Introduction

Report 20 of the Consortium project "Seismic Waves in Complex 3–D Structures" (SW3D) summarizes the work done towards the end of the sixteenth year and during the seventeenth year of the project, in the period June, 2009 — May, 2010. It also includes the DVD 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.

Consortium project "Seismic Waves in Complex 3–D Structures" has a new and simple address **sw3d.cz** of its WWW pages since November 13, 2007.

Our group working within the project during the seventeenth year has consisted of six research workers Václav Bucha, Petr Bulant, Vlastislav Červený, Luděk Klimeš, Ivan Pšenčík and Václav Vavryčuk.

Veronique Farra (Inst. Physique do Globe de Paris, France), Morten Jakobsen (University Bergen, Norway) and Mohan D. Sharma (Kurukshetra University, India) visited us during the period June, 2009 — May, 2010.

Just before this year's Consortium meeting, we organized an international workshop "Seismic waves in laterally inhomogeneous media VII" at the Teplá Premonstratensian Monastery in Czech Republic on June 21–26, 2010. Proceedings from the workshop will be published in a special issue of Studia Geophysica et Geodaetica. The special issue will be distributed to the Consortium members.

Research **Report 20** contains mostly the papers related to seismic or electromagnetic anisotropy (10 of 11 papers). Report 20 may roughly be divided into eight 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.

Velocity models suitable for ray tracing are usually obtained by minimizing the second–order velocity derivatives to a reasonable extent. When P. Bulant applied this otherwise successful method to a velocity model composed of an upper part with strong velocity gradient continuously matching a nearly homogeneous part, he encountered considerable problems. He describes these problems in the first paper of this part titled "Smoothing the 1–D velocity model of Dobrá Voda for ray tracing".

Paper "Sensitivity Gaussian packets" by L. Klimeš represents the expanded abstract submitted to the 80th Annual Meeting of Society of Exploration Geophysicists in 2010. The expanded abstract is related to the theory and algorithms proposed in Report 17 and Report 18. The expanded abstract briefly summarizes the results presented at the Consortium meeting on June 16–17, 2008.

In paper "Kirchhoff prestack depth migration in simple models of various anisotropy", V. Bucha tests the Kirchhoff prestack depth migration in several simple anisotropic velocity models. Each velocity model consists of two homogeneous layers separated by a curved interface. The velocity models differ by the anisotropy in the upper layer. Computer programs used for the 2–D and 3–D Kirchhoff prestack depth migration were distributed to the sponsors in 2005.

The second part, **Seismic ray theory**, is designed to contain general review papers on ray theory for seismic waves in heterogeneous isotropic or anisotropic elastic media, possibly including attenuation.

Paper "Seismic ray theory" by V. Červený and I. Pšenčík is a slightly modified version of the invited review paper for Encyclopedia of Geophysics, which will be published by Springer Verlag in 2011. In the paper, the main principles of seismic ray theory for heterogeneous isotropic and anisotropic media with curved structural interfaces are reviewed. Some extensions and modifications of seismic ray theory are also briefly discussed.

The third part, **Waves in weakly anisotropic elastic media**, addresses the problems relevant to wave propagation in heterogeneous weakly anisotropic elastic media.

The only paper of this part, "First–order reflection/transmission coefficients for unconverted plane P waves in weakly anisotropic media", by V. Farra and I. Pšenčík is devoted to approximate formulae for computation of plane–wave reflection/transmission coefficients of waves incident, under an arbitrary angle, at interfaces of arbitrary contrast, separating two homogeneous weakly anisotropic media. Results of numerical tests of accuracy of the approximate reflection/transmission coefficients for unconverted P waves are presented.

The fourth part, **Paraxial ray methods in anisotropic media**, addresses the general theoretical problems of paraxial ray approximation.

In 2002, L. Klimeš proposed the equations for calculating the third–order and higher–order spatial derivatives of travel time and all perturbation derivatives of travel time in smooth media without interfaces in his paper "Second–order and higher–order perturbations of travel time in isotropic and anisotropic media", which was distributed to the consortium members together with Report 12. The missing equations for the transformation of the third–order and higher–order spatial derivatives of travel time and all perturbation derivatives of travel time at interfaces, promised since 2002, are derived in paper "Transformation of spatial and perturbation derivatives of travel time at a general interface between two general media" in this report. The transformation equations are expressed in terms of a general Hamiltonian function and are thus applicable to any Hamilton–Jacobi equation.

Paraxial matrices are required in calculating the second–order and higher–order spatial and perturbation derivatives of travel time, and have found many other applications in the theory of wave propagation. In paper "Transformation of paraxial matrices at a general interface between two general media", L. Klimeš presents his derivation of the already known explicit equations for transforming paraxial matrices at a general smooth curved interface between two arbitrary media. The transformation equations are expressed in terms of a general Hamiltonian function and are thus applicable to any Hamilton–Jacobi equation.

