Introduction

Report 12 of the Consortium project "Seismic Waves in Complex 3-D Structures" (SW3D) summarizes the work done towards the end of the eighth year and during the ninth year of the project, in the period June, 2001 — May, 2002. It also includes the compact disk with updated and extended versions of computer programs distributed to the sponsors, and brief descriptions of the programs.

Our group working within the project during the ninth year has consisted of seven research workers: Johana Brokešová, Václav Bucha, Petr Bulant, Vlastislav Červený, Luděk Klimeš, Ivan Pšenčík and Václav Vavryčuk, and of two PhD students: Karel Žáček and Xuyao Zheng.

Karel Žáček worked for 3 months (July–September 2001) together with Ross Hill in the New Orleans branch of Chevron, and is going to spend summer 2002 in ChevronTexaco in San Ramon. Norman Bleistein (U.S.A.), Stanley M. Flatté (U.S.A.), Véronique Farra (France) and Sérgio A.B. da Fontoura (Brasil) visited us during the ninth year of the project.

During the ninth year of the project, Vlastislav Červený has been awarded the *Honorary Membership of EAGE* (European Association of Geoscientists & Engineers) "in recognition of his outstanding and lasting achievements in the field of geosciences", and received the *Gold Commemorative Medal of Charles University* "for his outstanding work in the field of geophysics and theoretical seismology". Vlastislav Červený and Ivan Pšenčík received the *Commemorative Medals* awarded by the Slovak Academy of Sciences on the occasion of 100 years of seismology in Slovakia. Karel Žáček received the *Award of the Minister of Education*, awarded annually to 5 outstanding university students in the Czech Republic.

Before discussing Report 12, let us mention other publication events, especially important for the consortium research project.

"Seismic Ray Theory" by Vlastislav Červený

Book "Seismic Ray Theory" (vii+713 pages, IBSN 0-521-36671-2) by V. Červený (2001) was published by the Cambridge University Press in July 2001. The preliminary (incomplete) versions of the book were distributed to the consortium members as special reports No.2 in 1994, No.5 in 1997 and No.9 in 1999.

Special issues of Studia Geophysica et Geodaetica and of Pure and Applied Geophysics

Two of four issues of volume **46** (2002) of *Studia Geophysica et Geodaetica* (SGG) are dedicated to Vlastislav Červený on the occasion of his seventieth birthday. Special issue No.2/**46** (2002) is distributed to the consortium members together with Report 12, and starts with the noticeable Preface written by Sven Treitel and Ivan Pšenčík. Special issue No.4/**46** (2002) will be sent to the consortium members by the end of 2002. Ivan Pšenčík serves as the guest editor of both issues. Of many papers related to the ray theory and its applications, we shall mention here only the papers prepared by our group.

Special issue No.2/**46** (2002) of *Studia Geophysica et Geodaetica* contains a new paper by L. Klimeš (2002f) on the second–order and higher–order perturbations of travel time in isotropic and anisotropic media. The second–order as well as higher–order travel–time perturbations can be calculated by numerical quadratures along an unperturbed ray in the reference medium, analogously as the first–order perturbations. This paper is not included in Report 12 because the special issue of the SGG is distributed together with the report.

The special issue of the SGG No.2 also contains a paper by V. Vavryčuk (2002) on the asymptotic elastodynamic Green function in the kiss singularity. The paper is a revised version of the contribution previously published in Report 11, pp. 249–262. The far–field asymptotic formula for the S–wave elastodynamic Green function at a kiss singularity in homogeneous anisotropic media is expressed in the form of a 1-D integral.

Special issue No.2/**46** (2002) of *Studia Geophysica et Geodaetica* is closed by the detailed I. Pšenčík's (2001) review of book "Seismic Ray Theory".

A paper by X. Zheng, I. Pšenčík, S. Horne and S. Leaney (2002) has been submitted for publication in special issue No.4/**46** (2002) of *Studia Geophysica et Geodaetica*. The paper is a revised version of the contribution previously published in Report 11, pp. 43–68. The authors apply the method of local determination of weak anisotropy parameters from qP-wave slowness and particle motion measurements (X. Zheng & I. Pšenčík 2002) to the walkaway VSP data from the Java Sea region.

Submitted for publication in special issue No.4 is also a paper by I. Pšenčík & V. Vavryčuk (2002) on the approximate relation between the ray vector and wave normal directions in weakly anisotropic media. The paper is a revised version of the contribution previously published in Report 11, pp. 279–300.

Note also that other 2 papers prepared by our group will be published in the ordinary issue No.3/**46** (2002) of *Studia Geophysica et Geodaetica*: • a paper by V. Červený (2002) on the Fermat's variational principle for anisotropic inhomogeneous media, which is a revised version of the contribution previously published in Report 11, pp. 211–236; • and the paper by L. Klimeš (2002g) presented in this Report 12.

