ITHEA

International Journal INFORMATION THEORIES & APPLICATIONS

2009 Volume 16 Number 1

International Journal
INFORMATION THEORIES & APPLICATIONS
Volume 16 / 2009, Number 1

IJ ITA is official publisher of the scientific papers of the members of the ITHEA® International Scientific Society

IJ ITA welcomes scientific papers connected with any information theory or its application.
IJ ITA rules for preparing the manuscripts are compulsory.
The **rules for the papers** for IJ ITA as well as the **subscription fees** are given on *www.ithea.org* .
The camera-ready copy of the paper should be received by http://ij.ithea.org.
Responsibility for papers published in IJ ITA belongs to authors.
General Sponsor of IJ ITA is the **Consortium FOI Bulgaria** (www.foibg.com).

International Journal "INFORMATION THEORIES & APPLICATIONS" Vol.16, Number 1, 2009

Printed in Bulgaria

Edited by the **Institute of Information Theories and Applications FOI ITHEA®**, Bulgaria,
in collaboration with the V.M.Glushkov Institute of Cybernetics of NAS, Ukraine,
and the Institute of Mathematics and Informatics, BAS, Bulgaria.

Publisher: **ITHEA®**
Sofia, 1000, P.O.B. 775, Bulgaria. www.ithea.org, e-mail: info@foibg.com

ISSN 1310-0513 (printed) **ISSN 1313-0463 (online)** **ISSN 1313-0498 (CD/DVD)**

ADAPTIVE APPROACH TO STATIC CORRECTION WITH RESPECT TO APRIORISTIC INFORMATION IN PROBLEM OF SEISMIC DATA PROCESSING

Tatyana Stupina

Abstract: *In that paper problems that arising in seismic data processing for real time are considered. The main issue is defects in investigation of mathematical and physical model of object. The static and kinematic residual correction problem is relevant for real time in spite of the modern graph of seismic data processing contains such procedures. The quality of final results that presented by seismic and depth-distance plot doesn't answer to modern requirements. Three adaptive approaches to realization of numerical method for regression model of static and kinematic residual correction problem are considered. Its use a priory information about number of supporting points of seismic profile at the most.*

Keywords: *the model of residual time of reflected waves, kinematic and static corrections, number of supporting points of seismic profile, line regression model, measure of a priori information, functional of quality, adaptive algorithm, the condition of stability.*

ACM Classification Keywords: *G1.10 Numerical Analysis - Applications, G3 Probability and statistics - Correlation and regression analysis.*

Introduction

The results of the seismic data processing depend on the correspondence of experimental (survey notes) data to theoretical model of environment under investigation. That variance usually concerns with variance of time of reflected waves and it is conditioned by two main reasons. The first is the heterogeneities of upper part of formation (static corrections). The second is difference of given unequal distance between source point and receiving point (kinematic corrections). The modern geophysical software contains enough effective algorithms for static and kinematic corrections, but usually it is founded on supposition of vertical waves transmission from datum to original ground [V.S. Kozirev]. Such supposition doesn't give us expected or satisfactory result [A.P. Sisoev], because it doesn't consider full information about heterogeneities of upper part of formation, that we can be described as:

1. The weathering zone,
2. The relief of original ground,
3. The deep heterogeneities.

The using of the most total information about environment also gives difficult. It is complexity of mathematical model. In addition we have to construct a stability algorithm. Thus that is fundamental problem of numerical mathematics. This paper considers and analyses a line regression model of the static and kinematic corrections for fixed observing system. The measure of a priory information is defined as number of supporting points of seismic profile. The adaptive approach is applied to realization numerical algorithm for increase of stability.

The Problem of Static Correction

The complication of mathematical model, as a rule, leads to additional expenses not only in respect of algorithmic and computing realization of a method, but also to a problem of presence of the additional information on studied object. Therefore now at the first stage as the research tool the linear tetra-factorial model of residual times of reflexions for the single-layered environment is considered, which with reference to CDP arrival-time curve looks like [V.S. Kozirev]:

$$t_{ij} = S_i + R_j + G_k + M_k x_{ij}^2 + N_{ij} \quad (1)$$

where t - double time of reflexion after introduction of primary aprioristic static and kinematic amendments, *i*, *j*, *k* - indexes of position of a source, the receiver and the common midpoints (CMP) accordingly, *G* - structural a component (a double transit time of a wave from level of reduction to reflecting border), *S* - superficially co-ordinated static amendment for a source, *R* - the same for the receiver, *M* - factor of the residual kinematic amendment, x - source-receiver offset, *N* - a noise component.

