PROTECTION OF BUS DRIVERS IN FRONTAL COLLISIONS

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ABSTRACT

The bus driver is a key person is an accident, he is skilled, he knows what to do, he can operate the systems in the bus, he can help to the passengers, but their fatality/injury risk is 10-100 times higher than that of the passengers. Nowadays there is no international regulation providing any protection for the bus drivers in case of frontal collisions. Based on the technical analysis of real bus head on impacts this paper tries to collect the major issues which may help to develop international regulations in this subject. These are:

- the major accident types, endangering the driver compartment (DC)
- the possible standard accidents which could be the basis of an approval test
- the survival space for the driver, other requirement
- static or dynamic tests? Impact loads (force, energy)
- possible approval test methods

The paper refers to a practical solution, which can help to protect the driver: the principle of the safety platform. A rigid (in its plane) platform is used in the DC with a soft, deformable connection to the frame of the DC. The driver seat, the steering column is fixed to this platform. On the effect of the horizontal impact load the safety platform is pushed back in the DC together with the driver seat and steering column providing the required survival space for the driver.

1. ACCIDENT ANALYSIS AND STATISTICS

The most frequent accident of buses is the frontal collision (head on impact) Many statistics have been already published in this subject, which prove that the rate of the frontal collision is 50-60% related to the total number of accidents. It is very difficult to compare the different statistics, because the basis of their collection and evaluation is different. Some of them considers only those accidents, in which:

a) bus occupants were killed
b) bus occupants were injured
c) people were killed (or injured) involving the partner vehicles and pedestrians, too.

The statistics show that there are two kind of dangerous bus accident:

– the rollover, which is rather rear (2-6%) but it has a very high rate of fatality (and injury)
– the frontal collision which happens very often, therefore the total number of fatalities and injuries is high.

A Hungarian statistics covers 1803 bus accidents during the years 1978-82 involving all the events where people were injured (or killed), see version “c” [1] Only 13,3% of the total number represents collisions with other heavy vehicles or rigid obstacles. Considering the collisions with cars and vans, too (altogether 41%), in this sample the head on impact has a rate of 57,2% A statistics from Spain from the years 1984-88 showed that the 50% of the coach accidents (505 events) in which people were killed (see version “c”) were simple head on collision and considering the multiple frontal collisions, too, this rate is 61% [2] Another, newer Spain statistics from the years 1995-99 – involving 1962 bus accidents – the rate of the frontal impact is 50%. The frontal collisions of buses may be categorized on different ways [4] One major category – may be the most important one – is the partial impact on the driver compartment (DC) This partial impact rate is roughly half of the total head on impacts (25-30%) and the dynamic impact load on the DC can be different:

- Having a certain angle (20-45^o) related to the longitudinal centre plane of the bus (see Fig.1.) Practically it means that the side corner of the front wall is hit by the impact load in a certain direction
- Offset impact on DC but parallel to the longitudinal centre plane (see Fig.2.) The final “result” could be very similar wheatear the impact load has a certain angle or its is parallel to the centre plane. The partial impact load can in act on DC in its total height, or mainly below the windscreen.
- Partial impact with pole like object (see Fig.3.) This is a special kind of impact because of the special object.

The accident statistics underlines a very important problem: the dangerous position of the bus driver in case of frontal collision. There are some statistical data from which this evidence may be proved. Table 1. summarises earlier data about the driver/passenger injury rate (D/P) supplemented with Spanish [2] [4] [5] and UK [8] data. To get these D/P injury rates from the general statistics, as a first approach we assumed that the average passenger capacity of a bus (coach) is around 50 and the buses involved in these accidents were nominally (fully) loaded. In other words that means 1 driver belongs to 50 passengers. Determining the D/P injury rates it was assumed that the injury probability of all the passengers is equal in case of frontal collisions. Only Japanese data were available specifically for bus frontal collisions, too. The other three statistics involves all type of bus

