ABSTRACT AND REFERENCES

APPLIED MECHANICS

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INVESTIGATION OF FORCE FACTORS AND STRESSES AT SINGULAR POINTS OF PLATE ELEMENTS IN SPECIAL CRANES (p. 6-12)

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The work addresses studying the possibilities of a numerical-analytical variant of the boundary elements method (BEM) in determining the internal force factors and stresses at singular points when bending thin isotropic plates. The simplest type of singularity has been investigated, a point of application of external concentrated forces and moments. The importance of a given problem is due to the fact that at these points the internal force factors tend towards infinity and it is not possible to determine the size using elementary methods. At the same time, these singular points are the significant stress concentrators (both tangential and normal), which is why calculating the limits to which the internal forces and moments tend is essential to analyze the strength of plate structures. In order to describe an external load, it is proposed to apply the Dirac delta function of two variables. The models of external loads are presented. A given proposal makes it possible to accurately calculate the limits to which the transverse forces, as well as bending and torsional moments, tend at singular points of thin plates. We simulated plate bending using the variational Kantorovich-Vlasov method, which is fully compatible with the models of external load. The internal force factors at the singular points of plates were determined while solving the boundary value problems, formed based on the algorithm of BEM. The MATLAB environment was used for programming and computation. Results of the calculations are characterized by high accuracy and reliability, in particular the errors in determining the deflections of plates at singular points do not exceed 2.0 % and the errors for bending moments are not above 3.0 %. Recommendations have been given to solving different types of boundary problems on bending the plates with singular points based on the proposed approach. It has been established that an accurate model of the external load in the form of concentrated forces and moments fundamentally enables determining the internal forces and moments at the singular points of thin plates applying an algorithm of the variational Kantorovich-Vlasov method. Up to now, there are no data on the importance of internal forces and moments at the singular points of plates. It is also shown that when calculating the internal forces and moments of plates, it is inappropriate to apply a single term from a series of the Kantorovich-Vlasov method; the errors amount to significant magnitudes of the order of 43–44 %.

Keywords: boundary elements method, bending of isotropic thin plates, concentrated loads, singular points.

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THEORETICAL RESEARCH INTO SPATIAL WORK OF A STEEL-REINFORCED-CONCRETE STATICALLY INDETERMINATE COMBINED STRUCTURE (p. 13-22)

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The constructed mathematical model and the developed algorithm for spatial calculation of combined steel-reinforced-concrete truss systems make it possible to determine parameters of the stressed-strained state in the structures' elements. It is proven that the built mathematical model satisfies three groups of conditions: equilibrium; compatibility of deformations that link deformations and displacements; physical conditions that link efforts and deformations. Owing to the devised procedure, we performed theoretical calculations to establish the actual diagrams "bending moment – deflection", "longitudinal force – deflection" depending on the magnitude and place of application of external load. The derived equalities that determine coefficients for the unknowns in a system of linear algebraic equations include the topology parameters and strength characteristics of the structures' elements. That has allowed us to search, within the framework of the developed algorithm, for a minimum of the objective function of the equally-stressed state in the elements of a spatial structure.

We investigated theoretically the strength and deformability of truss steel reinforced concrete structures for symmetrical and asymmetrical loads, taking into consideration the phased operation of the system. Employing an iterative search for a minimum of the objective function of the equally-stressed state at cross sections of the spatial structure's elements has helped establish a decrease in the normal stresses compared to the structures of other type. The results obtained made it possible to design actual construction structures. Therefore, there is reason to assert the practical significance of the constructed mathematical model and the developed algorithm, which were applied when designing the new, and recalculating existing, combined steel-reinforced-concrete truss systems.

Keywords: combined systems, equations of deformation compatibility, strength, deformability, steel-reinforced-concrete, truss.

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NUMERICAL METHODS FOR CONTACT ANALYSIS OF COMPLEX-SHAPED BODIES WITH ACCOUNT FOR NON-LINEAR INTERFACE LAYERS (p. 22-31)

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In order to ensure high technical characteristics of machines for various applications, it is necessary to increase the strength of the most loaded and heavy-duty elements of constructions, which are complex-shaped components under intense contact loads. When bodies get in contact over surfaces of close shape, new factors that have not been taken into account before come into play. In particular, nonlinear contact stiffness of the surface layers of the components is among them. Accordingly, nonlinear components appear in impenetration contact conditions instead of traditional linear ones. To study the contact interaction with account for such constraints, a new method for stress-strain state analysis and structural strength design of various machine parts has been developed on the basis of a modification of the Kalker's variational principle. Nonlinear models of the material behavior of the surface layers of contacting complex-shaped bodies were created and applied. The discretization of the resulting mathematical problem was performed with the help of the developed version of the boundary element method.

The developed models of contact interaction combine physical and structural nonlinearities. This provides more accurate modelling of stress-strain state of contacting complex-shaped bodies in comparison with conventional approaches. The peculiar variation of the contact pressure distribution with the change of the gap shape and the properties of the interface layer between the contacting bodies were studied on this basis. It is possible to derive more relevant recommendations to justify design and technological solutions with account for the results of such analysis. Eventually, this will enhance the technical characteristics of machines of various applications.

