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Assessment of the doctoral dissertation by mgr inż. Bartosz Owoc

"Analysis of the uncertainty of traveltime tomography in various scales of seismic experiments", prepared under the scientific supervision of dr hab. Mariusz Majdański, associate professor of PAS at the Institute of Geophysics of the Polish Academy of Sciences.

The main focus of the dissertation is on the uncertainty analysis of seismic traveltime tomography in various scales of seismic experiments, including near-surface seismic study (measurement line of a few kilometres length), industrial (dozens of kilometres long profile), and regional study (hundreds of kilometres). One example of real 2D data was used for each seismic scale. The seismic measurements were performed to identify geological structures of various size as faults, salt structures and unconformities. For the near-surface case, seismic tomography was applied jointly with other seismic methods, including seismic reflection imaging and multichannel analysis of surface waves. For verification of measurement data, the Author used the uncertainty analysis. Therefore, the impact of the starting model of the velocity field and the assumed picking precision were tested in a course of the study. Qualitative information on the correctness of the velocity field reconstruction by seismic tomography was also considered. Consequently, the Author was able to exclude from the interpretation elements of the tomographic inversion result, which were only extrapolations without validation in the data. Furthermore, based on the uncertainties estimated, the Author compared and combined traveltime tomography results with other seismic methods. The dissertation also includes solutions developed by the Author to improve seismic measurements and data pre-processing. The adaptation of industrial reflection seismic imaging methods to process legacy crust-scale dataset allowed to achieve a significant enhancement in the continuity, visibility, and separation of the Pn refraction phase. Furthermore, the use of the processing proposed by the Author allowed for picking of an increased number of first-arrival travel times. To justify the uncertainty analysis approach, synthetic tests were conducted for the regional dataset.

The structure and content of the dissertation

The text of the dissertation covers 113 pages in total, including summaries in Polish and English, table of contents and figures, acknowledgments, glossary of acronyms, symbols and generic and invented names, and list of literature. The dissertation contains 43 figures prepared in A4 format. The reference list includes 112 items, most of them published abroad.

The dissertation contains 4 chapters, which include 'Introduction', 'Methodology', 'Cases in different scale of seismic experiments', and 'Summary'. These 4 chapters consist of a total of 66 subsections grouped in 3 levels of the hierarchy.

In the Introduction (Chapter 1), the Author outlines the contents of the dissertation and define the main objective of the study: "Obtaining more accurate and realistic results by using uncertainty analysis in seismic experiments at different scales". Furthermore, the main research tasks addressed in the dissertation are listed:

1. Apply the traveltime tomography with uncertainty analysis for seismic experiments at various scales.
2. Improve identification of geological structures of different sizes.
3. Check how tomographic results depend on the starting model of the velocity field and the assumed picking precision.
4. Combine the results obtained by different methods in a more reliable and complex way using uncertainties.
5. Implement technical solutions that make measurements more cost-effective and easier to perform without losing data quality.
6. Adapt and apply reflection seismic imaging processing techniques to highly irregular data sets on a regional scale to increase the visibility of the Pn phase.

The second chapter presents the methodology used and its theoretical background, emphasising various attempts for uncertainty analysis. The chapter describes the basics of data inversion and seismic methods, especially seismic tomography. An essential topic covered in this chapter is the uncertainty analysis and processing of legacy crustal-scale data.

The next chapter presents one example of real 2D data for each seismic survey scale, i.e., near-surface, industrial, and regional, to resolve the research tasks set in the study. For all presented seismic experiments, ray-based tomographic inversion of first-arrival travel times and uncertainty analysis of its results were performed. They are the main computational part of the dissertation.

1. The aim of the near-surface case was to identify the local shape of the Mesozoic bedrock in the southern part of the Holy Cross Mountains by seismic methods. This section presents ways to improve the efficiency of measurements and data pre-processing. The emphasis is also put on seismic tomography, especially the analysis of its uncertainty. This part of the dissertation demonstrates the use of uncertainty analysis as a tool to compare and combine the results obtained with different seismic methods, i.e., seismic reflection imaging and multichannel analysis of surface waves.
2. The purpose of the industrial profile was to resolve geological structure in the central part of the Mid-Polish Swell. This example of the industrial-scale experiment focuses mainly on the uncertainty analysis of First-Arrival Traveltime Tomography, and testing the influence of picking precision on the tomography results. The industrial case presents a comprehensive analysis of the factors influencing seismic tomography

results, and more specifically, the starting model of the velocity field and the picking precision.

3. The example on a regional scale relates to the legacy dataset, the S02 profile, obtained during the SUDETES 2003 experiment. It demonstrates the use of adapted reflection seismic processing techniques to improve the Pn phase's visibility in shot gathers with irregular trace sampling. It also includes an attempt to verify the uncertainty analysis approach proposed by the author using synthetic tests.

