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Velocity distribution modelling on building site of the nuclear power plant of North Moravia - A case history

Modelování rychlostního rozložení na lokalitě jaderné elektrárny Severní Morava

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Abstract: To determine local microearthquake hypocentres, detailed knowledge of local seismic velocity distribution is required. For this reason a seismic survey along several refraction profiles has been performed on the building site of the nuclear power plant of North Moravia. Refraction data (travel times) from these profiles has been interpreted using 2D inverse technique described in Firbas - Skorkovská (1986, 1988). Since this interactive program package has been used for the first time with real data, individual steps of computation are described in some detail in this paper. Resulting 2D velocity models for selected profiles are presented.

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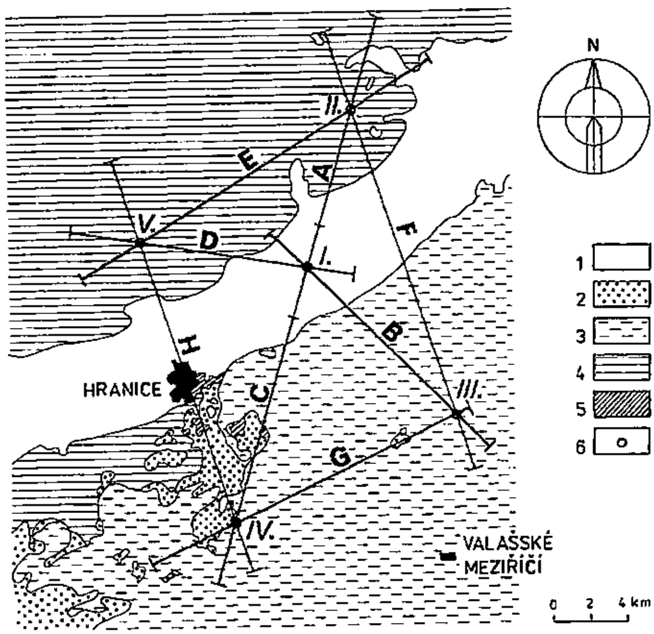
Introduction

The seismic hazard assessment of a nuclear power plant site requires delineating of seismically active faults in its vicinity. An active fault can be revealed by determining local earthquake hypocentres using microearthquake networks (Lee - Stewart 1981). Local seismic velocity distribution must be known in detail for accurate and reliable location of microearthquake hypocentres. If the number of stations in the network as well as the number of the earthquakes recorded is high enough, then the velocity distribution can be computed simultaneously with the hypocenter parameters utilizing data from local earthquakes. In Crosson (1976a, b) a method for such a simultaneous inversion is described for 1D layered velocity model. The problem of 3D velocity distribution estimation from teleseismic data is solved e.g. in Aki - Lee (1976). Perhaps the most straightforward approach is to determine the 3D velocity distribution inverting travel-times from controlled blasts.

The microearthquake network on the site of the nuclear power plant of North Moravia (Cidlinský et al. 1986) consists of five three-component stations only, which seems to be insufficient for the simultaneous inversion of hypocentre parameters and the 3D velocity distribution. Therefore an additional seismic measurement had to be performed to determine the velocity distribution. Seismic refraction method has been used along eight profiles (see Fig. 1). Since the geological structure of the site is rather complex, strong lateral velocity variations have been expected.

The inverse kinematic problem for laterally inhomogeneous (2D) structures can be solved by the method of "trial and error". This method is efficient in the case when the used computer program is written as an interactive one. This idea was materialized in the interactive program package 2-DIM (2-D Interactive Modelling) described in Firbas - Skorkovská (1986).

In 2-DIM package a simplified method of solving the direct kinematic problem is used. The approach used goes back to ideas presented in Aric - Gutdeutch - Sailer (1980) and makes use of ray tracing ideas developed by Červený and Pšenčík (1981). In the approach of Firbas and Skorkovská (1986, 1988) the x-z plane in which the velocity distribution is to be approximated is automatically divided into a set of triangles fully covering the model. At a point inside a triangle the velocity value is given by a linear combination of



1. Geological map of the site with the situation of seismic profiles and microearthquake network stations.
1 – Neogene (Badenian); 2 – Neogene (Carpathian); 3 – Paleogene (flysh); 4 – Culm; 5 – Devonian; 6 – a three-component station of the microearthquake network.

model. At a point inside a triangle the velocity value is given by a linear combination of the velocity values at the corners of the triangle. Consequently, the velocity gradient inside any triangle is constant and the raypath inside each triangle is represented by a part of a circle. In such a case the direct kinematic problem can be solved analytically. The computation of raypaths and travel times is simple and fast.

In this paper we will describe the first application of 2-DIM interactive program package to real field data. Therefore the computational procedure is being followed step-by-step including the data preparation stage. The possibilities offered by the program are described from the point of view of an interpreter, not a programmer. The authors' description of the program (Firbas - Skorkovská 1986, 1988) is extended wherever we feel it could be useful for an interpreter. The resulting velocity models for selected profiles are presented to demonstrate the possibilities of the program package and the algorithm used.

