Federal State Autonomous Educational Institution of Higher Education
Peoples' Friendship University of Russia named after Patrice Lumumba

Academy of Engineering
(name of the main educational unit (MEU) that developed the educational program of higher education)

WORKING PROGRAM OF THE DISCIPLINE

STRUCTURES & MATERIALS MODELLING
(name of discipline/module)

Recommended for the field of study/specialty:

01.04.02 APPLIED MATHEMATICS AND INFORMATICS
(code and name of the field of study/specialty)

The discipline is mastered within the framework of the implementation of the main professional educational program of higher education (EP HE):

SPACE MISSION AND SYSTEM DESIGN
(name (profile/specialization) of the educational institution of higher education)

2026

1. THE GOAL OF MASTERING THE DISCIPLINE

The course "Structures & Materials Modelling" is part of the Master's program "Space mission and system design" in the major 01.04.02 "Applied Mathematics and Informatics" and is studied in the second semester of the first year. The course is offered by the department of the partner university. It consists of seven sections and 18 topics and focuses on the mathematical foundations of material models, approximation to real-world behavior, elastic models, elastoplastic models, modeling of kinetics and microstructure, analysis of material failure, and models of elastic damage.

The goal of mastering the discipline is the formation of fundamental knowledge and skills in applying problem-solving methods necessary for professional activities, and increasing the overall level of students' literacy in Structures & Materials Modelling. After completing the course, students will be able to discuss the terms elastic-perfectly plastic, kinematic hardening, isotropic hardening, Bauschinger effect, and hysteresis loop; identify appropriate failure criteria relevant to simulation for structural materials; specify appropriate material properties and constitutive laws for models that are consistent with the materials and environments being analyzed; assess the significance of simplifying material behavior on the objectives of analyses; and assess the need for verification of material models.

2. REQUIREMENTS FOR THE RESULTS OF MASTERING THE DISCIPLINE

Mastering the discipline "Structures & Materials Modelling" aimed at developing the following competencies (parts of competencies) in students:

Table 2.1. List of competencies developed in students while mastering the discipline (results of mastering the discipline)

Cipher	Competence	Indicators of Competency Achievement (within this discipline)
UC-1	Capable of carrying out a critical analysis of problematic situations based on a systems approach and developing an action strategy	UC-1.1 Analyzes the task, identifying its basic components; UC-1.2 Searches for information to solve a given problem using various types of queries, suggests options for solving the problem, and analyzes the possible consequences of their use; UC-1.3 Analyzes ways of solving problems of ideological, moral and personal nature based on the use of basic philosophical ideas and categories in their historical development and socio-cultural context.
GPC-2	Capable of improving and implementing new mathematical methods for solving applied problems	GPC-2.1 Uses the results of applied mathematics to master and adapt new methods for solving problems in the area of professional interests; GPC-2.2 Implements and improves new methods for solving applied problems in the field of professional activity; GPC-2.3 Conducts a qualitative and quantitative analysis of the obtained solution in order to construct an optimal option.
GPC-3	Able to develop mathematical models and analyze them when solving problems in the field of professional activity	GPC-3.1 Develops mathematical models in the field of applied mathematics and computer science; GPC-3.2 Analyzes mathematical models for solving applied problems of professional activity; GPC-3.3 Develops and analyzes new mathematical models for solving applied problems of professional activity in the field of applied mathematics and computer science.
PC-3	Capable of participating in scientific research and development of design solutions in the field of ballistics, dynamics and flight control of spacecraft	PC-3.1 Knows the basic mathematical methods and modern tools in the field of ballistic design of space complexes and systems; PC-3.2 Possesses basic knowledge of standards, norms and rules for developing design solutions in the field of ballistics, dynamics and flight control of spacecraft; PC-3.3 Able to apply mathematical methods and modern information technologies in conducting scientific research and devel-

Cipher	Competence	Indicators of Competency Achievement (within this discipline)
		oping design solutions in the field of ballistics, dynamics and flight control of spacecraft.
PC-5	Capable of analyzing, including in English, methods for studying ballistic and dynamic characteristics when modeling spacecraft flight trajectories	PC-5.1 Knows proven and applied methods, including those from English-language sources, for studying ballistic and dynamic characteristics when modeling spacecraft flight trajectories; PC-5.2 Able to develop and modernize methods for studying ballistic and dynamic characteristics when modeling spacecraft flight trajectories; PC-5.3 Has mastered methods and approaches to studying ballistic and dynamic characteristics when modeling spacecraft flight trajectories.