Model (1) turns out from the equation concerning times T_{ij} of arrival of the reflected wave:

$$T(x,l) = a(x-l) + b(x+l) + \sqrt{t_0^2(x) + 4l^2 / v^2(x)} \quad (2)$$

describing CMP arrival-time curve for single-layered model of the environment, counted for a reduction line in system of co-ordinates (x,l): x - co-ordinate of CMP, l – half of the source-receiver offset. Thanks to possibility of reception and the account of the aprioristic information which are carried out by input of aprioristic model of arrival-time curve $T_a(x,l)$ with parameters $a_a(x-l)$, $b_a(x+l)$, t_{0a}, v_a, and having made the linearization procedure of models (2) (expansion in Taylor's series of function $\sqrt{(\bullet)}$ about a point 0), we will receive:

$$\tau(x,l) = T(x,l) - a_a(x-l) - b_a(x+l) - \sqrt{t_{0a}^2(x) + 4l^2 / v_a^2(x)} \approx$$

$$\approx s(x-l) + r(x+l) + g(x) + m(x)l^2 \quad (3)$$

the model defining residual time shifts $\tau(x,l) = \tau_{ij}$ in the form of (1).

Results of the spent correction at the made aprioristic assumptions of the arrival-time curve form are times of reflexions

$$T(x,l) = T_a(x,l) + \tau(x,l) \quad (4)$$

In the operational form the equation (1) registers as

$$Ap = \tau^* + \delta\tau \quad (5)$$

Matrix A - strongly rarefied, consisting from 0, 1 and x_{ij}^2; $p = (S_i, R_j, G_k, M_k)^T$ - a vector of estimated factors, $p \in D_p$ (space of admissible decisions); τ^* - a vector of true supervision; $\delta\tau$ - a vector of hindrances. Taking in account the big dimension of entrance parameters and presence between them certain communications the system of the equations is badly caused, and decisions - unstable [V.S. Kozirev, A.P. Sisoev]]. Solving out of such systems the various methods of regularization are applied, involve the additional information, simplify models to smaller number of parameters, narrowing a class of decision functions. However methods of regularization are not always effective in reception of satisfactory result in a case when it is necessary to consider aprioristic, presented by quantity of reference points, information in the course of reception of the decision [A.P. Sisoev].

In a considered problem the strong rarity of an operational matrix allows to write out iterative formulas of reception Least-Squares Method - estimations concerning criterion F_1 (item 4) for model (1) not resorting to direct transposing and the reference of matrixes of the big sizes:

$$G_k = \frac{1}{n_k} \sum_{(k)}^{n_k} (\tau_{ij} - S_i - R_j - M_k x_{ij}^2),$$

$$S_i = \frac{1}{n_i} \sum_{(i)}^{n_i} (\tau_{ij} - G_k - R_j - M_k x_{ij}^2),$$

$$R_j = \frac{1}{n_j} \sum_{(j)}^{n_j} (\tau_{ij} - S_i - G_k - M_k x_{ij}^2),$$

$$M_k = \frac{1}{\sum_{(k)}^{n_k} x_{ij}^2} \sum_{(k)}^{n_k} (\tau_{ij} - S_i - R_j - G_k) \qquad (6)$$

where n_k , n_i , n_j means multiplicity with which k'th CMP, i'th point of excitation and j'th point of reception are present at supervision, summation is conducted on traces in which they participate. From the presented dependences (3) it is visible, that initial approach is possible on any of factors S_i , R_j , G_k , M_k , hence the result of the solution will depend on a choice of initial approach. Moreover, minimization of criteria in general case of errors correlation with the unknown law of distribution and in case of stochastic of results of measurements (not planned experiment or experiment with errors in measurements) does not guarantee the stable solution.

