO.LT.1./V2) NM=0                                              00006890 HIGH0092
      IF(TG.LT.TN4)NM= 0                                                00006900 HIGH0093
      LK         =-19                                                   00006910 HIGH0094
      WRITE (6,98)                                                      00006920 HIGH0095
      KJMP=5                                                            00006930 HIGH0096
      LK        = 1-KJMP                                                00006940 HIGH0097
97    LK         =LK+KJMP                                               00006950 HIGH0098
      IF (LK .GT. NEND)  GO TO 99                                       00006960 HIGH0099
      WRITE (6,100) TD(LK),PHIZ(LK),PHIR(LK),LK                         00006970 HIGH0100
      GO TO 97                                                          00006980 HIGH0101
99    CONTINUE                                                          00006990 HIGH0102
98    FORMAT    (12X,'SUB. HIGH     TD,PHIZ,PHIR',2X)                   00007000 HIGH0103
100   FORMAT (3E18.6,I10)                                               00007010 HIGH0104
      RETURN                                                            00007020 HIGH0105
      END                                                               00007030 HIGH0106
```

```
      SUBROUTINE INTERP(XP,YP,N,X,Y)                                   00007040 INTP0001
      IMPLICIT REAL*8 (A-H,O-Z)                                        00007050 INTP0002
      DIMENSION  XP(1000),YP(1000)                                     00007060 INTP0003
1     IF (X .GT.XP(N))GO TO 6                                          00007070 INTP0004
      IF (X .LT. XP(1)) GO TO 6                                        00007080 INTP0005
2     DO 10 I=1,N                                                      00007090 INTP0006
      IF (XP(I) -X) 10,102,3                                           00007100 INTP0007
10    CONTINUE                                                         00007110 INTP0008
3     K         = I-1                                                  00007120 INTP0009
      DIF1      = XP(I) -XP(K)                                         00007130 INTP0010
      DIF2      = XP(I) -X                                             00007140 INTP0011
      RATIO     = DIF2/DIF1                                            00007150 INTP0012
      DIFY      =DABS (YP(I) - YP(K))                                  00007160 INTP0013
      DR        = DIFY*RATIO                                           00007170 INTP0014
      IF (YP(I) .GT. YP(K)) GO TO 4                                    00007180 INTP0015
5     Y         = YP(I) + DR                                           00007190 INTP0016
      RETURN                                                           00007200 INTP0017
4     Y         = YP(I) - DR                                           00007210 INTP0018
      RETURN                                                           00007220 INTP0019
102   Y         = YP(I)                                                00007230 INTP0020
      RETURN                                                           00007240 INTP0021
6     Y         = 0.                                                   00007250 INTP0022
      RETURN                                                           00007260 INTP0023
      END                                                              00007270 INTP0024
```

```
      SUBROUTINE PLN1(PO,TO,K,N,TC,NRY,V2)
      IMPLICIT REAL*8  (A-H,O-Z)
      COMMON/TINP/DELTM,DLTM,NDA,MTD,DLTP,NDB,JO,NDIRT
      COMMON/SPE/DELP(800),DD1,DD2,DD3,DD4,NO
      COMMON/ORSTF/C(100),S(100),D(100),TH(100),X
      COMMON/TRESL/PZ1(500),PR1(500)
      COMMON/MAGIC/PQ(1200),DDPT(1200),TTT(1200)
      COMMON/EXACT/PHIZ(1000),PHIR(1000),TT(1000),NEND,NM
      COMMON / LPRINT/ PRNT,PRNTS
      LOGICAL PRNT,PRNTS
      COMPLEX*16  PQ,DDPT,FNZ,FNR,FNZ1,FNR1,Q
      P         = 1./V2
      DO 80 I=2,NO
      J         = I-1
      P         = P+DELP(J)
      Q         = P+0.*(0.,1.)
      CALL HELP(K,N,P,TTP,DTP,NRY)
      IF(PRNT) PRINT 100,Q,P,DTP,TTP
      TT(I)     = TTP
      DDPT(I)   = DTP
      CALL PSICO(Q,FNZ,FNR,FNZ1,FNR1,I ,NRY)
      IF(PRNT) PRINT 100,FNZ,FNR,FNZ1,FNR1
      PHIZ(I)   = FNZ * (0.,-1.)
      PHIR(I)   = FNR * (0.,-1.)
      PZ1(I)    = FNZ1 * (0.,-1.)
      PR1(I)    = FNR1 * (0.,-1.)
      IF ((TO-TTP) .LT. DLTP) GO TO5
80      CONTINUE
100    FORMAT(8E15.4)
      WRITE(6,100) PO,TO
5     NO        = J+1
       I        = NO
4     IF(TO-TTP.LT.DLTP) GO TO 3
      PP        = PO - P
      P         = P + PP/2.0
      I         = I+1
```

```
      NQ          = I                                                   00007640 PLN10037
      Q           = P                                                   00007650 PLN10038
      CALL HELP(K,N,P,TTP,DTP,NRY)                                      00007660 PLN10039
      TT(I)       = TTP                                                 00007670 PLN10040
      DDPT(I)     = DTP                                                 00007680 PLN10041
      CALL PSICO(Q,FNZ,FNR,FNZ1,FNR1,I,NRY)                             00007690 PLN10042
      PHIZ(I)     = FNZ * (0.,-1.)                                      00007700 PLN10043
      PHIR(I)     = FNR * (0.,-1.)                                      00007710 PLN10044
      PZ1(I)      = FNZ1 * (0.,-1.)                                     00007720 PLN10045
      PR1(I)      = FNR1 * (0.,-1.)                                     00007730 PLN10046
      IF(PRNT) PRINT 100,FNZ,FNR,FNZ1,FNR1                              00007740 PLN10047
      GO TO 4                                                           00007750 PLN10048
    3 TT(1)       = TC                                                  00007760 PLN10049
      PHIZ(1)     = 0.                                                  00007770 PLN10050
      PHIR(1)     = 0.                                                  00007780 PLN10051
      PR1(1)      = 0.                                                  00007790 PLN10052
      PZ1(1)      = 0.                                                  00007800 PLN10053
      RETURN                                                            00007810 PLN10054
      END                                                               00007820 PLN10055
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```
      SUBROUTINE PLN2(PO,TO,K,MO,M,NRY)                                 00007830 PLN20001
      IMPLICIT REAL*8  (A-H,O-Z)                                        00007840 PLN20002
      COMMON/FIXP/DDN(100),ARN(100)                                     00007850 PLN20003
      COMMON/TINP/DELTM,DLTM,NDA,MTD,DLTP,NDB,JO,NDIRT                  00007860 PLN20004
      COMMON/MAGIC/PP(1200),DDPT(1200),TT(1200)                         00007870 PLN20005
      COMMON/EXACT/PHIZ(1000),PHIR(1000),TTT(1000),NEND,NM              00007880 PLN20006
      COMMON/TRESL/PZ1(500),PR1(500)                                    00007890 PLN20007
      COMMON/ORSTF/C(100),S(100),D(100),TH(100),X                       00007900 PLN20008
      DIMENSION FF(50)      ,GG(50)                                     00007910 PLN20009
      COMMON / LPRINT/ PRNT,PRNTS                                       00007920 PLN20010
      LOGICAL PRNT,PRNTS                                                00007930 PLN20011
      COMPLEX*16   PP,BT,DDPT,RP,RPP,GC,P                               00007940 PLN20012
      COMPLEX*16  FNZ,FNR,FNZ1,FNR1                                     00007950 PLN20013
      DO 5 I=MO,M                                                       00007960 PLN20014
      TTT(I)    = TT(I)                                                 00007970 PLN20015
      P         = PP(I)                                                 00007980 PLN20016
      CALL PSICO(P,FNZ,FNR,FNZ1,FNR1,I,NRY)                             00007990 PLN20017
      PHIZ(I)   = FNZ *(0.,-1.)                                         00008000 PLN20018
      PHIR(I)   = FNR *(0.,-1.)                                         00008010 PLN20019
      PR1(I)    = FNR1 * (0.,-1.)                                       00008020 PLN20020
      PZ1(I)    = FNR1 * (0.,-1.)                                       00008030 PLN20021
      IF(PRNT) PRINT 100,FNZ,FNR,FNZ1,FNR1                              00008040 PLN20022
5        CONTINUE                                                       00008050 PLN20023
100    FORMAT(8E15.4)                                                   00008060 PLN20024
3     NO          = MO-2                                                00008070 PLN20025
      DP          = DLTP                                                00008080 PLN20026
      P           = PO*(1.,0.)+0.*(0.,1.)                               00008090 PLN20027
      I           = MO-1                                                00008100 PLN20028
      Q           = PO                                                  00008110 PLN20029
      DDPT(I)     = SF2(Q,K,NRY,DP)                                     00008120 PLN20030
      TTT(I)      = TO                                                  00008130 PLN20031
      WRITE(6,100) P,DDPT(I)                                            00008140 PLN20032