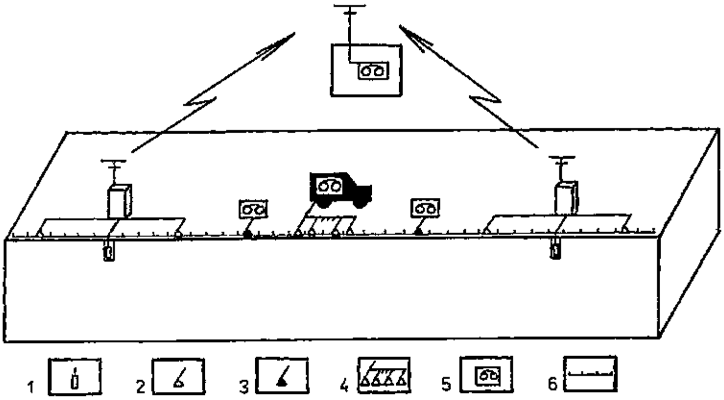
Data acquisition

At the stage of field measurements eight refraction profiles (named A to H) were surveyed on the site. Their layout together with the simplified geological map is shown in Fig. 1. Every profile connects two stations of the microearthquake network so that these could have been directly used as profile registration points. The remaining 3 "off-profile" stations of the microearthquake network were registrating as well during the profile measurements and so they have supplied us with additional "3D information".

Each of the five stations of the microearthquake network is equipped with a three-component geophone set fixed in a 6 m deep borehole. Three independent channels are available for the data transmission from any station to the recording center. The three signals from the three-component geophone are digitized, preprocessed and coded in the station encoder. Then they are transmitted by radio to the central recording station of the microearthquake network.

The two "profile stations" of the network were temporarily reconfigured. Only the Z-component of the three-component borehole geophone was used for registration and the two remaining telemetry channels were used for the transmission of the data from two "satellite geophones", i.e. geophones which were situated on the measured profile in a distance of about 2–3 km from the borehole and which were connected to the station encoder by a cable. Then the data from all three geophones (Z-component of the borehole geophone and two satellite geophones) were transmitted to the recording centre. The result of the above described reconfiguration was that three recording points with 2–3 km spacing were available instead of one single point.

By the reconfiguration of two "profile stations" of the microearthquake network 6 reception points were available. These points were supplemented by a standard seismic prospection equipment situated at a suitable location near the middle of the profile. In this case 10–14 geophones with 100 m spacing were used. To enlarge the number of reception points, two pieces of special equipment (one-channel, real-time station with analog registration) were used at every profile.



2. Typical profile geometry. 1 – a three-component borehole geophone; 2 – a "satellite" geophone; 3 – the geophone of supporting one-channel equipment;4 – the spread of the prospection seismic equipment; 5 – a registration device; 6 – shot points.

The position of each geophone was surveyed with high precision (few meters). As the position of all geophones mentioned was kept fixed during the period of profile measurements, no additional repositioning errors could enter the subsequent data processing. To ensure good lateral resolution of the velocity model, shot points with relatively small spacing (0.5 to 1 km) were used. Typical profile geometry is outlined in Fig. 2.

The absolute shot time was measured at each shot point with a special equipment and the operation of seismic prospection equipment was started automatically by a radio shot command as it is usual in reflection surveys. The network registration could have been done in trigger mode, but for security sake the tape recorder was forced to register all data well in advance of the planned shot time (15 to 30 s). The recording continued for approximately 1 minute to cover all useful seismic waves. The connection between the shot point and the network central station was maintained by radio. The detailed description of field measurements can be found in Cidlinský et al. 1986. The above described way of refraction measurement (utilizing fixed positions of all receivers on a profile during the survey) enabled us to shorten the measurement period substantially in comparison with standard methodology when a seismic spread is moved along the profile and shots from individual shot points have to be repeated to get the profile wave field. Further advantage of such a methodology was that the off-profile three-component stations of the microearthquake network formed additional measuring points which acquired additional data which could serve for a 3D velocity model study. The more dense grid of shot points used (in comparison with a sparse grid in standard refraction survey) allows to perform an energy attenuation study of the locality (needed e.g. for microearthquake energy estimation) and last but not least it allows to calibrate the network both kinematically and dynamically.

Travel time curves

For each seismic profile, records have been organized according to the common point of reception. Travel time curves (TTCs) have been formed after seismic waves were correlated and their onset times determined. For this purpose mainly the picking mode of an available interactive visualization program was used. The data from microearthquake network stations and seismic prospection equipment were converted to a common computer format to enable correlation and onset picking with the same accuracy. The magnetic records from the supporting one-channel analog stations were visualized, the onset times were picked on the analog records and the corresponding TTCs were formed. It became obvious, that refracted P-waves were the only wave type which could be reliably correlated over large range of epicentral distances. These waves formed the first arrival in each seismic record. Refracted S-wave could be identified at most records but the accuracy of its onset time reading was usually much worse than that of P arrivals and had not therefore been used in the current interpretation. Although essential effort was made, reflected waves were not reliably correlated. It is well known that for layered media the first arrival TTC consists of several branches representing P waves refracted in various layers. As the area under study was supposed to have a complex structure with several layers laterally limited in space, the separation of the first arrival "compound" TTC without good preliminary knowledge of the velocity structure was not possible. This assumption about "compoundness" of the first arrival TTC was verified in the course of the interpretational process and helped to avoid mistakes in wave type identification. So the created "compound" TTC was divided into separate segments corresponding to individual refracted waves only after some first stage of interactive interpretation.