Let's show on an example, that minimization of only functional F_1 not always can lead to desirable result. We will designate through g^* , f^* (we will drop parameters x and l) true, in essence unknown functions of arrival-time curve and "relief", through g_a , f_a - aprioristic functions of arrival-time curve and "relief", through $\tilde{g}, \tilde{f}$ - kinematic and static amendments. Then if we will present $A = (A_1, A_2)$, $C_1 = \|A_1\|$, $C_2 = \|A_2\|$, a rough estimate from above

$$\begin{aligned} \|\tau - \tilde{\tau}\| = \|Ap - A\tilde{p}\| = \left\|A(f^* - f_a, g^* - g_a) - A(\tilde{f}, \tilde{g})\right\| \\ \le C_1(\left\|f^* - f_a\right\| + \|\tilde{f}\|) + C_2(\left\|g^* - g_a\right\| + \|\tilde{g}\|) = \varepsilon \end{aligned} \qquad (7)$$

shows, that to one value of criterion there can correspond various values of the items entering into the sum. Even under condition of a priori known model of environment (the first items in brackets it is possible to name ineradicable errors of model) kinematic and static amendments can be mutually replaced. From here there was a research problem of algorithm of correction of a static at an iterative stage of minimization of discrepancy F_1 with the account of the aprioristic information.

The Aprioristic Information

At work with real (field) data the aprioristic information are:

1. Assumptions about agent and laws of distribution of waves (for the decision of a direct problem). For example, in a considered case parameters t_{0a}, v_a for the equation of CDP arrival-time curve for the reflected single-layered environment.
2. Quantity of the reference points necessary for interpolation of function of "relief" or heterogeneity of agent, we will designate through μ. We will notice, that generally algorithms of interpolation are unstable, relief function actually is discretely multiextremal, and assumptions of a "good" class of functions at times are far from practice.

Therefore in the researches we will stop on studying three interdependent characteristics: a frequency component of "relief", number of reference points, length of arrangement of a seismic profile.

Construction of the Multiobjective Decision-making

Pursuing an ultimate goal - reception of the stable solution, on a basis multiobjective decision-making we will construct an optimum subset of decisions $optD_p \in D_p$.

Let's consider the criteria to which optimum values should satisfy required decision $\tilde{p}$:

1. $F_1(\tilde{p}) = \|\tau - \tilde{\tau}\|_{L^2} \to \min\limits_{p \in D_p}$ - minimization of discrepancy by, for example, an iterative method, where $A\tilde{p} = \tilde{\tau}$;

2. $F_2(\tilde{p}) = \|p - \tilde{p}\|_{L^2} \to \min\limits_{p \in D_a}$ - minimization of an error of the decision on reference points, D_a - set of reference points on which heterogeneity of upper part of formation is a priori restored, $|D_a| = \mu$;

3. $F_3(\tilde{p}) = \|p^* - \tilde{p}\|_{L^2} \to \min\limits_{p \in D_p}$ - minimization of an error of the decision on synthetic data, where $Ap^* = \tau^*$;

4. $F_4(\tilde{p}) = |D_a| \to \min$ - minimization of number of reference points, use a big number of which is connected with essential economic expenses;

Listed above functions forms vector criterion $F(p) = (F_1(p), F_2(p), F_3(p), F_4(p)) \in \Re^4$. There are some variants of solving of such problems, of which it is possible to allocate with most widespread:

a) The Pareto construction of optimum set of decisions [V.V. Podinovskij];

b) Ranging of criteria or introduction of relative importance of criteria;

c) Construction of global criterion or secularization of vector criterion.

First two variants mean presence of the aprioristic information, possibly even expert knowledge of admissible value of norm of discrepancy, whereas the third is based on more automated decision-making. For investigated model we will in detail analyze synthesis of the second and third variant.