      CALL PSICO(P,FNZ,FNR,FNZ1,FNR1,I,NRY)                             00008150 PLN20033
      IF(PRNT) PRINT 100,FNZ,FNR,FNZ1,FNR1                              00008160 PLN20034
      PREZ        = FNZ                                                 00008170 PLN20035
      PIMZ        = FNZ * (0.,-1.)                                      00008180 PLN20036
```

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      PRER      = FNR                                                   00008190 PLN20037
      PIMR      = FNR * (0.,-1.)                                        00008200 PLN20038
      IF (PRNT) PRINT 100,PREZ,PIMZ,PRER,PIMR                           00008210 PLN20039
      F1        = 0.                                                    00008220 PLN20040
      G1        = 0.                                                    00008230 PLN20041
      SUM       = 0.                                                    00008240 PLN20042
      TUM       = 0.                                                    00008250 PLN20043
      IF(MO.LE.3) GO TO 46                                              00008260 PLN20044
      TNN       = TO-DP                                                 00008270 PLN20045
      CALL INTERP(TTT,PHIZ,M,TNN,Y)                                     00008280 PLN20046
      F1        = Y                                                     00008290 PLN20047
      FF(1)     = Y                                                     00008300 PLN20048
      CALL INTERP(TTT,PHIR,M,TNN,Y)                                     00008310 PLN20049
      G1        = Y                                                     00008320 PLN20050
      GG(1)     = Y                                                     00008330 PLN20051
      SUM       = SUM+2.*PIMZ*DSQRT(TO-TTT(NO))                         00008340 PLN20052
      TUM       = TUM+2.*PIMR*DSQRT(TO-TTT(NO))                         00008350 PLN20053
      IF (PRNT) PRINT 4, SUM                                            00008360 PLN20054
      IF (PRNT) PRINT 7, TUM                                            00008370 PLN20055
    7 FORMAT(5X,'TUM=',G18.6)                                           00008380 PLN20056
    4 FORMAT(5X,'SUM=',G18.6)                                           00008390 PLN20057
      DELL      = (TTT(NO)-TNN )/5.                                     00008400 PLN20058
      TT(1)     = TNN                                                   00008410 PLN20059
      FF(6)     = PHIZ(NO)                                              00008420 PLN20060
      GG(6)     = PHIR(NO)                                              00008430 PLN20061
      PHIZ(I)   = PHIZ(NO)                                              00008440 PLN20062
      PHIR(I)   = PHIR(NO)                                              00008450 PLN20063
      DO 41 J=2,6                                                       00008460 PLN20064
      TT(J)     = TT(J-1)   +DELL                                       00008470 PLN20065
      CALL INTERP(TTT,PHIZ,M,TT(J),Y)                                   00008480 PLN20066
      FF(J)     = Y                                                     00008490 PLN20067
      CALL INTERP(TTT,PHIR,M,TT(J),Y)                                   00008500 PLN20068
      GG(J)=Y                                                           00008510 PLN20069
      TUM       = TUM+(GG(J-1)+GG(J))/2.*DELL                           00008520 PLN20070
      SUM=SUM+(FF(J-1)+FF(J))/2.*DELL                                   00008530 PLN20071
      IF (PRNT) PRINT 7, TUM                                            00008540 PLN20072
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      IF(PRNT) PRINT4,SUM                                             00008550 PLN20073
41    CONTINUE                                                        00008560 PLN20074
46    TPP        = TTT(MO)                                            00008570 PLN20075
      TT(1)      = TTT(MO)                                            00008580 PLN20076
      IF(TTT(MO)-TO.GT.DP) GO TO 43                                   00008590 PLN20077
      SUM=SUM+2.*PREZ*DSQRT(TTT(MO)-TO)                               00008600 PLN20078
      TUM        = TUM+2.*PRER*DSQRT(TTT(MO)-TO)                      00008610 PLN20079
      IF (PRNT) PRINT4,SUM                                            00008620 PLN20080
      IF (PRNT) PRINT 7, TUM                                          00008630 PLN20081
      CALL INTERP(TTT,PHIZ,M,TPP,Y)                                   00008640 PLN20082
      FF(1)      = Y                                                  00008650 PLN20083
      CALL INTERP(TTT,PHIR,M,TPP,Y)                                   00008660 PLN20084
      GG(1)      = Y                                                  00008670 PLN20085
      DELL       = (TO+DP-TTT(MO))/5.                                 00008680 PLN20086
      DO 42 J=2,6                                                     00008690 PLN20087
      IF (PRNT) PRINT4,SUM                                            00008700 PLN20088
      TT(J)      = TT(J-1)  +DELL                                     00008710 PLN20089
      CALL INTERP(TTT,PHIZ,M,TT(J),Y)                                 00008720 PLN20090
      FF(J)      = Y                                                  00008730 PLN20091
      CALL INTERP(TTT,PHIR,M,TT(J),Y)                                 00008740 PLN20092
      GG(J)      = Y                                                  00008750 PLN20093
      TUM        = TUM+(GG(J-1)+GG(J))/2.*DELL                        00008760 PLN20094
      SUM        = SUM+(FF(J-1)+FF(J))/2.*DELL                        00008770 PLN20095
      IF (PRNT) PRINT 4, SUM                                          00008780 PLN20096
      IF (PRNT) PRINT 7, TUM                                          00008790 PLN20097
42     CONTINUE                                                       00008800 PLN20098
      F3         = FF(6)                                              00008810 PLN20099
      G3         = GG(6)                                              00008820 PLN20100
      PHIZ(I)    = (3.*SUM/DP-F1-F3)/4.                               00008830 PLN20101
      PHIR(I)    = (3.*TUM/DP-G1-G3)/4.                               00008840 PLN20102
      GO TO 44                                                        00008850 PLN20103
43     TTT(MO)   = TO+DP                                              00008860 PLN20104
      PHIZ(MO)   = PREZ/(DP**.5)                                      00008870 PLN20105
      PHIR(MO)   = PRER/(DP**.5)                                      00008880 PLN20106
      F3         = PHIZ(MO)                                           00008890 PLN20107
      G3         = PHIR(MO)                                           00008900 PLN20108
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      SUM      = SUM+2.*PREZ*DSQRT(DP)                                  00008910 PLN20109
      TUM      = TUM+2.*PRER*DSQRT(DP)                                  00008920 PLN20110
      PHIZ(I)  = (3.*SUM/DP-F1-F3)/4.                                   00008930 PLN20111
      PHIR(I)  = (3.*TUM/DP-G1-G3)/4.                                   00008940 PLN20112
      IF (PRNT) PRINT 4, SUM                                            00008950 PLN20113
      IF (PRNT) PRINT 7,TUM                                             00008960 PLN20114
 44     CONTINUE                                                        00008970 PLN20115
      PREZ1    = FNZ1                                                   00008980 PLN20116
      PIMZ1    = FNZ1 * (0.,-1.)                                        00008990 PLN20117
      PRER1    = FNR1                                                   00009000 PLN20118
      PIMR1    = FNR1 * (0.,-1.)                                        00009010 PLN20119
      IF(PRNT) PRINT 100, PREZ1,PIMZ1,PRER1,PIMR1                       00009020 PLN20120
      IF(MO.LE.3) GO TO 47                                              00009030 PLN20121
      DO 81 J=2,NO                                                      00009040 PLN20122
      AREA     = (PR1(J)+PR1(J-1))*(TTT(J)-TTT(J-1))                    00009050 PLN20123
      PHIR(J)  = PHIR(J)+AREA/2.                                        00009060 PLN20124
      AREA     = (PZ1(J)+PZ1(J-1))*(TTT(J)-TTT(J-1))                    00009070 PLN20125
      PHIZ(J)  = PHIZ(J)+AREA/2.                                        00009080 PLN20126
 81     CONTINUE                                                        00009090 PLN20127
      PHIZ(I)  = PHIZ(I)+2.*PIMZ1*DSQRT(TTT(I)-TTT(NO))                 00009100 PLN20128
      PHIR(I)  = PHIR(I)+2.*PIMR1*DSQRT(TTT(I)-TTT(NO))                 00009110 PLN20129
 47     CONTINUE                                                        00009120 PLN20130
      PHIZ(MO) = PHIZ(MO)+2.*PREZ1*DSQRT(TTT(MO)-TTT(I))                00009130 PLN20131
      PHIR(MO) = PHIR(MO)+2.*PRER1*DSQRT(TTT(MO)-TTT(I))                00009140 PLN20132
      JM       = MO+1                                                   00009150 PLN20133
      DO 82 J=JM,M                                                      00009160 PLN20134
      AREA     = (PR1(J)+PR1(J-1))*(TTT(J)-TTT(J-1))                    00009170 PLN20135
