Input and output data

The program reads one input and generate two output files. The structure of the input data **ZRAYAMP.DAT** is as follows:

1: TEXT — one line, format (A80)
Arbitrary alphanumeric comment on the model.

2: K2, MPRINT, KX — one line, free format

K2 Controls the extent of calculation.

- K2 = 1 travel times only.
- K2 = 2 calculation of arrival times, amplitudes and phase shifts (i.e., the quantities needed to compute the elementary impulse seismograms).

MPRINT Controls the printout of the description of the model in the output file ZRAYAMP.OUT.

- MPRINT = 0 only input data are printed.
- MPRINT = 1 input data and list of subintervals of depths together with the relevant parameters are printed.
- MPRINT = 2 printout as for MPRINT = 1, plus velocity-depth distribution.

KX Controls the type of ray calculations.

- KX = 1 Two-point ray tracing (necessary for the calculation of synthetic seismograms).
- KX = 2 Initial-value ray tracing. In this case data in 6 have no influence, but must be formally given in harmony with parameter MEP - see 5).

3: H(I), A1, VU(I), D1, E, SREL, REL(I), QF(I) — set of lines, free format
System of data for individual grid points of the model - one line for one grid point.

H(I) Depth of the grid point [km]. This value can be slightly changed in the process of smoothing the velocity-depth distribution, with the exception of the interfaces. H(1) = 0.

A1	A1 = 0	No velocity jump occurs at the grid point. The first and second derivatives of the velocity are smooth at this grid point. Put A1 = 0 for the Earth's surface.
	A1 = 100	Interface of the second order (the velocity is smooth but not its derivative).
	0.1 < A1 < 99	Interface of the first order. A1 then gives the P velocity immediately above the interface. The quantity VU(I) then represents the velocity immediately below the interface.

VU(I) P-wave velocity at the grid point (from bellow) [km/s].

D1, E Densities immediately above and bellow the interface [g/cm^3]. Put D1 = E = 0 if A1 = 0 or A1 = 100 with the exception of the Earth's surface where D1 = 0 and E is given.

SREL The ratio of the S and P velocities from above at the grid point. Put SREL = 0 if A1 = 0 or A1 = 100.

REL(I) The ratio of the S and P velocity at the grid point (from below).

QF(I) Quality factor for the P-waves between two grid points. Quality factor for S-waves = 2.25QF(I). For QF = 0 no attenuation is considered. The frequency dependence of the attenuation is applied in the program in the way that the TSTAR (integral along the ray from the source to the receiver from 1/(velocity$\times$quality factor)) is multiplied by 0.6366atan(1.5923/FHZ). (FHZ see bellow.)

The last grid point of the model is considered as the first-order interface. Termination of the input of model: 8 numbers in free format, the first should be equal to -1.

4: OD, TDD. — one line, free format
Controls the application of the smoothed spline algorithm to the depth-velocity distribution.

OD Degree of smoothing of the depth-velocity distribution by splines [km]. Higher accuracy (lower smoothing) is obtained for smaller OD.

TDT Absolute value of the step in variable $1/v^2$ [(km/s)$^{-2}$] for computation and print of the tables of the depth-velocity distribution (actually the depth - $1/v^2$ distribution). This distribution is calculated for each layer independently. If TDT < 0.0001, the depth-velocity distribution is not calculated even for MPRINT = 2. The depth-velocity distribution is not printed for a layer with the constant velocity. TDT has no meaning for MPRINT < 2.

5: ICONT, MEP, MOUT, IBP, IBS, IDP, IDS, IREAD, MPSOUR, ITMAX, NLAY — one line, free format

ICONT Controls the continuation of the computation.

ICONT = 0 termination of the computation. Last line in input data.

ICONT = 1 computation continues, line 6 follows.

MEP ABS(MEP) — the number of receiver positions, 1 < |MEP| < 100. The sign of MEP controls the way in which the system of receiver positions is specified.

MEP > 0 The receivers are distributed regularly along the profile. Only the position of the first receiver and the step in the x_1^R-coordinate are read - see 6).

