Національний технічний університет України «КИЇВСЬКИЙ ПОЛІТЕХНІЧНИЙ ІНСТИТУТ імені ІГОРЯ СІКОРСЬКОГО»

Department of Geoengineering

MATHEMATICAL MODELING OF GEOMECHANICAL PROCESSES

Work program of the discipline (Syllabus)

Details of the discipline

Level of higher education	*Third (educational and scientific)*
Branch of knowledge	*18 Production and technology*
Specialty	*184 Mining*
Educational program	*Geoengineering*
Discipline status	*Normative*
Form of study	*full-time / full-time / distance / mixed*
Year of preparation, semester	*2nd year, spring / autumn semester*
The scope of discipline	*6 credits / 180 hours (lectures - 8 hours, practical - 12 hours, individual lessons - 55 hours, independent work - 105 hours,)*
Semester control / control measures	*Test*
Timetable	rozklad.kpi.ua/
Language of instruction	*Ukrainian / English*
Information about course leader / teachers	Lecturer:*Prof., Zuievska Natalia Valerievna, (+38) 0509821770, zuevska@i.ua* Practical:*Prof., Zuievska Natalia Valerievna, (+38) 0509821770, zuevska@i.ua*
Course placement	https://classroom.google.com/c/MjUyNjU2ODI4OTM3?cjc=3tdbc2y

Curriculum of the discipline

1. Description of the discipline, its purpose, subject of study and learning outcomes

A specialist with modern methods of mathematical modeling of geomechanical processes, able to competently choose a mathematical model, choose the optimal type of foundation, properly carry out work on its construction, anticipate possible consequences arising from the operation of structures and effectively influence their development.

Program learning outcomes: *Develop and research conceptual, mathematical and computer models of processes and systems, effectively use them to gain new knowledge and / or create innovative products in geoengineering; freely present and discuss with specialists and non-specialists the results of research, scientific and applied problems of mining in state and foreign languages, qualified to reflect the results of research in scientific publications in leading international scientific journals.*

2. Prerequisites and postrequisites of the discipline (place in the structural and logical scheme of education according to the relevant educational program)

Prerequisites*: Based on disciplines: Geomechanics, Materials Science and Fundamentals of Construction, Technology, mechanization and organization of geotechnical construction, Building materials and structures of underground structures*

Postrequisites: *is the basis for the final cycle of work on the preparation of certification work*

3. The content of the discipline

Section 1. MATHEMATICAL MODELS OF MCC

Problems of mathematical modeling of problems of mechanics of continuous media.

Basic concepts of mathematical modeling. The main properties of the models. The main types and stages of modeling. Concepts, classification and basic properties of mathematical models. General scheme of building a mathematical model. The subject of mechanics of continuous media. Problems of mechanics of continuous media. Methods of mechanics of continuous media. Basic hypotheses of mechanics of continuous media.

Section 2. NUMERICAL METHODS IN GEOMECHANICS

Application of ITU to solve problems of deformed solid mechanics.

The concept of the finite element method. Basic operations with finite elements. Matrix formulation of relations of the theory of elasticity. Basic relations of the theory of elasticity. Matrix record of the relationship between Cauchy and Hooke's law. General algorithm of the finite element method.

Section 3. ALGORITHMS FOR PROGRAMMING THE METHOD OF FINITE ELEMENTS OF SOME PROBLEMS OF ELASTICITY AND THERMAL CONDUCTIVITY

Implementation of ITU in the one-dimensional case. One-dimensional element with piecewise linear basis functions. Linear triangular element. Application of triangular finite elements in the problem of thermal conductivity, boundary conditions. Application of quadrilateral finite elements in the elasticity problem **.**

Section 4. SOLUTION OF A PLANE PROBLEM OF MECHANICS OF A DEFORMED SOLID BODY BY THE FINISHED ELEMENTS METHOD IN THE MATHCAD PACKAGE

Implementation of ITU in the Mathcad package. Uploading data to Mathcad, preparing variables. Calculation of the stiffness matrix of the system. Search for axial deformations and stresses in elements. The basic equation of ITU is a system of linear algebraic equations (SLAR).

