General survey of bus frontal collisions: is regulation needed?

M Matolcsy
Scientific Society of Mechanical Engineers (GTE), Budapest, Hungary

Abstract: This paper tries to collect the main technical problems related to bus frontal collisions, showing examples from everyday practice. This is a general survey about the frontal collisions of buses and does not go into details in the individual subjects. The possibility and the necessity of international regulations is shown, but further studies are required to know how to do it.

Keywords: bus, frontal collision, occupant protection, driver compartment

1 TYPES OF HEAD-ON IMPACT ACCIDENTS

There is no one unified (standardized) categorization of bus frontal collisions, on the basis of which the question of international regulations could be discussed. There are different approaches based on different points of view. Let us mention four aspects, which should be cleared up in the future and should be used in the same way for accident statistics and for accident analysis.

1.1 Direction of impact load

When a bus hits another vehicle or any kind of object, the impact load on the front wall of the bus has a certain direction related to the longitudinal centre plane of the bus. This direction can be considered in an angle range of $\pm 45^\circ$. If this angle is considerable (e.g. more than $\pm 20^\circ$) it means in practice that the two side-corners of the front wall are hit by the impact load having this direction. Figure 1 shows examples of these kinds of collisions having a certain angle, acting on the side-corner of the driver's compartment (DC).

1.2 Partial or full head-on impact

The suggested categorization is based on the locality (or totality) of the head-on impact. The following categories can be discussed:

1. Total head-on impact, when the bus hits a wall, or wall-like solid object, or the front of a heavy commercial vehicle. Figure 2 gives examples of the result of this kind of collision. In this case the whole front wall is damaged and deformed, kinetic energy is absorbed by the whole bus front, mainly by the longitudinal beams of the underframe structure.
2. Partial (offset) impact on the DC. The final 'result' is very similar whether this impact comes at a certain angle or parallel to the centre plane of the vehicle (see Fig. 3). This offset impact can influence the DC to its total height or be concentrated below the windscreen (see Fig. 4(b)).
3. Partial (offset) impact on the door side of the bus front (see Fig. 4(a)).
4. Partial impact with a pole-like object (see Fig. 5). This is a special kind of impact because of the type of object. It can be central, left, or right side impact.

1.3 The involved persons

Two basic approaches are used in accident statistics (sometimes they are mixed):

1. Only the bus and its occupants (driver, passengers, crew) are considered in the statistics when the casualties are mentioned.
2. The partner vehicle involved in the accident (and also its occupants) is also considered.

This second approach raises a special issue, the aggressivity of the buses against the partners. But the partners are not forming a homogeneous group (pedestrians, bicycles, motorcycles, cars, etc.) so there are different concepts for aggressivity. Figure 6 gives examples:

(a) having bull bar on the front wall, the bus is very aggressive against every kind of partner;

The MS was received on 10 March 2003 and was accepted after revision for publication on 9 March 2004.
** Corresponding author: Scientific Society of Mechanical Engineers (GTE), 1371 Budapest, PO Box 433, Hungary.*

Fig. 1 Frontal collisions having a certain angle on the side of driver's compartment

Fig. 2 Full head-on collisions when the impact load has no angle

Fig. 3 Partial impact on the driver compartment (DC)

(b) completely smooth front wall could be good against pedestrians and bicycles;
(c) a special safety (rubber) bumper could be good against motorcycles and cars.

1.4 Simple or combined frontal collisions

In the simple frontal collision the bus hits another object (vehicle) and it stops on the road having suffered damage and caused personal injuries. The combined collision is not finished by the (first) frontal collision, but further events are happening, e.g.:

(a) the bus catches fire and burns out;
(b) the bus rolls over;
(c) the bus runs away and hits other objects, etc.

The statistical (and even technical) analysis of these combined accidents is very difficult. It is difficult to separate the origin of the different kinds of damage and injuries.

Fig. 4 Partial (offset) head-on collisions when the impact load has no angle

Fig. 5 Impact with a pole

Fig. 6 Different front wall and bumper concepts: (a) bull bar; (b) smooth front wall; (c) safety bumper

2 THE DRIVER–PASSENGER INJURY RATE BASED ON ACCIDENT STATISTICS

The statistical data collected and referred to below are not the result of one detailed statistical analysis. These references underline the need for some international regulations on this specific field and support the importance of the questions raised in this paper.

