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Interactive program for kinematic problems in laterally heterogeneous media

Program pro interaktivní řešení kinematických úloh v laterálně nehomogenních prostředích

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Abstract: An interactive program system for modelling velocity distribution of seismic waves in 2-D laterally heterogeneous stratified media with curved interface is described. The inverse kinematic problem can be solved by means of the method of successive approximations. Applied to ray equations, the method assumes piecewise linear approximation of the medium. The program system enables fast computation of rays or fans of rays, interruption of the computation in real time, and interactive change of all parameters of the velocity model within one passage of the program. All these features make an efficient shell for the inverse problem solution. The program system was written in BASIC for the desk-top computer Hewlett – Packard HP 9845 for full use of HP graphics software and graphics peripheral devices. An example is given of computation for a 2-D laterally heterogeneous stratified model. It is a test model suggested by W. D. Mooney for the Symposium of the Commission on Controlled Source Seismology at Einsiedeln, Switzerland, 1983. The program system was also tested on real data, but these results will be published in a following paper.

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Introduction

During the last fifteen years the increasing volumes of data forced the development of interpretational methods which would enable construction of sufficiently accurate mathematical models for areas with complicated structure, which in recent years have been in the focus of seismic investigations. The assumption of a laterally homogeneous stratified medium cannot elucidate the numerous characteristic features of the measured data, or may lead to erroneous conclusions. All the investigated real media are laterally heterogeneous and therefore methods have been developed for finding the distribution of real velocities in the depth section for laterally heterogeneous media, i.e. for solving both the direct and inverse problem.

One way of constructing a velocity model of laterally heterogeneous medium is the "trial and error" method. It is a method of successive approximations for solving the inverse kinematic problem. For this purpose interactive modelling seems to be optimum. Therefore the desk-top computer HP 9845 was chosen for computations. It makes it possible to use the HP graphics software and it is equipped with appropriate graphics peripherals (graphics screen, matrix printer, four-colour plotter A3).

Solution of the inverse problem using desk-top computer

The aim was to develop a fully interactive program system for fast construction of an accurate velocity model, using refraction data or combined refraction and reflection data by the "trial and error" method.

Two approaches to calculation of rays have been successively applied. First an approach solving seismic ray equations for laterally heterogeneous media (Červený–Molotkov–Pšenčík 1977) by the 4th order Runge–Kutta method was used. The developed program was based on programs of the Mathematical-Physical Faculty of Charles University (Červený–Pšenčík 1981) written in FORTRAN, where the velocity model and interfaces are given by a relatively dense grid of points. The interactive program was written for media without interfaces only as its expansion for media with interfaces became cumbersome and demanding for the computer memory.

The other approach of calculating seismic waves assumes piecewise linear approximation of the velocity distribution in the medium. Then the solution of ray equations is analytical and results are given by explicit expressions. This approach is based on the method (Aric–Gutdeutsch–Sailer 1980) which was further developed (Firbas–Skorkovská 1984). On its basis a fully interactive program system for the desk-top computer HP 9845 was written in BASIC, assuming full use of graphics HP software and graphics peripherals. The system was tested. Despite the limitations of the computer's internal memory capacity (64 Kb) it was feasible through extensive program segmentation to implement all changes of the velocity model in the main segment of program RAY. The program segmentation was done in such a way that every task of the program was coded in one segment only so the program speed in interactive mode was not lowered.

Description of the model

From the top the medium is bounded by a curved relief, from the bottom by a curved interface, and from the sides by two vertical boundaries. The model can consist of up to ten layers separated by curved interfaces. Each interface must intersect the whole area delimited by vertical boundaries. The interfaces must not mutually intersect, but may touch, or overlap. The model can therefore contain layers of zero thickness. The interfaces and layers are numbered downwards.

The whole studied area must be covered with vertical grid lines and the whole first layer with horizontal grid lines as well. The first vertical line coincides with the left boundary of the model, the last with the right boundary. The program works with a maximum of 19 vertical and 20 horizontal grid lines. Distances between all lines can be non-equidistant.

The velocity model enables a more detailed description of the first layer. The velocity distribution of the first layer is given by velocities at the grid points of non-equidistant rectangular grid formed by horizontal and vertical grid lines. The depths of the interfaces and the heights of the relief are given on all vertical lines. The velocity distribution of any deeper-seated layer is given by velocities below its upper and above its lower interface on all vertical lines. The program internally divides the medium into triangles where the analytical formulae for ray and travel-time are applied.

Description of waves

Program RAY can be used for computation of ray diagrams and times of arrivals of rays to the surface for multiple-reflected and reflected P and S waves, and for transformed waves. The refracted ray is a ray which refracts upon incidence on all interfaces. This type of rays can be computed automatically without additional information. If the refracted ray hits the interface under an over-critical angle, then its computation is prematurely terminated.

The behaviour of a multiple-reflected ray is given by a code. The code contains information about the layers through which the ray successively passes. It therefore implies on which interfaces the ray is reflected or refracted. The code is formed by a sequence of integer numbers corresponding to numbers of layers through which the ray passes. The part of the ray between two subsequent points of reflection or refraction is called "ray element". If the end points of the ray elements lie on different interfaces, the element is called "simple ray element" and one number (the number of the layer in which the ray element lies) in the code corresponds to it. If the end points of the ray element lie on the same interface, two equal numbers in the code (numbers of the layer in which the element lies) correspond to it and such an element is called "compound element". The compound element is therefore given as two single ray elements corresponding to a ray reflected in the given layer. The code definition is very close to that used in SEIS81 (Červený–Pšenčík 1981), but its use is expanded by the possibilities outlined later in this paper.

Short description of the program system

The program system consists of three segmented program units:

1. Program for constructing the input and for input of experimental traveltime curves.
2. Program for interactive computation of rays and for velocity model changes.
3. Program for selection and plotting of ray diagrams and corresponding experimental traveltime curves along with computed traveltimes.