      PHIR(J)  = PHIR(J)+AREA/2.                                        00009180 PLN20136
      AREA     = (PZ1(J)+PZ1(J-1))*(TTT(J)-TTT(J-1))                    00009190 PLN20137
      PHIZ(J)  = PHIZ(J)+AREA/2.                                        00009200 PLN20138
 82    CONTINUE                                                         00009210 PLN20139
      WRITE (6,111)  TTT(I),PHIZ(I),PHIR(I)                             00009220 PLN20140
111   FORMAT  (2X,'CRITICAL TIME',G20.8,5X,'PHIZ',G20.8,'PHIR',G20.8)   00009230 PLN20141
      RETURN                                                            00009240 PLN20142
      END                                                               00009250 PLN20143
```

```
      SUBROUTINE PSICO (P,FNZ,FNR,FNZ1,FNR1,I,NRY)                      00009260 PSIC0001
C***********************************************************************00009270 PSIC0002
C PSICO CALCULATES THE TWO TERMS IN BARKERS EXPANSION OF THE SOLUTION   00009280 PSIC0003
C                                                                       00009290 PSIC0004
C THE SUBPROGRAM REFFT ,RECVR ARE CALLED                                00009300 PSIC0005
C                                                                       00009310 PSIC0006
C CALL LIST:P,THE INTEGRATION PARAMETER,FNZ,THE FIRST TERM IN THE       00009320 PSIC0007
C VERTICAL RESPONSE ,FNR, SIMILAR FOR THE RADIAL, FNZ1, SECOND TERM IN  00009330 PSIC0008
 C VERTICAL RESPONSE,FNR1,SAME FOR RADIAL,I INDICATES WHICH VALUE OF P  00009340 PSIC0009
C ALONG THE CONTOUR (STORAGE ARRAY INDEX ),NRY IS THE RAY NUMBER        00009350 PSIC0010
C***********************************************************************00009360 PSIC0011
      IMPLICIT REAL*8  (A-H,O-Z)                                        00009370 PSIC0012
      COMMON/RAYPAR/KUD(100),KRSP(100),LTS(100),LTP(100),LREF(100,4)    00009380 PSIC0013
      COMMON/ORSTF/C(100),S(100),D(100),TH(100),X                       00009390 PSIC0014
      COMMON/MAGIC/PP(1200),DDPT(1200),TT(1200)                         00009400 PSIC0015
      COMMON/PLOTC/CON,NNF,NPT                                          00009410 PSIC0016
      COMMON/PLACE/THIC,H,KSSP                                          00009420 PSIC0017
      COMMON /LPRINT/ PRNT,PRNTS                                        00009430 PSIC0018
      LOGICAL  PRNT,PRNTS                                               00009440 PSIC0019
      DIMENSION RF(16)                                                  00009450 PSIC0020
      COMPLEX*16 P,RF,DR,G1,G2,G3,FNZ,FNR,FNZ1,FNR1,RC,DDPT,PP,RDS,DZ   00009460 PSIC0021
      ROD=D(2)/D(3)                                                     00009470 PSIC0022
       CALL REFFT(P,S(2),S(3),ROD,RDS)                                  00009480 PSIC0023
       RF(2)=RDS                                                        00009490 PSIC0024
      CALL RECVR(S(2),P,KRSP(NRY),DZ,DR,KSSP,RSS)                       00009500 PSIC0025
      RF(1)=RSS                                                         00009510 PSIC0026
      RC=(1.,0.)                                                        00009520 PSIC0027
      DO 100 J=1,2                                                      00009530 PSIC0028
      IF (LREF(NRY,J) .EQ. 0) GOTO 200                                  00009540 PSIC0029
      RC         = RC*RF(J)**LREF(NRY,J)                                00009550 PSIC0030
 200  CONTINUE                                                          00009560 PSIC0031
 100  CONTINUE                                                          00009570 PSIC0032
      IF(KSSP.EQ.1) GO TO 3                                             00009580 PSIC0033
      IF(NRY.EQ.1) KRSP(NRY)=0                                          00009590 PSIC0034
 3     CONTINUE                                                         00009600 PSIC0035
      G1         = DDPT(I)*RC*CON                                       00009610 PSIC0036
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      G2        = G1*CDSQRT(P/(2.*X))                                   00009620 PSIC0037
      FNZ       = DZ*G2                                                 00009630 PSIC0038
      FNR       = DR*G2                                                 00009640 PSIC0039
      G3        = G1/(-8.*CDSQRT(2.*P*X**3))                            00009650 PSIC0040
      FNZ1      = G3*DZ                                                 00009660 PSIC0041
      FNR1      = G3*DR*(-3.)                                           00009670 PSIC0042
      IF (PRNT) WRITE (6,300) P,C(3),C(2),S(3),S(2),KUD(NRY),KRSP(NRY), 00009680 PSIC0043
     1                        LTS(NRY),LTP(NRY)                         00009690 PSIC0044
      IF(PRNT) WRITE(6,400) (RF(J),LREF(NRY,J),J=1,4)                   00009700 PSIC0045
  400 FORMAT(1X,' RECVR ',4(2(E13.4),I2))                               00009710 PSIC0046
      IF (PRNT) WRITE (6,500) G1,G2,G3,RC                               00009720 PSIC0047
  300 FORMAT (1X,'RECVR',2(E15.4),4(F10.3),2X,4(I2))                    00009730 PSIC0048
  500 FORMAT (1X,'RECVR',8(E13.4))                                      00009740 PSIC0049
      RETURN                                                            00009750 PSIC0050
      END                                                               00009760 PSIC0051
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      REAL FUNCTION PTIM*8  (P,K,NRY)                                   00009770 PTIM0001
      IMPLICIT REAL*8  (A-H,O-Z)                                        00009780 PTIM0002
      COMMON/RAYPAR/KUD(100),KRSP(100),LTS(100),LTP(100),LREF(100,4)    00009790 PTIM0003
      COMMON/PLACE/THIC,H,KSSP                                          00009800 PTIM0004
      COMMON/STUFF/C(100),S(100),D(100),TH(100),X,RCSQ(100),RSSQ(100)   00009810 PTIM0005
      PSQ       = P ** 2                                                00009820 PTIM0006
      J         = 2                                                     00009830 PTIM0007
      E         = DSQRT(DABS(RCSQ(J)-PSQ))                              00009840 PTIM0008
      PTIM      = (TH(4) + LTP(NRY)*TH(2)) *E                           00009850 PTIM0009
      E         =DSQRT(DABS(RSSQ(J)-PSQ))                               00009860 PTIM0010
      PTIM      = PTIM + (TH(3) + LTS(NRY)*TH(2))*E                     00009870 PTIM0011
      PTIM      = P*X + PTIM                                            00009880 PTIM0012
      RETURN                                                            00009890 PTIM0013
      END                                                               00009900 PTIM0014
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      SUBROUTINE RAYDEF                                                 00012310 RYDF0001
      COMMON/RAYPAR/KUD(100),KRSP(100),LTS(100),LTP(100),LREF(100,4)    00012320 RYDF0002
      COMMON/PLACE/THIC,H,KSSP                                          00012330 RYDF0003
      COMMON /LPRINT/ PRNT,PRNTS                                        00012340 RYDF0004
      LOGICAL PRNT,PRNTS                                                00012350 RYDF0005
      REAL*8 THIC,H                                                     00012360 RYDF0006
      WRITE (6,800)                                                     00012370 RYDF0007
  800 FORMAT (10X,'WHOOPIE, WE MADE IT TO RAYDEF')                      00012380 RYDF0008
      READ (5,400) THIC,H,KSSP                                          00012390 RYDF0009
  400 FORMAT (2F10.0,I10)                                               00012400 RYDF0010
      WRITE (6,700) THIC,H                                              00012410 RYDF0011
 700  FORMAT (/10X,'LAYER THICKNESS ',F6.3/10X,'SOURCE DEPTH',F6.3)     00012420 RYDF0012
      IF (KSSP .EQ. 0) WRITE (6,1300)                                   00012430 RYDF0013
      IF (KSSP .EQ. 1) WRITE (6,1400)                                   00012440 RYDF0014
 1300  FORMAT (15X,'SHEAR SOURCE')                                      00012450 RYDF0015
 1400  FORMAT (15X,'COMPRESSIONAL SOURCE')                              00012460 RYDF0016
      READ(5,1200) (KUD(J),LTS(J),LTP(J),KRSP(J),J=19,64)               00012470 RYDF0017
 1200 FORMAT(4I2)                                                       00012480 RYDF0018
      KUD(1)=1                                                          00012490 RYDF0019
       KUD(2)=0                                                         00012500 RYDF0020
      KUD(3)=1                                                          00012510 RYDF0021
      KUD(4)=0                                                          00012520 RYDF0022
      KUD(5)=1                                                          00012530 RYDF0023
      KUD(6)=0                                                          00012540 RYDF0024
      KUD(7)=1                                                          00012550 RYDF0025
      KUD(8)=0                                                          00012560 RYDF0026
      KUD(9)=1                                                          00012570 RYDF0027
       KUD(10)=0                                                        00012580 RYDF0028
       KUD(11)=1                                                        00012590 RYDF0029
       KUD(12)=0                                                        00012600 RYDF0030
