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CONSIDERATIONS ON THE SIMPLIFIED NUMERICAL SIMULATION OF THE BUS LATERAL ROLLOVER

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ABSTRACT

The numerical simulation using finite element method, of the behavior of buses in case of lateral rollover, requires significant hardware resources and can lead to the numerical models whose resolution may take prohibitively long. Under these conditions, the simplified simulation of the phenomenon, considering only pre-impact of its part is a worthy alternative to consider. In this context, the article presents the main aspects to be taken into account in case of simplified simulation of the buses lateral rollover.

KEYWORDS: simplified numerical simulation, bus roll-over

1. Preliminary part

The bus accident with the most serious consequences is undoubtedly the accident produced in case of bus rollover.

Previous statement is sustained by statistics on bus accidents and their consequences.

Consequently, one of the most important requirements imposed on a bus structure and on the other system components, having protective role, is to provide an imposed level of passive safety for the bus occupants, in case of the bus rollover.

The bus structure must be designed so that, in case of bus rollover, the passengers are protected by an appropriate limiting volume for the structure deflection, volume which is called *survival space*.

The survival space looks like a prism having symmetry with respect to the vertical plane of symmetry of the bus. The length of the survival space is equal to the distance between seat index point of the rearmost seat and the seat index point of the most front seat. The positioning of the seat index point is in accordance with specifications of ISO 5353.

In figure 1 is showed the cross-section through the survival space and its position inside the bus.

Because of its importance, this area is governed by a series of regulations and standards:

- in the European Union and other countries are applied the provisions contained in ECE R66 Regulation;
- in U.S. are applied the provisions contained in FMVSS (Federal Motor Vehicle Safety Standards);
- in Canada for school buses are applied CSA D250 standards and in Australia are valid ADR59/00 standards.

The reference documents above mentioned, especially ECE R66 Regulation, underpin the performance criteria of the passive safety provided by buses and the experimental evaluation of this kind of security.

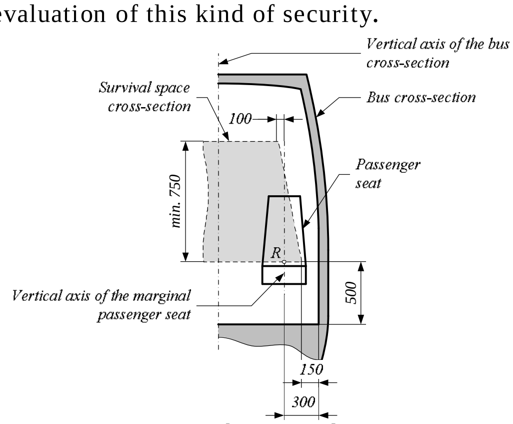

Fig. 1 – The survival space

2. Simulation types for bus lateral rollover using virtual models

In recent years, finite element method has proven to be one of the most powerful tools for exploring the field problems. Thus, finite element method has become a powerful design tool that allows the generation of models of reality affected by a small number of simplifying assumptions.

An important ahead step was taken in the study of dynamic problems using finite element method.

Numerical simulation of the behavior of mechanical systems using finite element method, known as mechanical event simulation, is a good example on this line because, mainly, it is possible to eliminate the rule-of-thumb methods.

In this area, simulation of bus structure behavior under the action of shock loads from rollover of the bus may be an important application of virtual engineering.

In terms of complexity of the virtual model which is used in simulation, there are two possible approaches:

- *Extensive simulation*: simulation of bus structure behavior under the action of shock loads from the rollover, using both virtual models of passenger compartment structure and of the base machine (more or less simplified);
- *Limited simulation*: simulation of bus structure behavior under the action of shock loads from rollover, using only the virtual model of passenger compartment structure.

The extensive simulation requires a great modeling effort, for generating the system geometry, and for generating the finite element model. Also, the extensive simulation requires, even in the stage of the problem modeling, significant hardware resources, which makes this approach be very expensive.