The generalized scheme of the program system is outlined in fig. 1.

Program MODEL

The program MODEL is used for construction and testing of input velocity model and for input of experimental traveltime curves. The program is segmented and consists of the main program and 14 subroutines.

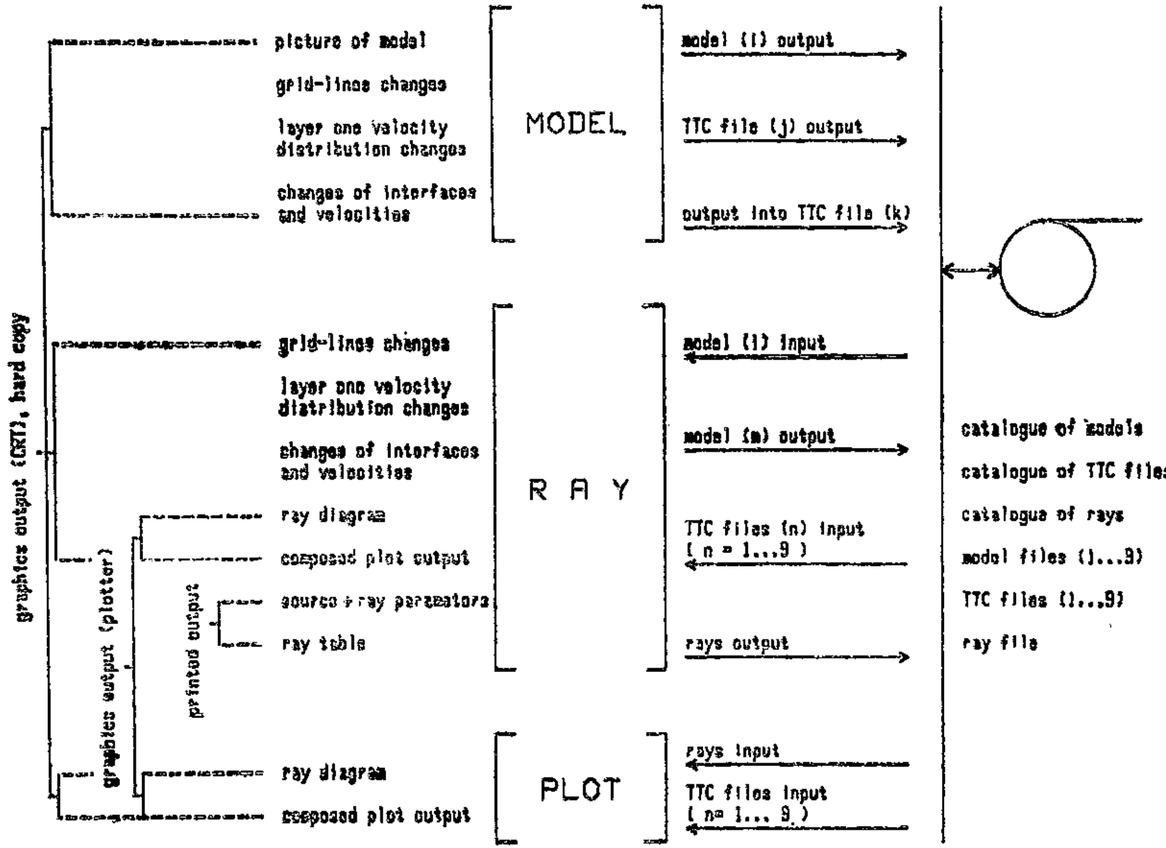
Input data are arranged as follows:

1. Each profile that is to be processed by the program RAY is named by four alphanumeric characters and name is recorded in the catalogue of profiles. The catalogue of profiles provides complete information about the profiles which can be further processed.
2. For each profile a set of files is used:
   a) catalogue of model files,
   b) catalogue of files of experimental traveltime curves,
   c) catalogue of rays,
   d) ray file.

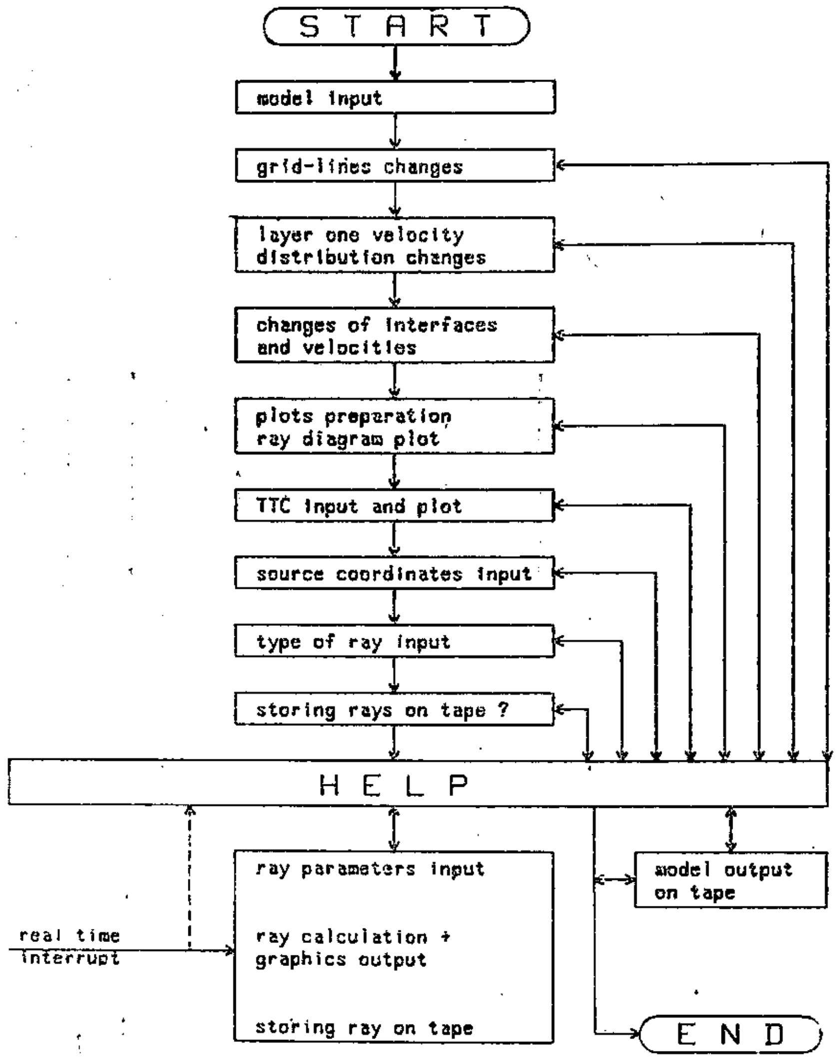
The catalogue of model files provides complete information about files with the velocity models which are available for processing by the program RAY. Each velocity model is stored in one file and its name is written in the catalogue of model files. There may be a maximum of nine files with velocity models for each profile.

