# GEOPHYSICAL INVERSION

Earth Science Engineering MSc / Geophysical Engineering specialization

2024/2025 Second Semester

COURSE COMMUNICATION DOCUMENT

**University of Miskolc**
**Faculty of Earth and Environmental Sciences and Engineering**
**Institute of Exploration Geosciences**

## *Course datasheet*

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| **Course Title:** Geophysical inversion<br>**Responsible instructor** (name, position, scientific degree)**:** Norbert Péter Szabó Prof. Dr., Ph.D., dr. habil., D.Sc., full professor | **Neptun code:** MFGFT720014<br>**Responsible department/institute:** Institute of Exploration Geosciences / Department of Geophysics |
| | **Type of course: C** |
| **Position in Curriculum (which semester):** 2 | **Pre-requisites (if any):** none |
| **Number of Contact Hours per Week (lec.+prac.):** 1+1 | **Type of Assessment (examination / practical mark / other):** practical mark |
| **Credits:** 2 | **Course:** full-time<br>**Program:** Earth Science Engineering MSc / Geophysical Engineering |

**Course Description**

In the frame of the course the Geophysical Engineering MSc students can learn how geological and geophysical information can be extracted from the measured data using advanced inversion methods.

**Competencies to evolve**

**Ability:** Able to apply integrated knowledge of environmental equipment, processes, technologies, and related electronics and informatics.

**Attitude:** Open and receptive to the knowledge and acceptance of professional, technological development and innovation in the field of environmental protection, and its authentic mediation. Assumes the professional and moral values related to the field of environmental protection. Seeks to plan and carry out tasks independently or in a working group at a professional level. Strives to carry out the required work in a complex approach based on a systems-based and process-oriented way of thinking. Striving to improve the knowledge of both him/herself and subordinated employees through continuous training.

**Autonomy and responsibility:** One can solve environmental engineering tasks independently, take decisions carefully, consult with the representatives of other (mainly legal, economic, energy) fields, independently, takes responsibility for the decisions. In making decisions, considers the basic requirements of occupational health and safety, technical, economic and legal regulations, and engineering ethics. Takes the initiative in solving environmental problems, identifies the shortcomings of the applied technologies, the risks of the processes and initiates the measures to reduce them. Shares the acquired knowledge and experience with formal, non-formal and informal information transfer with practitioners in their field. Evaluates the work of subordinated employees, promotes their professional development by sharing critical remarks, educates employees and subordinates on responsible and moral professional practice.

**The short curriculum of the subject**

Types of inverse problems. Forward modeling in gravity, magnetic, geoelectric surveying and well logging. Solution of the overdetermined inverse problem. The Weighted Least Squares method and the Marquardt-algorithm. Seismic toy example. Relationship between the damping factor and the condition number. Weighted solution in data space. Solution based on the Weighted Least Squares Method in case of mixed-determined inverse problems. Solution of the underdetermined inverse problem. Weighted solution in parameter space, smoothness constraints. Solution of the inverse problem by minimizing the $L_p$-norm. The method of Iterative Re-weighting Least Squares. Quality checking of the solution of the inverse problem. Covariance and correlation matrices in the data and the parameter space.

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| Solution of the nonlinear inverse problem using global optimization methods. Simulated Annealing and Genetic Algorithms. The joint inversion method. The series expansion-based inversion method. Combination of machine learning and inversion methods. Practical applications of the above inversion procedures using MATLAB codes. |
| **Assessment and grading**<br>Attendance at lectures is regulated by the university code of education and examination. Writing two tests at least satisfactory level, respectively during the semester is the requirement of signature.<br>**Exam grading scale**: unsatisfactory (0-45%), satisfactory (46-60%), medium (61-70%), good (71-85%), excellent (86-100%). |
| **The 3-5 most important compulsory, or recommended literature (textbook, book) resources**<br>W. Menke, 1984: Geophysical Data Analysis: Discrete Inverse Theory. Academic Press Inc.<br>Mrinal Sen and Paul L. Stoffa: Seismic Exploration - Global Optimization: Methods In Geophysical Inversion. Software, Elsevier Science Ltd. 1997.<br>Szabó N.P., Dobróka M.: Float-encoded genetic algorithm used for the inversion processing of well-logging data Global Optimization: Theory, Developments and Applications: Mathematics Research Developments, Computational Mathematics and Analysis Series. New York: Nova Science Publishers Inc., 2013. pp. 79-104.<br>P.J.M. van Laarhoven, E.H.L. Aarts, 1987: Simulated Annealing: Theory and Applications. D. Reidel. Publishing Company, ISBN 90-277-2513-6.<br>Szabó N.P., 2023: Geophysical inversion. Electronic textbook. https://exploration.uni-miskolc.hu/files/26294/Course-Geophysical%20inversion-SZNP.pdf |

## *Syllabus of the semester*

| Week | Lecture |
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| 10-Feb | Types of inverse problems. Solution of the overdetermined inverse problem. |
| 17-Feb | Solution based on the Weighted Least Squares method. |
| 24-Feb | The mixed determined inverse problem. Regularization with the damping factor. |
| 2-Mar | The solution of the underdetermined inverse problem. |
| 10-Mar | Solution of the inverse problem by minimizing the $L_p$-norm. |
| 17-Mar | 1st mid-term test. |

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| 24-Mar | The quality check of inversion results. Stability, accuracy and reliability of parameter estimation. |
| 31-Mar | Solutions of the nonlinear inverse problem using global optimization methods. |
| 7-Apr | Simulated Annealing. Applications in well logging. |
| 14-Apr | The Genetic Algorithm. Hyperparameter estimation. |
| 21-Apr | Easter Monday. |
| 28-Apr | Holiday declared by Rector. |
| 5-May | The joint inversion method. The series expansion-based inversion method. |
| 12-May | 2nd mid-term test. |
| 19-May | Repetition of writing tests. |

| **Week** | **Seminar** |
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| 10-Feb | Solution of the Weighted Least Squares method and the Marquardt-algorithm. |
| 17-Feb | Well logging inversion. 1D and multi-well applications. |
| 24-Feb | Geoelectric inversion methods. |
| 2-Mar | The 3D underdetermined gravity/magnetic inverse problem. |
| 10-Mar | The method of iterative re-weighting. |
| 17-Mar | 1st mid-term test. |

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| 24-Mar | Data and model covariance matrices. Confidence intervals of the estimated model parameters. |
| 31-Mar | The Metropolis Simulated Annealing method. |
| 7-Apr | The Float Encoded Genetic Algorithm. |
| 14-Apr | Machine learning-assisted inversion methods. Hyperparameter inversion algorithms. |
| 21-Apr | Easter Monday. |
| 28-Apr | Holiday declared by Rector. |
| 5-May | Coding the inversion algorithms using different types of geophysical datasets. |
| 12-May | 2nd mid-term test. |
| 19-May | Repetition of writing tests. |

## *Sample for the mid-term exam*

Please, describe the basics of damped LSQ method (i.e. Marquardt-algorithm), derive the normal equation. How can you calculate the estimation error of model parameters?

*The solution can be found in the university text book „The methods of geophysical inversion".*