3. PLACE OF THE DISCIPLINE IN THE STRUCTURE OF THE EDUCATIONAL EDUCATIONAL INSTITUTION

Discipline "Modeling of structures and materials" refers to the mandatory part of block 1 “Disciplines (modules)” of the educational program of higher education.

As part of the higher education program, students also master other disciplines and/or practices that contribute to the achievement of the planned results of mastering the discipline "Modeling of Structures and Materials".

Table 3.1. List of components of the educational program of higher education that contribute to the achievement of the planned results of mastering the discipline

Cipher	Name of competence	Previous courses/modules, practical training*	Subsequent disciplines/modules, practices*
UC-1	Capable of carrying out a critical analysis of problematic situations based on a systems approach and developing an action strategy	Databases; *Machine Learning and Big Data Mining***; *From Data Acquisition to Data Treatment***;	Practical Training in Receiving Remote Sensing Data from Satellites and its Interpretation (online from RUDN Mission Control Center) / Research; Practical Training and Research in Dynamics and Control of Space Systems (online from RUDN Mission Control Center) / Research work; Technological Training; Pre-Graduation Internship in Industry; System Design; Dynamics and Control of Space Systems;
GPC-2	Capable of improving and implementing new mathematical methods for solving applied problems		Pre-Graduation Internship in Industry; Technological Training; System Design; On-board Energy; Dynamics and Control of Space Systems;
GPC-3	Able to develop mathematical models and analyze them when solving problems in the field of professional activity	Programming;	System Design; On-board Energy; Dynamics and Control of Space Systems; Project "Drone Systems En-

Cipher	Name of competence	Previous courses/modules, practical training*	Subsequent disciplines/modules, practices*
			gineering. Part 2"; Pre-Graduation Internship in Industry; Technological Training;
PC-3	Capable of participating in scientific research and development of design solutions in the field of ballistics, dynamics and flight control of spacecraft	*Applied Mechanics and Engineering***; *Systems Engineering***;	Pre-Graduation Internship in Industry; Practical Training in Receiving Remote Sensing Data from Satellites and its Interpretation (online from RUDN Mission Control Center) / Research; Practical Training and Research in Dynamics and Control of Space Systems (online from RUDN Mission Control Center) / Research work; Technological Training; System Design; On-board Energy; Dynamics and Control of Space Systems; Project "Drone Systems Engineering. Part 2";
PC-5	Capable of analyzing, including in English, methods for studying ballistic and dynamic characteristics when modeling spacecraft flight trajectories	*English Language;* *Applied Mechanics and Engineering**;* *Systems Engineering**;* *Russian as a Foreign Language;*	Pre-Graduation Internship in Industry; Practical Training in Receiving Remote Sensing Data from Satellites and its Interpretation (online from RUDN Mission Control Center) / Research; Practical Training and Research in Dynamics and Control of Space Systems (online from RUDN Mission Control Center) / Research work; Technological Training; System Design; On-board Energy; Dynamics and Control of Space Systems;

* - filled in accordance with the competency matrix and the SUP EP HE
** - elective courses/practices

4. SCOPE OF THE DISCIPLINE AND TYPES OF EDUCATIONAL WORK

The total workload of the discipline "Modeling of structures and materials" is 5 credit units.

Table 4.1. Types of educational work by periods of mastering the educational program of higher education for full-time education.

Type of academic work	**TOTAL,** academic hours		**Semester(s)**
			2
Contact work, academic hours	*90*		*90*
Lectures (LC)	36		36
Laboratory work (LW)	18		18
Practical/seminar classes (SC)	36		36
Independent work of students, academic hours	*54*		*54*
Control (exam/test with assessment), academic hours	*36*		*36*
Total complexity of the discipline	**academic hours**	***180***	*180*
	credit	***5***	*5*

