The Analysis of Elastic-Plastic Mechanics of Bus Body Construction in Conditions of Rollover by Means of Simulation and Real Test

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***Abstract*—The results of experimental and calculative estimation of elastic-plastic mechanics of bus body construction in conditions of rollover are presented. The dynamical behaviors of light commercial (LCV) bus structures are described. The analysis of approaches that could be used for estimation of buses passive safety is made. The results of experimental estimation of construction materials characteristics are described. The comparative analysis of the test experimental data and simulation results is presented..**

Keywords-elastic-plastic characteristics of materials; bus body; rollover; passive safety; simulation; energy absorption.

I. INTRODUCTION

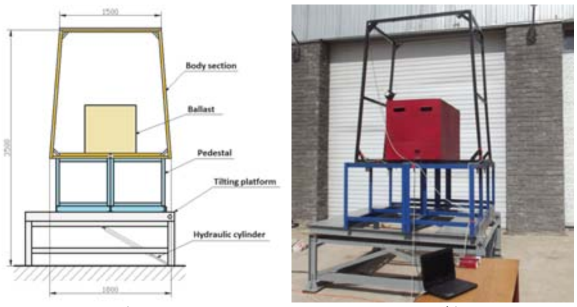
The problem of bus accident prevention is topical for any country. Road accidents with bus participation attend with serious injuries of passengers. It is well known that rollover is one of the most dangerous types of accident that is not as frequent as front or side collisions but quite dramatic by deceased people statistics. The improving of bus passive safety is possible and could be achieved by means of intelligent systems and using of robust body structures and seatbelts for passengers. The bus passive safety in rollover conditions is estimated according to ECE R66 Regulation. This Regulation allows carrying out estimation of the strength of the bus superstructure by using computer simulation. In addition, ECE R66 prescribes simulation model that should be able to describe the real physical behavior of the bus superstructure during the rollover [1]. Nowadays there are different modeling approaches of the body structure load conditions during the bus rollover [2-6]. In many of them the model loading is implemented with predetermined kinetic energy [3-6], but these approaches don't consider the bus rotation process which occurs when the bus impacts the ground (rigid surface). The positive side of these approaches is that they are easy to use. So there is a logical question: is it necessary to consider bus rotation process during the rollover and how it influences the results which can be obtained by computer simulation? This task can be solved by carrying out experiment and subsequent comparison between the test and the simulation data. The particular attention should be spent on estimation of construction materials characteristics that are used in bus body construction.

II. THE OBJECT OF RESEARCH

The object of study was a typical middle section of a bus, which is performed on the base of a light commercial vehicle (Fig. 1). The rollover process of a bus section was studied with the help of special rollover testbench. The tilting platform of a testbench fully complies with the requirements set out in Annex 5 of the Rules ECE R66. During tests the section is set to external support (pedestal), which provides position of the section's centre of gravity and the axis of rotation like in a typical complete vehicle. The centre of gravity of the section is also regulated by a box with ballast. The box and pedestal are attached to the base of the section without increasing the strength of superstructure. However, the box with ballast can influence the deformed shape of the section. It can occur after impact interaction between the box and section pillars. In this case, the deformed shape of the section will not correspond to deformed shape of bus construction obtained in the test for approval. Nevertheless, this assumption is not significant for conducted validation of computer simulation in the paper. Also there are no mass or dummies simulating the presence of passengers in the construction. This situation can occur in approval if the vehicle is not equipped with restraint systems (Annex 6 of the Regulation).The general scheme of the test equipment including the body section, pedestal, ballast and tilting platform as well as their actual image is shown in Fig. 2.

a) b) c)

Figure 1. Typical cross section of body construction used in buses made on bases LCV: a – scheme of section; b, c – passenger bus on basis of LCV chassis

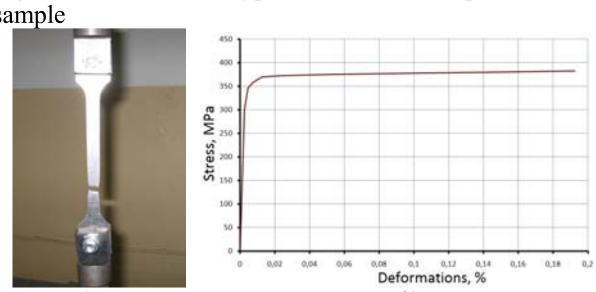


a) b)

