Introduction

Report 14 of the Consortium project "Seismic Waves in Complex 3-D Structures" (SW3D) summarizes the work done towards the end of the tenth year and during the eleventh year of the project, in the period June, 2003 — May, 2004. It also includes the compact disk with updated and extended versions of computer programs distributed to the sponsors, with brief descriptions of the programs, and with the copy of the SW3D WWW pages containing papers from previous reports and also from journals.

Our group working within the project during the eleventh year has consisted of seven research workers: Václav Bucha, Petr Bulant, Vlastislav Červený, Luděk Klimeš, Ivan Pšenčík, Jan Šílený and Václav Vavryčuk; and of PhD student Karel Žáček.

Karel Žáček works on the algorithm of Gaussian packet migration. He also worked for 3 months (September–November 2003) together with Ross Hill in the San Ramon branch of ChevronTexaco. PhD student Xuyao Zheng, who worked with us during previous years of the project, defended his PhD thesis "Determination of weak anisotropy parameters from qP–wave slowness and polarization vectors" at the Charles University, Prague on September 8, 2003. Xuyao also ended his postdoc stay in Petroleum Applied Research Group (OPERA) at Pau, France, and returned to China, where he started to work at Geophysical Institute of the State Seismological Bureau. Ellen Gomez from the UFPa Belém, Brazil, who spent with us a part of her PhD studies, defended her thesis "Estimativa de parâmetros elásticos de meios anisotrópicos (Determination of elastic parameters in anisotropic media)" at the UFPa, Belém, Brazil on June 20, 2003. Norman Bleistein (Colorado School of Mines, USA), Giancarlo Dal Moro (University of Trieste, Italy), Leo Eisner (Schlumberger Cambridge Research, United Kingdom), Véronique Farra (IPG Paris, France), Einar Iversen (NORSAR, Kjeller, Norway), Robert Patzig (University of Hamburg, Germany) and Kioshi Yomogida (Hokkaido University, Sapporo, Japan) visited us during the eleventh year of the project.

SEG Honors and Awards Committee and the SEG Executive Committee selected Vlastislav Červený to receive the **Maurice Ewing Medal** "in recognition of his lifetime contribution to our profession through his internationally recognized work in the ray theory of wave propagation".

Ivan Pšenčík served as the guest editor of the special issue No.1/**48** (2004) of *Studia Geophysica et Geodaetica* devoted to problems of seismic wave propagation in anisotropic media. Among 14 articles, the special issue contains final versions of 6 papers published in previous annual progress reports of the consortium project. The special issue is distributed to the consortium members together with this Report 14 (2004).

Research **Report 14** contains mostly the papers related to seismic anisotropy (8 of 15 papers). Report 14 may be roughly divided into seven parts, see the Contents.

The first part, **Seismic models and inversion techniques**, is devoted to various kinds of inverse problems, to the theory developed for application to their solution, and to the construction of velocity models suitable for ray tracing and for application of ray–based high–frequency asymptotic methods.

K. Žáček presents his algorithm of Gaussian–packet prestack depth migrations, including the first numerical results.

The second part, **Ray methods in isotropic and anisotropic media**, is devoted to the high–frequency methods in general, but does not contain the papers more specifically addressing problems of weak anisotropy or of viscoelastic media, which have been postponed to the third and fourth parts. This part also contains two papers describing applications of the SW3D ray tracing software distributed on the compact disk.

In the first paper of this part, V. Bucha shows the application of the SW3D software to two–point ray tracing and to calculation of ray–theory seismograms in the smoothed SEG/EAGE Salt Model with interfaces. The rays are traced from two shots located in a well. Rays from the shot below the salt include multiple reflections. In the analogous paper of the previous Report 13, the shot was located at the surface.

In the second paper, V. Bucha demonstrates the application of the SW3D software to the construction of reflection maps on the bottom flat interface in the smoothed SEG/EAGE Salt Model with interfaces.

In the third paper of this part, L. Klimeš summarizes equations for Gaussian packets in smooth isotropic media without interfaces. Evolution of the complex–valued second derivatives of travel time, which control the shape of the Gaussian packet, along the central ray is determined by quantities calculated by dynamic ray tracing.

The fourth paper of this part, by L. Klimeš, is a brief overview of various aspects of the summation of Gaussian beams and packets, including their relation to various generalizations of the Maslov method and to coherent–state transform methods. The notes on the relations between different methods also include references to selected papers.

In the fifth paper of this part, V. Vavryčuk discusses what is the maximum number of singularities (acoustic axes) in triclinic media and how to calculate their positions. The frequency of occurrence of singularities in randomly generated triclinic media is studied by numerical modelling.

The third part, **Weak anisotropy**, addresses the problems relevant to weakly anisotropic media.

In the first paper of this part, V. Farra & I. Pšenčík propose approximate ray tracing and dynamic ray tracing equations for qP waves propagating in inhomogeneous weakly anisotropic media. The equations are considerably simpler than the exact ones. Their right–hand sides depend only on 15 qP–wave weak anisotropic parameters making computations much more effective. The accuracy of travel time computations may be increased by use of simple second–order travel–time perturbation formula.

In their contribution, I. Pšenčík & E. Tessmer compare synthetic seismograms calculated by the ray method or its modification (quasi–isotropic approximation) and the Chebyshev spectral method.

