ABSTRACT AND REFERENCES

APPLIED MECHANICS

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EXAMINING ELASTIC INTERACTION BETWEEN A CRACK AND THE LINE OF JUNCTION OF DISSIMILAR SEMI-INFINITE PLATES (p. 4-10)

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We examined a two-dimensional mathematical model for the problem of elasticity theory on welded dissimilar elastic half-planes containing rectilinear cracks under the action of mechanical efforts on the shores of a crack. As a consequence, the intensity of stresses in the vicinity of tops of the cracks increases, which significantly affects strength of the body. This may lead to the growth of a crack and to the local destruction of a structure. Such a model represents to some extent a mechanism of destruction of the elements of engineering structures with cracks when the water, contained in them, freezes to ice. It creates normal pressure on the shores of the cracks. Based on the application of the apparatus of singular integral equations (SIE), the problem is reduced to the system of SIE of the first kind on the contours of cracks. We obtained numerical solutions to the corresponding integral equation in particular cases of two welded dissimilar half-planes with one randomly-oriented crack, as well as a two-link irregular crack, which crosses the line of junction when the crack's shores are exposed to uniformly distributed normal pressure. By employing these solutions, we determined stress intensity coefficients (SIC) at the tops of the crack, which are subsequently used to determine critical values of the normal pressure on the shores of the crack.

We built graphic dependences of SIC, which characterize distribution of the intensity of stresses at the tops of a crack, on the angle of crack inclination and elastic characteristics of half-planes. This makes it possible to analyze the intensity of stresses in the vicinity of a crack's tops depending on the geometrical and mechanical factors, as well as to determine the limit of permissible values of normal pressure on the shores of the crack at which the growth of the crack starts, as well as the local destruction of the body.

It is shown that the proper selection of elastic characteristics of the components of welded dissimilar half-planes can help achieve an improvement in the strength of the body in terms of the mechanics of destruction by reducing SIC at the crack's tops.

Keywords: stress intensity coefficient, singular integral equation, normally distributed pressure, welded dissimilar plates.

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INTRODUCTION OF THE METHOD OF FINITE-DISCRETE ELEMENTS INTO THE ABAQUS/EXPLICIT SOFTWARE COMPLEX FOR MODELING DEFORMATION AND FRACTURE OF ROCKS (p. 11-18)

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The paper has considered development of a model within the framework of the method of finite-discrete elements for describing processes of rock deformation and fracture. Analysis of the methods of mathematical modeling of geomechanical processes which makes it possible to take into account the medium damage or fracture was presented. A physical model of rock fracture was proposed. It considers the fracture process as formation of microcracks of separation and shear or their combination. Examples of numerical modeling of loading a rock sample by the scheme of uniaxial compression and splitting by compression along generatrixes and in conditions of volume compression were considered. Formulation and results of simulation of development of a stress-strain state in the vicinity of the rock outcrop within the framework of the method of finite-discrete elements were presented.

Within the framework of the study, an algorithm of implementing the method of finite-discrete elements in the Abaqus/Explicit software complex for strength calculations including all main stages of forming the numerical model from generation of an elemental grid to specification of boundary conditions has been worked out. A software solution for generation of the elemental grid was developed and capabilities of the Abaqus/Explicit software complex were expanded. This solution allows one to generate elemental grids for bodies of arbitrary shapes taking into account presence of surfaces of weakening within the body, both in flat and spatial formulations. The capabilities of the Abaqus/Explicit software complex were expanded in the field of modeling rock strength under the conditions of volumetric compression. According to the results of the performed studies, it was established that modeling of fracture formation (formation of shear and separation cracks) at the microlevel has allowed us to reliably represent processes of rock deformation and fracture. The possibility of using the method of finite-discrete elements for prediction of development of geomechanical processes in the vicinity of underground structures was presented.

The presented study results allow us to extend the scope of the method of finite-discrete elements to solve the problems of geomechanics and form the basis for application of this method in solving engineering problems.