During 1975–76 we have analysed 82 accidents in detail amongst the reported 910 bus accidents in Hungary during these two years [**1**]. Only those bus accidents were considered in which bus occupants were injured and the bus itself had considerable damage. The rate of the head-on impact was 52.5 per cent. In roughly half of the accidents the DC received considerable damage (26.3 per cent) The direction of the impact load on the DC was partly angular (15 per cent) and offset (11.3 per cent).

Another Hungarian statistic covers 1803 bus accident during the years 1978–82 involving all the events where people were injured or killed [**1**]. In the majority of the accidents (82.7 per cent) the partners were mainly in the 'victim position':

1. Running over pedestrians 27.7 per cent.
2. Collision with bicycle and motorcycle 27.3 per cent.
3. Collision with car and van 27.7 per cent.

Only 13.3 per cent of the total number represented collisions with other heavy vehicles or rigid obstacles. Considering the collisions with cars and vans, too (altogether 41 per cent) in this sample the head-on impact of buses has a rate of 57.2 per cent, which is close to the earlier figure (52.5 per cent). The 'result' of bus collisions with heavy vehicles (219 events) was altogether: 21 fatalities, 163 serious injuries, and 529 light injuries. There are some other publications for other types of vehicle (vans, trucks) that show a similar rate for frontal collisions. The statistical data show that there are two dangerous types of bus accident:

1. The rollover, which is rather rare (3–6 per cent), but has a very high rate of fatalities and serious injuries.
2. The frontal collision, which happens very often (55–60 per cent), therefore the total number of fatalities and injuries is very high.

While there is an international regulation already in force (ECE R.66) for the rollover of buses, there is no regulation dealing directly with the frontal collision of buses.

The accident statistics underline a very important problem: the vulnerable position of the driver in the case of frontal collisions. Japanese bus accident data from 1992–94 regarding large buses over 12 tons and including only the bus occupants [**2**], show the following data (see Table 1). These figures are recalculated and regrouped from the original data in line with the objective of this paper.

Comments. The number of uninjured persons in these accidents was around 4000, compared to the total number of casualties (4816). As a first approach we may assume that the average passenger capacity of a bus (coach) is around 50 and the buses involved in these accidents were nominally (fully) loaded. That means 1 driver belongs to 50 passengers. Assuming that the injury probability of the passengers is equal in case of frontal collision, independent of their seating position, the injury rates between the driver and passengers (D/P rate) can be calculated. The D/P rate for fatalities is extremely high, presumably due to the relative low number of fatalities. In this case one or two events may strongly influence this rate. There are some other bus and coach accident statistics—unfortunately only for all kinds of bus accident together [**1**, **4**, **5**]—which may be fitted into this analysis. Table 2 shows these D/P rates. The Japanese figures show that the serious drivers' casualties are caused mainly by frontal collisions. The D/P injury rate for frontal collisions may be estimated from the D/P rate of all accident using a multiplier 1.5. This seems to be a realistic

Table 1 D/P injury rates from Japan

	All kind of bus accidents		Frontal collisions only	
Type of injury	Number of driver/passengers	Injury rate	Number of driver/passengers	Injury rate
Fatality	5/3	83 : 1	5/2	125 : 1
Serious injury	23/85	13 : 1	22/60	18 : 1
Light injury	564/4136	7 : 1	259/2849	4 : 1

Table 2 D/P injury rates from different statistics

	All types of bus accident				Frontal collisions only
Type of injury	Japanese	Spanish	German	UK	Japanese
Fatality	83 : 1	6 : 1	8 : 1	5 : 1	125 : 1
Serious injury	13 : 1	2 : 1*	10 : 1	4 : 1	18 : 1
Light injury	7 : 1		6 : 1	3 : 1	4 : 1
Total number of casualties	4800	2400	4500	234.616	3200
Time of observation	1992–94	1984–88	1979	1971–92	1992–94

Note: *The Spanish statistic does not separate serious and light injury.

value. The conclusion of these figures is that the driver's vulnerability is very high in frontal collision, the D/P fatality rate is between 10 and 100, and the D/P rate of serious injury could be in the range of 8–20.