Figure 2. The section mounted on the tilting platform:
a – scheme, b – photo

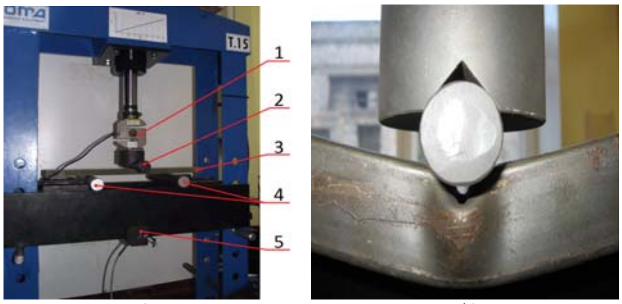
III. Experimental study of steel beam bearing capacity

It is well-known that the most stressed elements of body section during rollover have plastic shape deformations. It is very important to simulate this effect correctly, because it has serious influence of calculative results. For this purpose the mechanical characteristics of material were determined. Special tensile-testing machine was used (Fig. 3). Several test samples were cut out from the thin wall of the steel tube with rectangular section. The necessary stress-deformation curve was determined after the analysis of experimental data and was used during finite element model creating. The other experiment (three-point bending) was made for the samples of steel tubes that are used in bus structure construction. Fig. 4a shows the hydro-press with force sensor (1), loading cylinder (2), steel tube sample (3), cylindrical supports (4) and optical displacement sensor (5). Figure 4b shows the typical deformed shape of the test sample



a) b)

Figure 3. Experimental research of steel mechanical characteristics:
a – tensile-testing machine experiment; b – stress-deformation curve



a) b)

Figure 4. Three-point bending experiment:
a – hydro-press with measurement equipment; b – sample deformed shape

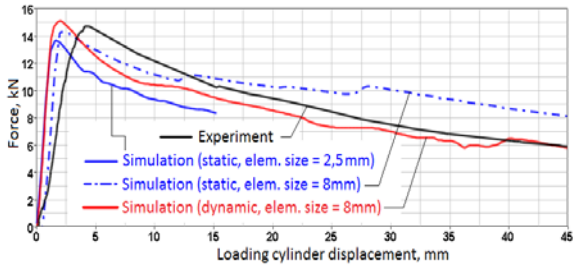


Figure 5. Force-displacement curves

The experimental results were compared with the similar simulation results where the test conditions were imitated. Several FEMs were created: detailed FEM with small (1…2,5mm) size of shell elements and less detailed FEM with 5…8mm mesh size that are usually used for bus structure modeling. Nonlinear static and dynamic tasks were analyzed. Fig. 5 shows force-displacement diagrams for different FEMs variants and simulation tasks. Despite the fact that curves have some divergence it could be concluded that simulation results have good compliance with experimental data.

IV. Finite element simulation

The tensile test of the specimens extracted from thin-walled tubes of the body section was conducted preliminary. Subsequently, the "stress-strain" curve obtained for plastic deformation area was assigned to the finite element model of the body section. The numerical simulation of the rollover process was similar to the approach of Niii N. and Nakagawa K., described in the study [2]. Finite-element analysis was conducted by using nonlinear explicit dynamic code LS-DYNA. The section pedestal, box with ballast, tilting platform and ditch surface were modeled by rigid bodies. The body section's material (*MAT_PIECEWISE_LINEAR_PLASTICITY) was switched to rigid by using *DEFORMABLE_TO_RIGID_AUTOMATIC option, during body section free fall. The whole rollover process takes 2.2 seconds; so FE analysis can require significant calculation time. During the material properties switching the time step size of the solver can be increased by 10 times and even more that's why calculation time can be decreased respectively. The gravity loading acts to model from time =

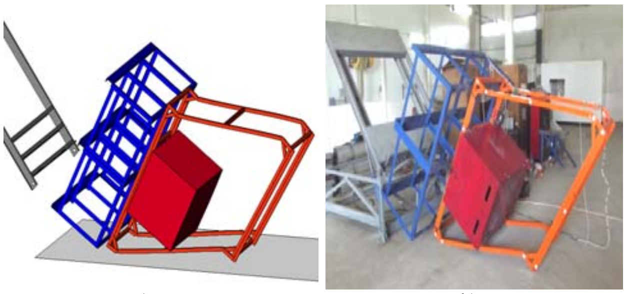
0 sec to time = 2 sec, and from t = 2 sec to t = 2.2 sec its value decreases to zero, allowing to measure residual deformations of the model. All model structural members are presented by shell elements. The average model finite element size is 6…10 mm. At the tilting platform shoulders the element size is 2.5 mm for contact interaction accuracy ensuring between the shoulders and body section pedestal.