Keywords: underground construction, rock, mechanics of fracture, method of finite-discrete elements.

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RESEARCH ON THE SAFETY FACTOR AGAINST DERAILMENT OF RAILWAY VEHICLESS (p. 19-25)

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The study highlights the necessity to specify the safety factor against derailing of the wheels of a railway rolling stock. The modeling of the wheels' derailment was carried out on the basis of considering the complete pattern of frictional interaction with the rails of the approaching and running-off wheels of a wheel pair.

The simulation included the following previously overlooked factors: the dependence of the vertical component of the frictional force in the flange contact of the approaching wheel on the angle of the wheel running onto the rail; the influence of the frictional force in the flange contact of the approaching wheel on the increase in the horizontal lateral load on the flange; and the influence of the frictional force in the contact of the running-off wheel on the increase in the lateral load on the flange of the approaching wheel.

The study has specified the safety factor – the Nadal criterion – against the derailment of the wheels of a railway stock. Unlike in the traditional approach, the safety factor of the wheel steadiness against derailment is assessed taking the frame force, rather than the lateral load on the flange, as the main factor of safety. This approach to determining the stability criterion gives more reliable results, since the frame force is more accessible for experimental and theoretical analysis.

The proposed safety factor against the derailment of a railway stock, for different values of the flange inclination angle and the friction coefficient, is 10–50 % lower than the classical Nadal stability criterion. This makes the proposed criterion more reliable in assessing the safety of a railway rolling stock derailment.

Keywords: railway stock, derailment, safety criterion/factor, approach angle, flange contact.

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SEARCH FOR THE CONDITIONS FOR THE OCCURRENCE OF AUTO-BALANCING IN THE FRAMEWORK OF A PLANAR MODEL OF THE ROTOR MOUNTED ON ANISOTROPIC VISCOUS-ELASTIC SUPPORTS (p. 26-33)

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Within the framework of the planar model of the rotor mounted on anisotropic elastic-viscous supports and balanced by a passive auto-balancer, conditions for the occurrence of auto-balancing were analytically determined.

An empirical criterion for stability of the main motion was applied. It was found that depending on the forces of viscous resistance in supports, the rotor has one or three critical speeds. These speeds are between two natural frequencies of rotor oscillation in absence of resistance forces in supports. Auto-balancing, respectively, occurs when the single critical speed is exceeded or between the first and the second and above the third critical speeds.

At low forces of viscous resistance, the rotor has three critical speeds. The first and the third critical speeds coincide with two natural frequencies of rotor oscillation in absence of resistance forces in supports. The second critical speed is between the first two. An additional (second) critical speed appears when the auto-balancer is mounted on the rotor. In the transition of this speed the behavior of the auto-balancer changes: the auto-balancer reduces the rotor imbalance at slightly lower rotor speeds and increases it at somewhat higher speeds.

At finite forces of viscous resistance in supports, depending on the magnitude of these forces, the rotor has one or three critical speeds.

At large forces of viscous resistance in supports, the rotor has one critical speed. Depending on the relationship between the coefficients of the forces of viscous resistance, this speed is closer to the smallest or the largest natural frequency of the rotor oscillation.

The results obtained were confirmed by computational experiments. It was established that the criterion correctly describes the qualitative behavior of the rotor – auto-balancer system: it determines the number of critical speeds and the region of the auto-balancing onset. Accuracy of determining critical speeds (the boundaries of the regions of auto-balancing onset) increases with:

– reduction of the auto-balancer mass with respect to the rotor mass;

– an increase in forces of viscous resistance to the motion of correction weights.

Keywords: rotor mounted on anisotropic supports, passive auto-balancer, auto-balancing, criterion of auto-balancing onset, critical rotor speeds.

