Calculation and experimental assessment of passive safety for special buses on truck chassis, taking into account the influence of operating temperature conditions

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Abstract. The problem of reducing the severity of accidents is one of the most important. About 30% of accidents with serious consequences are those involving buses. One of the most dangerous types of bus accidents is overturning. The power structure of the body of multi-passenger vehicles are subject to the requirements regulated by the UNECE Regulations No.66. A separate specific group consists of shift buses on the chassis of trucks, designed for operation in harsh natural and climatic conditions in areas with an under-developed road network. It is known that, depending on the type, nature and structure, structural materials have different strength characteristics at a given temperature. The strength characteristics of the materials used in the construction of bodies have a primary impact on the level of passive safety of buses. Therefore, there is an urgent task of assessing passive safety of this type of buses in the entire temperature range of their operation. The present article presents some experimental dependences of the strength material characteristics used in bodies on the temperature. A detailed finite element model-specific for this class of body buses from sandwich panels is shown. Some characteristics of this type body simulation are also discussed. Results of the study of passive safety of a shift bus with a body of sandwich panels in the temperature range of the bus operation are obtained. The necessity of assessing the passive safety in the entire temperature range of operation of this specific category of buses is shown.

1. Introduction

The problem of improving road safety is one of the most urgent problems. Despite the constant decrease in both accidents and the severity of their consequences, the number of accidents remains high. On average, more than 150 thousand accidents occur in the Russian Federation per year, in which 18 thousand people die and more than 200 thousand people are injured [1]. At the same time, special attention should be paid to improving passive safety of buses, in 2018 in an accident involving buses more than 8.8 thousand people suffered, and among accidents with serious consequences - about 30% were those involving buses [2].

Passive safety of multi-passenger vehicles is governed by UNECE Regulations No. 66-02 and relate to the strength of the upper part of the power structure when the bus rolls over from a ledge with a height of 0.8 m. At the same time, a regulated residual living space should be maintained in the cabin. According to Appendix 9 of these Rules, it is allowed to conduct passive safety assessment based on the results of computer simulation, provided that the computational model of the real construction is adequate and the tilting conditions are met. At present, computational-experimental methods are
becoming common [3-6], combining the advantages of both experimental and computational methods. Such studies are conducted at the Chair of "Cars and Tractors" of NNSTU. [7-9].

Among the existing structures of buses, a separate group consists of shift buses on the chassis of trucks. Body-such buses, as a rule, are made of multilayer panels ("sandwich panels"). "Sandwich panels" consist of outer and inner skins and aggregate in the form of low density foam. The design features of the sandwich panels used for the manufacture of the body of the van are shown in Figure 1.

![Figure 1. Structure "sandwich panels".](image_url)

To obtain reliable simulation results of shock interaction, modern calculated finite element model (FEM) packages are used based on explicit methods for solving the dynamic equation. When finite element modelling of bus tipping, it is necessary to create models of the vehicle that take into account all the features of the structures as much as possible (mass-dimensional parameters, materials, ways of connecting the structural elements, etc.). Therefore, the bodywork of the bus of three-layer panels was presented by a detailed finite element model consisting of one-dimensional bar, two-dimensional shell and three-dimensional volume elements.

Figure 2 shows the calculated FEM of the investigated bus. Some of its fragments are shown in Figures 3-4. The developed FEM of the shift bus consists of 376512 nodes and 228160 elements.

![Figure 2. Outlook of the shift bus.](image_url)
Figure 3. Enlarged fragment (section) of the connection between the roof and the rear panel of the body-van.

Figure 4. Enlarged fragment of the side members and sub-frame of a special rotational bus model.

In order to ensure reliability of the calculation results of the special rotational bus developed by FEM, an experimental determination of the characteristics of its materials was conducted. Experiments were subjected to the main carrier materials of the body. In this case, finite element modelling of loading samples with experimentally determined characteristics was carried out, the results were compared and corrections were made in the FE model. For example, see the results of experimental and calculated studies of the foam and the sample panel as a whole.

Foam tests were carried out under two loading conditions. Compression and stretching of the samples was carried out to determine the strength characteristics of the foam. Pictures of the process of conducting experiments with the foam and the appearance of FE models that repeat the test conditions are shown in Figure 5. Figures 6-7 show the graphs of the load changes applied to the samples during compression and tension in experiments and computer simulations.