The final chapter provides a summary of the most important results presented in this dissertation.

Selected elements of research presented in the dissertation have been previously published as peer-reviewed articles (Majdański et al., 2018; Owoc et al., 2019a; Marciniak et al., under review) and peer-reviewed extended abstracts (Owoc et al., 2018; Owoc et al., 2019b; Marciniak et al., 2019b; Marciniak et al., 2019c).

Overall assessment of the dissertation

The research reported in the dissertation is based on modern concepts in the field of seismic processing and modelling as well as uncertainty analysis. The doctoral candidate has demonstrated knowledge of seismic methods and tools, including various variants of numerical modelling. He has also shown the efficiency of innovative thinking and a critical approach to the accuracy of data. This is important since seismic tomography, as other field-based methods, has limitations, and the results are imprecise and have errors. Therefore, verification is essential to analysis of seismic measurements.

The main achievement of the reviewed work should be considered a comprehensive approach to the uncertainty analysis that was successfully used in all scales of seismic experiments, from near surface to regional. This enabled the separation of the interpretable part of the obtained tomographic velocity fields and the elimination of non-physical effects resulting from over-interpretation of the method. The uncertainty maps presented, and especially the results of synthetic tests, confirmed that the presented method of analysis correctly estimated uncertainties, both qualitative and quantitative. The effect of changing the starting velocity field model and the impact of picking precision as measured by the standard deviation (the quantitative uncertainty estimator) generally increased with depth. For the near-surface case, the starting model had the most significant impact due to excellent visibility of the first-arrivals of the P-wave in the recorded high quality wavefield. In contrast, the influence of picking was the most significant for the regional-scale tomographic results because of the sparse and high irregularity of low-quality data. Both mentioned factors turned out to have a comparable effect on the inversion of seismic data in the industrial case. The small anomalies on the quantitative uncertainty map, probably representing numerical artefacts, were removed by hit-count normalisation, the procedure that was tested on field data examples. Consequently, combination of quantitative information (standard deviation) and qualitative information (from the hit-count normalisation) defined artefact-free areas, where the quantitative uncertainty values were estimated.

It is worth emphasizing the careful and attractive way of preparing the graphic side of the dissertation, allowing the reader to effectively visualise the results presented. The

dissertation is written using the correct geophysical professional terminology, which, together with the previously mentioned advantages of the work, proves that the doctoral candidate has mastered the geophysics research skills.

Critical remarks

In addition to unquestionable achievements, the reviewed dissertation has - of course - also its weaker sides. These include the inconsistent structure of the dissertation generating repetitions and the insufficient geological context of the research limiting the possibility of verifying the results.

The thesis consists of three chapters, Introduction, Methodology and Summary, that were written solely for the purposes of this dissertation and chapter 'Cases in different scale of seismic experiments', partly including already published results. Of course, sections 3.1 and 3.2, based on already published papers, are not copied and pasted but they still preserve the structure of independent contributions. Section 3.3 that has not yet been published also resembles an independent manuscript. All three sections of chapter 3 have their own methodological parts that partly duplicate chapter 2. They also have their own conclusions that are later duplicated to a large extent in chapter 4. Consequently, the dissertation is full of repetitions, especially section 3.3, and its structure is not fully transparent. This is confusing not only for a reader but also for the Author himself, who describes on page 58 :"The author's contribution to this part of the dissertation (not published yet)". This is unfortunate wording since, according to legal regulations, a PhD candidate must be a sole author of the dissertation. He can estimate his contribution to individual papers if the dissertation is based on a collection of articles that is not a case here. Therefore, it would be better if the candidate included his publications in the dissertation in extenso. I understand that he did not do so because section 3.3 has not yet been published and 'Law on Higher Education and Science' does not allow for presenting "mixed' dissertations partly based on articles and partly on original research.

In several points of his dissertation, the Author support his conclusions with a statement that the results are mostly consistent with existing geological models. However, these subsurface geological models are based on seismic data and their interpretation, including those upon which industrial and regional cases are based. Therefore, this is partly a circular argument that means that the seismic interpretation presented in the dissertation does not contradict those published previously. The borehole data would be the only fully independent geological verification of the results. I am aware that sections 3.2 and 3.3 are based on archival seismic data and that nothing can be done about their tie to the wells. However, I am surprised that the seismic line used in the near surface experiment was not designed in such a way as to be tied to shallow holes existing in the Holy Cross Mountains.

The presentation of the geological context of the research has a number of drawbacks. This is especially true for section 3.3.1 of 'Geology of the Sudetes region (Central Europe)'. I do not intend to go into detail about my objections as the regional geological background is of marginal importance for the dissertation. A meticulous analysis of this matter would distort the proper proportions in my review. I only advise to revise it before possible publication. Therefore, below I limited myself to the most outstanding issues.