The catalogue of files of experimental traveltime curves contains complete information about files of experimental traveltime curves, including the number of traveltime curves. The maximum number of such data files for each profile is nine.

The program MODEL is used for creating a file with a velocity model. Another function of the program is to modify such an existing file. If a new profile is input,



1. Generalized flow-diagram of the computation and input-output operations of the program system (programs MODEL, RAY, PLOT)



2. Simplified diagram for the program RAY

```
SELECT FUNCTION:

0          SHIFT OF A X-GRID LINE
1          DELETION OF A X-GRID LINE
2          INSERTION OF A X-GRID LINE
3          TABLE OF X-GRID LINES
4 OR CONT  SHOW PICTURE OF THE MODEL
5          ESCAPE

NUMBER OF THE X-GRID LINES IS 11 (MAXIMUM VALUE 19)
```

Table 1

Table of program branching as displayed at the point of change of vertical grid lines its name is recorded in the catalogue of profiles. Subsequently, catalogues of models, traveltime curves, and rays are created.

The program enables interactive changes of all input values at the input stage of both the model and traveltimes. All data is tested at the input whether it is in reasonable limits.

Program RAY

The program RAY is the core of the program system. The program is segmented, consists of the main routine and 32 subroutines which form nine segments. The program can be used by an interpreter little acquainted with computers as in case of error the operator is instructed how to proceed.
The computation consists of six basic steps:

1. Input of the model and experimental traveltimes.
2. Changes of the model (if required).
3. Input of plotting parameters, selection and plotting of experimental traveltime curves.
4. Input of ray parameters.
5. Computation of rays with raypath plotting (interruption in real time possible).
6. Recording of the modified model on magnetic tape.

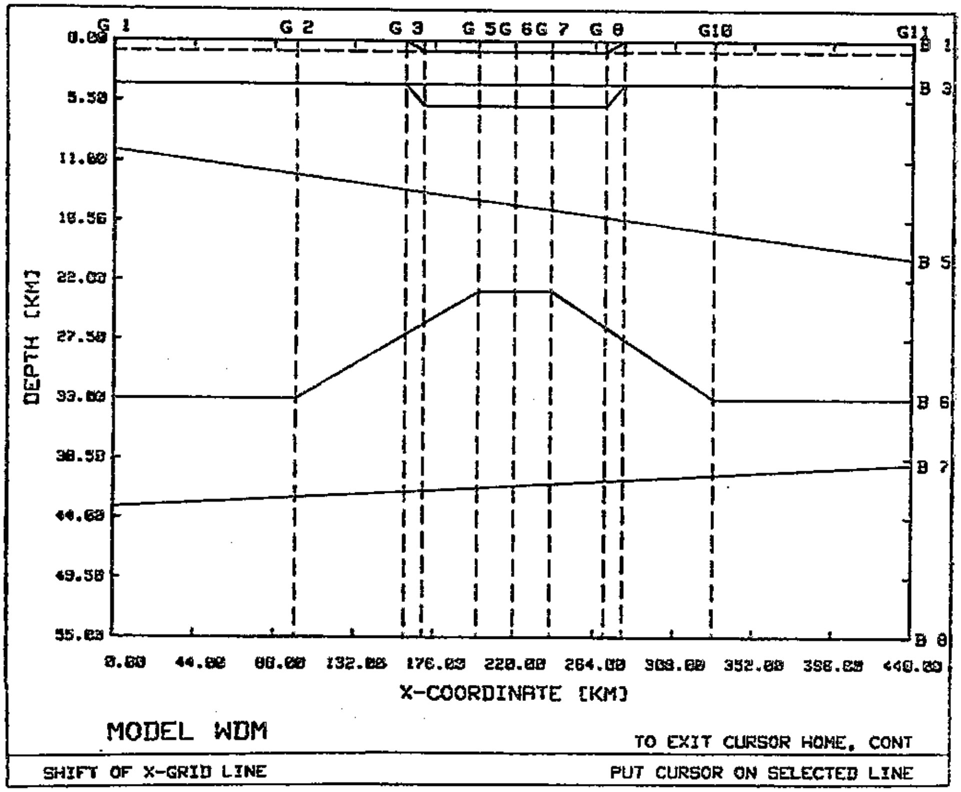
A simplified flow-diagram is in fig. 2. The computation starts with choice of a profile and of the appropriate velocity model. The choice is very simple as the table of existing velocity models available for the chosen profile is shown on the display.

As soon as the velocity model is stored in the internal memory, the model can be changed in three steps:

1. Changes of grid lines.
2. Changes of velocities in the first layer.
3. Changes of interfaces including changes of corresponding velocities under and over them.

The program enables to delete, add or shift any horizontal or vertical grid line and simultaneously tests on allowed input values. For instance, if a change of vertical grid line is required, the program prints a table of allowed actions (tab. 1).