The third paper of this part, by P. Bulant & L. Klimeš, is a continuation of the paper on the equations for common S–wave ray tracing in a smooth elastic anisotropic medium, and for the corresponding dynamic ray tracing, presented in Report 13. The respective dynamic ray tracing computer code has been debugged and partly tested. The anisotropic common ray approximation of the coupling ray theory is now numerically demonstrated. The authors compare anisotropic–ray–theory travel times computed by anisotropic ray tracing with the ones calculated by the anisotropic common ray approximation. The obtained travel–time errors due to the anisotropic common ray

approximation are compared with the errors due to the isotropic common ray approximation in three 1-D models of differing degree of anisotropy. The differences between the isotropic and anisotropic common ray approximations of the coupling ray theory are also shown on synthetic seismograms.

The fourth part, **Anisotropic viscoelastic media**, is devoted to the problem of homogeneous and inhomogeneous plane waves propagating in viscoelastic anisotropic media.

In the first two papers of this part, V. Červený and I. Pšenčík study, theoretically and numerically, the slowness vectors of plane waves, propagating in viscoelastic anisotropic media. Both inhomogeneous and homogeneous plane waves are considered. The main attention is devoted to the phase velocities, amplitude decay along the propagation direction, attenuation, attenuation angle and polarization vectors. Analysis of the obtained results reveals certain phenomena unfamiliar from studies of plane–wave propagation in perfectly elastic anisotropic or viscoelastic isotropic media.

In the third paper, by V. Červený, the reflection/transmission laws of homogeneous and inhomogeneous plane waves at a plane interface between two homogeneous viscoelastic media are studied. The proposed laws are valid for unrestricted anisotropy and viscoelasticity.

The fifth and sixth parts of Report 14 are devoted to new research directions within the consortium project. The fifth part, **Nonlinear waves**, is devoted to waves propagating in nonlinear materials.

I.A. Molotkov & I. Pšenčík study a very simple case: propagation of a longitudinal wave in a homogeneous isotropic nonlinear medium. Solving asymptotically elastodynamic equation for nonlinear elastic medium, they present a solution, which has several interesting properties unknown from propagation in homogeneous linear elastic media. For example, in addition to the longitudinal wave with basic frequency, another one with doubled frequency is generated. The longitudinal wave has non–zero transverse component.

The sixth part, **Seismic sources**, is devoted to the forward and inverse problems of source mechanisms, which become increasingly important in reservoir monitoring, especially in connection with hydraulic fracturing.

V. Vavryčuk shows in his contribution that seismic sources in anisotropic media have more complicated moment tensors than in isotropic media. Planar shear sources produce pure double–couple moment tensors in isotropic media, but generally non–double–couple (non–DC) moment tensors in anisotropic ones. The percentage of non–DC components is calculated for shear faulting in media with aligned dry or water–filled penny shaped cracks.

L. Eisner, J. Šílený & J. Rutledge have used waveform inversion to obtain full, unconstrained moment tensors of induced microseismic events in the Cotton Valley hydraulic fracturing experiment. The unconstrained moment tensors allow characterization of source signatures such as fault orientation, slip direction, volumetric, tensile or shear components of the induced seismicity. The retrieved mechanisms are consistent with pure–shear failure and inverted fault planes and slip directions agree with previous studies.

The final seventh part, **CD–ROM with SW3D software, data and papers**, contains the CD–R compact disk SW3D–CD–8.

Compact disk SW3D–CD–8, edited by V. Bucha & P. Bulant, contains the revised and updated versions of the software developed within the consortium research project, together with input data related to the papers published in the consortium research reports. A more detailed description can be found directly on the compact disk. Compact disk SW3D–CD–8 also contains over 190 complete papers from journals and previous reports, mostly in PostScript and GIF, few in PDF or HTML, refer to the copy of the Consortium WWW pages on the compact disk. Compact disk SW3D–CD–8 is included in Report 14 in two versions, as the UNIX disk and DOS disk. The versions differ just by the form of ASCII files. From new features of the SW3D software, let us mention the debugged versions of routines for anisotropic common S–wave ray tracing and dynamic ray tracing in models without structural interfaces. The programs for travel–time inversion have been generalized towards simultaneous arrival–time inversion for both hypocentres and model parameters. A new program for inversion of phase velocities of surface waves has been developed but it is not included on SW3D–CD–8 because we have not applied for the copyrights of the code to solve the forward problem. In case of interest, the program can be released on the next compact disk.

This Introduction is followed by the list of members of the SW3D Consortium during the eleventh year of the project. We are very pleased to welcome a new consortium member, ExxonMobil Upstream Research Company (Houston, U.S.A.). We hope ExxonMobil will find the membership in our Consortium profitable.

The Research Programme for the current, eleventh year of the Consortium project comes after the list of members. The Research Programme for the next year will be prepared after the discussion at the Consortium meeting, June 14–16, 2004. More detailed information regarding the SW3D Consortium Project is available online at "http://sw3d.mff.cuni.cz".

We use this opportunity to inform our sponsors about planned workshop on "Seismic waves in laterally inhomogeneous media VI", which will be held at the Castle of Hrubá Skála in Czech Republic on June 20–25, 2005. More information can be found at "http://www.ig.cas.cz/activities/swlimVI.php".

Acknowledgements

We are very grateful to all our sponsors for the financial support. The research has also been partially supported by the Grant Agency of the Czech Republic under Contracts 205/01/0927, 205/01/D097, 205/02/0383 and 205/04/1104, by the Grant Agency of the Charles University under Contracts 237/2002/B-GEO/MFF, 229/2003/B-GEO/MFF and 375/2004/B-GEO/MFF, by the Grant Agency of the Academy of Sciences CR under Contract A3012309, by the Ministry of Education of the Czech Republic within Research Project MSM113200004, and by the Academy of Sciences CR within research projects Z3012916 and K3012103.

Prague, June 2004

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