Figure 5. Compression of the foam sample, initial and final state:
(a) experiment, (b) computer simulation
It is seen that in all loading modes, the results of computer simulation qualitatively repeat the nature of the curves obtained in the experiments. When compressing the foam (Figure 5), the discrepancies in the results begin at the moment when the initial sample with a height of 50 mm is compressed to 5 mm. The emergence of such extreme deformation of the foam when tipping buses from "sandwich panels" is unlikely. When the foam is stretched and bent, the value of the peak load F obtained by computer simulation correlates well with the experimental results (their average value).

Based on an acceptable correlation of the results of calculations and experiments for the considered sample loading modes, the following foam characteristics were introduced into the van body model: material type * MAT_LOW_DENSITY_FOAM, density $5 \times 10^{-10}$ t/mm$^3$, modulus of elasticity 6.883 MPa, maximum tensile stress at failure 0.314 MPa, experimentally obtained dependence of stresses on compression deformations, the maximum principal relative deformation ($\epsilon_1$) at failure 0.056. Tests of panel cladding materials were carried out under tension conditions [7]

The prevailing loading mode on a body when tipping is a bend. Therefore, the validation of the finite element model of the panel was carried out under the conditions of the three-point bending of the “sandwich panel” fragment used in the design of the vehicle under study. Figure 8a shows a fragment of the experiment and the corresponding fragment of the simulation. Figure 8c presents the graphs of load changes in experiments and calculations.
Figure 8. Comparison of the calculation results and experiments on the schedule for the change in the flexural load acting on the sandwich panel fragment: (a) experiment; (b) type of the finite element model; (c) comparing the calculated and experimental dependence of the load on the movement.

According to the presented load change graphs, it can be said that the applied finite element model of the “sandwich panel” can be used to analyze the body behaviour in case of tilting. The qualitative character of the change in the curves in experiments and calculations coincides. The difference in peak load between calculation and experiments is minimal.

The experimental research conducted with the use of measurement equipment of the NNSTU Centre of collective using “Transport Systems”.

The results of computer simulation of the loading conditions of the rotational bus body are shown in Figures 9-10. Showing the deformation of the body, correlated with the contour of the residual living space, the shape of which is governed by the requirements of the Rules. It can be seen that along the entire length of the body there is a guaranteed gap between the legs of the frame and the contour of the living space. Thus, the considered design under the normal conditions (temperature + 20 °C) meets the requirements of UNECE Regulation No. 66 (revision 2), since it guarantees the preservation of residual living space inside the cabin when tilting.
Figure 9. Deformed view of the model (inside view).

As was noted in [7, 8], shift buses are operated in harsh climatic conditions, so it is advisable to evaluate their passive safety in the wide temperature range from +60 to -60 °C. Depending on the type, nature and structure of the materials have different strength characteristics at a given temperature. For metals, the sensitivity of mechanical characteristics to temperature changes depends on the type of crystal lattice [10]. In polymeric materials, the temperature dependence of the mechanical properties is determined by the class of the polymer, the chemical structure, the physical organization of the polymers, the morphology of their supra-molecular structure, the type and intensity of intermolecular bonds [11].

Figure 11 shows the dependence of the ratio of the Young's modulus at different temperatures to the Young's modulus under normal conditions of a sample of a composite material used as outer and inner panel skins. [8]

Figure 11– Dependence of the Young's modulus on the temperature of the composite sample.

From the presented graph it is seen that with a decrease in temperature in the studied interval, the Young's modulus monotonously increases, and with increasing temperature, the Young's modulus decreases. Up to \( t = +50 \) °C, this decrease is quite smooth. After reaching the critical temperature \( t = +50 \) °C, there is a sharp decrease in the stiffness characteristics of the material and at \( t = +60 \) °C there is a drop in it by more than 30%. From this it follows that in carrying out calculations for assessing the passive safety of vehicles with parts made from this material, it is necessary to conduct a series of experiments in the entire operating temperature range.

Conducting field tests of buses in this temperature range is quite difficult. Therefore, it is most advisable to assess their passive safety based on the results of computer simulation.

The simulation results of the tilting of a shift bus with the characteristics of materials corresponding to a temperature of +60 °C are shown in Figures 12-13.

Figure 12. Deformed view of the model (rear view).
From figures 12-13, it can be seen that the structural elements (side panel) are being introduced into the residual living space. That is, a bus body with mechanical characteristics of materials corresponding to a temperature of +60 °C does not have sufficient strength to fulfil the requirements of UNECE Regulation No. 66. Thus, the obtained results show that the assessment of passive safety of rotational buses built on the chassis of trucks designed for operation in difficult climatic conditions must be carried out in the entire temperature range of operation of buses. Compliance with the requirements of the UNECE Regulation No. 66 only under normal conditions cannot guarantee the preservation of the necessary residual living space, and hence the protection of passengers, when overturning in the entire temperature range.

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