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Experimental Research of the Behavior of a Bus Structure in Case of Rollover

The article highlights the main aspects to be considered in the experimental research on behavior of a bus structure in case of rollover. In this context, are presented the experimental procedure, the experimental objectives, the imposed measurements and the obtained results. In the final part of the article are presented some observations and conclusions of the authors.

***Keywords**: Experimental research, structure behavior, bus rollover*

1. Preliminary

Public transport or public transit is a term that means a shared passenger transport service which is available for use by the general public, as distinct from modes such as taxicab, car pooling or hired buses which are not shared by strangers without private arrangement.

Public transport modes include buses, trolleybuses, trams and trains, rapid transit (metro/subways/undergrounds etc) and ferries. Public transport between cities is dominated by airlines, coaches, and intercity rail. High-speed rail networks are being developed in many parts of the world.

Below are presented the main advantages of public transport compared to private transport, and some comments on them.

- Reducing air pollutant emissions and fossil fuel consumption. In this context, the using of the public transport can result in a reduction of an individual's carbon footprint. A single person, 35 km-round trip by car (e.g. home to work and work to home) can be replaced using public transportation and result in a net CO_2 emissions reduction of as much 2400 kg/year, **Eroare! Fără sursă de referinţă.**. Using public transportation saves CO_2 emissions in more ways than simply travel as public transportation can help to alleviate traffic congestion as well as promote more efficient land use. When all three of these are considered, it is estimated that 37 million metric tones of CO_2 will be saved annually. Another study claims that using public transport instead of private in the U.S. in 2005 would have reduced CO_2 emissions by 3.9 million metric tones and that the resulting traffic congestion reduction accounts for an additional 3.0 million metric tons of CO2 saved, [2]. This is a total savings of about 6.9 million metric tones per year given the 2005 values.

A 2002 study by the *Brookings Institution* and the *American Enterprise Institute* found that public transport in the U.S uses approximately half the fuel required by cars, SUV's and light trucks. In addition, the study noted that "*private vehicles emit about 95 percent more carbon monoxide, 92 percent more volatile organic compounds and about twice as much carbon dioxide and nitrogen oxide than public vehicles for every passenger mile traveled*", [3].

- <u>Public transport is more efficient than private transport in terms of energy consumption.</u>

In order to compare energy impact of public transportation to private transportation, the amount of energy per passenger mile must be calculated. The reason that comparing the energy expenditure per person is necessary is to normalize the data for easy comparison. Here, the units are in per 100 p-km (person kilometer). In accordance with [4], in terms of energy consumption, public transportation is better than individual transport in a personal vehicle. For instance, for busing in London, it was 32 kWh per 100 p-km, or about 2.5 times better than a personal car. This includes lighting, depots, inefficiencies due to capacity (i.e., the train or bus may not be operating at full capacity at all times), and other inefficiencies.

2. Essential safety requirements imposed on buses. Standards in this domain

Because of the significant advantages of public transport relative to private transport, it is expected that in the near future to increase the share of public transport. In this context it is important to mention that in the European Union will be taken action to encourage and facilitate public transport to the detriment of private transport.

A large part of the public transport is done with vehicles belonging to the buses class (buses, trolleybuses, coaches). As a result, increases the probability of the buses involvement in traffic accidents. The involvement of a bus in a traffic accident shows a higher risk than a car involvement due to the substantial number of people which are carrying with the bus. In these circumstances, one of the main performance requirements imposed on a bus is the requirement to ensure safety of passengers. Are two types of security that can be ensured by a bus for the inside people: *active safety* and *passive safety*.

Among the most significant functional characteristics of the buses, with a role in increasing the performance of active safety which is ensured to the inside people are:

- reducing the braking distance and simultaneously increasing of the bus stability, even under braking at the high speeds by increasing the tires adhesion;
- judicious distribution of the braking torque to the wheels and avoiding them blocking;
- ensuring the behavior autonomy of the bus steering, for different load levels and different road conditions;
- increasing the vehicle stability at high speeds in conditions of some external perturbations such as side wind action, taking into account the aerodynamic aspects and the transient processes occurring in tires with low rigidities;
- reducing of the aquaplaning effect.

The performance of the passive safety which is ensured by a bus is an essential characteristic. Mainly, passive safety which is ensured by a bus can be characterized by capacity to resist to mechanical shock loadings of its structure. Also, the deformed structure must ensure a minimum volume inside the bus, called survival space. In this respect, it is considering the possible traffic situations, which may produce a shock loading of the bus structure: *collision* (front collision, side collision, rear collision) or *rollover*.

Among the most significant functional characteristics of the buses, with a role in increasing the performance of passive safety which is ensured to the inside people are:

- the bus structure capability to absorb the impact energy on various directions;
- the existence and efficacy of occupant restraint systems (seat belts, airbags, etc.);
- the shape and dimensions of the interior space of the bus, so that, in case of impact, the bus deformed structure ensure a deflection limiting volume (survival space);
- the steering capability, as in a collision does not move to the interior of the vehicle and to ensure a large dissipation of the energy shock;
- minimal risk of fire.