       KUD(13)=1                                                        00012610 RYDF0031
       KUD(14)=0                                                        00012620 RYDF0032
       KUD(15)=1                                                        00012630 RYDF0033
       KUD(16)=0                                                        00012640 RYDF0034
       KUD(17)=1                                                        00012650 RYDF0035
       KUD(18)=0                                                        00012660 RYDF0036
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      LTS(1)=0                                                          00012670 RYDF0037
      LTS(2)=1                                                          00012680 RYDF0038
      LTS(3)=2                                                          00012690 RYDF0039
      LTS(4)=3                                                          00012700 RYDF0040
      LTS(5)=4                                                          00012710 RYDF0041
      LTS(6)=5                                                          00012720 RYDF0042
      LTS(7)=6                                                          00012730 RYDF0043
      LTS(8)=7                                                          00012740 RYDF0044
      LTS(9)=8                                                          00012750 RYDF0045
      LTS(10)=9                                                         00012760 RYDF0046
      LTS(11)=10                                                        00012770 RYDF0047
      LTS(12)=11                                                        00012780 RYDF0048
      LTS(13)=12                                                        00012790 RYDF0049
      LTS(14)=13                                                        00012800 RYDF0050
      LTS(15)=14                                                        00012810 RYDF0051
      LTS(16)=15                                                        00012820 RYDF0052
      LTS(17)=16                                                        00012830 RYDF0053
      LTS(18)=17                                                        00012840 RYDF0054
      LTP(1)=0                                                          00012850 RYDF0055
      LTP(2)=0                                                          00012860 RYDF0056
      LTP(3)=0                                                          00012870 RYDF0057
      LTP(4)=0                                                          00012880 RYDF0058
      LTP(5)=0                                                          00012890 RYDF0059
      LTP(6)=0                                                          00012900 RYDF0060
      LTP(7)=0                                                          00012910 RYDF0061
      LTP(8)=0                                                          00012920 RYDF0062
      LTP(9)=0                                                          00012930 RYDF0063
      LTP(10)=0                                                         00012940 RYDF0064
      LTP(11)=0                                                         00012950 RYDF0065
      LTP(12)=0                                                         00012960 RYDF0066
      LTP(13)=0                                                         00012970 RYDF0067
      LTP(14)=0                                                         00012980 RYDF0068
      LTP(15)=0                                                         00012990 RYDF0069
      LTP(16)=0                                                         00013000 RYDF0070
      LTP(17)=0                                                         00013010 RYDF0071
      LTP(18)=0                                                         00013020 RYDF0072
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      KRSP(1)=0                                             00013030 RYDF0073
      KRSP(2)=0                                             00013040 RYDF0074
      KRSP(3)=0                                             00013050 RYDF0075
      KRSP(4)=0                                             00013060 RYDF0076
      KRSP(5)=0                                             00013070 RYDF0077
      KRSP(6)=0                                             00013080 RYDF0078
      KRSP(7)=0                                             00013090 RYDF0079
      KRSP(8)=0                                             00013100 RYDF0080
      KRSP(9)=0                                             00013110 RYDF0081
      KRSP(10)=0                                            00013120 RYDF0082
      KRSP(11)=0                                            00013130 RYDF0083
      KRSP(12)=0                                            00013140 RYDF0084
      KRSP(13)=0                                            00013150 RYDF0085
      KRSP(14)=0                                            00013160 RYDF0086
      KRSP(15)=0                                            00013170 RYDF0087
      KRSP(16)=0                                            00013180 RYDF0088
      KRSP(17)=0                                            00013190 RYDF0089
      KRSP(18)=0                                            00013200 RYDF0090
      KR=18                                                 00013210 RYDF0091
       DO 200 NR=1,KR                                       00013220 RYDF0092
      DO 100 K=1,2                                          00013230 RYDF0093
  100 LREF(NR,K)=0                                          00013240 RYDF0094
  200 CONTINUE                                              00013250 RYDF0095
C     SH SOURCE                                             00013260 RYDF0096
      LREF(2,2)=1                                           00013270 RYDF0097
      LREF(3,1)=1                                           00013280 RYDF0098
      LREF(3,2)=1                                           00013290 RYDF0099
      LREF(4,1)=1                                           00013300 RYDF0100
      LREF(4,2)=2                                           00013310 RYDF0101
      LREF(5,1)=2                                           00013320 RYDF0102
      LREF(5,2)=2                                           00013330 RYDF0103
      LREF(6,1)=2                                           00013340 RYDF0104
      LREF(6,2)=3                                           00013350 RYDF0105
      LREF(7,1)=3                                           00013360 RYDF0106
      LREF(7,2)=3                                           00013370 RYDF0107
      LREF(8,1)=3                                           00013380 RYDF0108
```

```
      LREF(8,2)=4                                          00013390 RYDF0109
       LREF(9,1)=4                                         00013400 RYDF0110
       LREF(9,2)=4                                         00013410 RYDF0111
      LREF(10,1)=4                                         00013420 RYDF0112
      LREF(10,2)=5                                         00013430 RYDF0113
      LREF(11,1)=5                                         00013440 RYDF0114
      LREF(11,2)=5                                         00013450 RYDF0115
      LREF(12,1)=5                                         00013460 RYDF0116
      LREF(12,2)=6                                         00013470 RYDF0117
      LREF(13,1)=6                                         00013480 RYDF0118
      LREF(13,2)=6                                         00013490 RYDF0119
      LREF(14,1)=7                                         00013500 RYDF0120
      LREF(14,2)=6                                         00013510 RYDF0121
      LREF(15,1)=7                                         00013520 RYDF0122
      LREF(15,2)=7                                         00013530 RYDF0123
      LREF(16,1)=7                                         00013540 RYDF0124
      LREF(16,2)=8                                         00013550 RYDF0125
      LREF(17,1)=8                                         00013560 RYDF0126
      LREF(17,2)=8                                         00013570 RYDF0127
      LREF(18,1)=8                                         00013580 RYDF0128
      LREF(18,2)=9                                         00013590 RYDF0129
      READ(5,1000) IB,IE                                   00013600 RYDF0130
 1000 FORMAT(2I5)                                          00013610 RYDF0131
      READ(5,1100) ((LREF(II,JJ),JJ=1,2),II=IB,IE)         00013620 RYDF0132
 1100 FORMAT(2I2)                                          00013630 RYDF0133
      IF(PRNT) WRITE(6,600) ((LREF(J,L),L=1,2),J=1,6)      00013640 RYDF0134
      IF(PRNT) WRITE(6,600) ((LREF(J,L),L=1,2),J=7,12)     00013650 RYDF0135
 600  FORMAT(' R2 ',6(2I2, 2X))                            00013660 RYDF0136
 500   FORMAT(' RAYDEF ',4(12I2,2X))                       00013670 RYDF0137
         RETURN                                            00013680 RYDF0138
         END                                               00013690 RYDF0139
```

```
      SUBROUTINE RECVR(B1,P,KR,DZ,DR,KSSP,RSS)
C        TO COMPUTE  SURFACE RECEIVER AND REFLECTION FUNCTIONS
C     SH AT THE RECVR
      IMPLICIT COMPLEX*16 (A-H,O-Z)
      REAL*8 B1,RSS
      DZ=-2./CDSQRT(1/B1**2-P*P)
      DR = DZ
      RSS=1.