In limited simulation, in order to determine, by simulation, the distribution and magnitude of stresses and deformations induced in protective structure during shock, it is necessary to know the speed of the bus structure in the first moment of shock. In addition, in order to obtain results with the imposed accuracy level, it is necessary that, in simulation, the mass of the virtual model be equal to the mass of the real bus.

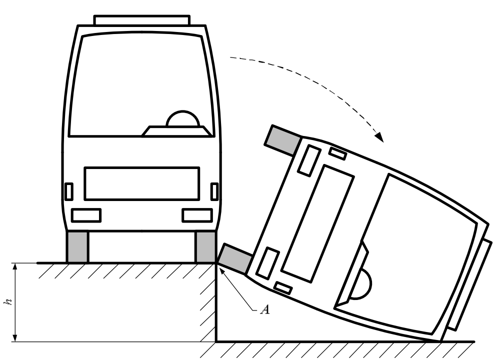

Fig. 2 – Experimental test of lateral rollover, according to ECE R66

Regardless of the type of simulation, it must comply with provisions contained in ECE R66 regulation relating to the experimental rollover test of the buses. Under this standard, rollover of the bus is made around axis A, from a regulated height, h (figure 2).

3. The simplified simulation basis of the impact in case of the bus lateral rollover

In simplified simulation of the impact that occurs in case of the bus rollover, is taken into account only the rollover part that precedes the impact.

Corresponding to this part of the rollover that precedes the impact, it is assumed that the structure is moving *vertically*, in gravitational field.

Thus, instead of simulating the entire rollover phenomenon it is simulated a vertical drop of the structure over a short period of time, preceding the impact.

This approach is suggested by the existence on some platforms FEA of powerful tools that allow the simulation of the impact between mechanical structures and rigid plans of impact.

The main advantages of using this approach are: reducing the modeling effort, good convergence of the iterative process of calculation and, therefore, reducing the time for solving nonlinear system in displacement associated to the finite element model.

For a good correspondence between the simplified simulation and the real phenomenon, it is necessary to calculate the vertical velocity, v, of the structure at the impact. Using this speed and length of time t, it is possible to calculate the initial velocity of the structure (at the start of the simulation) and initial distance between structure and impact plan:

$$v_0 = v - gt \tag{1}$$

$$d_0 = v_0 t + g\frac{t^2}{2} \tag{2}$$

The necessary steps in simplified simulating of the impact produced in case of the bus lateral rollover are the following:

- After generating the structure geometry, its model is positioned, using specific CAD tools, in overturned position, corresponding to the impact;
- The above-obtained geometric model is exported on the FEA platform to obtain the finite element model;
- Calculation of the translational velocity of the virtual structure at impact so as to ensure the same impact energy as the real rollover;

- Imposition of the pre-impact time;
- Generating of the finite element model and imposition of the required simulation parameters;
- Running the simulation.

In CAD environment, by measurements on the geometric model of the overturned structure (see a sample of the overturned structure in figure 3), it is possible to determine the following system characteristics:

- The angle between structure and horizontal plane at time of the beginning of lateral rollover (angle α in figure 4);
- The position of the center of gravity of the overturned structure, in transverse plane, relative to the origin which is considered on the axis of the lateral rollover (dimensions OA and AG in figure 4);
- The angle between the impact plane and the plane defined by the axis of the lateral rollover and theoretical line along which the impact occurs (angle β in figure 4).

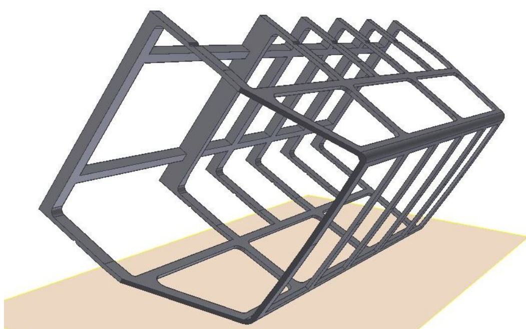

Fig. 3 – Overturned geometric model of the bus structure

The translational speed of the structure, at the time of impact, is determined on the conservative basis, using the calculation scheme shown in figure 4.