Keywords: contact interaction, Kalker's variational principle, boundary integral equations method, Winkler's layer.

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DEVELOPMENT OF THE PROCEDURE FOR THE ESTIMATION OF RELIABILITY OF REINFORCED CONCRETE BEAMS, STRENGTHENED BY BUILDING UP THE STRETCHED REINFORCING BARS UNDER LOAD (p. 32-42)

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We studied the stresses state of rectangular reinforced concrete beams strengthened by building up the stretched reinforcing bars under the action of load. We developed two principal methods for assessing the reliability of the strengthened beams based on various regulatory documents. According to the developed methods, we established reliability of the tested structures and obtained the results of qualitative and quantitative indicators for reliability, specifically, reliability indices and probabilities of failure-free operation. We analyzed an effect of the considered stochastic parameters of the reserve of bearing capacity of normal cross sections of strengthened beams on a general reliability estimate.

The establishment of actual indicators of reliability of beams strengthened under the action of load will make it possible to approach the issue of reconstruction of elements of buildings and structures more efficiently and economically. In particular, this relates to strengthening of bending of reinforced concrete elements under operation. In addition, the obtained results of reliability study make it possible to operate with those variable parameters that have the maximum influence on variance of the limiting bending moment of beams studied with sufficient accuracy of calculation.

The developed principal methods for assessing reliability make it possible to design strengthened reinforced concrete bending elements with the assigned level of reliability (efficiency of solutions) – probability of failure-free operation, which may be also the subject for further research. Finally, the obtained results make it possible to approach the choice of the strengthening method more effectively.

Thus, we propose a methodology adapted to the current design standards of Ukraine for assessment of reliability. It includes a relatively simple mathematical calculation apparatus. Moreover, in contrast to the results of earlier studies, the obtained values of reliability indicators are clear, since they have a distribution close to proportionality depending on a load level and a diameter of reinforcement extension. Thus, for reliability indices β_i, the range of values was from 3.35 to 3.45, and for the probability of failure-free operation $P(\beta)_i$ – from 0.999596 to 0.999720 (towards increasing the reliability level at a larger diameter of the reinforcement of extension and a load level at the moment of strengthening). The discrepancy between identical values of indices found in accordance with engineering and deformation models of calculation was about 8 % only. This fact allows the application of the developed methodology in the design practice. Therefore, taking into consideration the lack of research in the field of assessment of reliability of the reinforced concrete bending elements strengthened under the action of load, we can state that the results obtained are relevant.

Keywords: reinforced concrete beam, strengthening, stochastic parameters, reliability assessment, probability of failure-free operation, level of loading.

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CALCULATION OF TOOTHED GEAR MECHANISMS IN MACHINES AND ASSEMBLIES CONSIDERING THE EFFECT OF LUBRICANTS (p. 43-54)

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The basic criteria of operational efficiency of most toothed gear mechanisms is the contact endurance of the conjugated surfaces of the teeth and the flexural endurance of teeth legs. In this case, the calculation based on contact stresses is the principal one in terms of determining the geometrical dimensions of toothed gear mechanisms, while the calculation of tooth bending is performed for validation.

It is known that in order to prolong longevity and improve operational efficiency and load capacity of toothed mechanisms, different lubricants are used. However, given the insufficient body of research into the influence of a lubricant on contact endurance of the active surfaces of teeth, traditional methods for the calculation of toothed gears (for example, GOST 21354-87) equate a lubricant influence coefficient to unity, that is, a perfect case is considered when friction is absent. Such an approach leads to the inaccurate evaluation of load capacity of toothed gears that can be a reason for both their premature failure and the overestimation of their geometrical dimensions.

In this work, we have solved the contact problem on a contact between two bodies of arbitrary shape, close to half-planes, at the finite friction coefficient; it was found that the value of the resulting contact stress exceeds the stress, calculated according to the known Hertz solution, by 6 %.

The proposed procedure for the calculation of toothed gears in terms of contact strength at the finite friction coefficient, without assumptions about the smallness of the contact area and the shape of borders, makes it possible to estimate load capacity of the toothed gears considering the influence of lubrication and the existence of friction between the conjugated surfaces of the teeth.

We have derived the analytical expression for a lubricant influence coefficient based on the solution to the contact problem of pressure from a rigid stamp on the elastic half-plane in terms of the coefficient of friction between the conjugated surfaces of toothed gears. That allows the estimation of the true load capacity of toothed gears under the influence of various lubricants, which is of great theoretical and practical importance when designing machines and assemblies.

Keywords: a lubricant influence coefficient, friction coefficient, contact stress, tangential stresses, complex variables, biharmonic function.

