ANALELE UNIVERSITĂȚII
"EFTIMIE MURGU" REȘIȚA
ANUL XVIII, NR. 3, 2013, ISSN 1453 - 7394

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About the Study of the Bus Structure Behavior in Case of Rollover, Using Numerical Simulation

The objective of this paper is the highlighting of the main aspects that be considered in study of the bus structure behavior in case of roll-over, using numerical simulation of this real situation. In first part of the paper are presented, briefly, the general framework and the reference documents governing the mechanical protection of the passengers in case of the bus rollover. Next, the main parameters defining the numerical simulation of rollover bus are analyzed. Also is analyzed the influence of these parameters on the accuracy of the numerical results obtained by simulation. In this context, are given the necessary information to correctly modeling the reality so that the results to have an imposed accuracy.

Keywords*: Bus structure behavior, bus roll-over, numerical simulation*

1. Preliminary

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 a 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*.

Because of its importance, this area is governed by a series of regulations and standards: in the European Union and other countries apply 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 security.

2. Simulation types for bus structure behavior 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 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's 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:

- Limited simulation: simulation of bus structure behavior under the action of shock loads from rollover, using *only the virtual model of passenger compartment structure*;
- 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).

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 structural member which strikes the ground in the first moment of shock and magnitude of the force acting to this structural member for overturned position of the machine. Typically, these physical quantities are results of a preliminary calculation.

A convenient approach to determine the speed of the structural member which strikes the ground in the first moment of shock is to consider energy conservation.

Figure 1 shows the calculation scheme to determine the speed above mentioned, in case of bus rollover.

The calculus scheme shown in Figure 1 considers that the bus rollover is produced by free rotation around a longitudinal axis A and starts when center of gravity of the bus (G) and the axis A are in the same vertical plane. In the lateral overturned position, the bus rests on the ground along the axis A and axis B, containing the topmost edge of the bus structure.

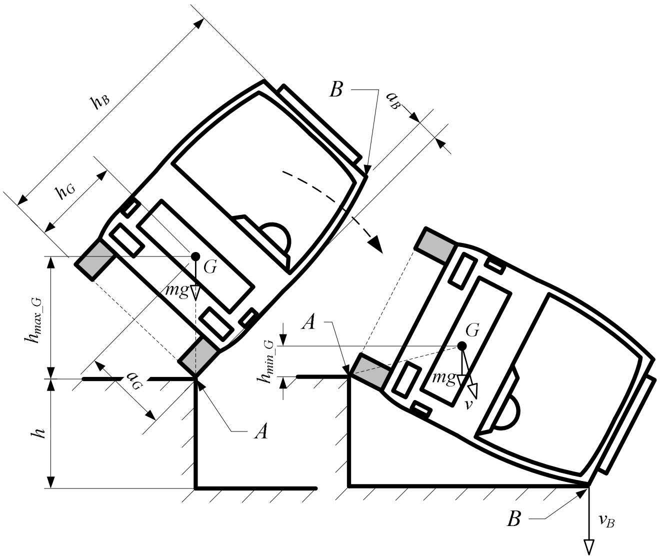

Figure 1. Calculus scheme for speed of bus structure in first moment of the impact

In Figure 1, m means the total operative mass of the bus. This includes the mass of the passengers and the bus mass, having tank full.

Based on the law of energy conservation, the energy of the bus having total operative mass, at the beginning of the rollover, is equal to the energy in first moment of impact.

Under this condition, with the notations used in Figure 1, we can write

$$mgh_{\max\_G} = mgh_{\min\_G} + m\frac{v^2}{2}, \tag{1}$$

resulting from this that the velocity v is

$$v = \sqrt{2g(h_{\max\_G} - h_{\min\_G})}. \tag{2}$$

At the impact moment, speed of the topmost structural member of ROPS is

$$v_{impact} = v_B = v \cdot \frac{dist_{(A,B)}}{dist_{(A,G)}} \tag{3}$$

where

$$dist_{(A,B)} = \sqrt{h_B^2 + (a_G - a_B)^2} \tag{4}$$

$$dist_{(A,G)} = \sqrt{h_G^2 + a_G^2} \tag{5}$$

After determining the impact speed v_{impact}, it is possible to performing limited simulation. In this context it simulates a mechanical event which takes into account only the virtual model of the bus structure*, having mass of the whole system*.