Let on n -th iteration of the equations (6), $n = 1, 2, 3...$, solution $\tilde{p}^{(n)} = (\tilde{f}^{(n)}, \tilde{g}^{(n)})^T$ of system $\tilde{\tau}^{(n)} = A\tilde{p}^{(n)} = (A_1 \tilde{f}^{(n)}, A_2 \tilde{g}^{(n)})^T$ is received, with value of discrepancy equal $\varepsilon^{(n)} = \left\| \tau - \tilde{\tau}^{(n)} \right\|$. We will designate through $\tilde{D}_p = \left\{ \tilde{p}^{(n)} : \delta_{\min} \le \left\| \tau - A\tilde{p}^{(n)} \right\| \le \delta_{\max}, n_{\min} \le n \le n_{\max} \right\}$ set of "trial" solutions, i.e. set of decisions which within several iterations satisfy to admissible quality on norm of discrepancy F_1. We will formulate three approaches to decision construction:

1. The first approach.

We build solution $\tilde{p} = \sum_n \lambda_n \tilde{p}^{(n)}$ of elements of set $\tilde{D}_p$, where $\sum_n \lambda_n = 1$ and weight number $\{\lambda_n\}$ ranked with the maximum value for minimum norm $\left\| \tilde{f}^{(n)} \right\| = \min_{\tilde{p} \in \tilde{D}_p \cap D_a} F_2(\tilde{p})$.

2. The second approach.

Consistently we correct solution $\tilde{p}^{(n)}$ to $p^{(n)}$, $p^{(n)} = \tilde{p}^{(n)} + p_1$, on reference points remaining in "trial" set, i.e. $\left\| \tau - \tau^{(n)} \right\| = \varepsilon^{(n)} \le \delta_{\max}$ and $\left\| f^{(n)} \right\| \le \left\| \tilde{f}^{(n)} \right\|$, where $p_1 = (f^{(n)} - \tilde{f}^{(n)}, 0)$.

3. The third approach.

$F = \lambda_1 \left\| \tau - \tilde{\tau}^{(n)} \right\| + \lambda_2 \left\| \tilde{f}^{(n)} \right\| \to \min_{\tilde{p} \in \tilde{D}_p \cap D_a}$, where $\lambda_1 + \lambda_2 = 1$.

Condition $\lambda_2 > \lambda_1$ means stronger requirements to performance of aprioristic conditions.

The Description of a Modeling Example

The synthetic data simulated for the single-layered formation and flank system of supervision, is schematically shown on fig. 1. Model parameters:

Velocity in weathering zone, V_1 = 600 m/s;

1. Velocity in the agent to the first reflecting horizon, V_0 = 1950 m/s;
2. The equation of "relief" $y(x) = \frac{1}{V_1}(c_1 + c_2 \sin(\omega x + \varphi))$, $\omega = \frac{2\pi}{T}$ - a frequency component of "relief", T = 200-1900, $c_1 = 20, c_2 = 10$.
3. Aprioristic time of reflecting horizon, t_0 = 1.5 s.
4. The equation of CDP arrival-time curve $t(x) = \sqrt{t_o^2 + x^2 / V_0^2}$
5. The system of supervision is flank with repeated overlapping: length of a profile of 10 000 m., quantity of channels 20, distances ΔRP = ΔSP = 50 m, max |RP-SP| = 1.3H, H = 1.5V_0/2 = 1462.5, length of arrangement 20*50-50=950, number of reference points from 10 to 100, RP – point of receiving and SP – point of source ;
6. The noise level is set by value mean-square σ (further on schedules it is signed «sigma») regulary distributed in the range of $\left[-\frac{l}{2}, \frac{l}{2}\right]$, $l = \sqrt{12}\sigma$, a random variable with a zero average of distribution.

The software procedure of calculation of times of arrival of the reflected wave (a direct problem) is realized. The inverse problem was solved by iterative Gauss-Zejdel method; on each step of it values of criteria F_1, F_2 and F_3, were estimated at fixed value F_4. The set of "trial" decisions was in such a way formed. The received results will allow to formulate recommendations to construction of global criterion $F = \lambda_1 F_1 + \lambda_2 F_3$, and then pass to Pareto construction of optimum set on (F, F_4). Researches of numerical modeling were spent for differently periodical functions of heterogeneity (item 3. of this paragraph), admissible noise levels (item 7) in the right part of the equation (5) and different quantity of reference points.