3 IMPORTANT SAFETY PROBLEMS IN FRONTAL COLLISIONS OF BUSES

Analyzing the accident statistics and types of bus frontal collisions, some technical safety aspects can be underlined. These subjects may be targets of international regulations in the future. It is interesting to compare these issues to the regulations of other types of vehicle.

3.1 Protection of the driver

The most dangerous impact situations for the driver are the partial impacts on the DC. The impact load—as discussed above—may have an angle or may be parallel to the longitudinal centre plane of the vehicle. The impact load may act along the total height of the front wall or only in a certain height range. A special impact load is produced by a pole-like object. When analyzing a hit on the DC, three basic things need to be considered:

1. The stiffness (load bearing capability) of the DC is much higher (by one or two orders) under its floor level than above it.
2. The stiffness of the DC rapidly decreases with the increasing angle of the partial impact.
3. The position of the DC in height ('h' is related to the road level) may vary widely which means the floor height of this compartment (under the driver's seat) may alter between 600 and 1300 mm. Examples are given in Fig. 7, starting from low-floor buses up to high-floor coaches.

'1' and '3' are natural consequences of the arrangements of the DC, which should be considered when working on regulations. But '2' may be changed or developed in the future, to provide a semi-uniform protection for the driver, independent of the direction of the impact. To protect drivers in the DC means the following:

(a) defining certain accident situations (standard accidents);
(b) providing a well-defined survival space into which no structural elements penetrate during the collision and during the structural deformation and damage;
(c) keeping the driver in this survival space during the collision; and
(d) avoiding unacceptably high biomechanical loads on the driver when restraining him or her.

3.1.1 Standard accident situations

To define appropriate accident situations is not very easy. First of all it is necessary to emphasize that in the case of a high-speed partial frontal collision, hitting the DC, the total kinetic energy is not absorbed by the DC itself:

1. Hitting a car or van the bus pushes this vehicle and the kinetic energy of the bus is absorbed—beyond the deformation work of the DC—during further motion of the two vehicles (braking energy, friction work) and by the deformation work of the car or van.
2. Hitting another similar heavy vehicle, both vehicles have further motion with changed direction and the other vehicle also endures serious structural deformations.
3. Hitting a rigid wall at a certain angle the bus runs away in a changed direction. Figure 8 shows a test in which the bus behaved in this way.

Fig. 7 Different height position of DCs: (a) h = 550–600 mm; (b) h = 950–1000 mm; (c) h = 1250–1300 mm

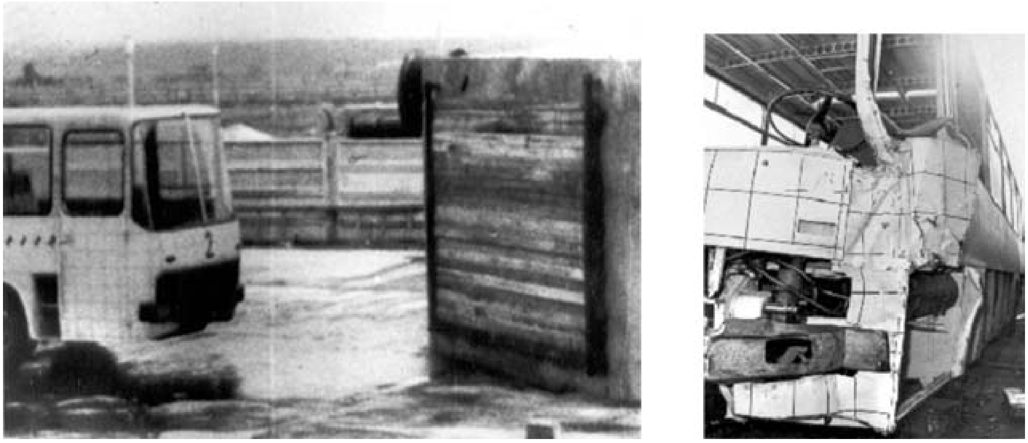

Fig. 8 Frontal collision test with an impact angle of 45° (impact speed 35 km/h)

4. Hitting a pole-like object; the pole itself absorbs a certain amount of energy and the bus may also have certain further motion when the pole breaks down.