MEP < 0 The receivers are distributed irregularly along the profile. The x_1^{Ri}-coordinates of all receiver positions are read in 6.

MOUT Controls the print of results on the screen. The input data are always reproduced. The printout then continues as follows:

MOUT = 0 Only the codes of generated waves are printed.

MOUT = 1 Elementary impulse seismograms (with the x_1^{Ri}-coordinate of the receiver) and external wave codes are printed.

MOUT = 2 More detailed print that allows to monitor the calculation.

IBP-IBS Switches which control the automatic generation of numerical codes of elementary waves. Only direct, refracted and primarily reflected waves (possibly converted at the point of reflection) can be generated automatically.
IBP controls the automatic generation of refracted and primarily reflected waves for a P-wave source.

IBP = 0 No refracted and primarily reflected waves are generated.

IBP = 1 PP refracted and PP primarily reflected waves are generated.

IBP = 2 PS primarily reflected waves are also generated.

IBS controls the automatic generation of refracted and primarily reflected waves for a S-wave source.

IBS = 0 No refracted and primarily reflected waves are generated.

IBS = 1 SS refracted and SS primarily reflected waves are generated.

IBS = 2 SP primarily reflected waves are also generated.

IDP controls the automatic generation of the direct P-wave (upwards from the source).

IDP = 0 Direct P wave is not generated.

IDP = 1 Direct P wave is generated.

IDS controls the automatic generation of the direct S-wave.

IDS = 0 Direct S wave is not generated.

IDS = 1 Direct S wave is generated.

IREAD Controls the manual generation of numerical codes of elementary waves.

IREAD = 0 No numerical codes are generated manually.

IREAD = 1 Numerical codes of certain elementary wave are manually generated, see line set 10.

MPSOUR Controls the source radiation pattern.

MPSOUR = 0 The radiation pattern does not depend on the ray parameter (isotropic radiation).

MPSOUR = 7 Double-couple radiation pattern applies for both P- and S- waves.

ITMAX Number of iteration permitted in the determination of the ray parameter in two-point ray tracing (maximum 99). If ITMAX = 0, then ITMAX = 20.

NLAY Controls the generation of the numerical code of the waves that propagate in the last layer (if IBP $>$ 0 and/or IBS $>$ 0).

NLAY = 1 The waves are not generated.

NLAY = 0 The refracted P- and S- waves in the last layer are generated. The waves reflected and possibly converted at the bottom of the model are not computed. Thus, in the computation the last layer represents a vertically inhomogeneous halfspace.

6: Specification of receiver positions along the surface of the Earth.

MEP $>$ 0 RMIN, RSTEP [km] — one line, free format
The receivers are distributed regularly along the profile. The x_1^{Ri} coordinate of the i-th receiver is given by the formula DST(I) = RMIN + RSTEP*(I-1). Take RSTEP $>$ 0!

MEP $<$ 0 DST(1), ..., DST(ABS(MEP)) —- one line, free format
DST(I) gives the x_1^{Ri}-coordinate of the i-th receiver. The receivers may be distributed irregularly along the profile. Take the receiver positions from left to right so that DST(I) $>$ DST(I-1) for any I.

7: XSOUR, ZSOUR, TSOUR, REPS, ROZD, FHZ — one line, free format

XSOUR The x_1^S-coordinates of the source [km].

ZSOUR The x_3^S-coordinate of the source [km], ZSOUR $\geq$ 0. ZSOUR must not be equal to depth H(I) of any of the first-order interfaces (with exception of the Earth's surface).

TSOUR Initial hypocentre time [s].

REPS The required accuracy [km] in the two-point ray tracing. If REPS = 0, then REPS = 0.05km.

ROZD Density [g/cm^3] at the source.

FHZ Frequency of waves [Hz] used in calculation of the attenuation. Put FHZ = 0 if attenuation is not considered (QF=0, see line 3).