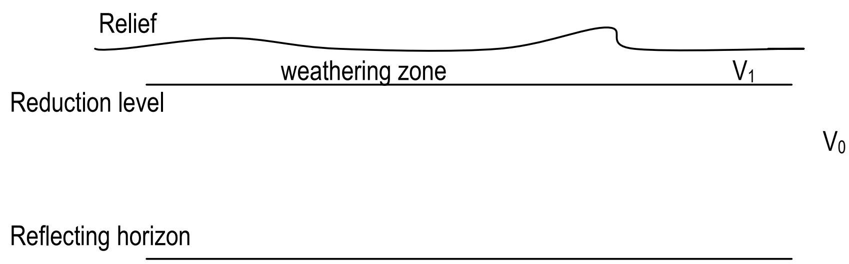

fig. 1. The scheme of single-layered formation

Algorithm Research

The first stage of program testing consisted in check of a program code of algorithm on correctness of realization, i.e. in research on convergence of iterative process (value of criterion F_1) at zero noise level, σ = 0 and various values of quantity of reference points (value of criterion F_4). On fig. 2 efficiency of algorithm is shown. The tendency of increase in speed of convergence and accuracy increase is obvious at bigger number of reference points. On all schedules the norm square in metrics L^2 is considered.

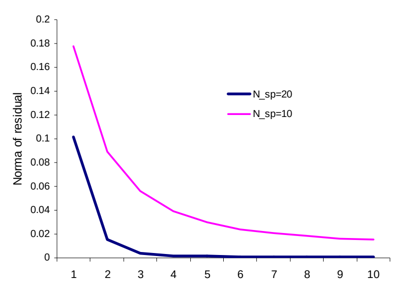

fig. 2 The algorithm accuracy relative to iterations

At the second stage for each iteration the values of criterion F_2, were numerically received. It was necessary to do in order to estimate on an example the relative contribution of each of criteria to the general (scalarized) on the third approach. Results on fig. 2 and fig. 3 show necessity of introduction of the scaling factor for criterion F_2. In the presented example it is equal approximately to one decimal order for number of reference points equal 10. It is clear, that this size will depend on aprioristic knowledge of noise level. For example, at known small enough noise level the value of discrepancy and also value of norm on reference points decreases with increase in quantity of iterations that allows to make the decision already on the fourth iteration.

On synthetic data there is a possibility to receive the error of the solution presented in the form of norm (criterion F_3). The schedule 4 reflects essential reduction of an error in drawing on bigger number of reference points and enough quick stabilization of value of an error (on 3-4 iterations). At comparison of schedules on fig. 3 and fig. 4 a question of possibility of an alternative estimation of quality of the solution arises, i.e. a norm estimation on reference points as on control sample. Passing to statistical estimations $\sqrt{\frac{F_2}{2\dim D_a}}$ and $\sqrt{\frac{F_3}{\dim D_p}}$, mean-square, on an example for 10th iteration it is possible to see their small difference $\sqrt{25 \cdot 10^{-5}}$ and $\sqrt{8 \cdot 10^{-5}}$.

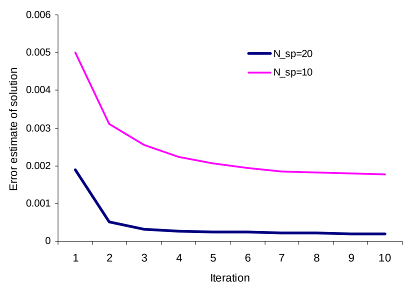

fig. 3 The Error estimate of solution on support points, Var[eps]=0.

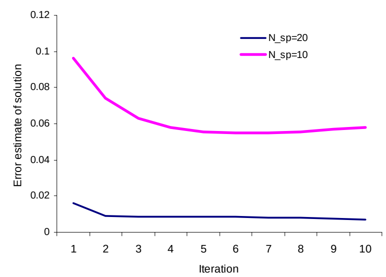

fig. 4 The error estimate of solution, Var[eps]=0.

At the third stage noise of various levels has been entered into model. The schedule in drawing 5 reflects polynomial dependence of accuracy of iterative algorithm in 10th iteration depending on noise level.