Although active safety performances of the buses have an important role in mitigating the effects road traffic accidents involving buses, they are not imposed by rules or regulations. This because, being functional performances of the buses, having influence on their competitiveness, these performances are, firstly, the priority objectives of the bus manufacturers.

In contrast with the active safety performance requirements, the passive safety performance requirements are imposed by regulations.

The main standards available internationally on passive safety requirements imposed on vehicles in bus class, are the following:

- ECE Regulation R 66 - *Standardized Specifications for Approval of Motor Coaches with Respect to the Stability of Their Structure*;

- ECE Regulation R 80 - *Standardized Specifications for Approval of Seats in Motor Coaches and of These Vehicles with Respect to the Stability of the Seats and Their Anchoring*;
- FMVSS 209 - *Seat Belt Assemblies*;
- FMVSS 210 - *Seat Belt Assembly Anchorages*;
- FMVSS 213 - *Child Restraint Systems*;
- FMVSS 217 – *Bus Emergency Exits and Window Retention and Release*;
- FMVSS 222 - *School Bus Passenger Seating and Crash Protection*;
- FMVSS 225 - *Child Restraint Anchorage Systems*;
- FMVSS 303 – *Fuel System Integrity of Compressed Natural Gas Vehicles*;
- SAE J2249 - *Wheelchair Tiedown and Occupant Restraint Systems for Use*;
- CSA D250-07 - *School Bus Safety*;
- ADR 59/00 – *Standards for Omnibus Rollover Strength*.

In Europe, as well as in a significant number of non-European countries, apply the provisions contained in ECE R66 Regulation and ECE R80 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.

There are also countries where is not applied any standard which refers to passive safety of the buses (e.g. some Asian countries), countries where serious bus accidents have a higher incidence.

3. The severity of bus accidents

As noted above, the main types of bus accidents are accidents caused by collision (frontal collision, side collision or rear collision) or rollover.

The severity of bus accidents is characterized by the number of people who have suffered serious injuries and the number of deaths due to accidents.

The statistics show that although most numerous bus accidents are caused by the frontal collision, however, the most dangerous are those produced by rollover of the bus.

If we consider the case of U.S. school transport, a study conducted by the National Center for Statistics and Analysis, the United States, during 11 years (1998-2008) there were 95,312 bus accidents, of which 1409 were accidents involving school buses. In these accidents have died 1564 people of which 1126 (about 72%) were occupants of the buses. Dividing the number of the occupant fatalities to the total number of the bus accidents is obtained an average of approx. 0.8 victims / 1 bus accident.

The same report mentions that during the same period there were a total number of 376 accidents produced by lateral rollover of the buses. These accidents have caused 339 fatalities (about 0.9 victims / 1 bus accident).

Similar results can be obtained by analyzing the statistical data recorded and in other countries.

As a result, we can formulate the following conclusions:

- the most dangerous bus accidents are caused by rollover;
- the most dangerous bus accidents which are caused by the collision are those caused by frontal collision, followed by those caused by lateral collision and those produced by rear collision.

4. Case study: roll-over a bus structure

The experimental research aimed the behavior a bus structure in the case of lateral rollover. The experimental research has complied with the requirements of ECE R 66 Regulation, [5].

In accordance with ECE Regulation R66, the study of bus structure behavior in case of lateral rollover is made by overturning of the bus around an axis parallel to the longitudinal axis of the machine (axis A, see fig. 1). The impact occurs with a surface having hardness at least equal with hardness of the road. Height from surface impact to the rollover axis is $h = 800\,mm$.

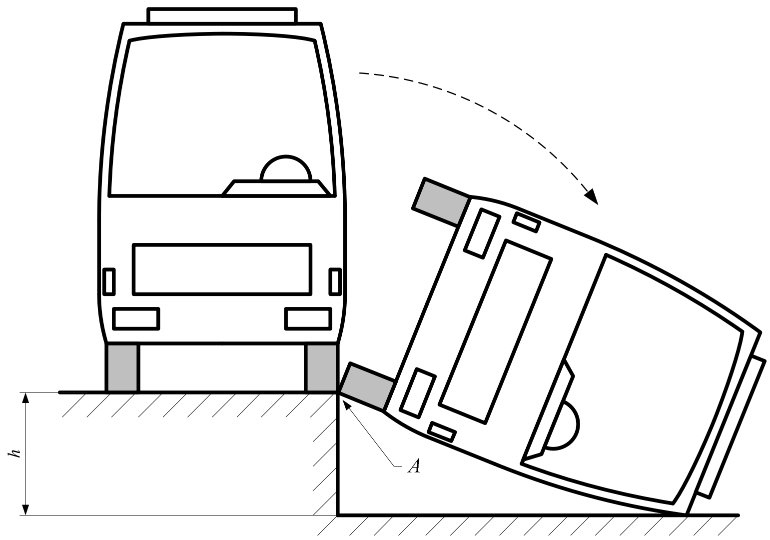

Figure 1. Rollover test in accordance with ECE Regulation R66

The purpose of the experimental test was to determine deformations of the bus structure after rollover and to check if there are penetrations in the survival space.

