Introduction

Volume 24 of the serial *Seismic Waves in Complex 3–D Structures* of the annual reports of consortium project "Seismic Waves in Complex 3–D Structures" (SW3D) summarizes the work done towards the end of the twentieth year and during the twenty–first year of the project, in the period June, 2013 — May, 2014. 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 volumes and articles from journals.

The yearly published printed serial *Seismic Waves in Complex 3–D Structures* on wave propagation has recently acquired ISSN 2336–3827.

Our group working within the project during the twenty–first year has consisted of five research workers: Václav Bucha, Petr Bulant, Vlastislav Červený, Luděk Klimeš and Ivan Pšenčík.

Véronique Farra (Institut de Physique du Globe de Paris, France), Einar Iversen (NORSAR, Kjeller, Norway), Nabil Masmoudi (King Abdullah University of Science and Technology, Thuwal, Saudi Arabia), Tijmen Jan Moser (Zeehelden Geoservices, 's-Gravenhage, Netherlands) and Xuyao Zheng (Institute of Geophysics, China Earthquake Administration, Beijing, China) visited us since the last annual SW3D consortium meeting in June, 2013.

This Introduction is followed by the list of members of the SW3D consortium during the twenty–first year of the project.

The Research Programme for the current, twenty–first year of the SW3D consortium project comes after the list of members. The Research Programme for the next year will be prepared after the discussion at the annual consortium meeting, June 23–24, 2014. More detailed information regarding the SW3D consortium project is available online at "http://sw3d.cz".

All 13 papers of this **Volume 24** are related to seismic anisotropy. Volume 24 may roughly be divided into five parts, see the Contents.

The first part, **Velocity 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.

Being inspired by the discussions with the researchers from BP and encouraged by their support, B. Růžek & I. Pšenčík present the first, very preliminary, step in travel–time inversion for weakly anisotropic media in paper "P–wave traveltime inversion in weakly anisotropic media: a preliminary study". Noise-free and noisy vertical seismic profiling travel times generated by ANRAY package, which are considered as observed, are inverted for weak–anisotropy parameters. Linear inversion is applied to the linearized formulae for travel times in homogeneous, weakly anisotropic media. Tests indicate which of the weak–anisotropy parameters, how reliably, and under what conditions, are recoverable.

Paper "Moveout approximations for P waves in media of monoclinic and higher anisotropy symmetries" by V. Farra & I. Pšenčík is an extension of two papers on the same topic of previous Report 23 of serial *Seismic Waves in Complex 3–D Structures*, which were devoted to transversely isotropic media with vertical axis of symmetry and to dip–constrained transversely isotropic media. Based on weak–anisotropy approximation (perturbation expansion in terms of deviations of anisotropy from isotropy), the authors now present P–wave moveout formulae of varying accuracy for monoclinic, orthorhombic or transversely isotropic media with horizontal axis of symmetry underlaid by a horizontal reflector coinciding with a symmetry plane. Corresponding approximate formulae for normal moveout velocities are also presented.

Papers “Kirchhoff prestack depth migration in orthorhombic velocity models with differently rotated tensors of elastic moduli” and ”Kirchhoff prestack depth migration in triclinic velocity models with differently rotated tensors of elastic moduli” by V. Bucha demonstrate the sensitivity of migrated images to the rotation of the tensor of elastic moduli (stiffness tensor) around coordinate axes x_1, x_2 or x_3. The papers extend the author’s study of the rotation around the x_2 coordinate axis presented in previous Report 23 of serial *Seismic Waves in Complex 3–D Structures*.

The second part, **Paraxial ray methods in anisotropic media**, addresses the general theoretical problems of paraxial ray approximation, including paraxial Gaussian beams and packets.

L. Klimeš described the rules for the phase shift of the Green tensor due to caustics in heterogeneous generally anisotropic elastic media in Report 6 of serial *Seismic Waves in Complex 3–D Structures*. In new paper “Phase shift of a general wavefield due to caustics in anisotropic media”, he modifies the rules to the phase shift of a wavefield with general initial conditions.

The complex–valued scalar ray–theory amplitude can be decomposed into its complex modulus and the phase shift due to caustics. Paper “Calculation of the amplitudes of elastic waves in anisotropic media in Cartesian or ray–centred coordinates” by L. Klimeš is devoted to the derivation and comparison of various expressions for the complex modulus of amplitude of both a general wavefield and the elastic Green tensor.

In paper “Superposition of Gaussian packets in heterogeneous anisotropic media”, L. Klimeš briefly derives the integral superposition of Gaussian packets in smoothly heterogeneous media, both isotropic and anisotropic. The superposition may correspond to the anisotropic ray theory, to the frequency–dependent coupling ray theory for S waves, to the prevailing–frequency approximation of the coupling ray theory for S waves, or to the isotropic ray theory.