Fig.1. Partial impact on DV under an angle of 40°

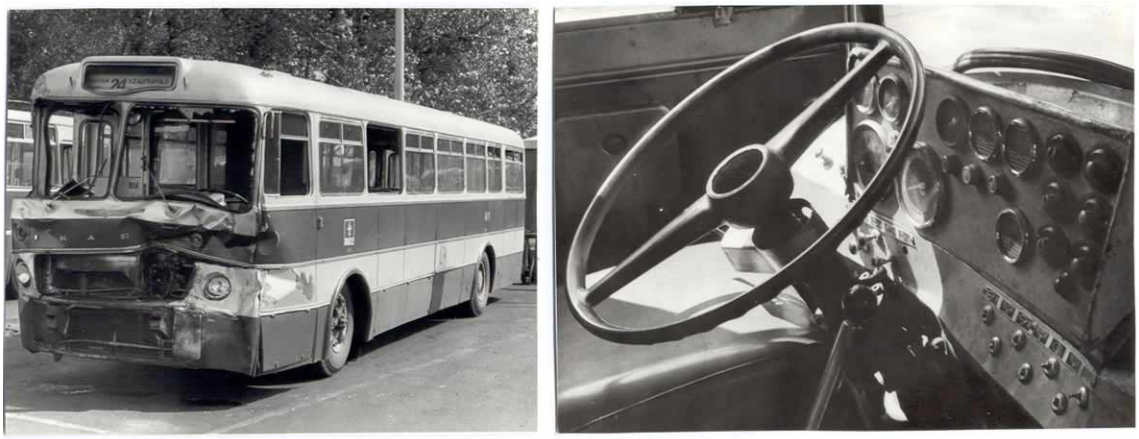

Fig.2. Offset partian impact on DC

D/P injury rata **Table I.**

Type of injury	All type of bus accident				Frontal collisions only
	Japanese	Spanish	German	U.K.	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

accidents, nothing detailed data about frontal collisions. The Japanese figures show that the serious driver's casualties are caused mainly by the frontal collisions. The extremely high D/P rate in fatalities is due to the relative low number of the fatalities in these Japanese statistics. In this case one or two events can strongly influence the D/P rate. The D/P injury rate for frontal collisions may be estimated from the D/P rate of all accidents using a multiplier of 1,5. This seems to be a realistic value. The conclusion of these figures is that the driver's danger is very high in case of frontal collision, the D/P fatality rate is between 10-100 and the D/P rate of serious injury could be in the range of 8-20. On the other hand the driver is a key person in the case of an accident. He has to control the bus after the frontal collision to avoid more dangerous situations, he is the only skilled person who knows what to do, he can help to the passenger to evacuate the bus if it is necessary, etc. So the driver's protection has a first priority.