If a grid line is to be shifted, the whole picture of the model is plotted (fig. 3) and the interpreter places the cursor near the line which is to be shifted. The program answers with the sequence number and the current coordinate of the grid line and expects the cursor input of a new grid line coordinate. The digitized new value is printed. If it is a non-acceptable value, it is automatically substituted with the nearest acceptable value. This coordinate can be changed from the key-



3. Model WDM (grid lines and interfaces) as shown on the display at the point of vertical grid lines changes, see table 1. Graphics cursor (not shown) serves for a vertical grid line selection and subsequently for digitization of its new coordinate

board, or the started shift of the grid line can be interrupted and the program control returned to the beginning of the program branch (changes of vertical grid lines). If the new grid line coordinate is accepted, the velocities in the first layer are automatically interpolated for this new grid line. The z-coordinates of all lower interfaces and velocities below and above them are also automatically interpolated. In this way the changes of horizontal and vertical grid lines can proceed.

In next step the velocities in the first layer can be changed. The program can display the first layer velocity model for up to ten vertical grid lines simultaneously. An example of graphics output for changing the first layer velocities is in table 2. The cursor is placed in the rectangle in which the velocity to be changed is located. The coordinates of the corresponding grid point are digitized, the original velocity value in the rectangle is erased and the value is offered for change together with information about the grid point coordinates. The new input value is plotted in the place of the old one. After the changes in the displayed part of the first layer of the velocity model are completed, another part of the velocity grid can be plotted and changes may proceed.

Individual interfaces can also be changed interactively. The allowed branching of the program at the changes of interfaces is shown in table 3.

Table 2

Example of a velocity grid section for the first layer (model TEST) displayed at the point of velocity changes. Graphics cursor for x, y point picking is not shown

DEPTH [KM]	1	2	3	4	5	6	7	8	9	10	
0.00	3.90	4.10	4.05	3.80	3.80	3.70	3.65	3.65	3.72	3.90	1
1.00	4.70	4.70	4.65	4.50	4.40	4.39	4.30	4.20	4.32	4.24	2
2.00	5.30	5.40	5.40	5.12	5.02	5.02	4.45	4.40	4.92	5.00	3
3.00	5.85	3.85	5.70	5.40	5.20	5.20	4.72	4.70	5.42	5.55	4
4.00	6.10	6.00	6.10	5.65	5.50	5.40	4.85	4.80	5.53	5.75	5
5.00	6.15	6.10	6.15	6.05	5.80	5.65	5.02	5.00	5.64	5.85	6
6.00	6.20	6.20	6.29	6.18	6.00	5.80	5.40	5.40	5.70	5.92	7
7.00	6.25	6.25	6.35	6.32	6.20	5.90	5.65	5.65	5.96	6.04	8
8.00	6.30	6.30	6.42	6.40	6.20	6.03	5.75	5.72	6.10	6.18	9
9.00	6.35	6.35	6.43	6.42	6.33	6.15	5.80	5.80	6.15	6.30	10
10.00	6.45	6.36	6.43	6.42	6.42	6.30	6.10	6.10	6.22	6.42	11
12.00	6.40	6.40	6.42	6.42	6.49	6.35	6.30	6.25	6.35	6.46	12
14.00	6.30	6.30	6.30	6.40	6.55	6.46	6.42	6.30	6.42	6.49	13
16.00	6.30	6.30	6.30	6.30	6.65	6.55	6.55	6.55	6.55	6.55	14
18.00	6.35	6.35	6.35	6.35	6.65	6.60	6.60	6.60	6.60	6.60	15
20.00	6.45	6.45	6.45	6.43	6.65	6.65	6.65	6.65	6.65	6.65	16
24.50	6.65	6.65	6.65	6.65	6.70	6.70	6.70	6.70	6.70	6.70	17
25.00	7.04	7.04	7.04	7.04	7.04	7.04	7.04	7.04	7.04	7.04	18
30.00	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	7.21	19
40.00	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	7.60	20
X-COORDINATE [KM]	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	

MODEL TEST

VELOCITY DISTRIBUTION

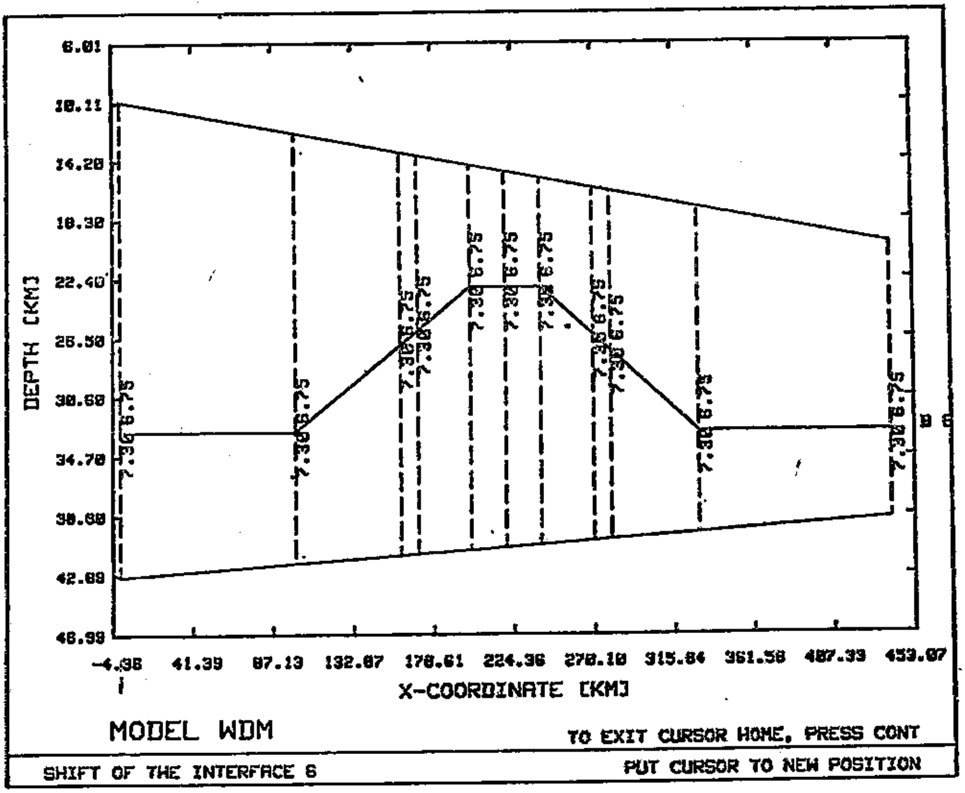
LOCATE CURSOR, PRESS CONT   TO EXIT THIS BLOCK LOCATE CURSOR HOME

SELECT FUNCTION:

