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Comparative Estimation Between Computer Simulation Results of the Bus Body Section Rollover and Experimental Data

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Abstract: This paper deals with a rollover computer simulation (according to ECE R66 Regulation) of the bus section, which is performed on the base of a light commercial vehicle. It gives an overview of the used simulation approaches. Comparison between the calculative and experimental data is implemented on the base of one of the specified methods. It considers in details the bus rotation process, which occurs when the bus impacts with ground. The results of the analysis allow us to make a conclusion about the bus rotation influence on the bus body deformation.

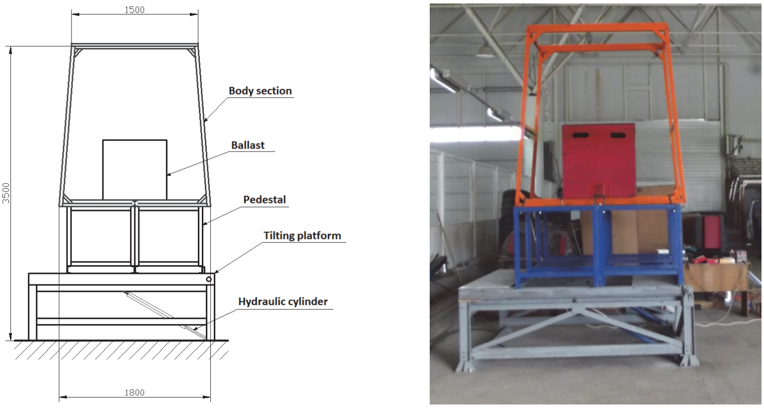
Keywords: ECE R66, finite element method, simulation, overview

1. Introduction

The bus passive safety in rollover conditions is estimated according to ECE R66 Regulation. This Regulation allows to carry 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 behaviour of the bus superstructure during the rollover [1]. Nowadays there are different modelling approaches of the body structure load conditions during the bus rollover [2-7]. In many of them the model loading is implemented with predetermined kinetic energy [3-7], but these approaches don't consider the bus rotation process which occurs when the bus impacts with ground. 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.

2. Object of study

The object of study has contour and structural elements similar to corresponding parameters of the body structure middle section of a typical bus, which is performed on the base of a light commercial vehicle. The tilting platform fully complies with the requirements set out in Annex 5 of the Rules. 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 figure 1.



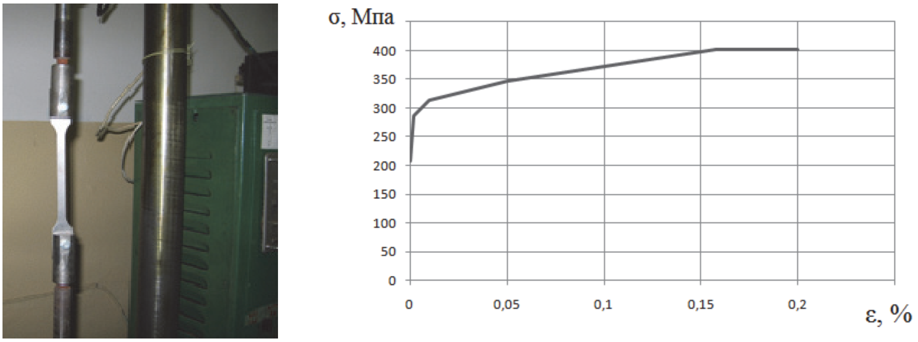
a) *b)*

Figure 1. The section mounted on the tilting platform: scheme (a), photo (b)

3. Finite element simulation

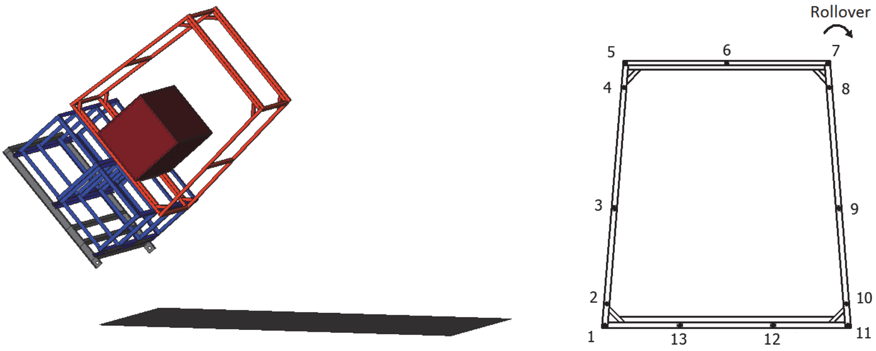
The uniaxial tensile test of the specimens extracted from thin-walled tubes of the body section was conducted preliminary. Subsequently, the "stress-strain" curve obtained for plastic deformation area was assigned to the finite element model of the body section. A fragment of tensile test and the obtained plastic hardening curve are shown in figure 2.

