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THEORETICAL ASSESSMENT OF THE CURRENT STATE OF THE WEIGHT CHECKING WAGON METAL STRUCTURE

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Annotation In this article, theoretical studies of the metal structure of a weight-checking wagon are carried out, which, first of all, include the development of a calculated finite element model of the body of a weight-checking wagon and conducting studies of the stress-strain state of the main load-bearing elements of the body of a weight-checking wagon under the action of operational loads on them.

When carrying out strength calculations of the metal structure of the weight–checking wagon, the wall thickness will be taken into account its reduction by the value of the average wear value, thereby it will be determined whether the design of the weight-checking wagon with existing wear will withstand the loads required by the norms.

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

Development of a finite element model of the body structure of a weighing calibration wagon. To study the stress-strain state and determine the main load-bearing elements of the body structure, a computational finite element model of the weighing wagon body was developed. Studies of the stress-strain state of the main load-bearing elements of the weighing wagon body under the action of operational loads are carried out using engineering software that implements the finite element method (FEM). 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, from which the fundamental works were used in the work [1].

The finite element method allows a new approach to the design of many wagon components, the design solutions of which were found mainly empirically based on experiments. Since previously used methods did not allow obtaining a reliable assessment of their strength, the use of FEM opens up a wide field of activity for various studies [2-7].

The finite element method is based on the equations of elasticity theory, and matrix relations are usually used.

The main provisions of the finite element method are as follows.

1.The design design diagram is divided into component parts called finite elements (FE). In finite elements, special points called nodes are identified. The displacements or derivatives of the displacements of these nodes are taken as unknown and are called degrees of freedom. They are

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designated by $d_{ik}^{(e)}$. The superscript indicates the end element number ($e = 1,2,3,...,E$ where E – number of finite elements).

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

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

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

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

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

functions of finite element shapes. Functions $N_{ik}(x, y, z)$, defining the law of changes in displacements from node to node are usually called functions, or approximating functions. Shape function $N_{ik}(x, y, z)$ is continuous and varies from 1 at node K to zero at other nodes and outside the element.

2. The basic system of equations is constructed to determine unknown displacements. To do this, the total energy of the finite element is calculated:

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

Integration here is carried out over the FE surface.

Considering that $\{d_{ik}\}^{(e)}$ does not depend on coordinates, the expression can be converted to the form

where the notations are introduced: $[K]^{(e)} = \int_{Ve}([L][N]^T D([L][N])dV = \int_{Ve}[B]^T[D][B]dV$

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

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

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Then the total energy of the entire structure will be equal to the sum of the energies of the final elements: $Э = \sum_{e=1}^{E} Э^{(e)} = \left(\sum_{e=1}^{E} \{d\}^{(e)} [K]^{(e)} \{d\}^{(e)} - \sum_{e=1}^{E} \{p\}^{(e)} \{d\}^{(e)} \right) \frac{1}{2}$

Derivative of $Э$ by $\{d\}^{(e)}$ is called a column matrix composed of derivatives of $Э$ according to movements included in $\{d\}^{(e)}$. Differentiating the total energy $Э$ by $\{d\}^{(e)}$ and using Lagrange's principle, we get: $\frac{\partial Э}{\partial \{d\}^{(e)}} = \sum_{e=1}^{E} [K]^{(e)} \{d_{ik}\}^{(e)} - \sum_{e=1}^{E} \{p\}^{(e)} = 0$ (1)

or

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

Matrix $[K]^{(e)}$ usually called the finite element stiffness matrix in the local coordinate system, $\{d_{ik}\}^{(e)}$ - vector of displacements of FE nodes in the same system. If we adopt a common (global) coordinate system for all structural elements, through $\{d\}$ designate the displacements of all structural nodes, and the stiffness matrix $[K]^{(e)}$ and vector of forces $\{p\}^{(e)}$ write in a global coordinate system of the same dimension as $\{d\}$, the equation (2.2) will look like this:

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

where $[K]^{(e)}$ и $\{p\}^{(e)}$ – written in a global coordinate system.

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

where

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

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

1. The solution of a system of algebraic equations is carried out using linear algebra methods. Typically the Gaussian method is used, but other methods can be used. Due to the high order of the system of equations, calculations are carried out using information technology. As a result of the solution, taking into account the boundary conditions, the displacements of all structural units are found.

2. The stress-strain state (SSS) of a structure is determined using expressions (4).

In order for the design diagram of the body of the weighing calibration wagon to correspond as closely as possible to the actual design and nature of the work, plate-and-rod finite elements were used to describe the elements of the wagon. The body model was developed using SolidWorks software, and calculation of stresses in elements, distribution of loads in the structure, as well as visualization of stresses and deformations were carried out using the ANSYS Workbench software package [8-10].

Body elements have six degrees of freedom at each node: movements 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. The mass type elements were connected to the frame elements using absolutely

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rigid connections. The design diagram of the weighing wagon body structure is shown in Figures (1–2), and with the finite element mesh - in Figure 3.