Corrections of travel times

The procedure described above gives the "raw" travel times which depend on a number of factors, namely:

1) global velocity distribution along the profile,
2) local velocity distribution at the shot point,
3) local velocity distribution at the point of reception,
4) error of shot time reading,
5) error of onset time reading, and
6) transmission delay in the recording equipment.

ad 1) The dependence of travel times upon the velocity distribution is the basic relation for the problem at hand. By the inversion of this relation the velocity distribution (strictly spoken only the model of the velocity distribution) can be derived. The other relations (points 2–6) are treated as small disturbances to this one and are to be removed from the data by corrections.

ad 2 & 3) These factors include the local deviations of real velocity distribution from that represented in the model. The decision about which changes in velocity distribution can be represented in the model and which are to be treated as the local deviations depends on the resolution power of the particular field measurement. In our case the velocity distribution below the weathering zone was included in the model while the influence of this weathering layer was removed by corrections. As the resulting TTCs were organized according to the common point of reception, it is obvious, that the corresponding reception point corrections shifts the TTC as a whole while the shot point corrections will smooth it. The shot point corrections were computed from the known charge depth and from the estimated velocity below the weathering zone. By such a procedure the accuracy better than 10 ms was achieved for the shot point corrections. Receiver point corrections could have been computed from the weathering layer parameters (thickness, velocity). However, as the receiver point correction and the correction for the registration equipment, delay act simultaneously, they were both treated as a single correction (see point 6 below).

ad 4) The error in shot time reading was less than 5 ms and could therefore be neglected.

ad 5) The survey was planned in such a way as to ensure that the first onset on individual traces could be read with accuracy of about 10 ms.To achieve this, test measurements were performed on the site to find an optimum charge weight for proper signal to noise ratio.The accuracy of 10 ms could not be improved substantially due to sampling frequency used by the recording equipment. The microearthquake network equipment operated with the sampling frequency of 125 Hz while the seismic prospection station used the sampling frequency of 250 Hz.

ad 6) As different types of registration equipment were used at various reception points, the resulting TTCs were shifted with respect to each other. Because the exact values of transmission delays of all equipment were difficult to measure, the appropriate corrections have been derived from the data. By a minimization procedure we have found the set of time shifts which gives the best agreement for all the reciprocal times on all TTCs. This procedure also contained the reception point corrections and a very good fit of reciprocal times was achieved. The maximum misfit of times at reciprocal points was in the range of the required accuracy, namely 10 ms.

Travel time curves created by the above described procedures were used as input data for further interpretation by the interactive modelling program package.

Starting velocity model

The starting model creation was the first step of our interpretation procedure. Program package can deal with velocity models consisting of layers separated by piecewise linear interfaces. The maximum number of layers is 10. It implies that max. 11 interfaces can be considered, the first of them being the relief and the last the bottom of the model.

The shape of each interface is defined by its intersections with vertical grid lines. Their number can be up to 20. The first and the last grid lines form left and right boundary of the model. The position of an interface between grid lines is determined by linear interpolation. Interfaces must not intersect but the coincidence of neighbouring interfaces is possible in any interval. In such a way rather complex structures can be easily modelled.

The velocity distribution is described differently for the first layer and for the others. It is well known that the first (uppermost) layer is often the most complicated one. This fact is respected by 2-DIM and a relatively complicated velocity distribution can be defined within the first layer. The velocity values are specified in a rectangular grid defined by vertical and horizontal grid lines. The vertical lines coincide with the lines used for the definition of interfaces. The spacings of both horizontal and vertical grid lines are arbitrary. The grid must cover the first layer completely. The first layer is limited by the first and the second interfaces. The velocity along these interfaces could be either interpolated from the values at grid points or given explicitly by the interpreter. In the case when the velocity along the first (or the second) interface are given explicitly, the values at grid points above (or below) the interface are ignored. After the velocity along the interfaces has been specified, the first layer is automatically decomposed into a set of triangles. The velocity at any point inside the first layer is then computed by linear interpolation.

The velocity distribution within the second and further (lower) layers is described in a more simple way. The values of velocity are given at the intersections of vertical grid lines with both interfaces limiting the layer. As each inner interface separates two layers and the velocity values are given for both the upper and the lower interfaces of any layer, two independent values can be specified for the velocity at any point of the interface. If these two velocities are different, the interface represents a first order velocity discontinuity at this point. If these velocities are equal, the interface corresponds to a velocity discontinuity of the second order.

The velocity at a general point inside any layer is computed by the linear interpolation method (Aric - Gutdeutsch - Sailer 1980, Firbas - Skorkovská 1986, 1988).

Within 2-DIM program package the module MODEL handles all the work with models. It maintains the catalogue of existing models, creates new models and updates the old ones. It is designed in a very user-friendly way enabling the interpreter to create a new model quickly and conveniently. For example it is not necessary to insert the velocity values at all grid points within the first layer, the omitted values are automatically filled in by linear interpolation from the specified ones. The velocity distribution along a vertical grid line can be also given by a constant gradient. If the velocity is constant along an interface,it can be entered as a single value. Every entered value can be easily changed either immediately or after finishing some block of input operations.