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 modelled 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 10 mm. At assumed locations of plastic hinges emergences the element size is 6 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. Total shell element number is equal to 230567. The composed model view is shown in figure 3.



a) *b)*

Figure 2. The fragment of uniaxial tensile test (a) and obtained plastic hardening curve for steel (b)



a) *b)*

Figure 3. The designed finite element model (a) and the control measured points location (b)

4. The comparison between the simulation and test data

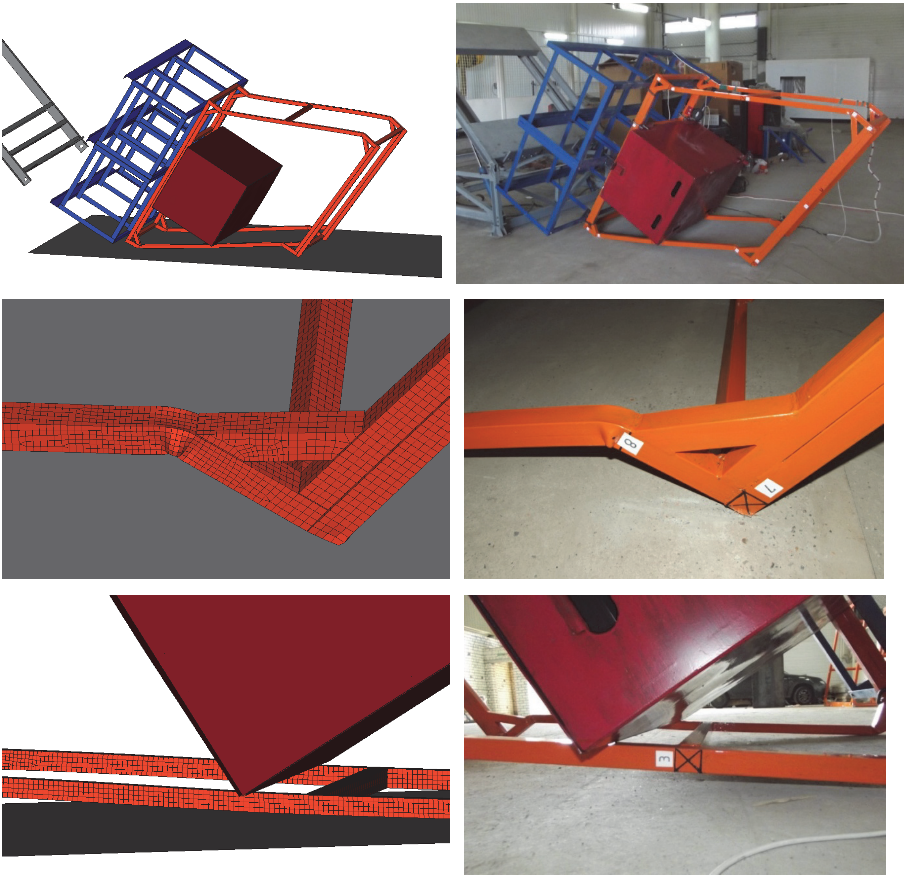
The distance between the control points before the impact and after it is measured in simulation and test. The residual deformations after unloading are measured after the impact. Comparison between the simulation and test results is conducted by the comparison between these distances. Maximal deformations during the impact is 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 behaviour of structures in the range of elastic deformation is more simple 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 modelling should be expected. Location of the control points is shown in figure 3. The measurements are shown in table 1. As it is seen from the table, the difference between the simulation and test results has range from 0,36 to 7,29 %. 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 figure 4.

Table 1. Comparison between the calculation and the test data

Numbers of control points	***Change of the distance, mm***		***Difference between the results, %***
	Test	***Calculation***	
1-7	***640***	***650***	***1.56***
1-8	***669***	***686***	***2.54***
6-2	***400***	***403***	***0.75***
6-3	***327***	***335***	***2.45***
3-13	***-153***	***-162***	***5.88***
4-12	***-384***	***-412***	***7.29***
3-12	***-247***	***-259***	***4.86***
5-11	***-427***	***-449***	***5.15***
11-4	***-478***	***-504***	***5.44***
6-10	***-261***	***-273***	***4.60***
6-9	***-211***	***-221***	***4.74***
9-12	***231***	***226***	***2.16***
8-13	***550***	***552***	***0.36***
9-13	***312***	***334***	***7.05***

It is seen from figure 4, that the box with ballast touches the vertical pillars of the body section. This situation also takes place at calculation. It is also seen, that locations of the plastic deformations areas at the calculation are the same as in the experiment.