5. CONTENT OF THE DISCIPLINE

*Table 5.1. Content of the discipline (module) by type of educational*oh work

Section number	Name of the discipline section	Topic Title		Topic Contents	Type of academic work*
Section 1	Introduction	1.1	Need for and requirements of material models	Purpose of material models in structural analysis. Requirements: physical basis, mathematical, predictive capability, computational efficiency consistency. Role of material models in design, safety assessment, and life prediction. Calibration and validation against experimental data.	LC, LW, SC
		1.2	Approximation of real behavior	Idealizations and simplifications in material modeling. Assumptions: homogeneity, isotropy, continuity, small deformations. Limitations of idealized models. Trade-offs between model accuracy and computational complexity. Treatment of heterogeneity and imperfections.	LC, LW, SC
Section 2	Elastic models	2.1	Linear and non-linear elasticity	Linear elasticity: Hooke's law, proportionality between stress and strain. Range of applicability and limitations. Non-linear elasticity: hyperelasticity and hypoelasticity. Strain energy functions for hyperelastic materials: Neo-Hookean, Mooney-Rivlin, Ogden models. Applications to rubbers, biological tissues, and large-deformation materials.	LC, LW, SC
		2.2	Anisotropy	Definition of anisotropy: direction-dependent material properties. Types of anisotropy: orthotropy, transversely isotropy, full anisotropy. Representation of anisotropic elastic constants using compliance and stiffness matrices. Material symmetry planes. Examples: composites, wood, crystalline materials, biological tissues. Transformation of properties with coordinate rotation.	LC, LW, SC
Section 3	Elastoplastic models	3.1	Yield criteria	Definition of yield as onset of permanent plastic deformation. Isotropic yield criteria for metals: Tresca criterion, von Mises criterion. Pressure-dependent yield criteria for soils and polymers: Drucker-Prager criterion, Mohr-Coulomb criterion. Yield surface representation in principal stress space. Experimental determination of yield parameters.	LC, LW, SC
		3.2	Plastic flow models	Flow rule relating plastic strain increments to stress state. Associated flow rule: plastic flow direction normal to yield surface. Non-associated flow rule for pressure-sensitive materials. Dilatancy and compaction during plastic deformation. Hardening rules: isotropic hardening, kinematic hardening, mixed hardening. Hard-	LC, LW, SC

Section number	Name of the discipline section	Topic Title		Topic Contents	Type of academic work*
				ening functions and evolution equations.	
		3.3	Associated plasticity	Definition and mathematical formulation of associated plasticity. Normality condition. Advantages: uniqueness, stability, existence theorems. Energy dissipation in associated plasticity. Limitations: overestimation of dilatancy for frictional materials. Examples of materials following associated flow: metals under certain conditions.	LC, LW, SC
		3.4	Rheology	Definition of rheology as the study of flow and deformation of materials. Viscosity and viscoelasticity. Mechanical analog models: Maxwell model for stress relaxation, Kelvin-Voigt model for creep, Standard Linear Solid model. Creep compliance and relaxation modulus. Time-dependent material behavior. Application to polymers, asphalt, biological tissues.	LC, LW, SC
		3.5	Concrete plasticity model	Specific features of concrete behavior: pressure sensitivity, brittle-ductile transition, post-peak softening. Concrete yield surfaces: Drucker-Prager cap model, Willam-Warnke model. Compression and tension asymmetry. Modeling of strain softening and localization. Implicit and explicit integration schemes for concrete plasticity.	LC, LW, SC
Section 4	Kinetics and microstructure modeling	4.1	Simulation of hydration kinetics	Process of cement hydration and its influence on material properties. Kinetic models for hydration reactions. Degree of hydration and its evolution over time. Heat release during hydration: adiabatic temperature rise. Coupling between hydration kinetics and mechanical property development. Numerical methods for solving kinetic equations.	LC, LW, SC
		4.2	Thermodynamic stability in the pore structure	Pore structure development during material formation. Thermodynamic equilibrium conditions in porous media. Capillary pressure and surface energy. Phase transitions within pores: freezing, evaporation, condensation. Influence of pore size distribution on material behavior. Hygrothermal coupling effects.	LC, LW, SC
		4.3	Modeling the hardened properties of the microstructure	Relationship between microstructure and macroscopic properties. Homogenization methods: direct homogenization, mean-field methods, full-field methods. Representative volume element concept. Prediction of stiffness, strength, permeability, thermal conductivity from microstructure. Image-based modeling using micro-CT data. Multiscale modeling approaches.	LC, LW, SC