1. "The Lower Silesia Block and the Bohemian Massif (BM) have many common features." Yes, because the Lower Silesia Block is part of the Bohemian Massif.
2. Lusatian thrust is not a proper boundary of the Sudetes since it is a Late Cretaceous feature.
3. Fore-Sudetic Block is part of the Sudetes and it has only thin sedimentary cover.

The dissertation is written in good quality technical English that is fully comprehensible. The text is sometimes too wordy, and usage of articles is occasionally incorrect. However, I assume that English is not a mother tongue for the Author and, therefore, I limited my corrections to technical terminology.

I am not sure whether the section devoted to labels on seismic recorders and their transport boxes meets the criteria of scientific research. This is rather a logistic issue. Of course, this is a rationalisation that can speed up fieldwork, but I am not convinced that this is science.

This is unusual that the effect of different staring models on the First-Arrival Traveltime Tomography results is practically identical to the influence of the picking precision even without considering ray coverage.

Figures are referred to in the text not in the order of successive numbering, e.g., on page 28 Figures 13, 17 and 19 are referred to directly after Figure 5.

"...the visible dependence of the relief on the tectonics and the lithology of Quaternary deposits (Lindner et al., 2001)." This is incorrect. In the original paper by Lindner et al. (2001), there is a sentence stating that location and development of river valleys depend on the lithology and tectonics of pre-Quaternary rocks.

The Author declares at the bottom of page 67:
"To obtain the final answer, which inversion approach gives a better reconstruction of the synthetic model, the uncertainty analysis was performed, described in the further part of this dissertation. However, it can be already concluded that the joint inversion was more appropriate for this dataset, which is consistent with the article by Majdański (2013)."
A reader may ask a question whether the uncertainty analysis is indeed necessary if the Author conclude in advance that the method consistent with the article by Majdański (2013) is better.

Location of profile S02 should be plotted on a geological map that would aid understanding of the text.

Referencing

There are 6 references in the text that are not included in the reference list:
Brückl, et al. (2007);
Chen and Jordan (2007) – probably it should be Chen et al. (2007);
Nercessian et al. (1984);
Guterch et al. (1998);
Souriau and Veinante (1975);

Karousová et al. (2012).

The paper of Hyvönen et al. (2007) is included in the reference list but not cited in the text.

Selected detailed comments to the assessed dissertation

Page 14: should be 'outliers' instead of 'outliners'.

Page 25: Equation (14) should be probably referred to instead of equation (6).

Page 29: "several were tested" – should be "several velocities were tested".

Page 34: incorrect wording – instead of "Quaternary basement" it should be "sub-Quaternary basement".

Page 35: Instead of "In this article..." it should be "In this dissertation...".

Page 38: There is something wrong with numbering of equations.

Page 46: Should be 'siliciclastic sediments' instead of 'silicas'.

Page 46 and elsewhere: spelling of chronostratigraphic subdivisions is inconsistent with International Chronostratigraphic Chart.

Page 51: "Both layers are much thicker at the distance of 8.5-11 km along with the profile." It should be "much thinner".

Page 51 and 81: It should be "top" instead of "ceiling".

Pages 52-57: References to Figures 18-21 are in general disorder. Numbering of figures is flawed because number 17 is doubled.

Page 57: "suspected fault" is not imaged on the industrial profile.

Page 67 and elsewhere: It should be "forward modelling" instead of forwarding modelling".

Page 81: It should be "base" instead of "bottom".

Page 81: "...combination of two uncertainty maps, qualitative of standard deviation and quantitative of e." It should be vice versa.

Pages 93-96 are inserted in the dissertation in a reversed succession.

Summary of the review

In the reviewed dissertation, the Author's original research achievements have a decisive advantage, proving his knowledge and mastery of the research technique in the field of the uncertainty analysis of traveltime tomography, analysis of seismic data, as well as the ability to conduct independent research.

The dissertation contains an original and methodically correct solution to the scientific problem, consisting in the analysis of the uncertainty of traveltime tomography in various scales of seismic experiments. Thus, the reviewed work meets the conditions set out in the Act of 20 July 2018 'Law on Higher Education and Science (Journal of Laws 2018 item 1668, as amended) and 'Detailed procedure for the award of the doctoral degree by the Institute of

Geophysics of the Polish Academy of Sciences' adopted by a resolution of the Scientific Council of IGF PAS No. 8/257/2012 of March 12, 2021. On this basis, the reviewer requests that Bartosz Owoc, MSc, be admitted to public defence of the theses presented in his dissertation.

St. Mazur

Kraków, May 17th, 2021 r.

References

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