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EVALUATION OF METAL PLASTICITY AND RESEARCH ON THE MECHANICS OF PRESSURE TREATMENT PROCESSES UNDER COMPLEX LOADING (p. 34-41)

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A calculating apparatus has been developed to help evaluate the stress-strain state in the plastic forming processes accompanied by a complex loading in which the Bauschinger effect can be manifested. The developed methods are based on the phenomenological approach in which a material map is devised in the form of flow curves, Bauschinger curves, a function φ characterizing the hereditary influence of the loading history, plasticity diagrams, and limiting strain surfaces. To evaluate the plasticity resource used, taking into account the non-monotonicity of loading, the relations for determining the main components of the guiding strain-rate tensor were obtained, which made it possible to simplify the calculation of the components of the damage tensor. With the help of the developed calculating apparatus, the applied plasticity resource was evaluated in the process of radial extrusion with the contour sag, which allowed setting the limiting parameters of the shaping. Also, as a result of the research, an increase in the plasticity of the metal was established by selecting rational loading paths in the space of the dimensionless coordinates η, μ_σ, and e_u. For example, in the process of radial extrusion with the contour sag due to a change in the nature of the deformation, it was possible to obtain a flange diameter of 44 mm, with the initial diameter of the cylindrical workpiece being 20 mm. The results obtained are important because in most cases the processes of metal pressure treatment are accompanied by non-monotonic deformation.

Keywords: plasticity of a metal, complex loading, stress tensor, stress deviator, Bauschinger effect, loading history.

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GEOMETRICAL MODELING OF THE INERTIAL UNFOLDING OF A MULTI-LINK PENDULUM IN WEIGHTLESSNESS (p. 42-50)

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We investigated a geometrical model of unfolding a rod frame of an orbital object as a process of oscillations of a multi-link pendulum under conditions of weightlessness and within an abstract plane. The initiation of oscillations is assumed to be driven by the pulse action on one of the nodal elements of the pendulum, implemented using a pulsed rocket engine. The transported (starting) position of a multilink pendulum shall be accepted in the "folded" form. A notation of the inertial frame unfolding is performed employing the Lagrange equation of the second kind, in which potential energy was not taken into consideration because of weightlessness.

It was established in the course of research:

– to unfold the structure, there is no need to synchronize the means of control over the magnitudes of angles in separate nodes;

– transverse oscillations of nodes (tremor) before the moment of full unfolding of a multi-link pendulum can be used as signal for the actuation of locks in order to fix the position of its adjacent links;

– based on a circuit for unfolding a single multi-link structure, it is possible to form multi-beam circuits with a shared non-movable attachment node (a triad as an example).

Reliability of the obtained approximate solution was tested using the created animated film about the unfolding process of the structure. An example of a four-link pendulum was studied in detail. The results might prove useful when designing the unfolding of large-size structures under conditions of weightlessness, for example, frames for solar mirrors.

Keywords: multi-link pendulum, large-scale structure, deployment in cosmos, mirror in space, Lagrangian equation of the second kind.

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DETERMINING PERFORMANCE EFFICIENCY OF THE DIFFERENTIAL IN A DEVICE FOR SPEED CHANGE THROUGH EPICYCLE (p. 51-57)

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We determined coefficient of performance efficiency for the multistage toothed differentials in a device for speed change when the drive link is a sun cogwheel of the first stage, the driven link is a carrier, or vice versa, with the epicycles of separate stages as control links.

Analytical dependences for determining performance efficiency of the multistage toothed differentials were derived using a method of potential power, which is the product of circular force on teeth and circular velocity of the point of initial circle of the satellite relative to the carrier, or the product of torque of a given force by angular velocity. Given the complexity of the task, we performed here a theoretical-computer study into performance efficiency of multistage toothed differentials in the devices for speed change with hydraulic systems using two- and three-stage transmissions as examples. By using a given procedure, it is possible to determine performance efficiency of the four- and multistage transmissions.

We constructed graphical dependences for performance efficiency of two- and three-stage transmissions. These charts enable visual tracking of change in the value of performance efficiency depending on angular velocity of the epicycle, transfer ratio, and the number of stages.