Section number	Name of the discipline section	Topic Title		Topic Contents	Type of academic work*
Section 5	Analysis of material failure	5.1	Loss of stability	Material instability as precursor to failure. Loss of ellipticity and localization of deformation. Bifurcation theory applied to constitutive models. Neutral loading and material softening criteria. Methods for detecting onset of instability in numerical simulations: eigenvalue analysis, acoustic tensor determinant.	LC, LW, SC
		5.2	Diffuse and local failure	Diffuse failure: distributed damage without formation of a single dominant crack. Local failure: strain localization into narrow bands. Factors promoting shear bands versus compaction bands. Regularization techniques for mesh dependency in strain-softening materials. Non-local models, gradient-enhanced models, and viscous regularization.	LC, LW, SC
Section 6	Elastic damage models	6.1	Degradation of stiffness due to progressive damage	Mechanisms of stiffness degradation: microcracking, void coalescence, fiber breakage. Relationship between damage variable and elastic modulus. Coupled damage-plasticity models. Evolution of Poisson's ratio during damage. Experimental measurement of stiffness degradation.	LC, LW, SC
		6.2	Scalar damage factor	Definition of scalar damage factor ranging from zero for intact material to one for fully damaged material. Phenomenological versus physically-based damage laws. Effects of loading history on damage accumulation. Comparison of Mazars damage model, Lemaitre damage model, and other formulations. Calibration of damage parameters from experiments.	LC, LW, SC
Section 7	Incorporation into analysis	7.1	Incorporation into general stress space	Extension of material models from uniaxial to multiaxial stress states. Three-dimensional formulation of yield criteria, flow rules, and damage laws. Mapping of stress invariants to model behavior under combined loading. Treatment of complex loading paths and load reversals.	LC, LW, SC
		7.2	Approximations on implementation into analysis software	Numerical implementation of material models in finite element analysis. Stress update algorithms: elastic predictor, plastic corrector. Return mapping algorithms for plasticity. Consistent tangent operator for quadratic convergence. Implementation considerations for implicit and explicit solvers. Material subroutines in commercial software. Verification and validation of implementation.	LC, LW, SC

* - to be completed only for FULL-TIME education: LC – lectures; LW – laboratory work; SC – practical/seminar classes.

6. LOGISTIC AND TECHNICAL SUPPORT OF DISCIPLINE

Table 6.1. Material and technical support for the discipline

Audience type	Equipment of the auditorium	Specialized educational/laboratory equipment, software and materials for mastering the discipline (if necessary)
Lecture	A lecture hall equipped with specialized furniture, a whiteboard (screen), and multimedia presentation equipment.	
Computer class	A computer room for conducting classes, group and individual consultations, ongoing monitoring and midterm assessment, equipped with personal computers (in the amount of ____ units), a board (screen) and technical means for multimedia presentations.	
Seminar	An auditorium for conducting seminar-type classes, group and individual consultations, ongoing monitoring and midterm assessment, equipped with a set of specialized furniture and technical means for multimedia presentations.	
For independent work	A classroom for independent student work (can be used for seminars and consultations), equipped with a set of specialized furniture and computers with access to the Electronic Information System.	

* - the classroom for independent work of students MUST be indicated!

7. EDUCATIONAL, METHODOLOGICAL AND INFORMATIONAL SUPPORT OF THE DISCIPLINE

Main literature:

1. “An Introduction to the Use of Material Models in FE”, Nawal K Prinja and Anup K Puri, NAFEMS
2. “Materials Science and Engineering An Introduction”, William D. Callister, Jnr.
3. “Modeling of Concrete Performance – Hydration and Microstructure”, K. Maekawa
4. “Numerical Modeling of Concrete Cracking”, G. Hofstetter and G. Meschke

Further reading:

1. “Nonlinear Finite Element Analysis of Solids and Structures”, Crisfield MA, John Wiley & Sons.
2. “Constitutive Modeling of High Performance Concrete”, Fédération Internationale du Béton (fib) – State of the art report.

Resources of the information and telecommunications network "Internet":

1. RUDN University Electronic Library System and third-party electronic library systems to which university students have access based on concluded agreements

- Electronic library system of RUDN - ELS RUDN http://lib.rudn.ru/MegaPro/Web

- Electronic Library System "University Library Online" http://www.biblioclub.ru
- EBS Yurayt http://www.biblio-online.ru
- Electronic Library System "Student Consultant" www.studentlibrary.ru
- Electronic Library System "Troitsky Bridge"

2. Databases and search engines
   - electronic fund of legal and regulatory documentation http://docs.cntd.ru/
   - Yandex search engine https://www.yandex.ru/
   - Google search engine https://www.google.ru/
   - SCOPUS abstract database http://www.elsevierscience.ru/products/scopus/

Educational and methodological materials for independent work of students in mastering a discipline/module:*

1. Lecture course on the subject "Modeling of structures and materials".

* - all teaching and methodological materials for independent work of students are posted in accordance with the current procedure on the discipline page in TUIS!

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