Introduction

Report 23 of the Consortium project "Seismic Waves in Complex 3–D Structures" (SW3D) summarizes the work done towards the end of the nineteenth year and during the twentieth year of the project, in the period June, 2012 — May, 2013. 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 articles from journals.

Our group working within the project during the twentieth 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) and Tijmen Jan Moser (Zeehelden Geoservices, 's-Gravenhage, Netherlands) visited us since the last annual Consortium meeting in June, 2012.

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

The Research Programme for the current, twentieth 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 annual Consortium meeting, June 17–18, 2013. More detailed information regarding the SW3D Consortium project is available online at "http://sw3d.cz".

Research **Report 23** contains mostly the papers related to seismic anisotropy (12 of 15 papers). Report 23 may roughly be divided into six 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.

In his paper of Report 17, L. Klimeš decomposed perturbations of elastic moduli and density into Gabor functions. When studying the waves scattered by individual Gabor functions, he concentrated on the narrow–band scattering generating Gaussian "sensitivity" packets. In paper "Sensitivity of seismic waves to structure: Wide–angle broad–band sensitivity packets", L. Klimeš generalizes the previously derived equations to the broad–band sensitivity packets whose shape considerably deviates from Gaussian.

In paper "Kirchhoff prestack depth migration in velocity models with and without vertical gradients: Comparison of triclinic anisotropy with simpler anisotropies" V. Bucha studies a possibility to distinguish the errors in migrated images caused by the inaccurate estimates of anisotropy and heterogeneity.

Papers "Kirchhoff prestack depth migration in velocity models with and without rotation of the tensor of elastic moduli: Poorly displayed part of migrated interface in correct model with triclinic anisotropy" and "Kirchhoff prestack depth migration in velocity models with and without rotation of the tensor of elastic moduli: Orthorhombic and triclinic anisotropy" by V. Bucha are devoted to the behaviour of the 3–D Kirchhoff prestack depth migration in simple anisotropic models with and without rotation of the tensor of elastic moduli. V. Bucha then studies the effects of incorrectly estimated anisotropy upon the migrated image.

In paper “Moveout approximations for P– and SV–waves in transversely isotropic media with vertical axis of symmetry”, V. Farra and I. Pšenčík propose the first–order and second–order P–wave and SV–wave moveout expressions for transversely isotropic media with the vertical axis of symmetry (VTI), based on the weak–anisotropy approximation. The accuracy of the results of the proposed expressions is tested by comparing them with the results of commonly used formulae.

In the next paper, “Moveout approximations for P– and SV–waves in dip–constrained transversely isotropic media”, V. Farra and I. Pšenčík generalize the results of the above described paper to 3–D dip–constrained transversely isotropic media. A dip–constrained transversely isotropic medium is a transversely isotropic medium, whose axis of symmetry is perpendicular to a dipping reflector. The accuracy of the results of the proposed expressions is tested by comparing the results with the results of the standard ray–tracing procedure.

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

In his paper of Report 19, L. Klimeš derived the relations between the propagator matrix of geodesic deviation (i.e., paraxial–ray propagator matrix) and the second–order derivatives of the characteristic function (i.e., second–order derivatives of two–point travel time) in general coordinates. The equations were derived for the homogeneous Hamiltonian function of the second degree with respect to the slowness vector, which corresponds to Finsler geometry. In paper “Relation between the propagator matrix of geodesic deviation and the second–order derivatives of the characteristic function for a general Hamiltonian function”, L. Klimeš generalizes the relations to an arbitrary Hamiltonian function. The generalization is especially useful for description of waves which propagate with different velocities in opposite directions (e.g., electrons in an electromagnetic field, sound waves in flowing media).

The relations derived in the above described paper contain the spatial gradient of the independent parameter along geodesics. It was thus desirable to find equations for calculating the gradient. In paper “Calculation of the spatial gradient of the independent parameter along geodesics for a general Hamiltonian function”, L. Klimeš combines the relations derived in the above described paper with the relations derived by Sir William Rowan Hamilton in 1832, and obtains the desired equations.