V. THE COMPARISON BETWEEN THE SIMULATION AND TEST DATA

The distance between controls points before the impact and after it measured in simulation and real test (Fig. 6). The residual deformations after unloading are measured after the impact. Comparison between the simulation and test results is conducted by the comparison between these distances. Maximal deformations during the impact are not measured in calculation. This is a shortcoming of the study. On the other hand, the stress-strain curve is a linear at elastic deformation. At plastic deformation the relationship between stress and strain is more complex, non-linear and requires a large number of iterations. The description of the behavior of structures in the range of elastic deformation is simpler task of finite element analysis than simulation of plastic deformation. Thus, in this case we can assume that obtaining good convergence of plastic strain values between experiment and calculation a good accuracy of elastic deformation modeling should be expected. The measurements are shown in Table 1.

The analysis of results showed that difference between the simulation and test results has range from 0,75 to 5,88 %. The obtained result means that the considered approach allows to get a good correlation with experimental data. A good correlation between the results is also confirmed by comparison of the body section deformations as shown in Fig. 7.

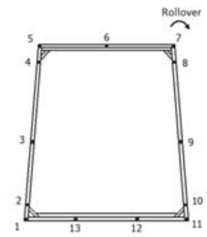
It is seen, that locations of the plastic deformations areas at the simulation are the same as in the experiment. It was found that at time t = 1,69 sec (at the moment of contact between the pedestal and the rigid ditch surface) the change of the kinetic energy is really high (the sharp increasing of the kinetic energy). A similar change of energy is described in details in M. Matolcsy and C. Molnar study [7], which analyzed the energy balance of the bus rollover process. That is to say, the kinetic energy portion is dissipated by the impact between lower parts of the section and the rigid ground. This impact practically doesn't have any influence on deformation of the upper parts of the section. Sliding of the body section along the ground surface is the most obvious parameter which influences the time moment of the fall of the pedestal from the tilting platform shoulders. If the fall occurs later, more amount of kinetic energy is dissipated by deformation of the upper parts section. So, if the friction coefficient between the construction and the ground surface is higher, section upper parts deformation is more significant.

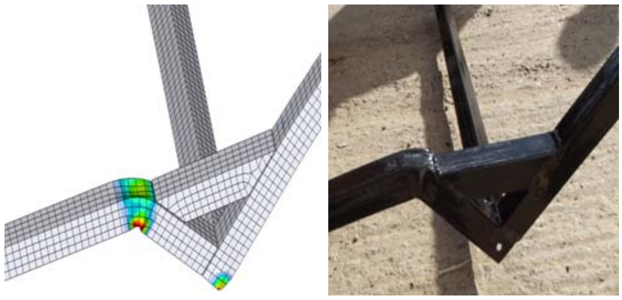


a) b)

Figure 6. Rollover of bus section: a – simulation; b – real test

TABLE I. COMPARISON BETWEEN THE CALCULATION AND THE TEST DATA

Numbers of control points	Change of the distance, mm		Difference between the results, %	Control measured points location (scheme)
	Simulation	Real test		
1-7	650	640	1,56	
1-8	686	669	2,54	
6-2	403	400	0,75	
6-3	335	327	2,45	
3-13	-162	-153	5,88	
5-11	-449	-427	5,15	
11-4	-504	-478	5,44	
6-10	-273	-261	4,60	
6-9	-221	-211	4,74	
9-12	226	231	2,16	



a) b)

Figure 7. Body section deformation condition at the simulation (on the left side) and at the real test (on the right side)

VI. CONCLUSIONS

On the basis of the performed study, it can be concluded that the finite-element simulation of bus rollover considering bus rotation process coincides with the experimental data. It is worth to underline that there is a computer simulation approach, where the bus model turns into the contact position with the ditch surface at the initial time of the simulation, and the angular velocity is assigned to all nodes of the model [3-5]. This approach doesn't consider the change of the bus rotation axis during the rollover process. Therefore the fall of the bus from the tilting platform shoulders occurs at the dissipated kinetic energy amount that doesn't correspond to its real value. It is important to consider the process of bus rotation which occurs before the bus impacts with ground surface. Also, the motion of the bus during deformation has an effect on the obtained results of simulation. It indicates that for obtaining a more accurate result of the calculation such features of the rollover as a free fall of the bus and his contact with the tilting platform should not be neglected.

ACKNOWLEDGEMENTS

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