When preparing starting models we used information about the geological structure of the site and the results of previous geophysical (mainly seismic) measurements in the investigated area (i.e. Cidlinský et al. 1986). Having gained some experience we used two types of interfaces in models, namely the interfaces of the first order and the velocity isolines. Any interface between two geological units was represented as the first order interface in the velocity model. In addition, several interfaces of second order were introduced which did not represent any geological surface. The velocity was kept constant along the second order interfaces, i.e. they represented velocity isolines. This approach enabled us to describe the velocity distribution within a geological layer in a more detailed way by dividing it into several fictitious layers with different velocity gradient. Isolines corresponding to the same velocity values were used for all profile models. These isolines were later used for the transformation of the set of 2-D velocity models into one composite 3-D model (not described in this paper).

It is specific for our situation that the first layer of the model corresponds to the Neogene sedimentary basin on almost all profiles (see Fig. 1). This basin is relatively shallow and narrow in the directions of the profiles. Having in mind the limited resolution power of the field measurements, we cannot make full use of the more detailed velocity description offered by the program for the first layer. On the E-profile, where this sedimentary basin is not present, the model could be represented as only one (the first) layer and the velocity distribution could have been described by a grid. However, for the reason of comparability, the way of modelling utilizing interfaces and isolines was used for all profiles.

The input of travel time data is also supervised by the module MODEL. Each TTC is characterized by its "shot point position" (which is in fact the point of reception position in our case where the roles of sources and receivers are exchanged).

Each point on the time-distance curve is specified by its x-coordinate and the corresponding travel time. When entering individual points of a TTC the interpreter may add the shot point position with zero travel time for the reason of the graphic output.

Ray computation

Module RAY is the main part of the whole program package 2-DIM. It performs the 2-D initial-value ray tracing in the specified model and allows the interpreter to compare the computed travel times with the field data and to update the model so as to improve the fit of the computed and the experimental travel times. Since much attention is paid to the description of RAY in Firbas - Skorkovská (1986),only some notes useful from the point of view of an interpreter will be presented here.

The picture of ray diagram and TTCs can be plotted on the graphic monitor or on the four-colour plotter. The latter possibility proved to be the more convenient one and was therefore preferred throughout the interpretation procedure. To improve the resolution of the TTC pictures the reduction velocity 6 km/s or 8 km/s was frequently used.

There are two parameters entered for each ray to be computed, i.e. the shot point position and the initial angle. The program checks whether the input coordinates of the shot point fall within the limits of the model. When the z-coordinate of the source above the first interface is entered, the program automatically places the shot point on this interface. This very useful feature enables the interpreter to specify the shot point on the Earth's surface without exact knowledge of its z-coordinate.

When the shot point position and the initial angle for a ray have been determined,computation starts. The path of the ray within the model can be followed on the plotter directly in the course of the ray computation. The true raypath within one triangle, which is a part of a circle, is replaced by a straight line for plotting purposes only. This simplification speeds up the plotting of rays but sometimes (mainly when the ray touches an interface with strong velocity contrast) the interpreter may lose some useful information, namely how close the ray has approached the critical angle for this interface.

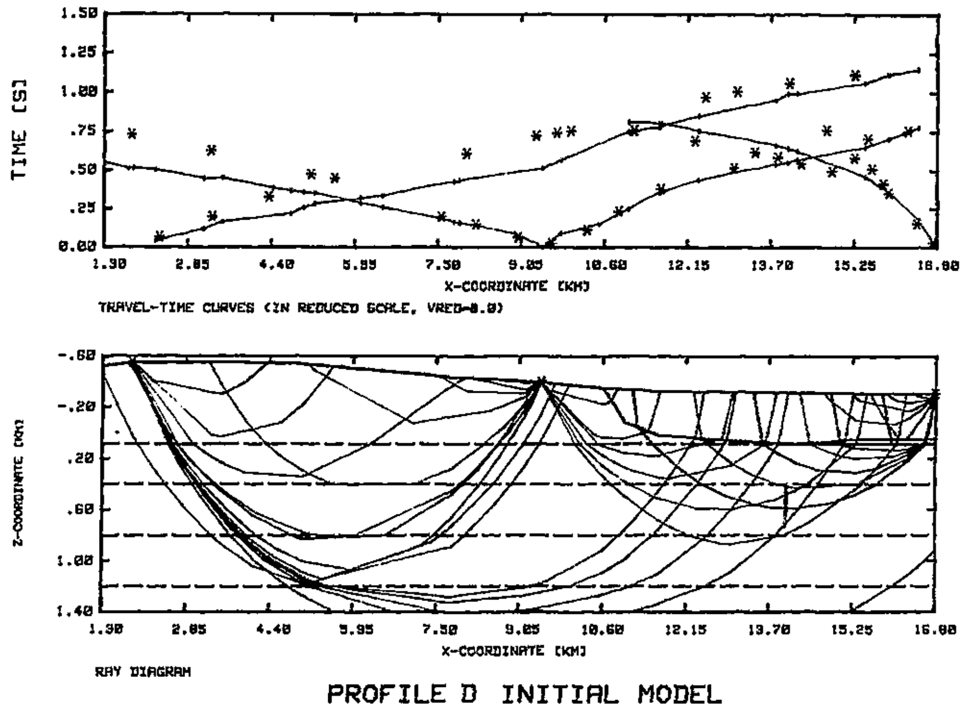
The behaviour of the computed ray at the interfaces can be either specified beforehand by a code or the ray can be controlled interactively, i.e. at every interface the interpreter decides whether the ray should continue across the interface as a refracted one or whether it should reflect. When only the refracted rays are of interest, this can be specified beforehand and the program does not stop at interfaces. The interpreter can also break the computation of any ray, whenever he decides that it is not the one he wants. If a ray cannot fulfill the requirements of the code (i.e. if it cannot reach the surface) the program informs about the reason of this failure, which is often the impact of the ray at the bottom or at the left or right boundary of the model. The use of the ray code is described in detail in Firbas - Skorkovská (1986, 1988). When a ray has successfully terminated, i.e. when it has reached the surface, the computed travel time is plotted (against the x-coordinate of the endpoint) into the prepared TTC plot.