The conclusion of this brief analysis shows that although the energy absorbed by the DC depends on the impact speed, this function is not progressive (second degree, quadratic), but a degressive one and may not be directly derived from the total kinetic energy of the bus. To determine those accident situations in which the survival space would be protected in the DC, the following should be considered:

(a) the direction of the impact load: parallel load and/or under an angle of 45°;
(b) dynamic or static load may be used when testing the DC;
(c) the magnitude of the load (force, impact energy);
(d) the geometry of the loading device (extent, form);
(e) the position of the loading device (related to the ground level or floor height of the DC).

3.1.2 *Survival space*

The survival space means the minimum room in which the driver has a high-level probability to survive the frontal collision without serious injury. No structural parts may intrude into this space as a consequence of the collision. The volume of this space depends on the extent of the driver's body (e.g. 95 per cent representation of the driver's population) and also on the restraint system of the driver, which allows a certain, limited motion of the driver. The major difficulty when defining the survival space is caused by the steering column and wheel, which are already in every survival space before the frontal collision, but their deformation and displacement can cause serious injury to the driver. Figure 9 shows this problem clearly: the dashboard, the instrument panel, the waist rail under the windscreen, the foot plate, etc. have penetrated into the survival space; the steering column and wheel were there originally, but had an unacceptable displacement and penetrated into the driver's body.

3.1.3 *Restraint system for the driver*

To keep the driver in the survival space requires the use of a restraint system. This system today is a 3-points seat belt, which is fixed to the driver's seat. Hopefully, in the future, airbag systems will be developed for bus drivers

Fig. 9 Loss of the residual space and motion of the steering wheel

too. There is no international regulation for a driver's seat to be equipped with a seatbelt and no international requirements on how to check the biomechanical limit loads on the driver.

We have developed a very effective method [**1**, **3**] to ensure the survival space for the driver. This is the concept of the safety platform. It is a very effective tool to pull out the driver from the deformed zone of the DC, but on the other hand the biomechanical loads on the driver may be increased by this method. This calls attention to the fact that driver protection is a rather complex problem and any kind of decision should only be taken very carefully.

3.2 Protection of the passengers

There are three major issues relating to this subject. Different accident situations need be considered here also.

3.2.1 Passenger restraint system

There is only one UN-ECE regulation that is related to the frontal collision of buses. Reg. 80 deals with the strength of passenger seats and their restraining effect in case of a certain frontal collision. These requirements are based on a 'standard' frontal collision, a total head-on impact against a rigid wall, where the impact speed of the bus is in the range of 30–32 km/h and the deceleration pulse is inside a given range, having an average value in time 6.5–8.5 g. However, there is no requirement or regulation to prove whether the real bus on which the passengers are travelling provides the described deceleration pulse or a more severe one when hitting a concrete wall with a speed of 30 km/h. This is a gap in Reg. 80. The shape of the deceleration pulse depends on two things, if the impact speed is standardized:

1. The stiffness of the wall (or any other kind of object) that is hit by the bus. This can be standardized for approval tests.
2. The longitudinal stiffness of the bus, which is determined mainly by its underfloor structure. Chassis-type buses (having thick longitudinal U beams) are more rigid than monocoque structures having lattice longitudinal beams or than shell-type bodies.

3.2.2 Evacuation possibility

Almost every large bus has a service door in the front overhang. There are a large number of buses that do not have another service door, only the front one. Although there is a requirement for emergency exits (emergency door, window, escape hatch), the best and easiest way to evacuate a bus is through the service door. As Fig. 10 shows, in many frontal collisions—even if it is a slight one on the door side—the front service door and its frame receives such severe damage that it is impossible to open it. Therefore, it is an obvious requirement that if the bus has only one service door and it is located in the front overhang then it should have a certain resistance against an offset impact load and afterwards be easy to open by hand.

3.3 Protection of the crew

The crew—mainly on long distance and tourist coaches—has a special seat, generally close to the front service door. Crew protection means two essential tasks:

1. To assure a certain survival space for the crew, which could be an interesting task considering the seat location as shown in Fig. 11.
2. To keep the crew and the crew seat in the original position.

Fig. 10 Distortion of front service doors


Fig. 11 Special position of crew seat

It will be noticed that the crew seat position shown in Fig. 11 is strongly related to the problem of evacuation, too.