The fifth part, **Gaussian beams in anisotropic media**, is devoted to Gaussian beams in 3–D heterogeneous anisotropic media.

Paper "Gaussian beams in inhomogeneous anisotropic layered structures using dynamic ray tracing in Cartesian coordinates" by V. Červený and I. Pšenčík is devoted to the theory of Gaussian beams concentrated close to rays of high frequency seismic body waves propagating in heterogeneous anisotropic layered structures. The basic role in the computation of Gaussian beams is played by a 2×2 complex–valued matrix of second derivatives of the travel–time field with respect to orthogonal coordinates in the plane tangent to the wavefront, computed along a reference ray. This matrix can be computed by dynamic ray tracing in various coordinate systems. The application of the ray–centred coordinate system in the computation of Gaussian beams was explained in detail in the related paper in Report 19. In this report, the computation of Gaussian beams in Cartesian coordinates is described. Two types of Cartesian coordinates are considered: a) the global Cartesian coordinates, b) the local Cartesian coordinates (called wavefront orthonormal coordinates). In addition, a simplified version of the dynamic ray tracing in global Cartesian coordinates is treated.

The sixth part, **Waves in attenuating media**, is devoted to waves propagating in isotropic or anisotropic attenuating media and described by the complex–valued travel time.

Paper "Boundary attenuation angles for inhomogeneous plane waves in anisotropic dissipative media" by V. Červený and I. Pšenčík is the first version of the manuscript which will be submitted to the Proceedings of the Fourteenth International Workshop on Seismic Anisotropy published in Geophysics. The paper is devoted to the computation of attenuation angles of inhomogeneous plane waves propagating in isotropic or anisotropic viscoelastic media and to the computation of their boundary values. In isotropic viscoelastic media, the boundary attenuation angle is always 90°. In anisotropic media, however, the boundary attenuation angle is not known a priori and must be computed. Simple and safe algorithms for the exact computation of attenuation angles and boundary attenuation angles, valid for isotropic and anisotropic, viscoelastic or perfectly elastic media, are presented. The importance of boundary attenuation angles in the analysis of inhomogeneous waves is explained.

A very suitable approximate method for calculating the complex–valued travel time in attenuating media is the perturbation from the reference travel time calculated along real–valued reference rays to the complex–valued travel time defined by the complex–valued Hamilton–Jacobi equation. The accuracy of this approach strongly depends on the choice of the reference and perturbation Hamiltonian functions. In paper "Perturbation expansions of complex–valued travel time along real–valued reference rays", M. Klimeš and L. Klimeš propose a novel general method for constructing the reference and perturbation Hamiltonian functions for any given complex–valued Hamiltonian function.

The seventh part, **Electromagnetic waves in bianisotropic media**, is devoted to electromagnetic waves propagating in heterogeneous bianisotropic media, i.e., in media where both permitivity and permeability depend on the direction of propagation.

The only paper of this part, "Sensitivity of electromagnetic waves to a heterogeneous bianisotropic structure", represents the invited paper for the URSI 2010 International Symposium on Electromagnetic Theory in Berlin, Germany, August 16–19, 2010. L. Klimeš applies the theory proposed in his paper "Sensitivity of seismic waves to the structure" from Report 17 to electromagnetic waves. This invited paper is thus related to the same topic as the expanded abstract "Sensitivity Gaussian packets" from the first part of this report.

The eighth and final part, **DVD–ROM with SW3D software, data and papers**, contains the DVD–R compact disk SW3D–CD–14.

Compact disk SW3D–CD–14, edited by V. Bucha and 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–14 also contains over 390 complete papers from journals and previous reports in PostScript, PDF, GIF or HTML. Refer to the copy of the Consortium WWW pages on the compact disk. Compact disk SW3D–CD–14 is included in Report 20 in two versions, as the UNIX disk and DOS disk. The versions differ just by the form of ASCII files.

This Introduction is followed by the list of members of the SW3D Consortium during the seventeenth year of the project.

The Research Programme for the current, seventeenth 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 28–29, 2010. More detailed information regarding the SW3D Consortium Project is available online at "http://sw3d.cz".

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 205/07/0032, 205/08/0332 and P210/10/0736, by the Grant Agency of the Academy of Sciences of the Czech Republic under contract IAA300120801, by the Ministry of Education of the Czech Republic within research project MSM0021620860, and by the European Commission within FP7 project 230669 "Advanced Industrial Microseismic Monitoring".

Prague, June 2010

Vlastislav Červený
Luděk Klimeš
Ivan Pšenčík