It is the interpreter's responsibility to select the initial angles of rays in such a way that their end points would cover all the range of the experimental TTC. It is well known that several rays with quite different initial angles can exist which end at the same point on the surface. These rays can correspond to various branches of refracted waves or they can also represent the waves reflected at the interfaces inside the model. When the travel times of those rays differ substantially, there is no problem to choose the ray which corresponds to the wave branch whose travel times have been recorded in the field. When the travel times of several rays with the same endpoint are close to each other, the ray with minimum travel time should be selected for further interpretation because very often it is the one the onset time of which has been picked on the field records.

Sometimes finding the initial angle for which the corresponding ray ends within a desired range of epicentral distances might be rather difficult. It is well known that the epicentral distance is a very sensitive function of initial angle in the situation when the corresponding rays strike some interface with strong velocity contrast under the angle slightly less than critical. Although we often know that the initial angle resulting in the demanded epicentral distance exists and, moreover, we also know the interval within which the angle falls, still a rather time consuming procedure is required to find it. We therefore expect to supplement the program with a simple routine able to find the ray which ends in the point specified. In such a way only the successful rays would be plotted. This improvement would speed up the useful ray finding procedure and relieve the interpreter of some portion of routine work. As an automatic two-point ray tracing in 2-D structures is a complicated procedure, the simple routine which we expect to implement should handle only those specific cases when the interpreter is sure about the existence and about the initial angle limits of the desired ray.

Model updating

Having obtained a set of computed travel times the interpreter can proceed to the most important and the most difficult part of the interpretation procedure. He has to compare

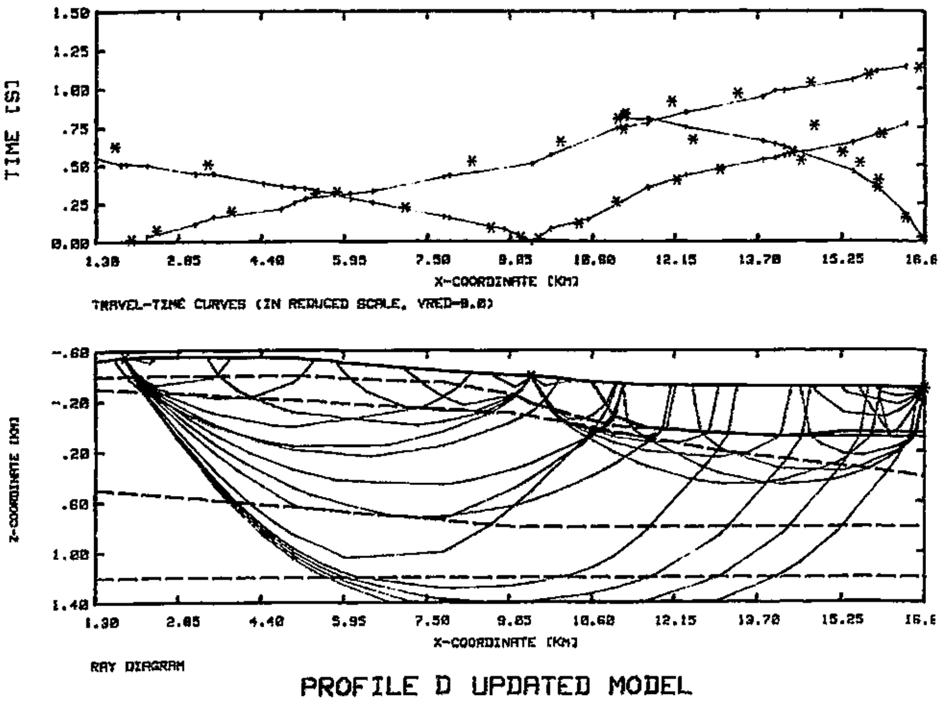


3. Computational procedure. Ray diagram, experimental TTCs (I) and computed travel times (*) for the initial velocity model at the profile D. First order interfaces ——, isolines —.

the computed travel times with the experimental TTCs, to consider the misfits and subsequently to try to improve the velocity model.

An experimental travel time curve is given as a set of discrete points in the (x, t) plane. Since it is very difficult to find the ray terminating exactly at the point where the experimental travel time is available, an interpretation method for the experimental TTCs is needed. The most simple of such methods, i.e. the linear interpolation, is performed by the plotting routine, so that the resulting experimental travel time plot is piecewise linear. This approximation is quite sufficient in most cases, so that the lines connecting the data points can be considered the part of the TTC and the computed travel times can be fitted to them. Some caution is needed when the data points are sparse or the relief between the endpoints varies strongly.