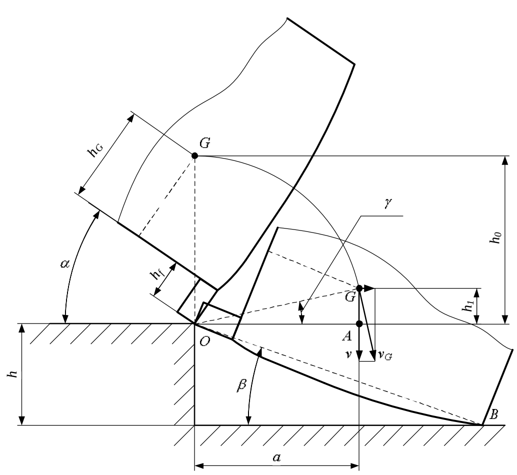

Fig. 3 – The calculus scheme of the translational speed at the time of impact

In this context, the translational speed of the structure at the impact can be calculated based on system energy conservation. Thus, the energy of the system at the beginning the lateral rollover is equal to the energy of the system at the impact:

$$E_0 = E_1 \tag{3}$$

where E_0 denotes the energy of the system at beginning of the lateral rollover, and E_1 denotes the energy of the system at the impact.

The energy of the system at the start of the lateral rollover is pure potential energy and using notations used in figure 4, this energy is provided by:

$$E_0 = mgh_0 \tag{4}$$

At impact, the energy of the system is composed by a potential part and a kinetic part. With notations used in figure 4, we get:

$$E_1 = mgh_1 + \frac{mv_G^2}{2} \tag{5}$$

In the formulas (5.2) and (5.3), m is the operative mass of the bus, and v_G is the peripheral speed of the structure to the impact, speed which is calculated in the gravity center of the structure.

By imposing the energy conservation - formula (5.1) - we obtain:

$$v_G = \sqrt{2g(h_0 - h_1)} \tag{6}$$

At impact, the translational speed of the gravity center of the structure is:

$$v = v_G \cos\gamma = \sqrt{2g(h_0 - h_1)} \cdot \cos\gamma \tag{7}$$

where

$$\gamma = \arctan\frac{h_1}{a} \tag{8}$$

The distance h_0 can be calculated using ground clearance (h_f), the position of the structure gravity center in relation to the passenger compartment floor (h_G), and angle α (see figure 4):

$$h_0 = \frac{h_f + h_G}{\cos\alpha} \tag{9}$$

Next, using the translational velocity v it is simple to determine the two basic parameters (v_0 and d_0) of the simplified simulation using the falling of the structure in gravitational field.

4. Conclusions

The numerical simulation of the behavior of the bus structures, in case of rollover for their compliance evaluation, versus experimental evaluation, presents several advantages, among which the most important are presented below.

- Numerical simulation eliminates the need of experimental installations and of the phisical model of the tested structure.
- Numerical simulation allows for a detailed investigation of shock.
- Numerical simulation can take into account an arbitrary number of boundary conditions.

The main disadvantages of numerical simulation of the behavior of bus structures are:

- Imperfection of the material models.
- Large period of time necessary for solving numerical models associated with the finite element models.

Disregarding the disadvantages which are presented in the previous paragraph, numerical simulation of mechanical structures behavior is, today, a very powerful tool for engineers.

However, obtaining the results which are not only plausible, but true, is conditioned by the deep understanding of the problems, it correct modeling and by setting the appropriate parameters for the simulation.

It is also advisable to validate the numerical simulation of the behavior of bus structures in case of rollover, even using their simplified models. Once is validated the modeling procedure, the numerical simulation can be used to evaluate all of the protective structures belonging to the class of structure that was used for validation.

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