1 OR CONT THE PICTURE OF THE MODEL
2 SHIFT AN INTERFACE AND VELOCITY CHANGE
3 DELETE AN INTERFACE
4 INSERT AN INTERFACE
5 END OF CHANGES

Table 3

Table of program branching as displayed at the point of interface changes



4. The picture shown on the display when the sixth interface is shifted. For convenience the velocities above and below the shifted interface are shown as well. Graphics cursor (not shown) serves for selection of the shifted grid point and for digitization of its new coordinate

If, for instance, a shift of the sixth interface is required, only the part of the model is displayed corresponding to the first and to the second layer. The velocity values are plotted along the interface to be changed. An example of graphics output for the shift of the sixth interface is in fig. 4. The choice of a new z-coordinate and of a vertical grid line where the interface is to be changed is performed simultaneously. The selected z-coordinate of the cursor represents the new z-coordinate of the interface. The cursor must be in close vicinity of the grid line for which the shape of the interface is to be changed. The old and the new coordinate are shown together with the coordinate of the vertical grid line and the operator is given the opportunity to accept it, or to modify it from the keyboard. After the new interface coordinate is accepted, the changed part of the interface and the corresponding velocities are erased from the picture. The corresponding velocities above and below the interface can be changed from the keyboard. In this way the whole interface or its part can readily be shifted.

Before changing the picture in the display, if it is required, a hard copy of the picture can be done. Thus information about all successive changes of the model can be preserved.

Next step is input of ray diagram parameters. All parameters have default values which can be changed according to the user's requirements. The output device is a four-colour plotter HP 9872A or graphics display. The program makes it possible to choose either a ray diagram plot only or to produce a composed graphics output, i.e. plot the ray diagram along with experimental traveltime curves and computed times of ray arrivals. The latter alternative seems to be more suitable as it makes it possible to simultaneously follow the computation of rays and directly compare the experimental traveltimes with the computed times of ray arrivals.

The traveltime curves for plotting in the composed graphics output can be interactively chosen from all available files with experimental traveltime curves corresponding to the chosen profile. The traveltime curves from a file can easily be chosen from the displayed list of traveltime curves. Immediately after the choice is completed, the chosen traveltime curves are plotted. Examples of composed graphics outputs are in figs. 6 and 7.

The next program step is the input of source coordinates and choice of the type of rays which will be computed. According to the behaviour of the rays at the interface the following types of rays can be selected:

a) refracted rays,
b) single reflected rays,
c) multiple reflected rays,
d) rays interactively controlled in the course of computation.

The difference between a single reflected and a multiple reflected ray is useful for the user's convenience. Rays of both types are internally code controlled but the code of the ray single reflected from an interface is automatically computer generated after the sequence number of the reflecting interface is input.

The interactive control of the ray in the course of computation means that after each incidence of the ray on an interface the interpreter can decide whether the ray will refract or reflect.

If a multiple reflected ray is required, the code of the ray must be given from the keyboard, but the computer assists at this task. After an inquiry whether it is an upward- or downward-pointing ray, the end point of the first ray element is automatically set. The display shows information about the interface which the ray should hit and another element of the ray can be chosen. At any stage of the code input it is possible to cancel the code input and return to a new source selection, a new type of ray, or to restart the code selection.

If the initial point of the ray element lies on an internal interface, choice can be made between a simple and a compound ray element (up- or down-oriented from the interface). For every ray element input the table of allowed functions is repeatedly shown on the display. The input of the code is successfully completed if the last ray element hits the surface of the model and no back reflection is requested.

As the last step the inquiry follows whether the rays to be computed should be stored on magnetic tape for later processing by the PLOT program or not.

At this point the first program pass is ended. Now, at the main branching point HELP the program is waiting for the interpreter's command. The possible program branching is displayed, see table 4. Either individual rays or fans of rays can be computed. In the latter case the number of rays in the fan, the initial angle at the source, the step of this angle and the step reduction factor must be given. In the course of computation of a ray or a fan or rays the passage of the ray through the medium in real time can be followed. The computation can be interrupted by a function key, the computed ray deleted, erased from the screen and the program control returned to the branching point HELP. If a composed graphics output has been chosen, the arrival time of the successful ray can be immediately plotted.

Table 4

Table of program branching at the point HELP, see fig. 2

1	NEW RAY DIAGRAM PLOT
2	ADDITIONAL TTC PLOT
3	CHANGES OF GRID-LINES IN THE FIRST LAYER
4	CHANGES OF THE VELOCITY DISTRIBUTION IN THE FIRST LAYER
5	CHANGES OF INTERFACES IN THE MODEL
6	NEW SHOT POINT
7	RAY COMPUTATION CONTROL
8	STORING-OF RAYS ON THE TAPE - ENABLE-DISABLE
9 OR CONT	RAY COMPUTATION
10	SAVE THE MODEL ON THE TAPE
11	END OF COMPUTATION (HARD COPY, SAVE THE MODEL ON THE TAPE)

Table 5

Example of a printer output for rays reflected at the seventh interface in the WDM model

```
X SOURCE = 50.000[KM]                         RAY CONTROLLED BY CODE
Z SOURCE =  0.000[KM]                         RAY ORIENTED DOWNWARDS
                                   CODE 1 2 3 4 5 6 6 5 4 3 2 1
```

RAY TABLE

RAY NO	X END	Z END	T END	PHI INIT	ERROR INDICATION
12	2.869	0.000	14.600	-25.0000	
13	23.349	0.000	13.379	-15.0000	
14	41.012	0.000	12.825	-5.0000	
15	57.798	0.000	12.791	5.0000	
16	75.235	0.000	13.268	15.0000	
17	95.165	0.000	14.385	25.0000	
18	120.959	0.000	16.531	35.0000	
19	161.291	0.000	20.873	45.0000	

If recording on magnetic tape is required, the computed ray is recorded in the ray file. One line is printed for each ray, containing the number of the ray, the angle at the source, the coordinates of the ray end point, the arrival time, and optionally the error message. An output is exemplified in table 5. After the computation of a ray or a fan of rays has been completed, the program returns to the branching point HELP.