In paper “Summation integrals for a Green function in a 3-D inhomogeneous anisotropic medium”, V. Červený & I. Pšenčík present expressions for the Green function in 3–D heterogeneous anisotropic media, based on the summation of paraxial ray approximations or paraxial Gaussian beams. These expressions are also specified for homogeneous anisotropic media and for heterogeneous weakly anisotropic media. Computation of these expressions requires only the initial value ray tracing and dynamic ray tracing performed in Cartesian coordinates. In dynamic ray tracing, it is sufficient to compute only 3×2 parts of the 3×3 paraxial matrices.

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

In paper “Approximate P–wave ray tracing and dynamic ray tracing in weakly orthorhombic media of varying symmetry orientation”, N. Masmoudi & I. Pšenčík present and test the procedure for computing the first–order and second–order weak–anisotropy approximation of P–wave travel times in weakly orthorhombic media with varying orientation of symmetry elements. A great advantage of the procedure consists in preserving the orthorhombic symmetry throughout the velocity model. In contrast to commonly used procedures, whose velocity models are specified by 21 elastic parameters, the velocity model is specified by only 6 weak–anisotropy parameters and three Euler angles. With the second–order travel–time correction, the procedure yields results which do not differ much from exact ones.

Einar Iversen suggested to use the SH and SV rays in a transversely isotropic medium as the reference rays for the prevailing–frequency approximation of the coupling ray theory for S waves. In paper “Prevailing–frequency approximation of the coupling ray theory for S waves along the SH and SV reference rays in a transversely isotropic medium”, L. Klimeš & P. Bulant describe the corresponding numerical algorithm and apply it to transversely isotropic velocity models QI2 and QI4. The prevailing–frequency approximation of the coupling ray theory along the SH and SV reference rays provides very accurate seismograms in these two velocity models.

Being inspired by the above mentioned results, P. Bulant & L. Klimeš intended to trace the anisotropic–ray–theory rays in anisotropic velocity models which were not transversely isotropic with hope to use them as the reference rays for the prevailing–frequency approximation of the coupling ray theory. In contribution “Anisotropic–ray–theory geodesic deviation and two–point ray tracing through a split intersection singularity”, they demonstrate that there are anisotropic velocity models in which neither geodesic deviation, amplitude nor the phase shift due to caustics can be calculated along many anisotropic–ray–theory rays. In contribution “Anisotropic–ray–theory rays in velocity model SC1_II with a split intersection singularity”, they show sharp bending of the anisotropic–ray–theory rays connected with a rapid rotation of the eigenvectors of the Christoffel matrix, indicate abrupt changes of the anisotropic–ray–theory geometrical spreading and amplitude, and demonstrate formation of caustics and wavefront triplications caused by the anisotropy.

The fourth 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 and gas storage.

Petr Bulant recently started to partially work as a consultant in small enterprise Seismik focused on passive seismics, where he creates velocity models suitable for ray tracing, and calculates the ray–theory approximations of the Green tensors. The Green tensors are then used to determine the real–valued seismic moment tensor using the method of Jan Šílený. In this method, the real–valued seismic moment tensor is determined from the maximum real–valued vectorial amplitude picked in the polarization diagram. Application of this method thus requires the approximation of the complex–valued Green–tensor amplitude by a real–valued Green–tensor amplitude with a phase shift. The required approximation is proposed in paper “Approximating the complex–valued Green–tensor amplitude by a real–valued Green–tensor amplitude” by L. Klimeš.

The fifth and final part, **DVD–ROM with SW3D software, data and papers**, contains the DVD–R compact disk SW3D–CD–18.

Compact disk SW3D–CD–18, edited by V. Bucha and P. Bulant, contains the revised and updated versions of the software developed within the SW3D consortium research project, together with input data related to the papers published in serial *Seismic Waves in Complex 3–D Structures*. A more detailed description can be found directly on the compact disk. Compact disk SW3D–CD–18 also contains over 470 complete papers from journals and previous volumes of serial *Seismic Waves in Complex 3–D Structures* in PostScript, PDF, GIF or HTML, and 3 books by V. Červený and his coauthors in PDF. Refer to the copy of the SW3D consortium WWW pages on the compact disk. Compact disk SW3D–CD–18 is included in Volume 24 in two versions, as the UNIX disk and DOS disk. The versions differ just by the form of ASCII files.

Prague, June 2014

Vlastislav Červený
Luděk Klimeš
Ivan Pšenčík