Ivan Pšenčík also prepared the promotional *Special Issue* (2002) of *Studia Geophysica et Geodaetica*, containing a collection of 13 papers on seismic wave propagation published in SGG from 1978 to 1997.

I. Pšenčík and V. Červený served as guest editors of the topical issue of *Pure and Applied Geophysics*, **159**(2002), devoted to the "Workshop Meeting on Seismic Waves in Laterally Inhomogeneous Media V" in Zahrádky, Czech Republic, in June 2000. The topical issue should appear in the middle of 2002 and will contain 9 papers prepared by our group: • paper by P. Bulant & L. Klimeš (2002) on the coupling ray theory, previously published in Report 7, pp. 215–223 and Report 11, pp. 263–277; • paper by L. Klimeš (2002a) on perturbation of the polarization vectors, previously published in Report 8, pp. 97–102; • paper by L. Klimeš (2002b) on the Lyapunov exponents for 2-D ray tracing, previously published in Report 8, pp. 83–96; • paper by P. Bulant (2002) on the application of the Sobolev scalar products in the construction of velocity models, previously published in Report 10, pp. 75–82 and Report 11, pp. 133–159; • paper by K. Žáček (2002) on smoothing the Marmousi model using the Sobolev scalar products, previously published in Report 10, pp. 41–62 and Report 11, pp. 160–179; • paper by

L. Klimeš (2002c) on application of the medium covariance functions to travel–time tomography, previously published in Report 4, pp. 13–24, Report 6, pp. 13–24 and Report 11, pp. 73–89; • overview of correlation functions of random media by L. Klimeš (2002d), previously published in Report 6, pp. 25–40 and Report 11, pp. 91–109; • paper by L. Klimeš (2002e) on the estimation of the correlation function from travel times, previously published in Report 4, pp. 25–38 and Report 11, pp. 111–131; • paper by X. Zheng & I. Pšenčík (2002) on the local determination of weak anisotropy parameters from qP–wave slowness and particle motion measurements, previously published in Report 11, pp. 15–41.

Report 12

Research Report 12 contains mostly the papers related to seismic anisotropy (11 of 14 papers). Report 12 may be roughly divided into five parts, see the Contents.

The first part, **Inversion techniques for isotropic and anisotropic media** is devoted to various kinds of inverse problems and to the theory developed for application to their solution.

In the contribution by I. Pšenčík and X. Zheng, the authors generalize their scheme for the local evaluation of elastic moduli from measurements of slowness and polarization vectors of P waves to S waves.

K. Žáček briefly summarizes his ongoing work on the approximate decomposition of the wavefield into Gabor wavelets of shape varying in dependence on spatial position, slowness vector, time and frequency.

The paper by L. Klimeš derives explicit equations for approximate linearized reflection/transmission coefficients at a generally oriented weak–contrast interface separating generally anisotropic media. The equations for the coefficients have a very simple form, common for all reflected and converted waves. The equations are designed primarily for application in inverse problems, especially for understanding the sensitivity of reflected waves to linear combinations of elastic moduli.

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 dissipative media, which have been postponed to the third and fourth parts.

The first paper of this part, by V. Červený & I. Pšenčík is devoted to detailed specification of the formulae for the ray–theory amplitudes used in the program package SEIS designed for calculation of synthetic seismograms in laterally varying layered isotropic 2-D models.

The 6×6 paraxial–ray propagator matrix depends not only on the kind of independent variable along rays, but also on the variation of the Hamiltonian with the length of the slowness vector. L. Klimeš very simply generalizes his previously published paper, written for the homogeneous Hamiltonian of the second degree, towards the homogeneous Hamiltonian of an arbitrary degree. This enables the dependence of the paraxial–ray propagator matrix on the Hamiltonian to be demonstrated. For convenience, the new alterations in the text of the published paper are marked with red.

In the third paper of this part, L. Klimeš presents the relations of the wave–propagation metric tensor to the curvature matrix and Gaussian curvature of the slowness surface and to the curvature matrix and Gaussian curvature of the ray–velocity surface using the ray–centred coordinates.

V. Červený derives the expressions for the first–order perturbations of two–point rays, including the first–order perturbations of the slowness vector, in anisotropic inhomogeneous media. The equations are based on the 6×6 paraxial–ray propagator matrix, and are explicit (do not require a solution of any system of equations).

In the last paper of this part, V. Vavryčuk studies the behaviour of rays near singularities in anisotropic media.

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

V. Vavryčuk studies the geometry of parabolic lines on the slowness surface in weakly anisotropic media, and their relation to the singular directions.

V. Farra & I. Pšenčík study effects of the first-order perturbation formulae on the accuracy of the determination of directions of acoustical axes, specifically singular and longitudinal directions in weakly anisotropic media.

P. Bulant & L. Klimeš discuss the quasi–isotropic approximations of the coupling ray theory, introduce the exact solution for a plane S wave propagating in the 1-D anisotropic "oblique twisted crystal" model, and compare the coupling ray theory and its three quasi–isotropic approximations with the exact solution.