4. Training materials and resources

Basic literature:

1. Rock Mechanics - an introduction for the practical engineer/E. Hoek, Ph.D., M.Sc. (Eng.), B.Sc. (Eng.).Senior Chief Research Officer, Rock Mechanics Division, National Mechanical Engineering Research Institute, South African Council for Scientific and Industrial Research, Pretoria, Republic of South Africa https://www.rocscience.com/assets/resources/learning/hoek/Rock-Mechanics-Introduction-1966.pdf

2. Potts DM, Zdravkovic L. Finite Element Analysis in Geotechnical Engineering. Application. Thomas Telford Limited, 2001 https://www.icevirtuallibrary.com/doi/book/10.1680/feaigea.27831

3. NUMERICAL METHODS IN GEOMECHANICS/Antonio Bobet//School of Civil Engineering, Purdue University, West Lafayette, IN, USAThe Arabian Journal for Science and Engineering, Volume 35, Number 1B,l 2010

http://ssu.ac.ir/cms/fileadmin/user_upload/Moavenatha/Mposhtibani/Mdaftar_fani/KhadamatKarkonan/Articles/EN/351B-p.3.pdf

Additional literature:

1. Zienkiewicz OC, Taylor R. The finite element method. - Fifth edition. —Butterwoth-Heinemann, 2000.

Segerlind, L. Application of the finite element method: trans. with English / L. Segerlind. - M .: Mup, 1979. - 392 c.

2. Norry, D. Introduction to the finite element method: trans. with English / D. Norry, J. de Vries. - M .: Mup, 1981. - 304 c.

3. Numerical and Analytical Study of the Distribution of Concentrated Pressure in the Wall of a Steel I-beam//D N Kuznetsov, N A Ponyavina, S Yu Belyaeva/International Science and Technology Conference (FarEastCon 2020)

https://iopscience.iop.org/article/10.1088/1757-899X/1079/2/022008/pdf

3. Belotserkovsky, OM Numerical modeling in the mechanics of continuous media / OM Belotserkovsky. - M.: Наука, 1984. - 520 c.

4. Strang, G. Theory of the finite element method: trans. with English / G. Strang, J. Fix. - M .: Мир, 1977. - 349 с.

5. Matrix Algebra for Engineers. Jeffrey R. Chasnov./ The Hong Kong University of Science and Technology, 189 p, 2019 https://www.math.hkust.edu.hk/~machas/matrix-algebra-for-engineers.pdf

6. Gallagher, R. Finite element method. Fundamentals / R. Gallarer. - M.: Mir, 1984. - 428 s. https://pnu.edu.ru/media/filer_public/2013/04/10/6-4_gallager_1984.pd

7 Introduction to Finite Element Analysis / The University of Manchester 2010 https://www.nafems.org/downloads/working_groups/etwg/intro_to_fea.pdf

8. Matrix algebra for beginners, Part I matrices, determinants, inverses. Jeremy Gunawardena Cambridge, USAб 2006 https://vcp.med.harvard.edu/papers/matrices-1.pdf

9. Problems and Solutions in Matrix Calculus. Willi-Hans Steeb/International School for Scientific Computing at University of Johannesburg, South Africa, World Scientific Publishing, Singapore 2016 https://issc.uj.ac.za/downloads/problems/newkronecker.pdf

10. Stiffness and Deflection Analysis of Complex Structures / MJ Turner, RWClouhg, HC Martin, LJ Topp // Journal of the Aeronautical Sciences. - 1956. - № 23. - P. 805-824.

13. Rice, J. Matrix calculations and mathematical software: trans. with English / J. Ray. - M.: Mir, 1984. - 264 s.

16. Finite element method: textbook. manual for universities / ed. P. M. Varvak. - Киев: Вища шк., 1981. - 176 с.

17. Alexandrov, AV Fundamentals of the theory of elasticity and plasticity / AV Alexandrov, VD Potapov. - M .: Высш. school, 2004. - 380 p.

18. Golub, J. Matrix calculations: trans. with English / J. Golub, C. Van Lone. - M .: Мир, 1999. - 548 с.

19. Melosh, RJ Basis for Derivation of Matrices for the Direct Stiffness method / RJ Melosh // American Institute of Aeronautics and Astronautics. - 1965. - № 1. - P. 1631-1637.

20. Norry D., de Vries J. Introduction to the finite element method: Per. с англ.— М .: Мир, 1981.— 304 с.

Educational content

5. Methods of mastering the discipline (educational component)

Names of lecture topics and a list of main issues

Section 1. MATHEMATICAL MODELS OF MCC

System modeling is most often implemented using modern computer technology. This approach implies the need for prior formalization of the conceptual model of the object of study and its presentation in a form suitable for the implementation of certain algorithms of numerical analysis or computer simulation.

Both approaches require the use of modern mathematical methods used in the creation of modeling algorithms. Even when using specialized software packages, the researcher must have the basics of appropriate mathematical methods, because the use of such packages usually requires the selection of the optimal algorithm and certain parameters of its implementation, sometimes from several dozen possible options. This necessitates the study of basic methods of mathematical modeling of systems by future professionals.

Section 2. NUMERICAL METHODS IN GEOMECHANICS

The main idea of the CE method is as follows: a continuous medium or structure is modeled by breaking it into small areas (finite elements), in each of which the behavior of the medium is described by its own set of specific functions representing displacements or stresses in the specified area. The integrity of the object is ensured by the interaction of finite elements at a number of points, which are called nodal points or nodes. Mathematical description of the interaction of finite elements in nodes leads to the construction of a system of algebraic equations, the solution of which ultimately reduces the solution of the original problem.