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GEOMETRICAL SYNTHESIS OF SPATIAL SIX-LINK GUIDING MECHANISMS (p. 54-62)

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The study considers problems of geometric synthesis of spatial hinge-lever six-link mechanisms with linear displacement of the final link performing the guiding function. The variants of arranging the mechanisms and their design features to provide the maximum course of the final link with minimum lengths of levers have been found. The geometric parameters of the mechanism in its generalized form have been determined and specified the kinematics and layout schemes. The influence of geometric parameters and layout variants on the kinematic parameters of the mechanisms has been studied. Dependencies have been obtained to determine the geometric parameters of the basic mechanism by the specified course of the final link and the permissible angles of transmission in the hinges of the levers. Parametric dependencies are provided in the article to help calculate accurately the optimal geometry of the mechanism by the criterion for minimizing the lengths of the levers at acceptable transmission angles and the required range of displacements. A scheme has been proposed for calculating spatial dimensional chains for determining the shape of the parts. 3D modeling has revealed the variability of geometric parameters, which helped formulate layout versions of the mechanism. A technique for geometric synthesis has been developed and variants of spatial hinge-lever six-link mechanisms in dynamics have been modeled in accordance with this technique, which made it possible to show the features of the motion of the links.

The carried out research has determined possible ways of developing new variants of spatial hinge-lever six-link mechanisms, and it has opened new possibilities of their application as a guiding mechanism. The results of the research can be used in designing platforms for lifts, robot manipulators, machine tools, and in mechatronics.

Keywords: Sarrus linkage, six-link spatial mechanism, path generating mechanism, linear displacement, geometric synthesis.

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INFLUENCE OF ELASTICITY OF UNBALANCE DRIVE IN VIBRATION MACHINES ON ITS OSCILLATIONS (p. 62-69)

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The dynamics of the vibration machine with unbalance vibration exciter taking into account the elasticity of its connection with the asynchronous motor is studied.

The expression describing torsional oscillations of the elastic coupling in the steady (near-steady) operation of the vibration machine and the formula of the vibratory moment for the machine with plane oscillations of the working body are obtained. The amplitude-frequency characteristics of oscillations of the vibration machine drive using “soft” and “rigid” elastic couplings are constructed. It is shown that resonant oscillations can arise in the vibration machine drive. The nature of changes in the magnitude of the vibratory moment (additional dynamic load on the motor caused by oscillations of both the bearing body of the vibration machine and the elastic coupling), depending on the vibration exciter speed is determined. It is shown that the presence of the elastic coupling in the vibration machine drive in certain operation modes can lead to an increase in the motor load and promotes the appearance of the Sommerfeld effect during start-up. Critical frequencies of the vibration machine drive with unbalance vibration exciter are specified. Recommendations on the choice of natural frequencies of the drive in order to avoid resonant oscillations are formulated.

By means of computer simulation, the emergence of resonant torsional oscillations of the vibration machine drive during the passage of the natural frequency region and the associated manifestation of the Sommerfeld effect are demonstrated. The effectiveness of the proposed recommendations for reducing drive oscillations is confirmed.

The results obtained will allow avoiding resonant oscillations in the vibration machine drive, thereby reducing the dynamic loads in the elements of its design and increasing the reliability and durability of the drive parts.

Keywords: vibration machine, unbalance vibration exciter, drive oscillations, elastic coupling, Sommerfeld effect.

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GEOMETRICAL MODELING OF THE UNFOLDING OF SPATIAL ROD STRUCTURES, SIMILAR TO THE FOUR-LINK PENDULUM, IN WEIGHTLESSNESS (p. 70-80)

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We have continued studying geometrical models of unfolding, under conditions of weightlessness, the orbital rod structures whose elements are connected similar to a four-link pendulum [21–24]. The links of the structure move due to the action of pulses from pyrotechnic jet engines at the endpoints of the links. The description of the motion of the derived inertial unfolding of a rod structure is based on the Lagrange equation of the second kind, and, given the conditions of weightlessness, constructed using solely the kinetic energy of the system.

The relevance of the subject is defined by the need to improve and study the new technological schemes for unfolding the frames of space infrastructures. These include the frames of parabolic antennas, whose elements are a family of similar confocal parabolas obtained when one of them rotates, at a certain angular step, around a common axis. In addition, it is of interest to consider the new technologies for performing mounting operations in orbit using the structures of mechanical grippers (the type of a "robot's arm"), located outside spacecraft.

Based on the inertial unfolding of four-link rod structures, we developed schemes of action of manipulators to grip cylindrical bodies whose axes are in parallel or perpendicular relative to the surface of a spacecraft. We have defined parameters and initial conditions for starting the motion of a four-link rod structure in order to obtain the required arrangement of links. It is shown that the implementation of variants of the inertial unfolding requires that the endpoints of links should be exposed to the action of a set of pyrotechnic devices whose pulses' magnitudes are determined by the coordinates of vector $\mathbf{U}'$={0.1, 1.9, 1.3, 2.5} in conventional units and the time it stops should be determined. We have constructed plots of change over time in the functions of the angles' values as the generalized coordinates, as well as the first and second derivatives from these functions. The result is the evaluation of strength characteristics of the system at the time of braking (stopping) the process of unfolding.

The results are intended for the geometrical modeling of variants of unfolding four-link rod structures under conditions of weightlessness. For example, frames for orbital infrastructures, as well as mechanical manipulators to grip space objects.

Keywords: rod structure, process of unfolding in space, manipulator to grip bodies, Lagrange equation of the second kind.

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