Nevertheless, there are parts of the TTCs where the linear interpolation of travel times fails completely. As mentioned above, experimental TTC may not represent a single seismic wave, but at each receiver position the wave with the shortest travel time is

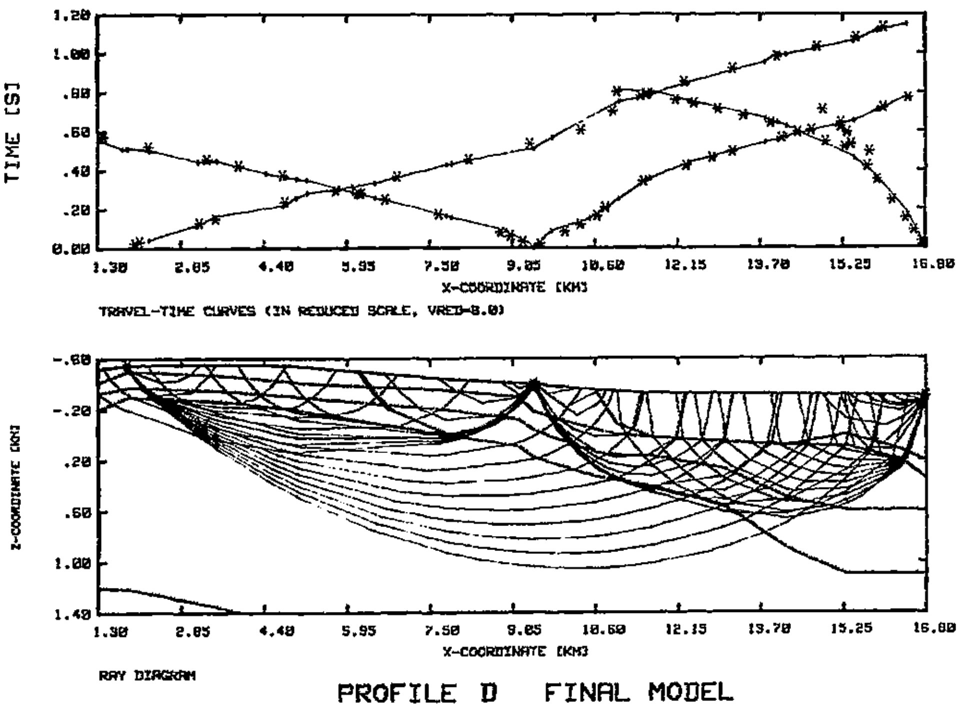


4. Computational procedure. Ray diagram, experimental TTCs (I) and computed travel times (*) for the updated velocity model at the profile D (after first iteration). First order interfaces —, isolines - -.

represented. Thus there is a possibility that the two subsequent TTC points correspond to different waves (or TTC branches) and the straight line interpolated between them must not be taken as a part of the TTC. Such connecting line has no physical meaning and the computed travel-times must not be fitted to it. The difficulties described above can be expected wherever the slope of an experimental TTC changes substantially. The interpreter should reveal such cases and be extremely careful when fitting the computed travel-times at those epicentral distances.

By making some changes in the velocity model the interpreter can improve the fit of the computed and the experimental travel times. After obtaining some experience this procedure is fairly straightforward and fast.

In this case the best way to obtain the velocity model consistent with the field data was (in consent with Firbas - Skorkovská 1986, 1988) to fit the travel times in smaller epicentral distances first. By this method the shallow parts of the velocity model were modified first and they usually need not be corrected in latter stages of the model

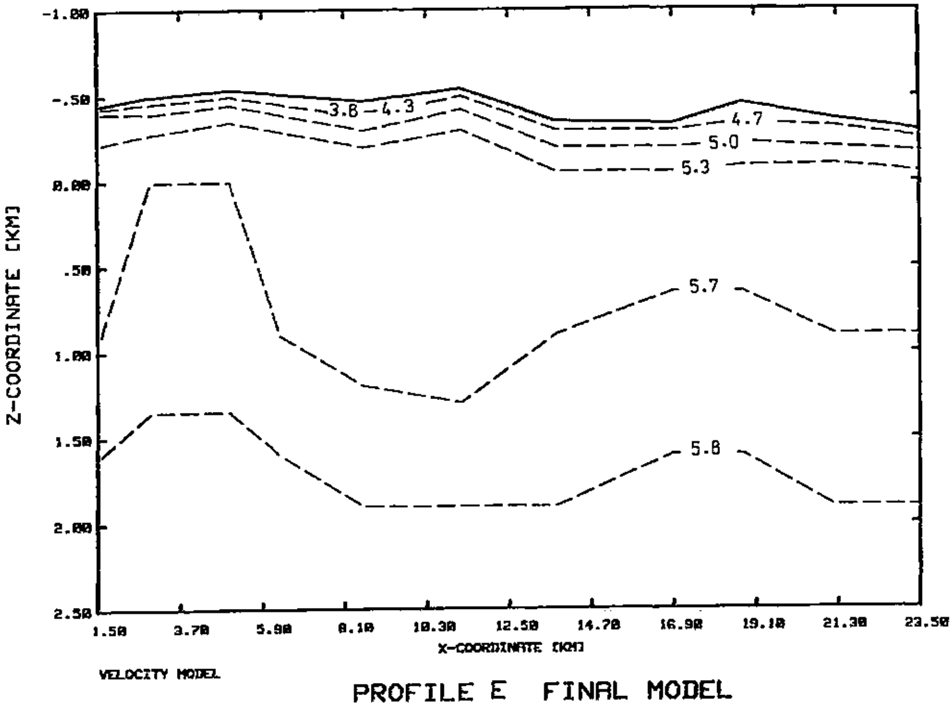


5. Computational procedure. Ray diagram, experimental TTCs (I) and computed travel times (*) for the final velocity model at the profile D (after 9 iterations). First order interfaces —, isolines - -.

improvement procedure. The iteration procedure was stopped when the fit better than 20 ms was achieved for most experimental TTC points. In most cases we were able to get a satisfactory fit in less than ten iterations.