L. Klimeš & P. Bulant apply the equations for the second–order travel–time perturbations derived by L. Klimeš (2002f) to the estimation of the errors due to the common ray approximations of the coupling ray theory. The errors are demonstrated on a numerical example, together with the errors of other quasi–isotropic approximations.

The fourth part, **Isotropic and anisotropic dissipative media**, is devoted to the problems of elastic wave propagation in dissipative media.

The first paper of this part, by J. Brokešová & V. Červený, is devoted to the viscoelastic reflection/transmission problem for general orientation of propagation and attenuation vectors in isotropic media.

V. Červený & I. Pšenčík apply the equations, derived by V. Červený in the fourth paper of the second part of this report, to the complex–valued two–point rays in inhomogeneous anisotropic weakly dissipative media. Specifically, a formula for the determination of the initial-value attenuation vector at the initial point of the ray is presented.

The final fifth part, **CD–ROM**, contains the CD–R compact disk SW3D–CD–6, edited by V. Bucha and P. Bulant. Compact disk SW3D–CD–6 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–6 also contains over 120 complete papers from journals and previous reports, mostly in PostScript, few in PDF or HTML, refer to the copy of the Consortium WWW pages on the compact disk. Compact disk SW3D–CD–6 is included in Report 12 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 ninth year of the project. We have been very pleased to welcome three new consortium members, Pontifícia Universidade Católica (Rio de Janeiro, Brasil), University of California (Santa Cruz, U.S.A.), and WesternGeco (Houston, U.S.A.). We hope they will find the membership in our Consortium profitable.

The Research Programme for the current, ninth 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 3–5, 2002. More detailed information regarding the SW3D Consortium Project is available online at "http://sw3d.mff.cuni.cz".

Please note that the former WWW address "http://seis.karlov.mff.cuni.cz/consort/main.htm" of the Consortium project "Seismic Waves in Complex 3-D Structures" (SW3D) has been simplified to "**http://sw3d.mff.cuni.cz**".

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References

Bulant, P. (2002): Sobolev scalar products in the construction of velocity models — application to model Hess and to SEG/EAGE Salt Model. *Pure appl. Geophys.*, **159**, 1487–1506 .

Bulant, P. & Klimeš, L. (2002): Numerical algorithm of the coupling ray theory in weakly anisotropic media. *Pure appl. Geophys.*, **159**, 1419–1435 .

Červený, V. (2001): Seismic Ray Theory. Cambridge Univ. Press, New York.

Červený, V. (2002): Fermat's variational principle for anisotropic inhomogeneous media. *Stud. geophys. geod.*, **46**, No. 3.

Klimeš, L. (2002a): Perturbation of the polarization vectors in the isotropic ray theory. *Pure appl. Geophys.*, **159**, 1437–1445 .

Klimeš, L. (2002b): Lyapunov exponents for 2-D ray tracing without interfaces. *Pure appl. Geophys.*, **159**, 1465–1485 .

Klimeš, L. (2002c): Application of the medium covariance functions to travel–time tomography. *Pure appl. Geophys.*, **159**, 1791–1810 .

Klimeš, L. (2002d): Correlation functions of random media. *Pure appl. Geophys.*, **159**, 1811–1831 .

Klimeš, L. (2002e): Estimating the correlation function of a self–affine random medium. *Pure appl. Geophys.*, **159**, 1833–1853 .

Klimeš, L. (2002f): Second–order and higher–order perturbations of travel time in isotropic and anisotropic media. *Stud. geophys. geod.*, **46**, 213–248 .

Klimeš, L. (2002g): Relation of the wave–propagation metric tensor to the curvatures of the slowness and ray–velocity surfaces. *Stud. geophys. geod.*, **46**, No. 3.

Pšenčík, I. (2002): Seismic Ray Theory by Vlastislav Červený (review). *Stud. geophys. geod.*, **46**, 383–386.

Pšenčík, I. & Vavryčuk, V. (2002): Approximate relation between the ray vector and wave normal directions in weakly anisotropic media. *Stud. geophys. geod.*, **46**, No. 4, submitted.

Vavryčuk, V. (2002): Asymptotic elastodynamic Green function in the kiss singularity in homogeneous anisotropic solids. *Stud. geophys. geod.*, **46**, 249–266.

Žáček, K. (2002): Smoothing the Marmousi model. *Pure appl. Geophys.*, **159**, 1507–1526 .

Zheng, X. & Pšenčík, I. (2002): Local determination of weak anisotropy parameters from qP-wave slowness and particle motion measurements. *Pure appl. Geophys.*, **159**, in press.

Zheng, X., Pšenčík, I., Horne, S. & Leaney, S. (2002): Local determination of weak anisotropy parameters from a walkaway VSP data in the Java Sea region. *Stud. geophys. geod.*, **46**, No. 4, submitted.

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