Change of the kinetic energy (it is shown in figure 5) during the rollover process shows the fall of the pedestal from the tilting platform shoulders at time t = 1.69 sec. It is confirmed by sharp increasing of the kinetic energy. Sharp decreasing of the kinetic energy means that there is contact between the pedestal and the rigid ditch surface. A similar change of energy is described in details in M. Matolcsy and C. Molnar study [8], which analysed 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.



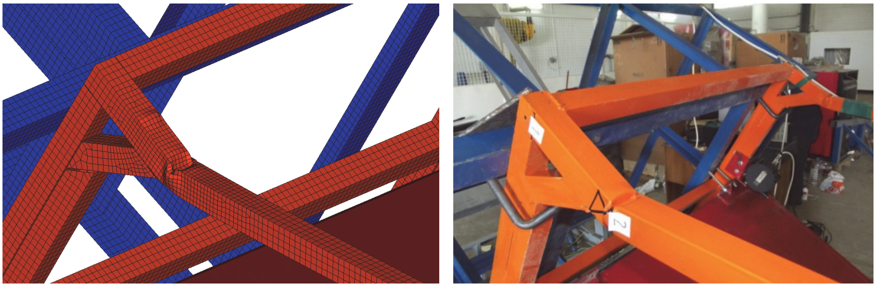


Figure 4. Body section deformation condition at the simulation (on the left side) and at the test (on the right side)

The rotation axis of the bus body construction changes during the rollover process. The tilting platform shoulders and the pedestal positions at different time moments are shown in fig.6. The rotation axis changing influences the moment of inertia of the rotating bus body construction, and so influences the kinetic energy value. Also, the "S" distance between the lower edge of the pedestal and rotation axis influences the time moment of the fall of the pedestal from the tilting platform shoulders.

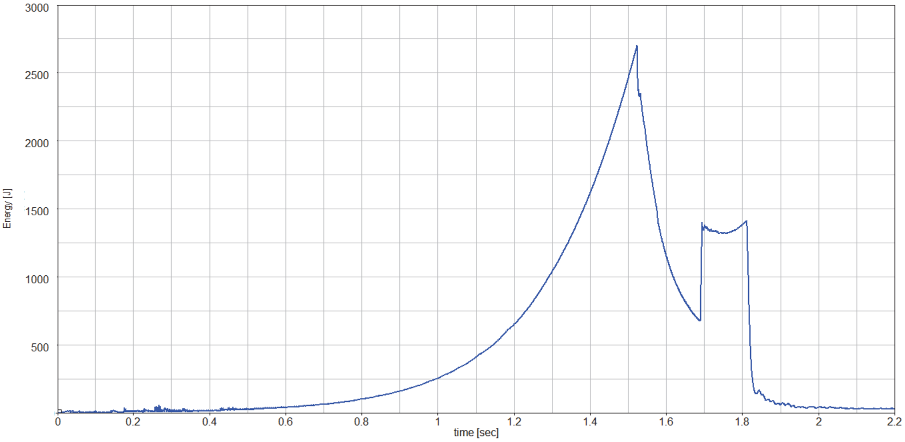
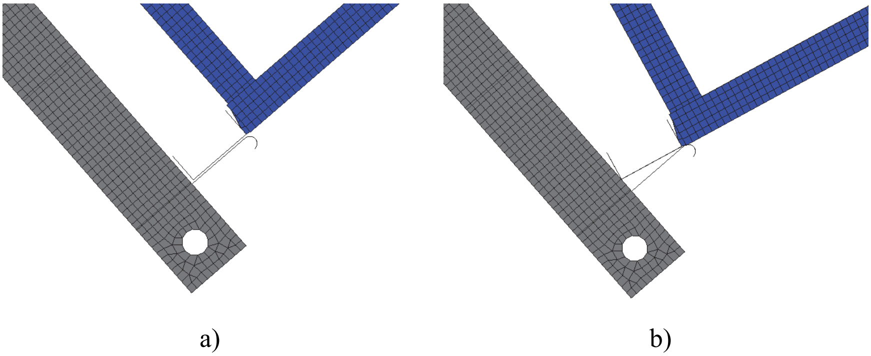


Figure 5. Kinetic energy distribution versus time



a)
b)