In paper “Paraxial Super–Gaussian beams”, L. Klimeš demonstrates to some extent surprising behaviour of the paraxial approximation of beams with “supergauss” amplitude profiles of forms $\exp(-ax^4)$, $\exp(-ax^6)$, etc. These beams do not behave like Gaussian beams with the Gaussian amplitude profile of form $\exp(-ax^2)$, but behave like conventional ray–theory beams with real–valued travel time which suffer from singularities at caustics.

U. bin Waheed, I. Pšenčík, V. Červený, E. Iversen and T. Alkhalifah test the accuracy of two–point paraxial travel time formula in the velocity models of smoothly varying isotropic and anisotropic media in paper “Two–point paraxial traveltime formula for inhomogeneous isotropic and anisotropic media: tests of accuracy”. Travel time between two arbitrarily selected points situated in a vicinity of a reference ray, along which dynamic ray tracing quantities are available, is approximately estimated and compared with travel time obtained by standard two–point ray tracing. The tests indicate that the accuracy of the formula depends primarily on the length and the curvature of the reference ray and depends only slightly on anisotropy.

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

In paper "First–order P–wave ray synthetic seismograms in inhomogeneous, weakly anisotropic, layered media", I. Pšenčík and V. Farra extend the first–order ray tracing for P waves propagating in heterogeneous weakly anisotropic media, presented in papers in the previous Reports, from smooth media to layered media. All the basic formulae are given. The accuracy of results is tested by comparison with results obtained by standard anisotropic ray theory.

In their paper of previous Report 22, L. Klimeš and P. Bulant proposed the approximation of the coupling–ray–theory Green tensor by two S waves described by the coupling–ray–theory travel times and the coupling–ray–theory amplitudes. This approximation enables to interpolate the coupling–ray–theory results within ray cells. Their paper "Interpolation of the coupling–ray–theory S–wave Green tensor within ray cells" describes the current progress in this field.

The fourth part, **Waves in isotropic attenuating media**, is devoted to waves propagating in isotropic attenuating media.

Amplitudes of PP reflected spherical waves at a plane interface between two homogeneous viscoelastic media are studied in paper "PP spherical–wave reflection coefficients for viscoelastic media" by V. Červený, I. Pšenčík and V. Bucha. The typical feature of spherical–wave reflection coefficient is its behaviour in the overcritical region, which differs from the behaviour of the plane–wave reflection coefficient. The spherical–wave reflection coefficient is frequency dependent, its maximum is shifted beyond the critical point, and is followed by oscillations in the interference region of reflected and head waves. The spherical–wave reflection coefficients are studied using the reflectivity method. The possibilities to determine the quality factors of attenuating media from the spherical–wave reflection coefficients are discussed.

The fifth 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.

Point sources of acoustic waves situated on material interfaces in fluid, inhomogeneous, non–moving, non–dissipative media are studied in paper "Point sources of acoustic waves at interfaces (reciprocity relations approach)" by V. Červený. The main attention is devoted to volume injection point sources. The reciprocity relations by Fokkema and van den Berg are used to prove that the acoustic pressure wave field at any point of the medium does not change when the volume injection point source crosses the interface. The results obtained for the acoustic wave fields in fluid media allow also certain conclusions for strain–glut and stress–glut point sources at material interfaces of elastic isotropic and anisotropic media.

Paper "Effects of 1–D versus 3–D velocity models on moment tensor inversion in the Dobrá Voda locality at the Little Carpathians region, Slovakia" by Z. Jechumtálová and P. Bulant represents a revised and extended version of their paper of Report 22. The authors continued in their work on moment tensor inversion in the Dobrá Voda locality, and supplemented their paper with inversion for the pure double couple model, which enabled them to estimate the significance of the non–double–couple components retrieved during the full moment tensor inversion. They also added two examples of the moment tensor inversion of real local events in the Dobrá Voda locality.

The sixth and final part, **DVD–ROM with SW3D software, data and papers**, contains the DVD–R compact disk SW3D–CD–17.

Compact disk SW3D–CD–17, 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–17 also contains over 450 complete papers from journals and previous reports in PostScript, PDF, GIF or HTML, and 3 books by V. Červený in PDF. Refer to the copy of the Consortium WWW pages on the compact disk. Compact disk SW3D–CD–17 is included in Report 23 in two versions, as the UNIX disk and DOS disk. The versions differ just by the form of ASCII files.

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