      RETURN
      END
```

```
      SUBROUTINE REFFT(P,B1,B2,D,RDS)                                   00013800 REFT0001
C***********************************************************************00013810 REFT0002
C REFFT CALCULATES THE REFLECTION FUNCTION FOR RAY INTERACTION WITH AN  00013820 REFT0003
C SOLID INTERFACE.NOTE THAT THIS SUBROUTINE IS WRITTEN ESPECIALLY FOR   00013830 REFT0004
C A SH SOURCE                                                           00013840 REFT0005
C                                                                       00013850 REFT0006
C THE SUBPROGRAM CR IS CALLED. CR CALCULATES THE RADIAL ETA=SQRT(1/     00013860 REFT0007
C (VELOCITY)**2 - P*P)                                                  00013870 REFT0008
C                                                                       00013880 REFT0009
C CALL LIST: P,THE INTEGRATION PARAMETER ,B1 IS VELOCITY IN THE LAYER,B200013890 REFT0010
C ,IS VELOCITY IN THE HALF-SPACE,D RATIO OF THEIR DENSITIES,RDR,THE     00013900 REFT0011
C REFLECTION FUNCTION FOR THE LOWER(SOLID-SOLID) INTERFACE              00013910 REFT0012
C                                                                       00013920 REFT0013
C IF THE SEVERAL KINDS OF SOURCES ARE INTEGRATED IN ONE PROGRAM THIS    00013930 REFT0014
C SUBROUTINE MUST BE GIVEN A DISTINCT NAME                              00013940 REFT0015
C***********************************************************************00013950 REFT0016
      IMPLICIT COMPLEX*16 (A-H,O-Z)                                     00013960 REFT0017
      REAL*8 B1,B2,D,DS                                                 00013970 REFT0018
      EA = CR(P,B1)                                                     00013980 REFT0019
      EB = CR(P,B2)                                                     00013990 REFT0020
      DS = D*B1**2/B2**2                                                00014000 REFT0021
      EC = DS*EA                                                        00014010 REFT0022
      RDS = (EC-EB)/(EC+EB)                                             00014020 REFT0023
      RETURN                                                            00014030 REFT0024
      END                                                               00014040 REFT0025
```

```
      SUBROUTINE SETUP(K,MM,NS,NO,MO,MPLOT,MPUNCH)
C***********************************************************************
C THE PROGRAM IS EXECUTED THROUGH THIS SUBROUTINE ,WHICH CALLS THE
C FOLLOWING SUBPROGRAMS DIRECTLY; RAYDEF,TS,HIGH,ADJUST,INTERP.PRINTED
C AND PUNCHED OUTPUT OF THE TIME SERIES OF SURFACE RESPONSE ARE PRODUCED
C HERE :THE VARIABLE LIST: K IS ALWAYS 1,MM IS APPARENTLY NO LONGER USED
C NS DESIGNATES THE FIRST RAY,NO, THE LAST RAY;MO=0 INDICATES THAT THIS
C IS THE FIRST TIME SETUP CALLED,IF NOT THE FIRST TIME USE ANY OTHER
C NUMBER .GT.1,MPLOT IS NOT USED,MPUNCH.LT.1 PRODUCES PUNCHED OUTPUT
C***********************************************************************
      IMPLICIT REAL*8  (A-H,O-Z)
      COMMON/CONFIX/DEL,NN,NDP,TMX,XDIM,YDIM,DP,KO
      COMMON/FOURCT/MF,NMF,KMF,KNMF
      COMMON/THZ/TT(1000),PPZ(1000),PPR(1000)
      COMMON/EXACT/PHIZ(1000),PHIR(1000),TD(1000),NEND,NM
      COMMON/RAYPAR/KUD(100),KRSP(100),LTS(100),LTP(100),LREF(100,4)
      COMMON/PLACE/THIC,H,KSSP
      COMMON/LPRINT/PRNT,PRNTS,KST,KEND,PRNTC
      DIMENSION PPC(800)
      REAL*4 ZZX(890),ZZY(890),ZXDIM,ZYDIM
      LOGICAL PRNT,PRNTS,PRNTC
      IF(MO.EQ.0) CALL RAYDEF
C IF MO.EQ.0 CALL RAYDEF TO ESTABLISH RAY PARAMETERS (SEE PREVIOUS
C COMMENTS ON READ IN OF RAY PARAMETERS)
      NF     = 1
      IF(MO.GT.1) GO TO 11
C IF MO.NE.0 DO NOT INITIALIZED THE ARRAYS WHICH CONTAIN THE OUTPUT
      I        = K
      TT(1)    = TS(I)
C TS IS A SUBPROGRAM WHICH ESTABLISHES THE TIME OF FIRST SIGNAL ARRIVAL
      PPZ(1)   = 0.
      PPR(1)   = 0.
C PPZ AND PPR WILL CONTAIN THE VERTICAL AND HORIZONTAL SURFACE RESPONSE,
C RESPECTIVELY
C TT IS AN ARRAY OF SAMPLING TIMES FOR THE TIME SERIES
      DO 10 J=2,NN
```

```
      TT(J)    = TT(J-1) +DEL
C NOTE THAT DEL = DP SET IN MAIN
      PPZ(J)   = 0.
      PPR(J)   = 0.