The survival space looks like a prism having symmetry with respect 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 2 is showed the cross-section through the survival space and its position inside the bus.

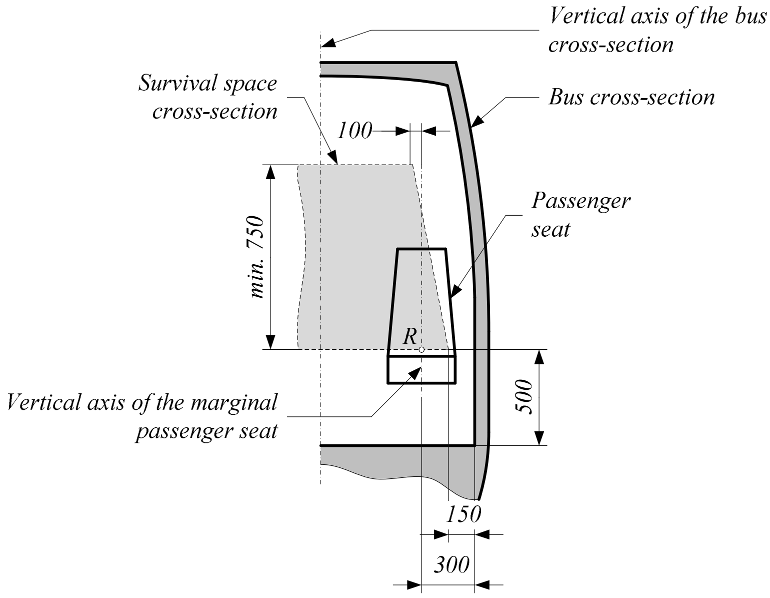

Figure 2. The survival space

The determination of deformation of the bus structure after the rollover test was based on d_1 and d_2 distances, measured before and after test. Were considered 12 distances d_1 and d_2, which were measured in the perpendicular planes to the longitudinal axis of the bus, between B and C axes and the edge of a rectilinear longitudinal piece fixed on the bus floor (see Fig. 3). The measurements points for DD1 and DD2 distances were placed equidistant ($230\,mm$) along the length of the interior space designed for bus occupants.

The experimental procedure had the following steps:

- the measuring of the distances d_1 and d_2 on the undeformed bus structure;
- the pivoting around the axis A of the bus until center of gravity is in the vertical plane containing the axis A;
- the releasing of the bus which perform a free rotation around the axis A;
- the measuring distances d_1 and d_2 on the deformed bus structure.

Before rollover test, was determined the rotation angle (α) of the bus with respect axis A, so that the vertical line passing through center of gravity of the bus is in the vertical plane containing the rollover axis. For this, the bus was rotated to the position corresponding to unstable equilibrium, and, after it, the angle α was measured using an inclinometer.

After completing the experimental sequence described above, resulted $\alpha \cong 41^{\circ}$

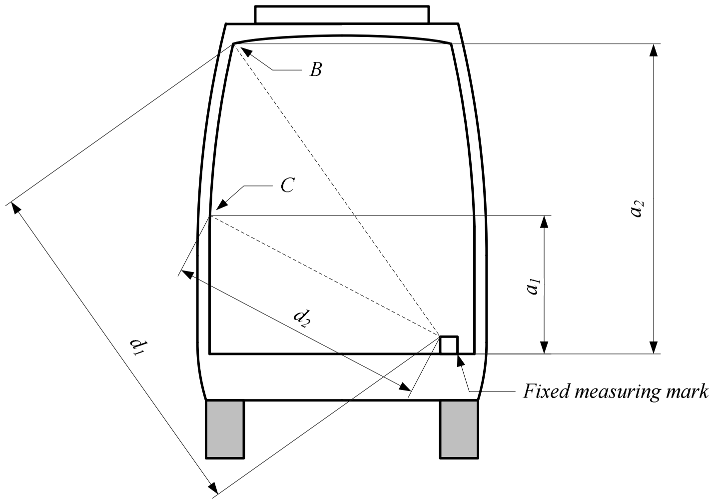

Figure 3. The measured lengths before and after experimental test

The experimental results are shown in Table 1.

Table 1. Experimental results

	Before test				After test			
	a_1 [mm]	a_2 [mm]	d_1 [mm]	d_2 [mm]	a_1 [mm]	a_2 [mm]	d_1 [mm]	d_2 [mm]
1	730	1295	1670	1485	725	1260	1622	1445
2							1625	1451
3							1625	1450
4							1624	1452
5							1621	1452
6							1618	1456
7							1620	1457
8							1618	1450
9							1615	1448
10							1616	1445
11							1616	1438
12							1609	1437

The distances a_1, a_2, d_1 and d_2 were measured with an error of $\pm 3\,mm$.

In figure 4 is showing the bus structure subjected to rollover test before and after rollover.

Figure 4. The tested bus structure before and after experimental test

5. Conclusions

The study of the behavior of bus structures in case of rollover is a high priority in demarche to ensure the imposed passive safety for bus occupants. The processing of experimental results obtained in experimental research described in the previous paragraph, shows that the bus structure under test ensure the survival space imposed, after deformation produced by rollover.

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