3.4 Protection of the partners

Two very important groups of problems belong with this subject.

3.4.1 Underrun protection

The mostly plastic bumpers and the thin plates of the front walls cannot prevent a car underrun. The longitudinal beams of the bus underframe structures may behave in this case like a knife, ‘cutting’ the car. In the case of buses there are two other aspects: where the DC is in a very low position, the underrun protection means DC protection, too, and many times the underrun protection means the protection of vitally important control devices.

Earlier we thought that the safety bumper of the bus could protect the bus itself. After some laboratory tests and a full-scale frontal collision test (see Fig. 12), we concluded that the safety bumper can only be effective at very low speeds (5–7 km/h). Now we know that the goal of developing and using safety bumpers on buses is to avoid car underrun and to reduce bus aggressivity against smaller vehicles.

3.4.2 Reducing aggressivity

The aggressivity of a bus against other partners on the road depends on the following:

1. The total mass of the bus (the mass ratio between the bus and its partners).
2. The impact energy represented by the bus when it is in motion (it has a certain speed).
3. The stiffness of the bus at the contact area of the collision, in the direction of impact load (the stiffness ratio between the bus and its partners).
4. The geometry and surface of the contact area of the collision.
5. The compatibility of the protective devices (e.g. bumpers) of the partners.

The aggressivity and compatibility of cars is well investigated these days.

3.5 Protection of control devices

A lot of very important control devices are located under the DC, such as: steering gear and steering mechanism, brake pedal and main brake valve with compressed air piping (sometimes air reservoirs, too), elements of front suspension, etc., and also on the side wall of DC, the main electric panel and electronic control devices. Figure 13 shows the results of frontal accidents from this point of view. The problem is as follows: if these

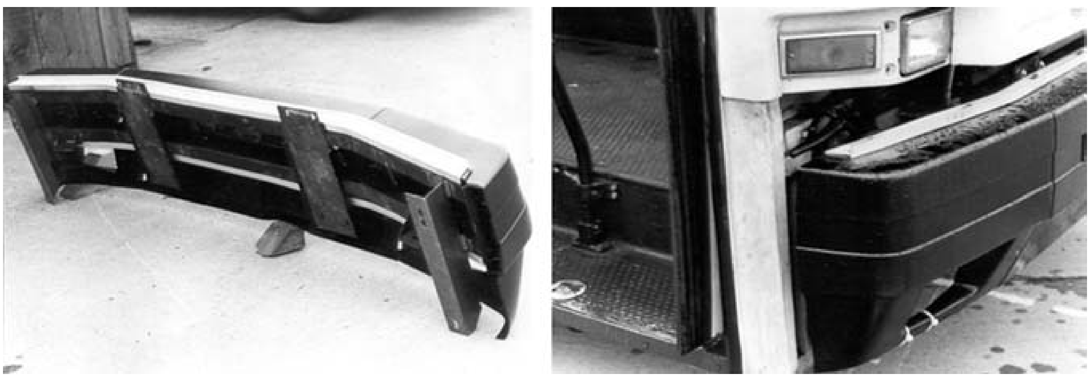
Fig. 12 Front impact test with safety bumper

Fig. 13 Damage of control systems and units

control units and elements are not well protected, even in the case of a smaller accident (head on collision, car underrun) in which the casualties would be negligible, but the driver cannot control the further motion of the bus, which then runs into a more severe accident situation. This is a very interesting safety issue and it has to be decided where and how to specify the approval test: together with the DC or with the underrun protection.

4 EXISTING INTERNATIONAL REGULATIONS RELATED TO THE FRONTAL IMPACT OF OTHER VEHICLES

The UN-ECE vehicle regulations are competent for the future development of vehicles. Among these regulation (today, altogether, 113) there are only two (Reg. 16 and Reg. 80) that are connected to the frontal impact of

Table 3 ECE regulations related to frontal collision of different vehicle categories