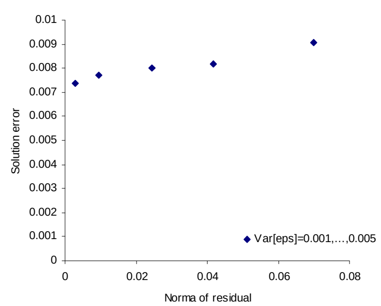

fig. 5 Analysis of stability domains by error on support points, Var[eps]=0.001,…,0.005

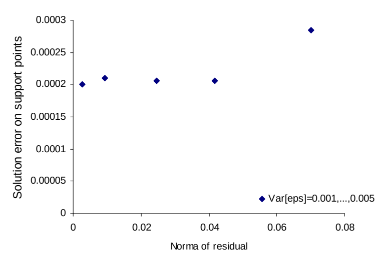

fig. 6 Analysis of stability domains by error on solutions, Var[eps]=0.001,…,0.005

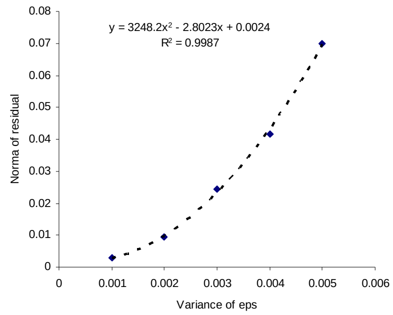

fig. 7 The algorithm accuracy relative to noise level, N_sp=20

Analyzing results of modeling two-dimensional criteria area (F_1 , F_2) on fig. 6 and area (F_1 , F_3) on fig. 7 it is possible to make a conclusion on essential joint increase in values of criteria at noise level bigger than 0.004.

At the fourth stage the influence of «relief form» on convergence and accuracy of the decision was numerically estimated. It was considered while one parameter presented in item 5, sub item 3, frequency component T. In all previous examples T it was equal 700, which make 0.73 from length of arrangement. Results on schedules fig. 8, 9, 10, and 11 illustrate an existing problem of reception of the stable solution at value of T (equal 200, 235) less than a quarter of length of arrangement. The schedule on fig. 8 shows fast stabilization of process on small enough value of discrepancy. For T = 200 iterative process already from the third iteration starts to disperse slowly. Results on fig. 10 and 11 show change of accuracy of the decision and norm of discrepancy at various quantity of reference points. Some law of division of schedules on decimal parity and oddness of quantity of reference points is observed. Probably, that it is connected with uniformity of distribution of reference points on all length of a profile.

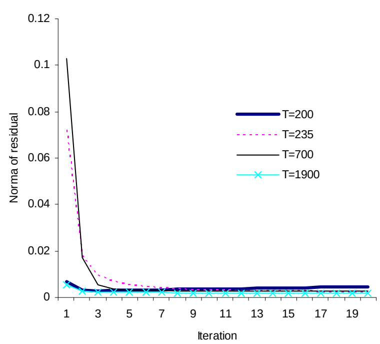

fig. 8 The algorithm accuracy relative to iterations for different wave period and N_sp = 20, Var[eps] = 0.001

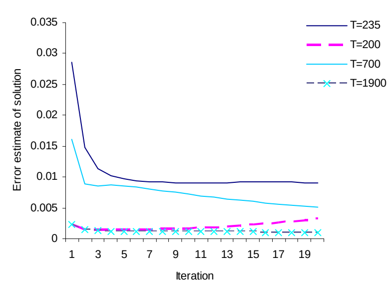

fig. 9 The error estimate of solution relative to iterations for different wave period and N_sp = 20, Var[eps] = 0.001

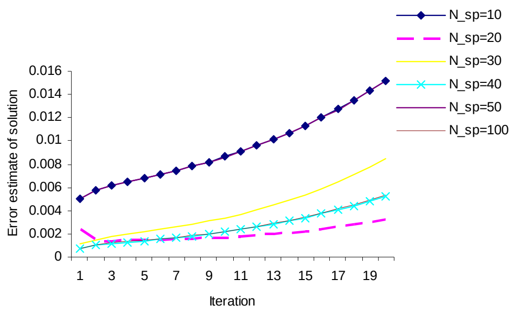

fig. 10 The error estimate of solution relative to iterations for different number of support points and T = 200, Var[eps] = 0.001