Before the end of the computation it is checked whether the model has been changed. In such a case the new model can be stored as a new model variant.

Program PLOT

The program PLOT serves for selection and plotting of rays recorded by the program RAY on magnetic tape.

The rays can be repeatedly selected according to various criteria:

a) name of velocity model,

b) coordinates of the source,

c) chosen ray code,

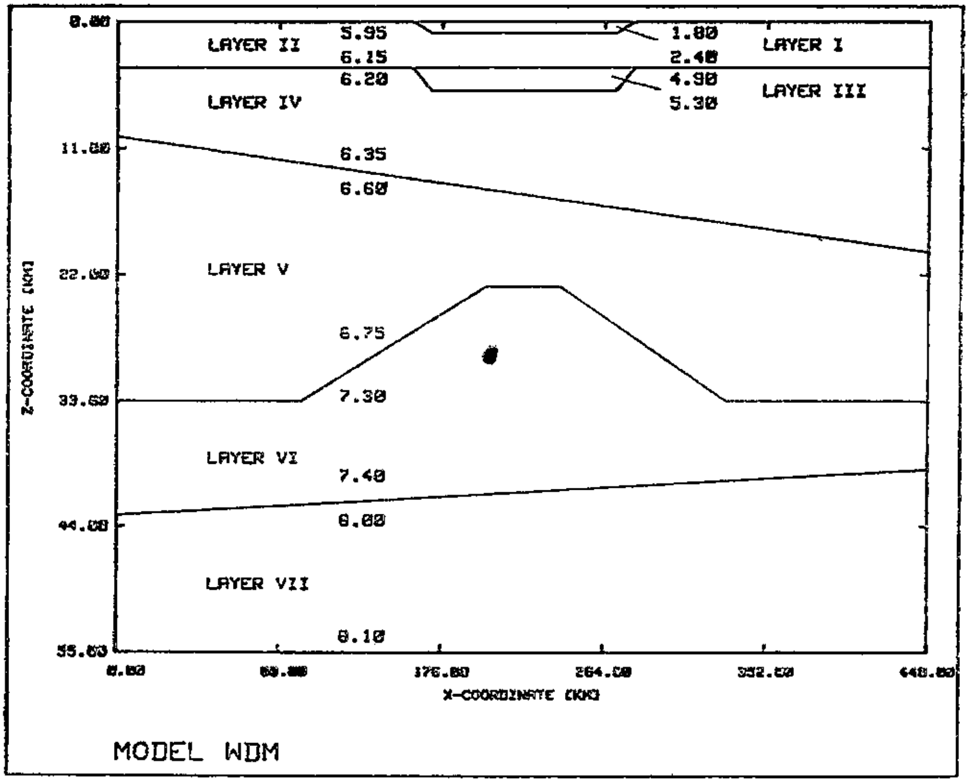
d) refracted rays only,

e) sequence numbers of rays in the ray file.

The output graphics device is plotter or graphics display. Either a simple ray diagram can be plotted or a composed graphics output can be chosen. When the experimental traveltimes are to be plotted, their selection is the same as in the program RAY. The picture can be plotted also by parts, which enables plotting of long profiles or plotting in selected scale.

Model example and tests

The program function is exemplified by computation for the model o W. D. Mooney (U.S. Geological Survey, Menlo Park) which was prepared for the Symposium of the Commission on Controlled Source Seismology at Einsiedeln, Switzerland, 1983. This model named WDM consists of seven layers (fig. 5). It is laterally inhomogeneous because both the velocity distribution and shapes of the interfaces vary along the profile. The layers are numbered with roman figures. Velocities ($km \cdot s^{-1}$) below the upper and above the lower interfaces bounding individual layers are shown. The coordinates of the interfaces are given on all vertical grid lines. The positions of the lines can be seen in fig. 3. Computations were done for two reflected waves from the sixth (code 1234554321) and the seventh (code 123456654321) interface. The composed graphics output for the wave reflected on the sixth interface is in fig. 6 and for the wave reflected on the seventh interface in fig. 7. Computation of 10 rays in the fan where the rays are