Extensive simulation can consider the entire process of rollover of the bus, or a part of this process, prior to the impact.

If the entire process of rollover is considered in the simulation, are not required any preliminary calculations, because all forces in the system, during the simulated event, are caused by gravitational field and motion.

If in simulation is considered only a part of the rollover process, it is necessary to assign to model an appropriate initial angular velocity ($\omega \neq 0$), corresponding to the simulation start time.

Obviously, the second way is recommended because it shortens the time required to solve the numerical model and also it is possible to move the focus of the analysis on the phenomena which occur during the shock.

3. Preprocessing parameters with decisive influence on the precision of the results which are obtained in numerical simulation of rollover

The obtaining of the results with an acceptable accuracy level in the numerical simulation for the rollover of the bus structures is conditioned to their proper modeling. In this context, the essential modeling aspects are discussed below.

- Geometry of the structure.

In general, a FEA program includes a graphical engine for generating of the structure's geometry which will be analyzed. However, the current trend is to generate the geometry of the structure outside the FEA program, in a specialized CAD program. Then, geometry is imported in FEA program using a standard graphics format.

It is recommended that ROPS geometry to be generated using parameters so any changes dictated by ensuring the imposed conformity to can be made easier.

- Selection of the correct finite element type.

Usually, this selection is made to best represent the geometry and type of analysis required. The finite elements may also contain mid-side nodes for models that are expected to experience bending.

In general, the bus structures are frameworks which are made from rectangular or circular pipes. Given this, for the mesh associated to the structure is recommended to use bi-dimensional finite elements. Thus is avoiding excessive schematization of the structure, when using one-dimensional finite elements, or excessive great models having needs to expensive resources when using three-dimensional finite elements.

- Choosing the correct material models

This phase has a decisive influence in obtaining the accurate results.

The most commonly used material in making of the bus structures is steel with breaking tenacity.

Should be noted that shock load that occurs in a rollover event is likely to cause permanent deformations in structure. Therefore, the numerical simulation will have the appropriate settings in terms of considering the large deformations and the solving method. Therefore, in FEA packages, for steel materials, if large displacements are possible and the stresses may exceed the yield stress, according to the type of material, will choose a bilinear model.

- Simulation parameters

It is advisable to specify the appropriate *length of time* which would be observed in simulation of the event. Additionally is specified the *number of steps* to take per second to calculate the displacements and stresses over time.

Also, it is advisable to specify the appropriate load curves that will be used to scale the magnitudes of all of the loads during the analysis and any acceleration field if necessary.

It is necessary, specify the location of all *contact surfaces*, so that when solving model can be correctly detected all areas of impact.

Last, but not finally, very important for an acceptable accuracy of the results is the specification of the *convergence criterion* and the *corresponding tolerance*. Usually, convergence criterion is "displacement only" and corresponding tolerance is "displacement tolerance". The dynamic nature of mechanical event simulation requires that Newton's Second Law be applied throughout the event. Equilibrium iterations are required to enforce observance of this law.

Convergence is achieved when the equilibrium residual is below the displacement tolerance value. A displacement tolerance is used because the system of equations solved is in terms of displacements. The small tolerances will lead to accurate results, but to large time analysis. In such situations, one approach that can be helpful is to perform a trial analysis with the convergence tolerance relaxed. This type of trial analysis will likely reaches completion and run faster than an analysis with a tighter convergence tolerance. Thus, it is possible to spot any modeling problems and identify areas of greatest stress concern where the finite element mesh should be refined.

4. Advantages and disadvantages of numerical simulation of the behavior bus structures in case of rollover

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 the experimental installations and of the phisical model of the tested structure.
- Numerical simulation allows 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.

5. Conclusions

Even with reserve of the disadvantages which are presented in the previous paragraph, numerical simulation of mechanical structures behavior is, today, a very powerful tool for the 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 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 the structure that was used for validation.

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