The finite element model of the weighing wagon body includes 180,720 finite elements and 57,714 nodes.

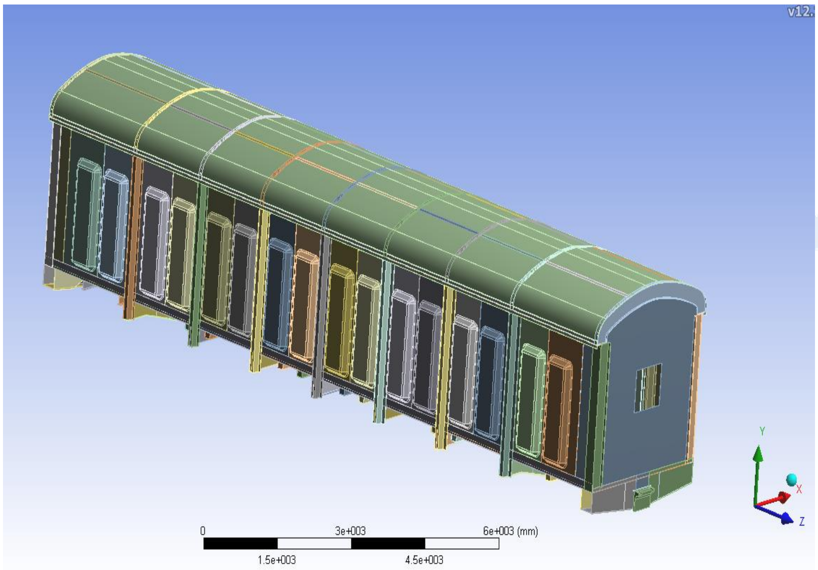

Figure 1 – General view of the calculation model of the weighing wagon body

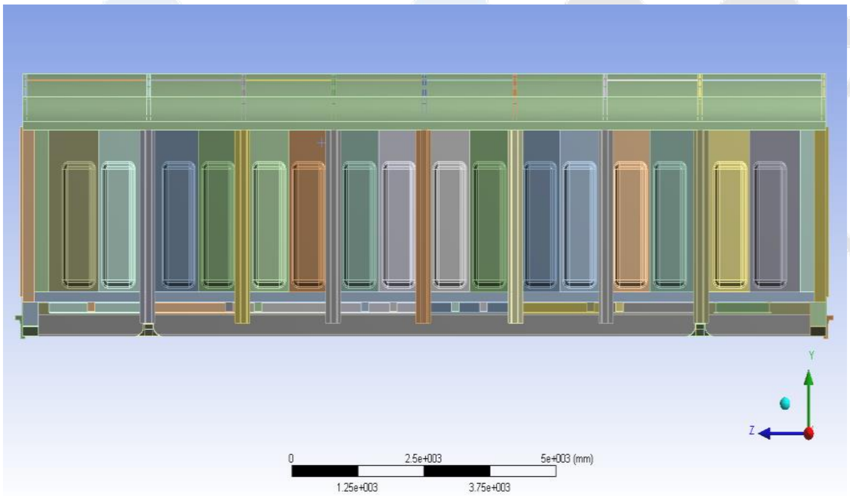

Figure 2 – Longitudinal view of the calculation model of the weighing wagon body

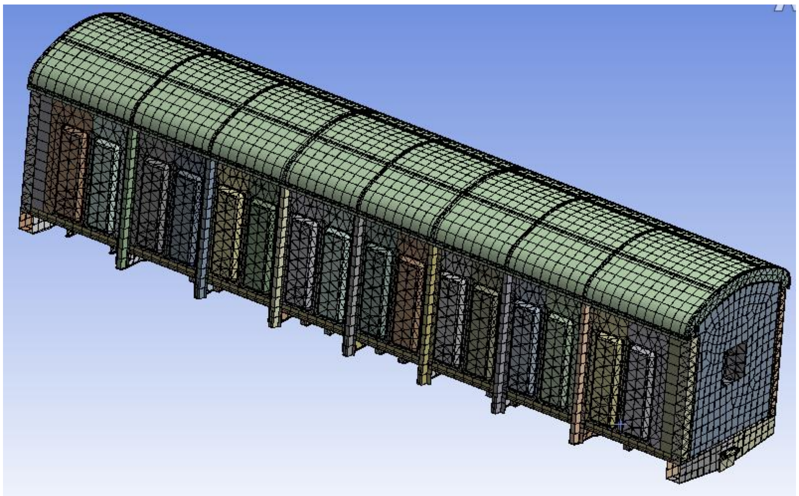

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Figure 3 – General view of the finite element model of the weighing wagon body

Conclusion. A computational finite element model of the weighing wagon design has been developed using SolidWorks engineering software, which makes it possible to take into account various design changes in wagon components under modern operating conditions.

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