 10    CONTINUE
 11     CONTINUE
C ITERATE OVER THE RAYS FROM NS TO NO
      DO 32 N=NS,NO
      WRITE (6,103)  N
 103  FORMAT (5X,'RAY NUMBER',I3)
      CALL HIGH(NDP,TMX,K,KI,N)
C THE SUBPROGRAMME HIGH CALSULATES THE SURFACE RESPONSE FOR EACH RAY
      CALL ADJUST(NN,NFIX)
      N2       = 1
      M        = NM+1
      IF(NFIX.LT.1) GO TO 37
      N2       = NFIX+1
      N1       = NFIX-1
      IF(N1.LE.2) GO TO 42
      DO 31 J=1,N1
      CALL INTERP(TD,PHIZ,NEND,TT(J),Y)
      PPZ(J)   = PPZ(J)+Y*NF
      CALL INTERP(TD,PHIR,NEND,TT(J),Y)
      PPR(J)   = PPR(J)+Y*NF
 31     CONTINUE
 42    CONTINUE
      PPZ(NFIX)= PPZ(NFIX)+NF*PHIZ(M)
      PPR(NFIX)= PPR(NFIX)+NF*PHIR(M)
 37      CONTINUE
       DO 33 J=N2,NN
      CALL INTERP(TD,PHIZ,NEND,TT(J),Y)
      PPZ(J)   = PPZ(J)+Y*NF
      CALL INTERP(TD,PHIR,NEND,TT(J),Y)
      PPR(J)   = PPR(J)+Y*NF
 33     CONTINUE
      L=0
```

```
32     CONTINUE                                                         00010630 STUP0073
7     IF(.NOT.PRNT) GO TO 12                                            00010640 STUP0074
      PRINT 13,(TD(J),PHIZ(J),PHIR(J),J=1,NEND)                         00010650 STUP0075
      PRINT 14,(TT(J),PPZ(J),PPR(J),J=1,NN)                             00010660 STUP0076
13    FORMAT (1H0,15X,'TD',15X,'PH',/,3(E18.6))                         00010670 STUP0077
14    FORMAT (1H0,15X,'TT',15X,'PP',/,3(E18.6))                         00010680 STUP0078
   12 CONTINUE                                                          00010690 STUP0079
      NQ = NN/10                                                        00010700 STUP0080
      NP = NQ + 1                                                       00010710 STUP0081
      NR = NN + NQ                                                      00010720 STUP0082
      DO 20 I = 1, NQ                                                   00010730 STUP0083
      ZZX(I) = TT(1) - (NQ-I+1)*DP                                      00010740 STUP0084
   20 ZZY(I) = 0.0                                                      00010750 STUP0085
       NDIM=NN                                                          00010760 STUP0086
      IER=0                                                             00010770 STUP0087
      CALL DDGT3(TT,PPZ,PPC,NDIM,IER)                                   00010780 STUP0088
      DO 300 IZ = NP, NR                                                00010790 STUP0089
      ZZX(IZ)=TT(IZ-NP+1)                                               00010800 STUP0090
300   ZZY(IZ)=PPC(IZ-NP+1)                                              00010810 STUP0091
      WRITE(6,202)(ZZX(IZ),ZZY(IZ),IZ=1,NR)                             00010820 STUP0092
202   FORMAT('  DEBUG 202 ',2E20.10)                                    00010830 STUP0093
1     CONTINUE                                                          00010840 STUP0094
      IF(MPUNCH.LT.1) GO TO 2                                           00010850 STUP0095
      WRITE(7,200) TT(1),DP,NN                                          00010860 STUP0096
      WRITE(7,100) (PPC(J),J=1,NN)                                      00010870 STUP0097
2      CONTINUE                                                         00010880 STUP0098
100   FORMAT (5E15.6)                                                   00010890 STUP0099
 200  FORMAT(2E15.6,I10)                                                00010900 STUP0100
      RETURN                                                            00010910 STUP0101
      END                                                               00010920 STUP0102
```

```
REAL FUNCTION SF2*8 (P,K,NRY,DP)                                          00010930 SF020001
IMPLICIT REAL*8  (A-H,O-Z)                                                00010940 SF020002
COMMON/STUFF/C(100),S(100),D(100),TH(100),X,RCSQ(100),RSSQ(100)           00010950 SF020003
COMMON/RAYPAR/KUD(100),KRSP(100),LTS(100),LTP(100),LREF(100,4)            00010960 SF020004
PSQ        = P ** 2                                                       00010970 SF020005
J          = 2                                                            00010980 SF020006
ESQ        =DABS (RCSQ(J)-PSQ)                                            00010990 SF020007
E          =DSQRT(ESQ)                                                    00011000 SF020008
TE         = (TH(4)+TH(2)*LTP(NRY))*RCSQ(2)/(ESQ*E)                       00011010 SF020009
ESQ        =DABS (RSSQ(J)-PSQ)                                            00011020 SF020010
E          =DSQRT(ESQ)                                                    00011030 SF020011
TE         = (TH(3) + TH(2)*LTS(NRY))*RSSQ(2)/(ESQ*E) + TE                00011040 SF020012
TE         = TE*2.                                                        00011050 SF020013
SR         = 1.                                                           00011060 SF020014
SF2        = SR/DSQRT(TE)                                                 00011070 SF020015
RETURN                                                                    00011080 SF020016
END                                                                       00011090 SF020017
```

```
      SUBROUTINE TIME2(PR,PI,DL,Q,DPT,T,KN,N,PIL)                       00011100 TME20001
C***********************************************************************00011110 TME20002
C FOR A PARTICULAR VALUE OF THE COMPLEX INTEGRATION PARAMETER P,TIME2   00011120 TME20003
C FINDS A VALUE FOR THE COMPLEX PARAMETER TIME SUCH THAT THE IMAGINARY  00011130 TME20004
C PART OF TIME IS MINIMIZED                                             00011140 TME20005
C                                                                       00011150 TME20006
C NO SUBPROGRAMS ARE CALLED                                             00011160 TME20007
C                                                                       00011170 TME20008
C CALL LIST:PR,THE SPECIFIED REAL PART OF P;PI,A GUESS AT THE IMAGINARY 00011180 TME20009
C PART,DL,A SPECIFIED FRACTIOM OF PI USED AS AN ITERATION STEP,Q IS THE 00011190 TME20010
C FINAL VALUE OF THE COMPLEX INTEGRATION PARAMETER P,DPT IS DP/DT FOR   00011200 TME20011
C THIS VALUE,T IS THE COMPLEX INTEGRATION PARAMETER T FOR THIS VALUE OF 00011210 TME20012
P,KN HAS NO APPARENT USE,N IS THE RAY NUMBER,AND PL IS A MINIMUM VALUE  00011220 TME20013
C FOR PI                                                                00011230 TME20014
C***********************************************************************00011240 TME20015
      IMPLICIT REAL*8  (A-H,O-Z)                                        00011250 TME20016
      COMMON/RAYPAR/KUD(100),KRSP(100),LTS(100),LTP(100),LREF(100,4)    00011260 TME20017
      COMMON/LPRINT/PRNT,PRNTS,KST,KEND,PRNTC,NDC,DET                   00011270 TME20018
      COMMON/STUFF/C(100),S(100),D(100),TH(100),R                       00011280 TME20019
      COMMON/PATHC/PO,TO,K                                              00011290 TME20020
      DIMENSION E(100)                                                  00011300 TME20021
      COMPLEX*16 P,E,BL,T,PC,DPT,Q                                      00011310 TME20022
      DIMENSION Y1(100),Y4(100),X1(100),X4(100)                         00011320 TME20023
      LOGICAL PRNT,PRNTS,PRNTC                                          00011330 TME20024
      NRY        = N                                                    00011340 TME20025
      X1M        = 1.E+4                                                00011350 TME20026
      X4M        = 0.0                                                  00011360 TME20027
      NNN        = 0                                                    00011370 TME20028
      I          = 0                                                    00011380 TME20029