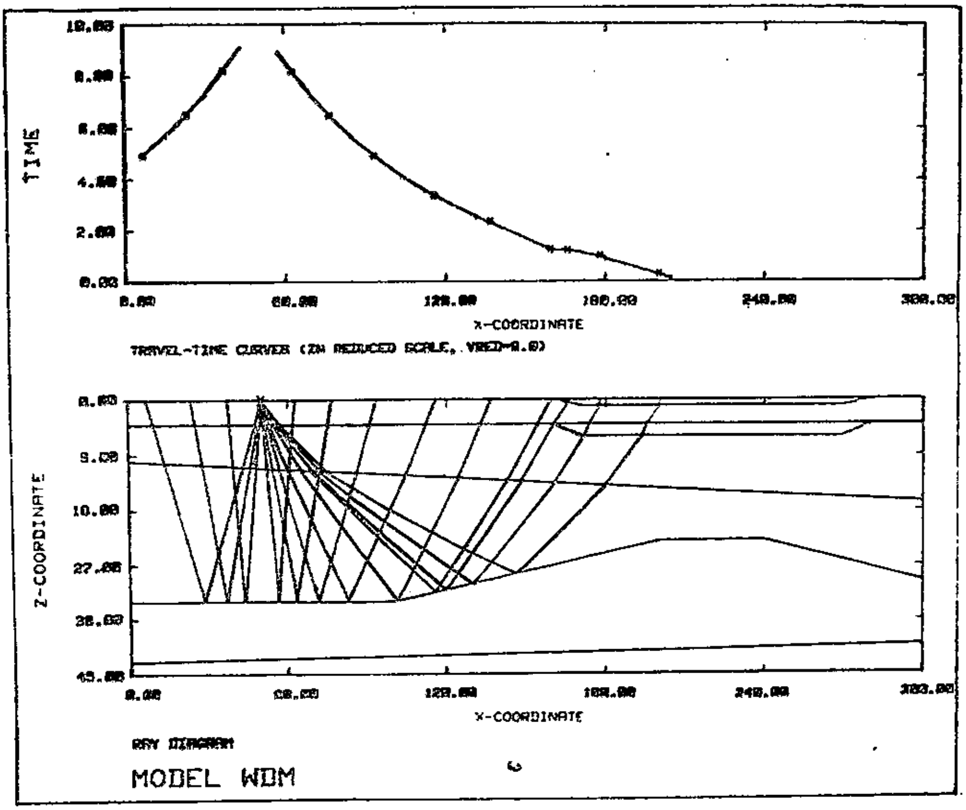
5. Two-dimensional laterally inhomogeneous velocity model suggested by W. D. Mooney. Velocities in km . s^{-1}

on average 25 points long including the graphics output on plotter lasts four minutes 18 seconds. For comparison, the traveltimes computed for the WDM model by the program TRIANGL (Červený–Jánský 1985) were used in the role of experimental traveltime curves. The "experimental" traveltime curves and the computed times have been plotted with reduction velocity 6 km/s. The results produced by the program RAY are in good agreement with the traveltime curves computed by the program TRIANGL.

In the period 1986–1987 the program was also tested on real refraction data. The present version is based on the gained experience. The examples will be published in a following paper.

Conclusion

The program system for solving the direct kinematic problem and the inverse kinematic problem by the "trial and error method" for laterally inhomogeneous medium with curved interfaces was developed. The system is fully interactive and



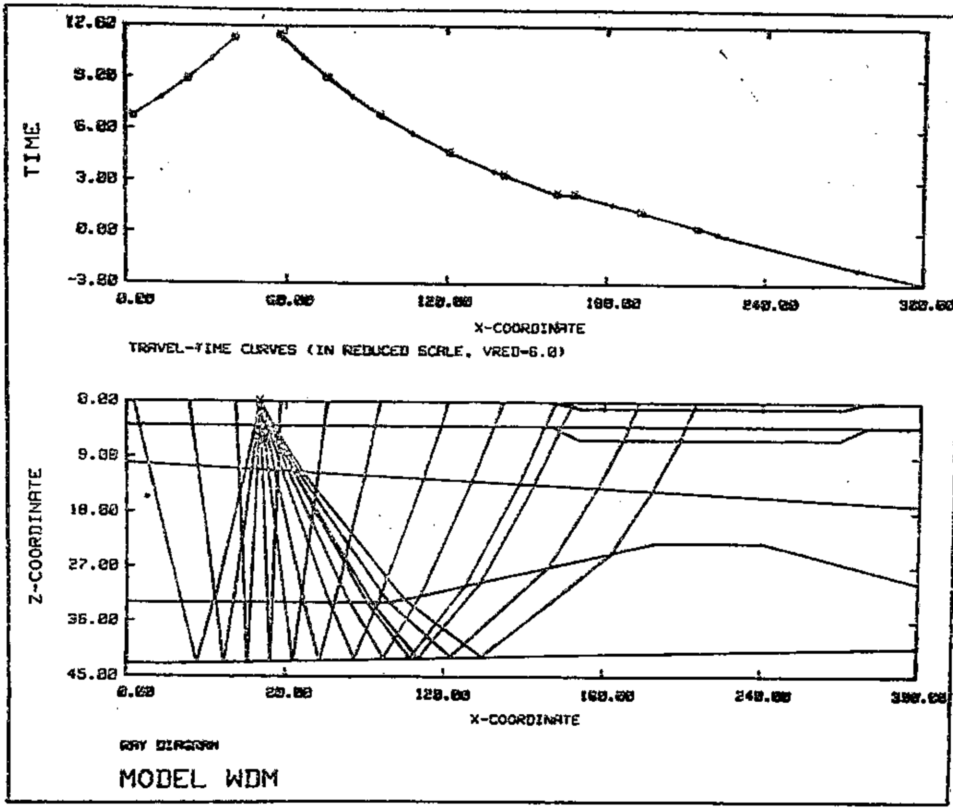
6. Example of a composed graphics output for the WDM model. The rays reflected from the sixth interface are shown. Traveltimes are plotted with the reduction velocity of 6 km . s^{-1}

so enables fast and precise modelling on any velocity distribution consisting of several layers separated by curved interfaces. The system is formed by three programs – MODEL, RAY and PLOT. The core of the whole system is the program RAY for fast computation of rays and fans of rays.

Within one run of the program RAY interactive and fast changes of all parameters of the velocity model can be performed. The program RAY can be applied for verification of velocity models, using various types of waves from different shotpoints as well.

The program system was written in BASIC for the desk-top computer HP 9845. Owing to the interactive operation the time needed for construction of a velocity model was many times reduced as compared with batch-processing. The system was successfully tested on model refraction data and its possibilities were verified for real field data.