8: PPAR(1), PPAR(2), PPAR(3), PPAR(4) — one line, free format
Double couple source parameters (see Aki and Richards). Given only if MPSOUR = 7. If MPSOUR$\neq$7, isotropic source is supposed. In this case

the amplitude radiated as the S-wave is three times larger than the P-wave amplitude.

PPAR(1) Dip [rad]

PPAR(2) Seismic moment Mo [10^9 Nm], then displacement in μm.

PPAR(3) Strike [rad]

PPAR(4) Rake [rad]

9: AMIN1, ASTEP1, AMAX1, AMIN2, ASTEP2, AMAX2 — one line, free format
Control the basic system of initial angles in the determination of the parameter of rays in the shooting method.

AMIN1,ASTEP1,AMAX1 Minimum ray declination, declination step, and maximum ray declination. The values determine the system of initial angles [rad] for refracted, primarily reflected and converted waves generated automatically and for other manually generated elementary waves, the first element of which propagates from the source downwards.

AMIN2,ASTEP2,AMAX2 Minimum ray declination, declination step, and maximum ray declination. The values determine the system of initial angles for refracted, primarily reflected and converted waves generated automatically and for other manually generated elementary waves, the first element of which propagates from the source upwards. In both cases the parameters represent the initial value, the step and the end value of the angle [rad]. The ray with initial angle equal to zero emerges from the source parallelly with the x_1-axis in the direction of increasing x_1. The following conditions must be generally fulfilled: $0 \leq$ AMN1 $<$ AMX1 $\leq \pi$, ASTEP1 $>$ 0 and $0 \geq$ AMIN2 $>$ AMAX2 $\geq -\pi$, ASTEP2 < 0. For MPSOUR = 7 (see 5)) value π is replaced by $\pi/2$.

10: KC, KCA, JC(1), ..., JC(KCA) — set of lines, free format
Manual generation of numerical codes of elementary waves. Given if IREAD = 1. For each code the following data must be given.

KC	KC = 1	The ray propagates from the source downwards.
	KC =-1	The ray propagates from the source upwards.

KCA The number of segments of the ray. KCA < 100.

JC(I) ABS(JC(I)) gives the ordinal number of the layer where the i-th physical element of the ray is situated. JC(I) > 0 : P-wave element, JC(I) < 0 : S-wave element. I = 1, 2, ..., KCA.

The last line for the whole set must contain 3 zeros (the indication of the end of the elementary code list).

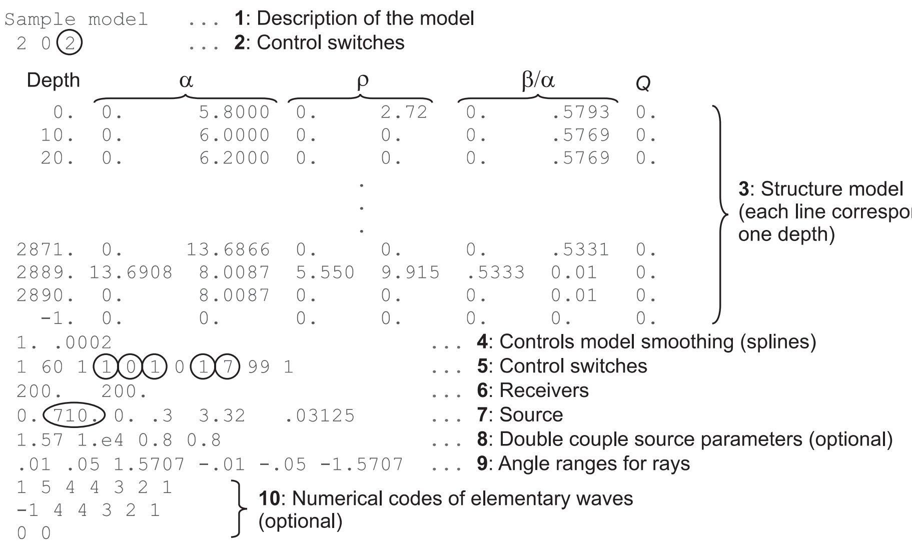

Figure 1: An example of the input data file. Circles denote the most frequently changed switches controlling the computation.

