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THEORETICAL ASSESSMENT OF THE CURRENT STATE OF THE METAL CONSTRUCTION OF THE WEIGHT VERIFICATION CAR

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Abstract: In this article, theoretical investigations of the metal structure of the scale-testing railway car are carried out. These investigations primarily involve the development of a computational finite element model of the body of the scale-testing railway car and the study of the stressed-deformed state of the main load-bearing elements of the car body under the influence of operational loads. When performing strength calculations for the metal structure of the scale-testing railway car, the wall thickness is adopted, taking into account its reduction due to the average wear (corrosion) value. This determines whether the structure of the scale-testing railway car can withstand the existing wear (corrosion) loads required by the standards.

Keywords: weight-checking wagon, body, wagon, finite element method, railway.

Introduction

Development of a finite-element model of the weight-checking car body structure. To study the stress-strain state and determine the main load-bearing elements of the body structure, a calculated finite-element model of the weight-checking car body has been developed. Studies of the stress-strain state of the main load-bearing elements of the weight-checking car body under the influence of operating loads are carried out using engineering software implementing the finite element method (FE). The essence of the method and examples of its use for various calculations using information technology and computer modeling are described in detail in a large number of literary sources, of which fundamental works were used in the work [1]. The finite element method makes it possible to apply a fundamentally new approach to the design and analysis of many wagon units, whose design solutions were previously determined mainly on an empirical basis through experimental testing. Earlier calculation methods did not always allow for a sufficiently reliable assessment of strength, stress distribution, and deformation of complex structural elements. As a result, the safety margins and efficiency of such designs could not be accurately evaluated.

The application of the finite element method (FEM) significantly expands the possibilities for detailed analysis, as it enables the modeling of complex geometries, material properties, and real operating loads. This method allows engineers to obtain a more precise picture of stress–strain states in wagon structures, identify critical zones, and predict potential failures. Consequently, the use of FEM opens up a wide range of opportunities for scientific research and practical engineering studies aimed at improving the reliability, durability, and safety of railway wagons. [2-7].

The finite element method is based on the fundamental equations of elasticity theory, which describe the relationship between stresses, strains, and displacements in solid bodies. In practical applications, these equations are usually expressed in the form of matrix relationships, which makes it possible to efficiently solve complex engineering problems using computer technologies.

The main provisions of the finite element method are as follows. First, the continuous structure under consideration is divided into a finite number of smaller, simpler elements, known as finite elements, which are connected to each other at nodes. Second, within each element, the displacement field is approximated by simple interpolation (shape) functions defined in terms of the nodal displacements. Third, material properties and geometric characteristics are assigned to each element in accordance with the real structure. Fourth, based on the governing equations of elasticity and the principle of minimum potential energy or virtual work, a system of algebraic equations is formulated for the entire structure. Finally, by solving this system of equations, nodal displacements are obtained, from which stresses, strains, and other required parameters can be determined, allowing a comprehensive assessment of the strength and stiffness of the structure.

1. The design scheme of the structure is divided into components called finite elements (FE). In finite elements, special points called nodes are distinguished. The displacements or derivatives of the displacements of these nodes are taken as unknowns and are called degrees of freedom. They are denoted by $d_{ik}^{(e)}$. The upper index indicates the number of the finite element ($e = 1, 2, 3, ..., E$ where E is the number of finite elements).

The first lower index indicates the direction of movement ($i = x, y, z$), and the second indicates the node number in the final element ($K = 1, 2, 3, ..., m$, where m is the number of nodes in the FE).

Then, in each finite element, the law of change of displacements $N_{ik}(x, y, z)$ between the nodal points is given. This allows us to express the displacements of any point through the displacements of the boundary nodes and the coordinate function that determines the law of change of displacements between the nodal points:

$$u^{(e)}(x, y, z) = [N(x, y, z)]^{(e)} \{d_{ik}\}^{(e)}$$

$$\{d_{ik}\}^{(e)} = \begin{Bmatrix} d_{x1} \\ d_{y1} \\ d_{z1} \\ . \\ . \\ . \\ d_{xm} \\ d_{ym} \\ d_{zm} \end{Bmatrix}$$ – column matrix of displacements or derivatives movements of nodes;

$$[N(x, y, z)] = \begin{bmatrix} N_{x1} & 0 & 0 & N_{x2} & 0 & 0 & ... & N_{xm} & 0 & 0 \\ 0 & N_{y1} & 0 & 0 & N_{y2} & 0 & ... & 0 & N_{ym} & 0 \\ 0 & 0 & N_{z1} & 0 & 0 & N_{z2} & ... & 0 & 0 & N_{zm} \end{bmatrix}$$ – matrix functions of forms of a finite element.

The functions $N_{ik}(x,y,z)$ that define the law of change of displacements from node to node are commonly called functions or approximating functions. The function of form $N_{ik}(x,y,z)$ is continuous and changes from 1 at node K to zero at other nodes and beyond the element.