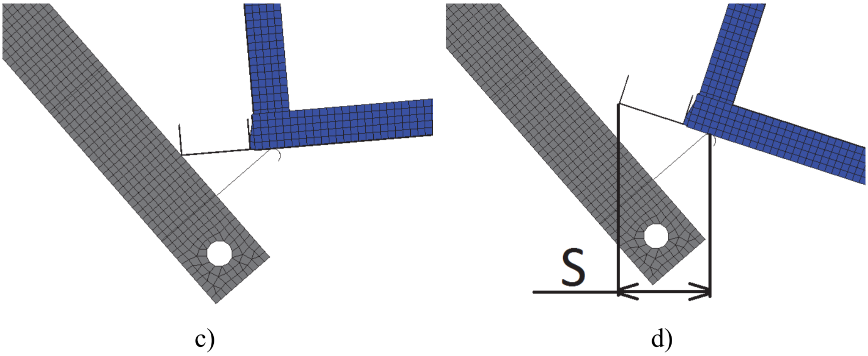


Figure 6. The tilting platform shoulders and the pedestal position at time:
a) t=0 sec, b) t=0,9 sec, c) t=1,3 sec, d) t=1,5 sec

Rotational motion of structure during deformation influences the value of structure strain. Motion of structure during deformation occurs along the radius R, which is equal to the distance between the zones of plastic deformation, arising at the base, and corresponding zones located in the upper corners of the section (figure 7). With the decreasing of the radius the drop of the section base (bus chassis) from tilting platform happens with smaller bus superstructure deformations. Finally, above mentioned factors influence the bus body deformation.

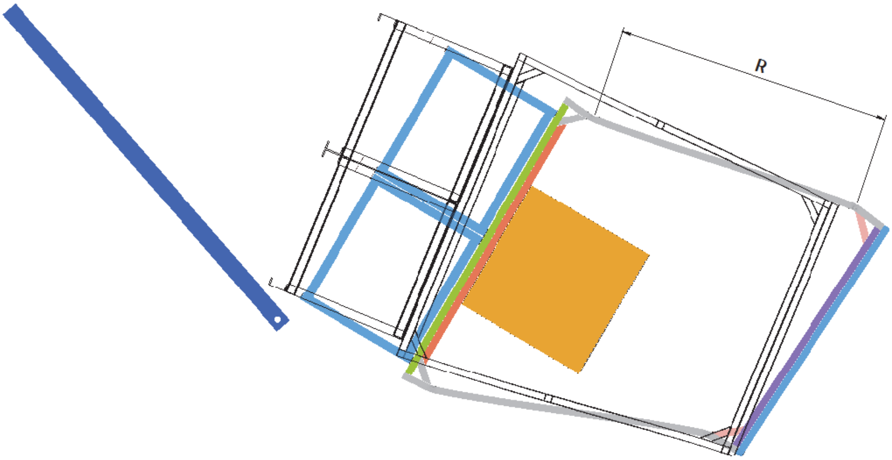


Figure 7. Changing of the vertical pillars length projection during deformation

5. Conclusions

On the basis of the performed study, it can be concluded the finite-element simulation of bus rollover considering bus rotation process coincides with the experimental data. Other computer simulation approaches used nowadays, where the fixed bus body construction is impacted by the rigid body [6],[7] (pendulum, rigid wall with translational or rotational motion) don't consider the fall of the bus from the tilting platform shoulders, change of the bus rotation axis during the rollover process and mass distribution along the bus body construction. 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. All this shortcomings are eliminated by the rollover modelling considering bus rotation process before the impact. One more phenomenon, which can be considered only by this rollover simulation approach, is the additional bus rotation components. These components occur due to different COG heights of the individual sections of the bus. Due to it the first bus body construction impact into the ditch surface is occurred by one of the extreme corners of the roof (front or rear). Numerical value of this phenomenon influence can be obtained at the rollover test of more difficult asymmetrical construction, which has irregular mass distribution. All the above mentioned factors influence the bus body construction deformation values.

Thus, at the bus passive safety estimation by using computer simulation, considering the bus rotation process during the rollover, is important for obtaining more accurate results.

It is important to consider the process of bus rotation which occurs before the bus impacts with ground surface at passive safety estimation by using computer simulations. 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. Thus, at the approval, the known methods of verification such as experimental tests of separate elements of bus structure [4], analysis of the balance of the calculative values of the energy [9] and implementation of experimental modal analysis [10] cannot be sufficient to obtaining accurate results of finite element modelling of the bus rollover. Based on the above mentioned, it is also desirable to conduct the experimental verification of the adequacy of finite element model motion on the example of a single section of the bus.

Acknowledgement

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