In Figs. 3–5 the development of the velocity model at the D-profile is illustrated. Fig. 3 shows the initial model. In Fig. 4 the updated model after the first iteration and in Fig. 5 the final velocity model after the 9th iteration is presented. Only three travel time curves are plotted in each picture, nevertheless all experimental TTCs were respected in the procedure of improving the model. The experimental travel times are marked by vertical bars while the computed times by asterisks. As can be clearly seen, the fit of travel times is much better after the first iteration (Fig. 4) than for the initial model (Fig. 3). For the final velocity model very good fit was obtained (Fig. 5).

To demonstrate the complexity of the models obtained we present the final models for the profiles E, F and H at Figs. 6 to 8, where the interfaces of the first order and the



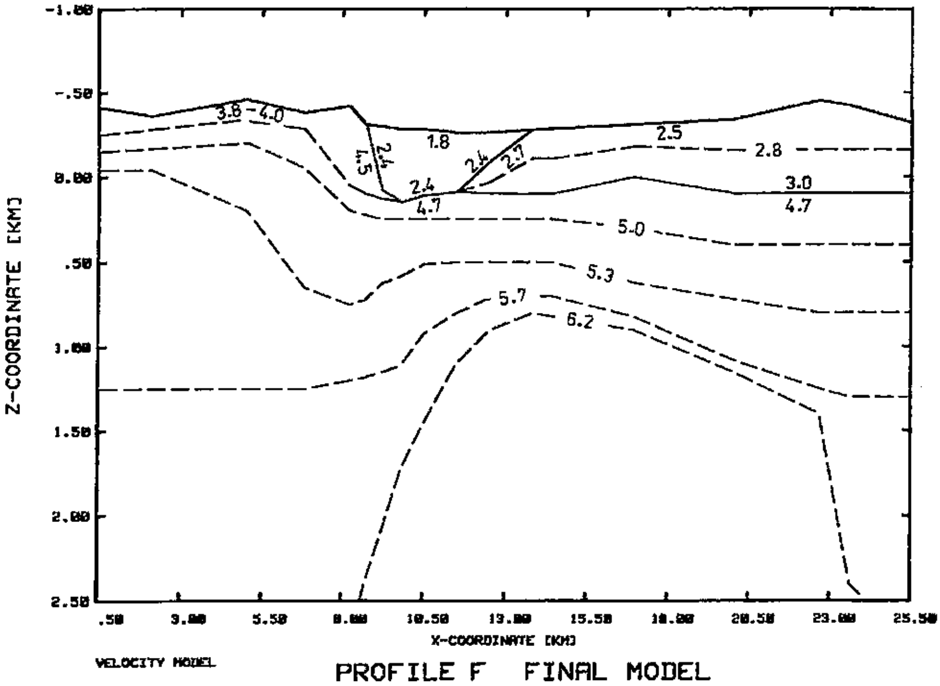
6. Example of the resulting 2D velocity model for profile E.

interfaces of the second order (velocity isolines) are plotted by the solid and the dashed line respectively.

Conclusions

The method described in Firbas - Skorkovská (1986, 1988) was used to derive 2-D laterally inhomogeneous velocity models based on the seismic field measurement performed on the building site of the nuclear power plant of North Moravia. The interactive program system 2-DIM developed by the authors of the above mentioned papers was used here for the first time with field data.

During the process of computation some important features of the program system became obvious:



7. Example of the resulting 2D velocity model for profile F.

a) rather complicated laterally inhomogeneous velocity structures can be approximated with a satisfactory degree of accuracy and the corresponding velocity models can be constructed easily,

b) input field data (travel times) can be entered rather conveniently,

c) the calculation of rays is fast enough, and

d) the composed plots (ray diagrams combined with both experimental and computed travel times) supply the interpreter with all the information necessary for fast and successful model updating, so the acceptable fit of travel times can be obtained in a relatively low number of iterations.