2. The main system of equations for determining unknown displacements is constructed. For this, the total energy of the finite element is calculated:

$$Э^{(e)} = \frac{1}{2}\left[\int_{Ve}([L][N]\{d\}^{(e)})[D]([L][N]\{d\}^{(e)})dV - (\int_{Ve}([N]\{d\}^{(e)})^T\{R\}dV + \int_{Se}([N]\{d\}^{(e)})^T\{q\}dS)\right].$$

Integration is carried out here along the CE surface.

Considering that $\{d_{ik}\}^{(e)}$ does not depend on the coordinates, the expression can be transformed into the form where the following designations are included:

$$[K]^{(e)} = \int_{Ve}([L][N]^T D([L][N])dV = \int_{Ve}[B]^T[D][B]dV$$

$$[p]^{(e)} = \int_{Ve}[N]^T\{R\}dV + \int_{Se}[N]^T\{q\}dS$$

$$[B] = [L]\cdot[N]$$

Then the total energy of the entire structure will be equal to the sum of the energies of the finite elements:

$$Э = \sum_{e=1}^{E} Э^{(e)} = \left(\sum_{e=1}^{E}\{d\}^{(e)}[K]^{(e)}\{d\}^{(e)} - \sum_{e=1}^{E}\{p\}^{(e)}\{d\}^{(e)}\right)\frac{1}{2}$$

The derivative of E with respect to $\{d\}^{(e)}$ is called a column matrix composed of the derivatives of E with respect to the displacements included in $\{d\}^{(e)}$. Differentiating the total energy E from $\{d\}^{(e)}$ and using Lagrange's principle, we get:

$$\frac{\partial Э}{\partial\{d\}^{(e)}} = \sum_{e=1}^{E}[K]^{(e)}\{d_{ik}\}^{(e)} - \sum_{e=1}^{E}\{p\}^{(e)} = 0 \quad (1)$$

or

$$\sum_{e=1}^{E}[K]^{(e)}\{d_{ik}\}^{(e)} = \sum_{e=1}^{E}\{p\}^{(e)}\ . \quad (2)$$

The matrix $[K]^{(e)}$ is usually called the stiffness matrix of the finite element in the local coordinate system, $\{d_{ik}\}^{(e)}$ is called the displacement vector of the CE nodes in the same system. If a general (global) coordinate system is adopted for all structural elements, the displacements of all structural units are denoted by $\{d\}$, and the stiffness matrix $[K]^{(e)}$ and the force vector $\{p\}^{(e)}$ are written in a global coordinate system of the same dimension as $\{d\}$, then equation (2.2) takes the form:

$$\sum_{e=1}^{E}[K]^{(e)}\{d\} - \sum_{e=1}^{E}\{p\}^{(e)} = 0\ ,$$

where $[K]^{(e)}$ and $\{p\}^{(e)}$ – are recorded in the global coordinate system.

Then

$$[K]\{d\}=\{p\}\ , \quad (3)$$

where

$$[K]=\sum_{e=1}^{E}[K]^{(e)} \ \ ; \ \{p\}=\sum_{e=1}^{E}\{p\}^{(e)}\ . \quad (4)$$

The resulting equation (3) is fundamental for the finite element method.

1. The solution of the resulting system of algebraic equations is performed using methods of linear algebra. Most commonly, Gauss's method is applied; however, other numerical solution methods may also be used depending on the size and characteristics of the system. Since the system of equations is usually of a very high order, manual calculations are impractical, and therefore all computations are carried out using modern information technologies and computer software.

As a result of solving the system of equations with the specified boundary conditions taken into account, the displacements of all structural units and nodes of the model are determined. These displacement values form the basis for further calculations, making it possible to determine stresses, strains, and internal forces in the elements, and to assess the strength, stiffness, and overall reliability of the structure under the given loading conditions.

2. The determination of the stress–strain state (SDS) of the structure is carried out using expressions (4). In order to ensure that the adopted calculation scheme of the weight-checking wagon body corresponds as closely as possible to its actual design and operating conditions, plate-rod finite elements were used to model the structural components of the wagon. This approach makes it possible to accurately represent both plate-type and beam-type elements of the metal structure and to reliably simulate their joint behavior under load.

The three-dimensional model of the wagon body was developed using SolidWorks software. Further analysis, including the calculation of stresses in individual elements, the distribution of loads throughout the structure, and the visualization of stress and deformation fields, was performed using the ANSYS Workbench software package. The use of these modern computer-aided engineering tools ensures a high level of accuracy in the assessment of the structural behavior of the weighing wagon and provides a clear representation of critical zones in terms of strength and deformation. [8-10].

The body elements have six degrees of freedom at each node: displacements in the direction of the X, Y, Z axes of the nodal coordinate system and rotations around the X, Y, Z axes of the nodal coordinate system. Mass-type elements were connected to the frame elements using absolutely rigid connections. The calculation scheme of the weight-checking car body structure is shown in Figures 1-2, and with the finite element mesh - in Figure 3.

The finite-element model of the weighing car body includes 180,720 finite elements and 57,714 units.