 6     P         = PR*(1.,0.)+PI*(0.,1.)                                00011390 TME20030
      T          = P*R                                                  00011400 TME20031
      J          = 2                                                    00011410 TME20032
      BL         = 1./(C(J)**2)-P*P                                     00011420 TME20033
      E(J)       = CDSQRT(BL)                                           00011430 TME20034
      T          = T+E(J)*(TH(4)+TH(2)*LTP(NRY))                        00011440 TME20035
      J          = 3                                                    00011450 TME20036
```

```
      BL        = 1./(S(2)**2)-P*P                                        00011460 TME20037
      E(J)      = CDSQRT(BL)                                              00011470 TME20038
      T         = T+E(J)*(TH(3)+TH(2)*LTS(NRY))                           00011480 TME20039
      IF(PRNTC) WRITE(6,110) P,E(2),T                                     00011490 TME20040
      IF(PRNTC) WRITE(6,111) E(3),I,NNN                                   00011500 TME20041
  111 FORMAT('0E(3)=',2G18.6,' I=',I5,' NNN=',I5)                         00011510 TME20042
      TI        = T*(0.,-1.)                                              00011520 TME20043
      IF (DABS(TI) .LE. DET) GO TO 2                                      00011530 TME20044
      IF(I.GT.90) GO TO 2                                                 00011540 TME20045
      I         = I+1                                                     00011550 TME20046
      X1(I)     = 100.                                                    00011560 TME20047
      X4(I)     = 0.0                                                     00011570 TME20048
      IF(TI.GT.0.) Y1(I)=TI                                               00011580 TME20049
      IF(TI.GT.0.) X1(I)=PI                                               00011590 TME20050
      IF(TI.LT.0.) Y4(I)=TI                                               00011600 TME20051
      IF(TI.LT.0.) X4(I)=PI                                               00011610 TME20052
      IF(I.EQ.1) GO TO 43                                                 00011620 TME20053
      IF(NNN.GT.1) GO TO 44                                               00011630 TME20054
      IF(TI*TL.LE.0.) GO TO 44                                            00011640 TME20055
   43  IF(TI.GT.0.) PI=PI-DL                                              00011650 TME20056
      IF(TI.LE.0.) PI= PI+DL                                              00011660 TME20057
      IF(PI.LE.1.E-5) PI=PK/2.                                            00011670 TME20058
      NNN       = 1                                                       00011680 TME20059
      PK        = PI                                                      00011690 TME20060
      TL        = TI                                                      00011700 TME20061
      GO TO 6                                                             00011710 TME20062
   44  DO 52 J=1,I                                                        00011720 TME20063
      IF(X1(J).GT.X1M) GO TC 53                                           00011730 TME20064
      X1M       = X1(J)                                                   00011740 TME20065
      NJ        = J                                                       00011750 TME20066
   53 IF(X4(J).LE.X4M) GO TC 54                                           00011760 TME20067
      X4M       = X4(J)                                                   00011770 TME20068
      MJ        = J                                                       00011780 TME20069
   54  CONTINUE                                                           00011790 TME20070
   52   CONTINUE                                                          00011800 TME20071
      Y1M       = Y1(NJ)                                                  00011810 TME20072
```

```
      Y4M        = Y4(MJ)                                                00011820 TME20073
      DPI        = (X1M-X4M)/(Y1M-Y4M)                                   00011830 TME20074
      DPM        = Y1M*DPI                                               00011840 TME20075
      PI         = X1M-DPM                                               00011850 TME20076
      NNN        = 2                                                     00011860 TME20077
      IF(PI.LE.PIL) PI=PIL                                               00011870 TME20078
      GO TO 6                                                            00011880 TME20079
2        CONTINUE                                                        00011890 TME20080
      BL         = 0.                                                    00011900 TME20081
      BL         = BL-(TH(4)+TH(2)*LTP(NRY))/E(2)                        00011910 TME20082
      BL         = BL-TH(2)*LTS(NRY)/E(3)-TH(3)/E(3)                     00011920 TME20083
      BL         = R+P*BL                                                00011930 TME20084
      Q          = P                                                     00011940 TME20085
      DPT        = 1./BL                                                 00011950 TME20086
      IF(PRNTC) WRITE(6,110) P,E(2),T,DPT                                00011960 TME20087
  110 FORMAT(1H0,4X,'P=    ',2G18.6/5X,'E(1) =',2G17.6/5X,'T=    ',2G18.6/ 00011970 TME20088
     1 5X,'DPT=   ',2G18.6)                                              00011980 TME20089
       RETURN                                                            00011990 TME20090
      END                                                                00012000 TME20091
```

```
      REAL FUNCTION TS*8 (K)
      IMPLICIT REAL*8  (A-H,O-Z)
      COMMON/PLACE/THIC,H,KSSP
      COMMON/RAYPAR/KUD(100),KRSP(100),LTS(100),LTP(100),LREF( 100,4)
      COMMON/ORSTF/CC(100),SS(100),DD(100),TTH(100),XX
      COMMON/STUFF/C(100),S(100),D(100),TH(100),X,RCSQ(100),RSSQ(100)
      DIMENSION T(200)
      COMMON/LPRINT/PRNT,PRNTS,KST,KEND,PRNTC,NDC,DET
      LOGICAL PRNT,PRNTS,PRNTC
      DO 10 N=1,2
      DEL       = 1./SS(2)
      IF(KSSP.EQ.0) GO TO 81
      IF(LTS(N).GT.0) GO TO 81
      DEL       = 1./CC(2)
81      P       = -1.E-9
      DAT       = 1.E+12
      CALL FIND2(P,M,DEL,DAT,PO,TO,N)
       P=1/SS(N+1)
      TTP       = TO
      IF(PO.LE.P) GO TO 6
      CALL HELP(K,N,P,TTP,DTP,N)
6     T(N)      = DMIN1(TO,TTP)
10      CONTINUE
      TS        = DMIN1(T(1),T(2))
       N        = 2
      IF (PRNT)WRITE (6,1) (T(J),J=1,N)
1     FORMAT (5X,'T 1,2,3',3(E18.6))
100    FORMAT(I10,2E18.6)
      RETURN
      END
```

```
C*********************************************************************
C
C B. GORDON AND C.M. NAUTIYAL
C
C   MAY 12, 1972
C
C THIS PROGRAM GENERATES CALCOMP PLOTS OF THE OF TERRY BARKER'S
C PROGRAM MODELING THE RESPONSE OF AN ELASTIC LAYER OVER AN ELASTIC
C HALF-SPACE AS CONVOLVED WITH A SPECFIED SOURCE FUNCTION.
C
C THREE PLOTS ARE PRODUCED,THE UNCONVOLVED OUTPUT,THE CONVOLVED OUTPUT,
C AND THE SOURCE FUNCTION, ALL PLOTS ARE IN SAME SCALE IN TIME.
C
C THE SUBROUTINE CONVLV IS USED.
C
C  THE SOURCE FUNCTION,SRC,A LINEAR ARRAY,IS SPECFIED IN A DATA
C STATEMENT
C
C XDIM,YDIM  SPECIFY THE SIZE OF THE OUTPUT
C
C DELTA IS HALF WIDTH OF THE SOURCE ASSUMED SYMMETRIC
C NOTE THAT THE BEGINNING OF THE OUTPUT  IS PADDED WITH  ZEROS TO 10%
C OF ITS LENGTH
C******************************************************************
      REAL*8 P,SRC,PC
      DIMENSION P(1000),SRC(1000),PC(2000),PPLCT(1000),TPLOT(1000)
      DIMENSION XL(2),YL(4),YM(4)
      DIMENSION SRCP(1000)
      DIMENSION PPL(1000)
      DATA XL/'TIME',' SEC'/
      DATA YL/'CONV','OLVE','D OU','TPUT'/
      DATA YM/'UNCO','NVOL','V OU','TPUT'/
C SPECIFY SOURCE FUNCTION
      DATA SRC/0.,2.5,5.,2.5,0.,995*0./
C SPECIFY PROGRAM PARAMETERS
      XDIM=6.