Section 3. ALGORITHMS FOR PROGRAMMING THE METHOD OF FINITE ELEMENTS OF SOME PROBLEMS OF ELASTICITY AND THERMAL CONDUCTIVITY

The basic concepts of the finite element method for one-dimensional and two-dimensional problems are considered. An example of solving a one-dimensional differential equation by the Galerkin method is considered.
A linear triangular element is described and a natural coordinate system is introduced. The representation of vector quantities in the finite element method is shown. Algorithms for programming the finite element method for one-dimensional and two-dimensional (triangular and quadrilateral) finite elements are presented.

Section 4. SOLUTION OF A PLANE PROBLEM OF MECHANICS OF A DEFORMED SOLID BODY BY THE FINISHED ELEMENTS METHOD IN THE MATHCAD PACKAGE

In geomechanics and in the design of underground structures have to perform the calculation of the stress-strain state of the rock mass, which in most cases includes finding a solution to the boundary value problem of the theory of elasticity in the formulation of flat deformation. The presence of irregularly shaped cavities, complex configuration of the calculation area, physical inhomogeneity and anisotropy of the properties of the material greatly complicate or make it impossible to find a solution in analytical form. Therefore, in solving such problems, numerous methods have become widespread, among which the most perfect
is a finite element method (ITU).

The name of the topic of practical classes and a list of key issues

One-dimensional ITU. Solution of a differential equation by the finite element method

The problem of thermal conductivity. A two-dimensional problem of stationary heat distribution is considered

Problems of the theory of elasticity. A two-dimensional problem of the theory of elasticity (plane-stress state) for a plate is considered

6. Independent work of a student / graduate student

The name of the topic for self-study

Calculation of a pipe with thick walls (Lamé problem).

A two-dimensional problem with the definition of a plane-deformed state. Determination of displacements.

Policy and control

7. Course policy (educational component)

The system of requirements for students:

- attending lectures and practical classes is a mandatory component of studying the material
- at the lecture the teacher uses his own presentation material; uses Google Class to teach current lecture material, additional resources, practical work, etc .; The tutor gives you access to a specific Google Class directory for downloading e-reports
- Presentation works are written independently; the result is sent in a file to the appropriate Google Class directory and protected in the lecture.
- incentive points are awarded for: active participation in lectures ;, preparation of reviews of scientific papers; presentations on one of the topics of the VTS discipline, etc. Number of encouraged points by more than 10
- penalty points are set for: late delivery of laboratory work. The number of penalty points is not more than 10

8. Types of control and rating system for evaluation of learning outcomes (RSO)

1. The student's rating from the credit module is calculated from 100 points, of which 52 points are the starting scale. The starting rating (during the semester) consists of points that the student receives for:

- writing calculation tasks for the lecture course;
- execution of the presentation;
- incentive and penalty points.

2. Scoring criteria:

2.1. Calculation works:

- each calculation work consists of 1 task - 20 points;
- absence from class without good reason - penalty -2 points.

2.2. Execution of the presentation:

- flawless work - 30 points;
- there are certain shortcomings in the preparation or performance of work - 25 points;
- absence from class without good reason - penalty -1 point.

3. The condition of the first certification is to obtain at least 20 points and perform all calculation work (at the time of certification). The condition of the second attestation is to receive at least 60 points, to perform all calculation works (at the time of attestation).

4. The condition of admission to the test is the enrollment of all calculation works, and the starting rating is not less than 60 points.

6. The sum of starting points is transferred to the credit score according to the table:

Table of correspondence of rating points to grades on a university scale:

Scores	*Rating*
100-95	Perfectly
94-85	Very good
84-75	Fine
74-65	Satisfactorily
64-60	Enough
Less than 60	Unsatisfactorily
Admission conditions are not met	Not allowed

9. Additional information on the discipline (educational component)

List of questions to be submitted for semester control

1. Name the most famous numerical methods used in geomechanics?
2. What is the idea of the finite element method?
3. What is the "stiffness matrix" in ITU?
4. What is the "elasticity matrix" in ITU?
5. Name the stages of solving problems of ITU geomechanics.
6. What is the algorithm for solving elastic problems in ITU?
7. What is the essence of the method of boundary elements?
8. What is a "singular solution"?
9. What are the possibilities of ITU and MGE? What are their advantages and disadvantages?
10. What is the essence of the method of discrete elements? Its advantages and disadvantages

Work program of the discipline (syllabus):

Folded Professor of the Department of Geoengineering, Doctor of Technical Sciences, Zuevskaya NV

Approved department ___________ (protocol № ___ from _____________)

Agreed IEE Methodical Commission (protocol № __ from _______)