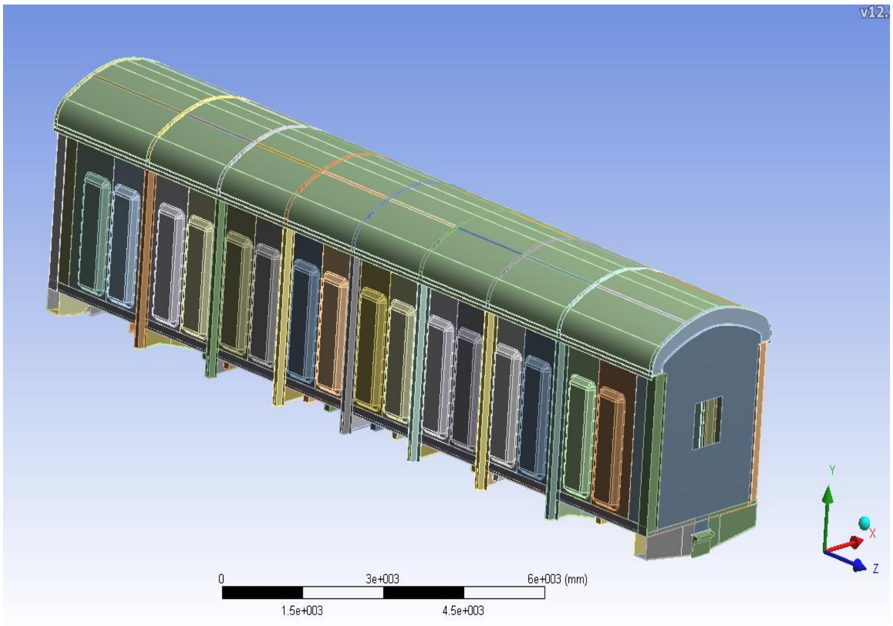

Figure 1 - General view of the calculated model of the weighing car body.

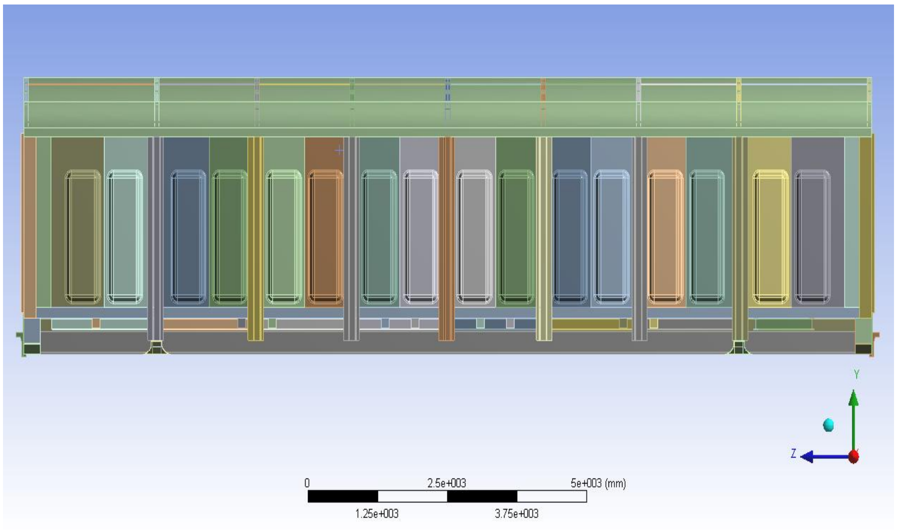

Figure 2 - Longitudinal view of the calculated model of the weighing car body.

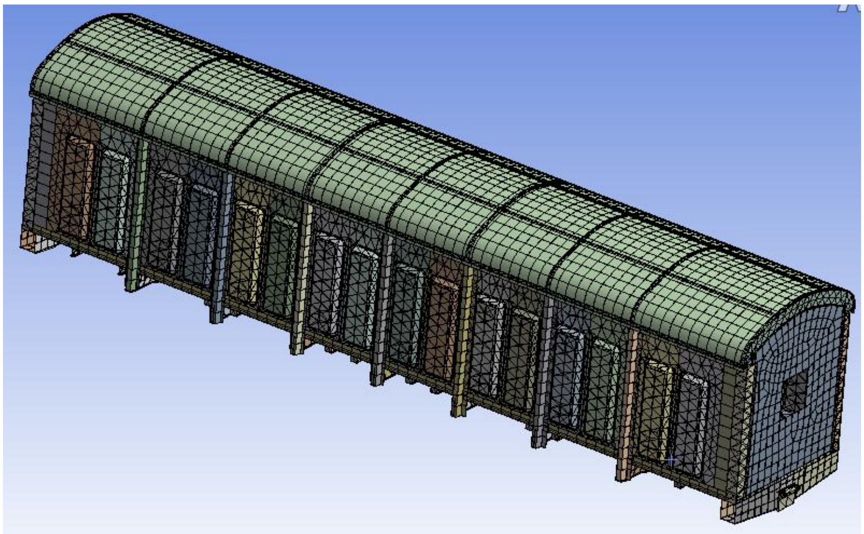

Figure 3 - General view of the finite-element model of the weighing car body.

Conclusion. A calculated finite-element model of the weight-checking wagon structure using SolidWorks engineering software has been developed, which allows for consideration of various structural changes in wagon units under modern operating conditions.

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