It was established that for the two- and three-stage toothed differentials the condition of automatic braking is not applicable because performance efficiency is far greater than zero. In all cases, an increase in the number of stages in toothed differential results in the decrease of performance efficiency, which confirms general patterns.

The results obtained might have practical application at the stage of development and design of new devices for speed control, they make it possible to estimate operation of multi-stage toothed differentials in terms of energy consumption and automatic braking, thereby creating a basis for further research.

Keywords: performance efficiency, toothed differential, change in speed, satellite, epicycle.

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SEARCH FOR TWO-FREQUENCY MOTION MODES OF SINGLE-MASS VIBRATORY MACHINE WITH VIBRATION EXCITER IN THE FORM OF PASSIVE AUTO-BALANCER (p. 58-66)

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Dynamics of a single-mass vibratory machine with rectilinear translational motion of the platform and a vibration exciter in the form of a ball, a roller, or a pendulum auto-balancer was analytically explored.

The steady-state motion modes, close to dual-frequency modes were found. At these motions, loads in the auto-balancer create constant imbalance, cannot catch up with the rotor and get stuck at a certain frequency. In this way, loads operate as the first vibration exciter, exciting vibrations at frequency of the loads getting stuck. The second vibration exciter is formed by unbalanced mass on the auto-balancer body. The mass rotates at rotor speed and excites more rapid vibrations with this frequency. It was found that despite a strong asymmetry of supports, the auto-balancer excites almost perfect dual-frequency vibrations. Deviations from the dual-frequency law are proportional to the ratio of loads' mass to the mass of the entire machine and do not exceed 2 %.

It was established that at small forces of external and internal resistance, when the loads' mass is much smaller than the platform's mass, etc., there are three characteristic rotor speeds. These speeds are larger than the resonance velocity of platform oscillations. At the same time:

– at the rotor speeds smaller than the first characteristic speed, there is only frequency when the loads get stuck, in this case it is smaller than the resonance velocity of platform oscillations;

– at the above-resonance rotor speeds, located between the first and the second characteristic speeds, there are three frequencies when the loads get stuck, among which only one is below-resonance;

– at the above-resonance rotor speeds, located between the second and the third characteristic speeds, there are three frequencies of the loads getting stuck, in this case, they are all above-resonance;

– at the above-resonance rotor speeds, exceeding the third characteristic speed, there is only one frequency when the loads get stuck, in addition, it is above-resonant and close to the rotor speed.

Only at the rotor speeds smaller than the second characteristic speed, there always exists one, and only one, below-resonance frequency of the loads getting stuck.

Keywords: inertial vibration exciter, dual-frequency vibration, resonance vibratory machine, auto-balancer, single-mass vibratory machine, Sommerfeld effect.

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COMPUTER VARIANT DYNAMIC FORMING OF TECHNICAL OBJECTS ON THE EXAMPLE OF THE AIRCRAFT WING (p. 67-73)

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This article describes a mathematical apparatus of dynamic formation of technical objects on the basis of a study that has devised it with the aim to improve and develop computerized structural and parametric geometric models by appropriate integration with their available mathematical support. The practical value of the obtained results consists in creating a methodology for computer variant dynamic shaping, which helps flexibly combine the designing and manufacturing of technical objects, as is illustrated by the example of the wing of an aircraft. The proposed techniques provide an automated design of the wing surface and a computer simulation of such technological operations for manufacturing a centreplane longeron as cutting, pressure treatment, assembly, etc. The created structural and parametric geometric models contribute to the multicriteria optimization of technical objects throughout the lifecycle. The described approach can also be used for the computer variant dynamic formation of such structural units of the airframe as ribs, panels, sections, bends, and the like. Through further studying, the research materials can be distributed to diverse products of mechanical engineering and other industries.

Keywords: computer variant dynamic formation, aircraft wing, structural and parametric geometric modeling.

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