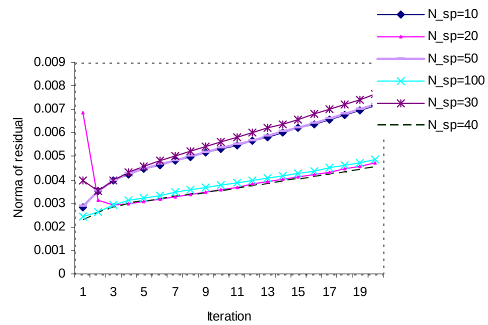

fig. 11 The norma of residual relative to iterations for different number of support point, T = 200 and Var[eps] = 0.001

Basic Results of Researches

With reference to investigated model it is possible to draw following conclusions:

- Fast enough convergence of iterative algorithm at zero noise and a maximum quantity of reference points.
- At mean square noise level smaller than 0.004 it is possible to construct the solution according to the offered approaches. Thus the admissible set of solutions can start to be formed from the third iteration.
- It is possible to draw a conclusion that only at careful enough analysis of aprioristic data about the model and "relief" model (heterogeneity) and the complex approach to estimation of quality of the made decision, it is possible to receive rather stable solutions of a problem of correction of static amendments.

For ours investigation we have created programming instrument. It is algorithm for numerical research, that was realized in the programming language C++ in the environment of Microsoft Visual C ++. The basic program mainframes:

1. Data input;
2. Formation of a matrix of system of supervision with record in a format in a file;
3. Functions of construction of heterogeneity of agent, CDP arrival-time curve, noise.
4. Iterative algorithm of the solution of the inverse problem with a conclusion of numerical values by criteria.

Conclusion

The linear model of residual times of the reflections, considering static and kinematic amendments for a relief with the account of the aprioristic information on the model is presented in the present work. It has been noticed, that such problems remain actual in connection with the big conditionality of their solutions. Four adaptive approaches to decision-making is offered, i.e. as much as possible considering the aprioristic information presented by quantity of reference points on a seismic profile. The offered approaches are based on introduction combined functionals of model quality and decision updating at a stage of iterative formation of the solution.

For the homogeneous single-layered isotropic environment of the set power, the fixed system of supervision of certain length, numerical modeling by the technique presented in work is spent. The results reflecting convergence of iterative process of the solution of inverse problem are received (definition of parameters of correction of statics without kinematics distortion), possibility of application of four offered approaches to decision-making on set of admissible decisions is shown.

In the conclusion we will notice, that the considered problem is “inverse incorrectly set” and settles by construction of « quasi-solution». The decision strongly enough depends on quality of initial data and a class of functions in which the decision is under construction. Except application of the mathematical apparatus used for an accurate substantiation of used methods, any practical problem always demands an individual approach to its solution, not looking on the standard approaches.

The author of work had practical experience in solving inverse problems also in other fields of knowledge (medicine, hydrology, ecology). In general, it would be desirable to notice, that the expert information strongly enough narrows space of possible decisions, less difficult models more often gives the comprehensible solution. Very often behind consideration frameworks there is a question on possibility of application of model to observable data in problems of the big dimension and complexity of model.

Bibliography

[V.S. Kozirev, 2003] V.S. Kozirev, A.P. Zjukov, I.P. Korotkov, A.A. Zjukov, M.B. Shneerson. Taking into account of heterogeneousness of upper part of formation in exploration seismology. Modern technologies, Moscow: “Nedra-Busness center”, 2003, 227 pp.

[A.P. Sisoev, 1988] A.P. Sisoev. Analyze of stability of evaluation static and kinematic parameters in reflection method. Mathematical problems of interpretation data of exploration seismology. Novosibirsk, Nauka, 1988.

[L. Hatton, 1989] L. Hatton, M. Uerdington, Dj. Mejkin. Processing seismic data. Theory and practice. Moscow: Mir, 1989, 216 pp.

[V.M. Glogovskij, 1984] V.M. Glogovskij, A.R. Hachatryn. Static correction in its true value kinematic parameters of reflection. Geology and Geophysics. 1984, №10.

[V.V. Podinovskij, 1982] V.V. Podinovskij, V.D. Nogin. Pareto-optimal decision of multicriterion problem. 1982, 256 pp.

Authors' Information

Tatyana A. Stupina *– Trofimuk Institute of Petroleum-Gas Geology and Geophysics of SBRAS, Koptyug Ave 3, Novosibirsk, 630090, Russia; e-mail: stupinata@ipgg.nsc.ru*