K tisku doporučil I. Pšenčík
Přeložila D. Malíková



7. Example of a composed graphics output for the WDM model. The rays reflected from the seventh interface are plotted with the reduction velocity of 6 km . s^{-1}

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Program pro interaktivní řešení kinematických úloh v laterálně nehomogenních prostředích

(Résumé anglického textu)

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t Byl vyvinut plně interaktivní programový systém, který umožňuje rychle a s dosratečnou přesností určit rychlostní rozložení seizmických vln pro dvourozměrné v stevnaté laterálně nehomogenní prostředí. K účelu byla zvolena metoda postupných aproximací při řešení obrácené kinematické úlohy (metoda "trial and error"). Pro výpočet paprsků pak byla rozvinuta metoda, která předpokládá po částech lineární aproximaci prostředí, pro kterou pak řešení paprskových rovnic je dáno analytickými výrazy.

Programový systém byl vyvinut pro stolní počítač HP 9845, je plně interaktivní a využívá grafický HP software a grafické periférie (grafická obrazovka, čtyřbarevný plotter A3, maticová tiskárna). Systém sestává ze tří segmentovaných programů MODEL, RAY a PLOT. Program MODEL vytváří a testuje vstupní rychlostní model a dále slouží ke vstupu experimentálních hodochron. Program PLOT slouží k výběru paprsků, uložených programem RAY na magnetickou pásku, a jejich následnému vykreslení. Základem celého systému je program RAY, který umožňuje rychle počítat paprsky, vějíře paprsků, sledovat šíření paprsků v prostředí v reálném čase, výpočet přerušit a zároveň v rámci jednoho průchodu programu interaktivně a rychle měnit všechny parametry rychlostního modelu.

Program RAY umožňuje prověřovat rychlostní modely od povrchu do hloubky, používat různé typy vln a časy šíření se vlnění od různých odpalovacích bodů. Dále program umožňuje do výpočtu zahrnout apriorní informace.

Programový systém je napsán v jazyce BASIC pro stolní počítač HP 9845. Využívá se tedy malá výpočetní technika, která je cenově dostupná ve srovnání s velkými počítači. Zároveň díky interaktivnímu přístupu byla doba potřebná k vytvoření rychlostního modelu několikanásobně zkrácena ve srovnání se zpracováním na počítači, pracujícím v režimu dávkového zpracování dat. Programový systém byl úspěšně testován na datech řídké refrakce a jeho praktické možnosti při tvorbě nehomogenních rychlostních modelů byly ověřeny. Popis použití programu při řešení obrácené úlohy na reálných datech je obsahem připravovaného článku.

Vysvětlivky k tabulkám

Tabulka 1. Tabulka možných činností programu, jak se zobrazuje na obrazovce při změnách vertikálních čar mříže.

Tabulka 2. Příklad výřezu rychlostní sítě 1. vrstvy (modelu TEST), jak se zobrazí na obrazovce při změnách rychlostí 1. vrstvy. Grafický kursor, sloužící k výběru měněné hodnoty rychlosti, není zobrazen.

Tabulka 3. Tabulka možných činností programu, jak se zobrazí na obrazovce při změnách rozhraní.

Tabulka 4. Tabulka možného větvení programu RAY v rozhodovacím bodě HELP, jak se zobrazuje na obrazovce (srov. s obr. 2).

Tabulka 5. Příklad výstupního tisku na tiskárně při výpočtu paprsků odražených od sedmého rozhraní pro model WDM.

Vysvětlivky k obrázkům

1. Zobecněné schéma výpočtu a vstupních/výstupních operací programového systému (programy MODEL, RAY a PLOT).
2. Zjednodušený blokový diagram programu RAY.
3. Celkový obrázek modelu WDM (síťových čar a rozhraní), jak se zobrazí na obrazovce při posunu vertikálních čar (viz tab. 1). Grafický kursor (není zobrazen) slouží k volbě posouvané vertikální síťové čáry a následně k digitalizaci její nové x-souřadnice.
4. Obrázek, který se zobrazí na obrazovce, je-li posouváno 6. rozhraní. Pro usnadnění změn jsou znázorněny i rychlosti pod a nad posouvaným rozhraním. Grafický kursor (není zobrazen) slouží současně k volbě posouvaného bodu rozhraní a digitalizaci jeho nové souřadnice.
5. Dvourozměrný laterálně nehomogenní sedmivrstevný rychlostní model, který předložil W. D. Mooney. Rychlosti jsou uvedeny v km . s^{-1}.
6. Příklad složeného grafického výstupu pro model WDM. Pro zvolený zdroj (50 km, 0 km) jsou vykresleny paprsky odražené od šestého rozhraní. Časy příchodu paprsku stejně jako experimentální hodochrony jsou vykresleny v redukovaném měřítku s redukční rychlostí 6 km . s^{-1}.
7. Složený grafický výstup pro paprsky odražené od sedmého rozhraní. Model, zdroj i použitá redukční rychlost jsou stejné jako pro grafický výstup na obrázku 6.

Программа для решения кинематических задач в латерально-неоднородных средах диалоговым способом

В докладе описана диалоговая программная система, предназначенная для моделирования распределения скоростей сейсмических волн в двумерной неоднородной слоистой среде с криволинейными границами раздела. Программа предназначена для решения обратной кинематической задачи методом постепенных аппроксимаций. Метод, используемый для решения уравнений луча, предполагает линейную по частям аппроксимацию среды. Программная система обеспечивает быстрое вычисление лучей или веера лучей, прерывание расчета в реальном времени и диалоговое изменение всех параметров скоростной модели в рамках одного прохода программы. Программная система написана на языке BASIC для настольного калькулятора Hewlett-Packard HP 9845 и предполагает полное использование графи-

ческого программного матобеспечения и соответствующих графических периферийных устройств. Приведен пример расчета для двумерной латерально-неоднородной слоистой модели. Эта проверочная модель была предложена В. Д. Муным на симпозиуме Комиссии по управляемым сейсмическим источникам в 1983 г. во Швейцарии. Программная система была проверена по реальным данным и приобретенные результаты подготовляются к опубликованию.

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