The program generates two outputs. The output file **ZRAYAMP.OUT** is partly of an informative character. It allows the user to check whether the input data have been read in correctly and provides information about the calculation. Possibly, the reasons why the calculations had to be stopped are given. Optionally, for MOUT=1 (see 5 in ZRAYAMP.DAT), it provides the resulting travel times and amplitudes at the ray endpoints. The structure is as follows:

1. Input data are always printed under appropriate heading.

2. Approximation of the model. The extent of the printed data depends on the value of MPRINT, see the input data, line 1

if MPRINT = 1 The division of the medium into layers and parameters of the depth-velocity distribution in individual layers are printed under the heading: V (P velocity), 1/V**2, HZ (input grid depth), H (smoothed grid depth used in further computations), A, B, C, D (coefficients of the depth- velocity distribution), I (ordinal number of the grid point).

if MPRINT = 2 The same output as for MPRINT = 1 plus data on the depth-velocity distribution under the heading: V, 1/V**2 (with step TDT and independently for each layer), H, HV/DH (derivative of the *P*-wave velocity with respect to depth). The position of each first-order interface is marked by a row of asterisks.

3. Output for individual waves for a given set of input data 5-10.

if MOUT = 0 Internal wave codes (consecutive numbers of the wave in generation of the numerical codes) and external wave codes (parameters KC, KCA and JC(I), I = 1, 2, ..., KCA).

if MOUT = 1 Also coordinates of the receivers, corresponding arrival times, horizontal and vertical amplitudes and phase shifts of the displacement vector. For KX = 2 the first number in the line corresponds to the value of the initial angle of the ray (the one from the basic system of initial angles - see 8)). For KX = 1, the ray angle (obtained by iterations in two-point ray tracing) is given as the last number in the line.

if MOUT = 2 The output is completed by certain results of iterations in the process of determining the ray parameter in the shooting method. These are:

- IND, XO, AA - for each endpoint of the ray in the basic system of rays.
- IND, ITER, DD, XO, PNEW - for each endpoint of the ray in the iterations to the receiver position.
- IND, ITER, XO, PNEW - for each endpoint of the ray in iterations for some special rays. Examples are the boundary rays between the shadow and illuminated regions (labeled SH), the critical rays (labeled CR)

The meaning of individual symbols:

XO - x_1-coordinate of the endpoint of the ray.

DD - x_1-coordinate of the receiver. It should not differ from XO by more than the shooting tolerance REPS (see 7 in ZRAYAMP.DAT)

ITER - The successive number of the iterations.

AA - Initial angle in the basic system of the initial angles.

PNEW - Initial angle of the ray, in iteration to the receiver positions.

IND - Reason of the termination of the ray calculation:

IND = 3	The termination point is situated at the surface of the medium (successful ray).
IND = 9	Overcritical incidence at an interface where the numerical code of the wave requires a transmission.
IND = 14	The ray specified by the manual generation of the code does not exist in a given model.
IND = 18	The ray turned downwards by refraction in the first layer whereas it should reach the surface of the medium.
IND = 19	The deepest point of penetration of the ray in the ray in the refraction occurs exactly at the boundary of the layer.
IND = 20	Required conversion of the wave is not possible because a refraction occurs at the deepest point of penetration of the ray instead of a reflection.

The output file **ZRAYAMP.RES** contains the results of ray calculations for all rays point-by-point. The system of data for individual ray points is:

DELTA(I), Z(I), T(I), STRAIN(I), AMPZ(I)

DELTA(I) - angle distance of the i-th point in degrees

Z(I) - depth of the point in km

T(I) - time at the point in sec

PHASEZ(I) - phase of the amplitude at the point

AMPZ(I) - modul of the amplitude of the vertical displacement component at the point (the amplitude includes radiation pattern, geometrical spreading, R/T coefficients and coefficients of conversion if the point is situated at the free surface)

The end of ray is indicated by the line:
9000.000000 9000.000000 9000.000000 9000.000000
9000.000000
After this, data for a new ray follow.