```

```
      YDIM=2.                                                           MAIN0037
      DELTA=.4                                                          MAIN0038
C READ IN PUNCHED DATA                                                  MAIN0039
      READ(5,100) TT,DP,NN                                              MAIN0040
      PRINT 200, TT, DP, NN                                             MAIN0041
  200 FORMAT(' TT=',G15.6,'  DP=',G15.6,'  NN=',I10)                    MAIN0042
      READ(5,101)(P(I),I=1,NN)                                          MAIN0043
  100 FORMAT(2E15.6,I10)                                                MAIN0044
  101 FORMAT(5E15.6)                                                    MAIN0045
  102 FORMAT(3(I10,G15.6))                                              MAIN0046
C PERFORM CONVOLUTION WITH SOURCE FUNCTION                              MAIN0047
      NS = 2*DELTA/DP +1.5                                              MAIN0048
      CALL CONVLV(NN,P,NS,SRC,PC)                                       MAIN0049
C PAD RECORD WITH ZEROES                                                MAIN0050
      NQ = NN/10                                                        MAIN0051
      NA = NQ + 1                                                       MAIN0052
      NB = NN + NQ                                                      MAIN0053
      DO 15 I = 1, NQ                                                   MAIN0054
      SRCP(I) = 0.0                                                     MAIN0055
      TPLOT(I) = TT-(NQ-I+1)*DP                                         MAIN0056
      PPL(I) = 0.0                                                      MAIN0057
   15 PPLOT(I) = 0.0                                                    MAIN0058
      DO 16 I = NA,NB                                                   MAIN0059
      SRCP(I) = SRC(I-NA+1)                                             MAIN0060
      TPLOT(I) = TT + (I-NA)*DP                                         MAIN0061
      PPL(I) = P(I-NA+1)                                                MAIN0062
   16 PPLOT(I) = PC(I-NA+1)                                             MAIN0063
C LIST OUTPUT                                                           MAIN0064
      PRINT 201                                                         MAIN0065
  201 FORMAT('OOUTPUT AFTER CONVOLUTION-BEFORE CONV-SOURCE FUNC'//)     MAIN0066
      PRINT 202,(TPLOT(I),PPLOT(I),PPL(I),SRCP(I),I=1,NB)               MAIN0067
  202 FORMAT(4G15.6)                                                    MAIN0068
C PLOT ON CALCOMP                                                       MAIN0069
      CALL NEWPLT('M8800','6894','WHITE ','BLACK')                      MAIN0070
      CALL PICTUR(XDIM,YDIM,XL,8,YM,16,TPLOT,PPL   ,NB,0.,0)            MAIN0071
      CALL PICTUR(XDIM,YDIM,XL,8,YL,16,TPLOT,PPLOT,NB,0.,0)             MAIN0072
```

```
      DO 17 I = 1, NB                                                   MAIN0073
   17 TPLOT(I) = TPLOT(I) - TT                                          MAIN0074
      CALL PICTUR(XDIM,YDIM,XL,8,'SOURCE FUNCTION ',16,TPLOT,SRCP,NB,0.,MAIN0075
     1 0)                                                               MAIN0076
      CALL ENDPLT                                                       MAIN0077
      CALL EXIT                                                         MAIN0078
      STOP                                                              MAIN0079
      END                                                               MAIN0080
```

```
C     SUBROUTINE CONVLV(LX,XX,LY,YY,CC)
C
C TITLE - CONVLV = CONVOLVE
C       COMPLETE CONVOLUTION OF TWO TRANSIENTS
C
C
C                     ---ABSTRACT---
C
C             CONVLV CONVOLVES TWO TRANSIENTS, X(I) I=0,1,...,LX-1
C             AND Y(I) I=0,1,...,LY-1 , TO PRODUCE THE COMPLETE
C             CONVOLUTION FUNCTION
C
C                            LX-1
C                    C(I)  =  SUM ( X(J)*Y(I-J) )
C                             J=0
C
C                    FOR I = 0,1,...,LX+LY-2
C                    WHERE
C                       LX AND LY ARE INPUT PARAMETERS
C                       Y(K) IS ASSUMED = 0.0 FOR K OUTSIDE OF
C                            THE RANGE 0 TO LY-1
C             NOTE THAT THE CONVOLUTION IS INDEPENDENT OF THE ORDER
C             OF THE INPUTS X AND Y.
C
C             TECHNIQUE USED IS AN ALGORITHM BASED ON ANALOGY TO
C             MULTIPLICATION OF POLYNOMIALS
C
C
C                     --STATISTICS--
C
C LANGUAGE   - FORTRAN IV
C EQUIPMENT  - NO SPECIAL REQUIREMENTS
C STORAGE    -
C AUTHOR     - J.F. CLAERBOUT.  TRANSLATED FROM FORTRAN II TO FORTRAN
C              BY R.A. WIGGINS,  6/65
C
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C LIBRARY ROUTINES REQUIRED - NONE
C
C
C                    ----USAGE----
C
C SAMPLE CALL
C     CALL CONVLV(LX,XX,LY,YY,CC)
C
C INPUTS
C
C    LX          IS NO. OF TERMS IN X VECTOR
C
C    XX(I)       I=1,...,LX  CONTAINS  X(0),...,X(LX-1) RESPECTIVELY
C
C    LY          IS NO. OF TERMS IN Y VECTOR
C                MUST EXCEED ZERO  (PROGRAM EXITS IF ZERO OR LESS)
C
C    YY(I)       I=1...LY    CONTAINS  Y(0),...,Y(LY-1) RESPECTIVELY
C                EQUIVALENCE (XX,YY) IS PERMITTED
C
C OUTPUTS
C
C    CC(I)       I=1,...,LX+LY-1 CONTAINS C(0),...,C(LX+LY-2) RESPECTIVELY
C                           WHERE C(I) IS GIVEN IN ABSTRACT
C                EQUIVALENCE (XX,CC)  ALLOWED IF XX NOT EQUIVALENT TO YY.
C
C EXAMPLES
C
C 1. SHOWING REVERSIBILITY OF X AND Y
C    INPUTS  - LX = 3  XX(1...3) = 1.,2.,3.
C              LY = 2  YY(1...2) =  10.,1.
C
C USAGE   -         CALL CONVLV(LX,XX,LY,YY,CC1)
C                   CALL CONVLV(LY,YY,LX,XX,CC2)
C    OUTPUTS - CC1(1...4) = CC2(1...4) = 10.,21.,32.,3.
C
```

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C 2. ILLEGAL INPUT CASES (NO OUTPUT)                                    00000740 CONV0073
C    INPUTS  - SAME AS EXAMPLE 1. EXCEPT START WITH OUTPUT VECTORS      00000750 CONV0074
C                CLEANED, I.E. CC1(1...4) = CC2(1...4) = 0.,0.,0.,0.    00000760 CONV0075
C    USAGE   -          CALL CONVLV(-2,XX,LY,YY,CC1)                    00000770 CONV0076
C                       CALL CONVLV(LX,XX,0,YY,CC2)                     00000780 CONV0077
C    OUTPUTS - CC1(1...4) = 0.,0.,0.,0.    (ILLEGAL LX)                 00000790 CONV0078
C              CC2(1...4) = 0.,0.,0.,0.    (ILLEGAL LY)                 00000800 CONV0079
C                                                                       00000810 CONV0080
C PROGRAM FOLLOWS BELOW                                                 00000820 CONV0081
C                                                                       00000830 CONV0082
C                                                                       00000840 CONV0083
      SUBROUTINE CONVLV(LX,XX,LY,YY,CC)                                 00000850 CONV0084
      IMPLICIT REAL*8  (A-H,O-Z)                                                 CONV0085
C                                                                       00000860 CONV0086
C DUMMY DIMENSION STATEMENTS                                            00000870 CONV0087
      DIMENSION  XX(2),YY(2),CC(2)                                      00000880 CONV0088
C CHECK LEGALITIES                                                      00000890 CONV0089
      IF (LX.LE.0) GO TO 9999                                           00000900 CONV0090
      IF (LY.LE.0) GO TO 9999                                           00000910 CONV0091
C CLEAR PORTION OF OUTPUT AREA                                          00000920 CONV0092
      LC        = LX+LY-1                                               00000930 CONV0093
      IB        = LX+1                                                  00000940 CONV0094
      DO 10 I=IB,LC                                                     00000950 CONV0095
 10   CC(I)     = 0.                                                    00000960 CONV0096
C                                                                       00000970 CONV0097
C DO CONVOLUTION                                                        00000980 CONV0098
C                                                                       00000990 CONV0099
      IX        = LX                                                    00001000 CONV0100
      DO 30  I=1,LX                                                     00001010 CONV0101
      X         = XX(IX)                                                00001020 CONV0102
      CC(IX)    = 0.                                                    00001030 CONV0103
      DO 20  J=1,LY                                                     00001040 CONV0104
      K         = IX+J                                                  00001050 CONV0105
      CC(K-1)   = CC(K-1)+X*YY(J)                                       00001060 CONV0106
 20   CONTINUE                                                          00001070 CONV0107
 30   IX        = IX-1                                                  00001080 CONV0108
```

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C                                                              00001090 CONV0109
C  EXIT                                                        00001100 CONV0110
C                                                              00001110 CONV0111
 9999 RETURN                                                   00001120 CONV0112
      END                                                      00001130 CONV0113
```