No. of the reg.	Subject of the regulation	Scope of the reg.	Remarks
Reg. 12	Protection of the drivers against the steering mechanism in the event of impact	M_1 and N_1 below 1500 kg	Dynamic impact test (48 km/h and 24 km/h) without dummy against rigid barrier. Requirements for the motion of steering wheel and force limitation
Reg. 16	Safety belt and restraint systems. Vehicle equipped with safety belt	Used in all kind of vehicles	All kind of safety belts and belt anchorage systems
Reg. 17	Seats and their anchorages and head restraints	M_1	Geometrical and functional requirements, also strength requirements against static load
Reg. 26	External projections of vehicle	M_1	Surface requirements (geometrical and hardness) to reduce the aggressivity of cars
Reg. 29	Protection of the occupants of commercial vehicle cab	Trucks (N_3)	Dynamic tests for front wall and roof of the cab. Survival space is required for the driver
Reg. 33	Structural behaviour of impacted vehicle in a head-on collision	M_1	Dynamic impact test (48 km/h) without dummy. Geometrical requirements and certain limitation of the deformations, door-opening requirements
Reg. 42	Front and rear protective devices (bumpers, etc.)	M_1	Dynamic low-speed test with a rigid impactor, longitudinal (4 km/h) and corner impacts (2.5 km/h). No damage in lighting and signalling devices, fuel system, exhaust system, etc.
Reg. 61	External projection of commercial vehicles	N_1, N_2, and N_3	Dynamic impact test of the car against concrete barrier with dummies. Biomechanical requirements, easy taking out the dummies after test, no fuel leakage, door-opening capability
Reg. 80	Strength of bus seats and their anchorages	Buses (M_3)	Bus passenger seat as a unit may be tested independently and also its anchorages to the body. Static and dynamic test methods may be used for approval
Reg. 93	Front underrun protection	N_2 and N_3	The goal of this regulation is to reduce the aggressivity of the vehicles against pedestrians and weaker partners in frontal collision
Reg. 94	Occupant protection in case of frontal collision	M_1	Geometrical and strength requirements, checked by static test

buses. Table 3 summarizes briefly those regulations that are in connection to frontal impact of different vehicle categories. At first glance it can be established that these regulations do not form a logical system concerning their subjects, scopes, and test methods. It would be a logical question that if we have already certain regulation for cars (and/or trucks) why do we not have them for buses? The regulations in Table 3 and the other arguments discussed in this paper could help us in the future to work out new regulations for buses in the case of frontal collisions. It can be done in three ways:

(a) to work out completely new regulation for buses;
(b) to work out a regulation for buses on the basis of other existing regulations;
(c) to extend the scope of an existing regulation to buses, too.

5 CONCLUSIONS

Analyzing real bus accidents and accident statistics, as well as the existing regulations related to the frontal collisions of other vehicles, the following subjects should be considered for international regulations:

1. Protection of the driver in the DC. Approval of DC for partial impacts.
2. Protection of the crew against total and partial impact, if they have a special seat.
3. Approval of safety bumper. Underrun protection, protection of safety control devices.
4. External protection of bus frontwall.
5. Assuring the deceleration impulse of the seat test. Structural stiffness in total head on impact.
6. Integrity of front service door in partial head-on impact.

REFERENCES

1 **Matolcsy, M.** Crashworthiness of bus structures and rollover protection. In *Crashworthiness of transportation systems*, 1997, pp. 321–360 (Kluwer Academic Publishers, The Netherlands).

2 **Sukegava, Y., Matsukawa, F., Kuboike, T.** and **Oki, M.** Heavy duty vehicle crash test method in Japan. Sixteenth International Conference on *Enhanced Safety Vehicles*, Windsor, Canada, 1998, paper No. 98-94-0-13, p. 7 (NHTSA, Washington, DC).

3 **Matolcsy, M.** and **Molnár, Cs.** Energy absorption and strength problems of bus driver compartment. In Proceedings of Conference on *Vehicle and Science*, Bled, 1979, **1**, pp. 24–39 (JUMV, Bled).

4 **Aparicio, F.** and **Garrcia, A.** Coaches in traffic accidents. A study of the Spanish situation during the years 1984–88. In Proceedings of XXIth Meeting of Bus and Coach Experts, Budapest, 1990, **II**, pp. 3–14 (GTE, Budapest).

5 Driver and passenger casualties. All buses and coaches, 1971–92. Informal Document No. 6 of the sixteenth meeting of GRSG, ECE, Geneva, October 1993 (presented by UK).