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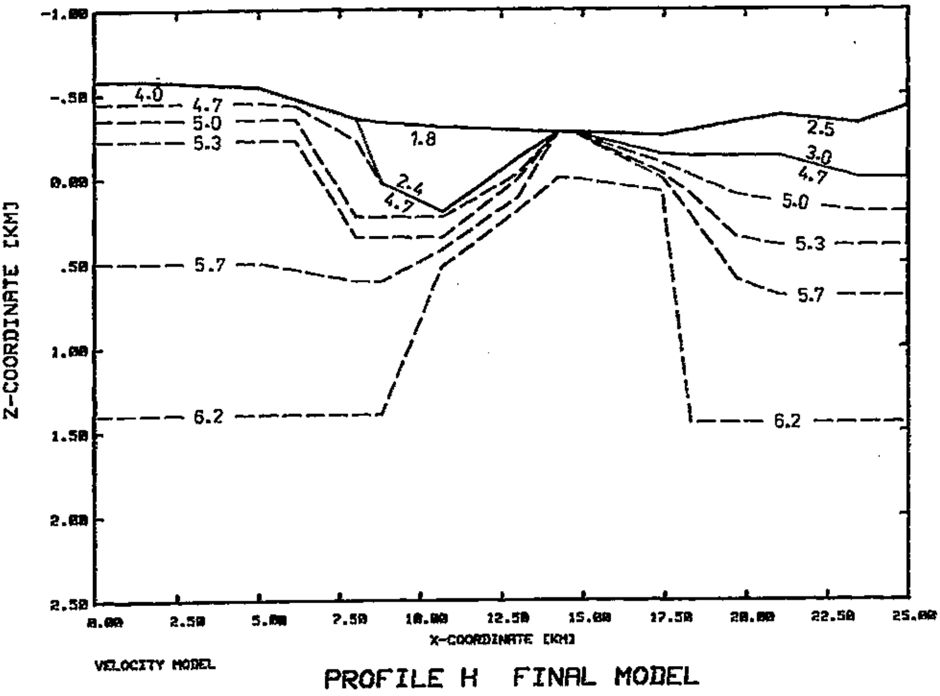

8. Example of the resulting 2D velocity model for profile H.

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Modelování rychlostního rozložení na lokalitě jaderné elektrárny Severní Morava

(Resumé anglického textu)

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V současné době stále narůstá pozornost věnovaná sledování seizmicity lokalit velkých staveb, zejména jaderných elektráren. Pomocí citlivých seizmologických měření je statisticky sledováno časoprostorové rozložení ohnisek místních zemětřesení a na základě těchto dat je vyhodnocováno případné seizmické ohrožení lokality.

Pro přesné a spolehlivé určení ohniska zaregistrovaného seizmického jevu je nezbytná dobrá znalost rychlostního modelu dané lokality. Při sestavování se vychází ze znalostí o geologické stavbě území a z výsledků předcházejících geofyzikálních (především seizmických) měření. Při nedostatku těchto dat je nutno pro sestavení spolehlivého třírozměrného rychlostního modelu provést a vyhodnotit speciální měření.

Na lokalitě jaderné elektrárny Severní Morava bylo proměřeno celkem osm refrakčních profilů. Protože geologická stavba zájmového území je dosti složitá, bylo nutno očekávat, že výsledné rychlostní modely budou silně laterálně nehomogenní. Obrácená kinematická úloha seizmiky v dvourozměrném laterálně nehomogenním prostředí je složitý problém, k jehož řešení je vypracováno množství metod. Zvolili jsme řešení pomocí počítačového modelování s využitím programového systému 2-DIM (2D-Interactive Modelling), vytvořeného v s.p. Geofyzika Brno. Pro sestavení 2D-rychlostního modelu pro zpracovávaný profil se používá tzv. metoda „trial and error", kde je pro zvolený počáteční model řešena přímá kinematická seizmická úloha, tj. jsou spočteny teoretické hodochrony, které jsou porovnány s hodochronami naměřenými. Na základě tohoto srovnání je změněn model a jsou pro něj spočteny nové teoretické hodochrony. Tímto postupem lze již po několika iteracích dojít k dobré shodě teoretických a naměřených hodochron.

V článku je podán podrobný popis programového systému 2-DIM z hlediska uživatele, protože jde o jeho první použití na reálná data. Postup výpočtu je sledován krok za krokem včetně přípravy dat. Pozornost je věnována některým nedostatkům, které se v systému vyskytují. Aby byly demonstrovány možnosti programového systému a použitého algoritmu, jsou předkládány výsledné 2D-rychlostní modely pro tři vybrané profily.

Vysvětlivky k obrázkům

1. Geologická mapa oblasti se situací seizmických profilů a stanic sítě detailního seizmického rajónování (DSR).
   1 – neogén (baden); 2 – neogén (karpat); 3 – paleogén (flyš); 4 – kulm; 5 – devon; 6 – třísložková stanice sítě DSR.

2. Typické uspořádání profilu.

1 – třísložkový geofon ve vrtu; 2 – „satelitní" geofon; 3 – geofon podpůrné jednokanálové aparatury; 4 – roztažení prospekční seizmické aparatury; 5 – registrační zařízení; 6 – body odpalu.

3. Postup výpočtu. Paprskový diagram, naměřené hodochrony (I) a vypočtené časy šíření (*) pro startovací rychlostní model na profilu D. Rozhraní prvního řádu ——, izolinie - - - -.
4. Postup výpočtu. Paprskový diagram, naměřené hodochrony (I) a vypočtené časy šíření (*) pro zlepšený rychlostní model na profilu D (po první iteraci). Rozhraní prvního řádu ——, izolinie - - - -.
5. Postup výpočtu. Paprskový diagram, naměřené hodochrony (I) a vypočtené časy šíření (*) pro konečný rychlostní model na profilu D (po 9 iteracích). Rozhraní prvního řádu ——, izolinie - - - -.
6. Příklad výsledného 2D-rychlostního modelu pro profil E.
7. Příklad výsledného 2D-rychlostního modelu pro profil F.
8. Příklad výsledného 2D-rychlostního modelu pro profil H.