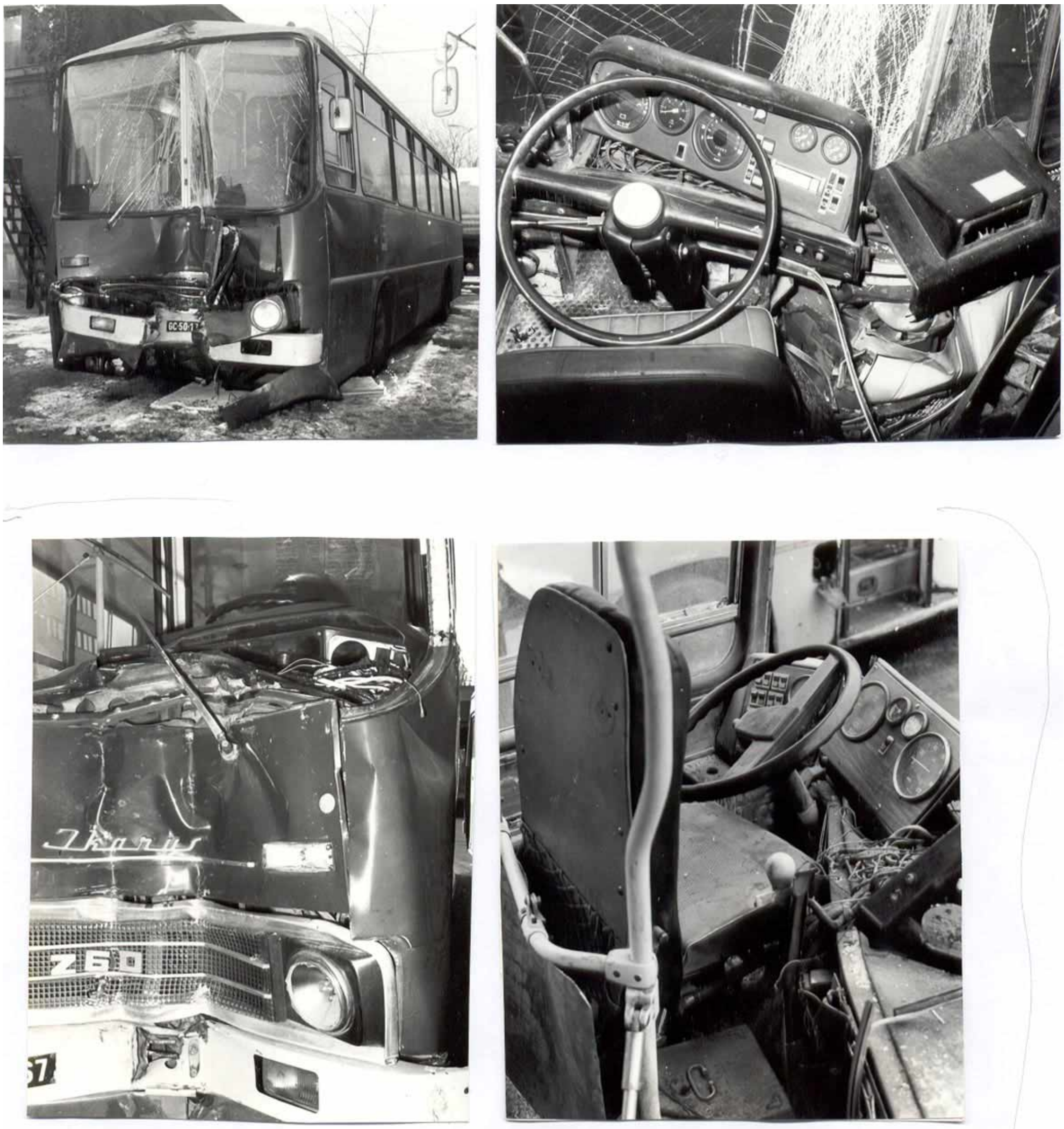

Fig.3. Partial impact with pole like object

2. PROTECTION OF THE DRIVER IN THE DRIVER'S COMPARTMENT.

Thinking about an international safety regulation for driver's protection in case of bus frontal accident the following problems should be considered and discussed:

- which are those realistic accident situations in which the driver shall be protected, in which a certain survival space shall be assured, or in other words standard accident(s) shall be determined
- how to define a survival space in the DC, into which no structural elements penetrate during the standard accident. The difficulty is caused by the steering wheel and column, because they are already in the possible survival space before the collision.
- how to keep the driver in the survival space during the standard accident(s).
- how to avoid unacceptable high biomechanical loads on the driver during the standard accident(s)
- how to derive good approval test (or tests) from the standard accident(s). Good approval test means relative simple, not to expensive, repeatable test method

To apply a partial impact load on the DC raises an important problem: the position of the DC in height (related to the road level) may vary in a wide range in the different bus constructions. Fig.4. shows examples including low-floor (LF) buses (and double decker coaches) where this position is low and high decker coaches (HD) as the other extreme. The position of the DC may be characterized by the height of its floor level (h) just under the driver

Fig.4. Different positions of the driver compartment

Fig.5. Position of minibus driver compartment

Fig.6. A bus without front wall after head on collision

seat, which could be different from the floor level of the passenger compartment if there is an elevated platform in the DC. Fig.4. shows a range h=550 – 1300 mm. If we are generally speaking about buses, the minibuses should be also considered, where h = 250 – 300 mm is a realistic figure (See Fig.5.) Belonging to the height position of the DC two other constructional features shall be considered, too:

- the stiffness (load bearing capability) of the DC is much higher – with one or two orders – under the floor level than above it. This is due to the longitudinal beams of the underfloor structure, the bumper system, the reinforced brackets of the steering and suspension systems and the floor structure of the passenger compartment in the front overhang, which is rigid in its plane. All of these structures and structural elements are in or below the floor level. This can be seen on Fig.6. The bus had a frontal collision and the reparation of the damage is just started. The first step was to cut down the damaged front wall. The dense, compact structure below the DC floor is well illustrated on the picture. The stiffness of the underfloor structure depends on the height position of the DC (h) and roughly it can be said that bigger height stronger, stiffer structure. Above the floor level only the front wall can offer resistance to the dynamic impact load and if the DC has a side door, the side wall cannot support it.
- The stiffness of the DC depends on the direction (angle) of the impact load. Generally it can be said that bigger impact angle results less stiffness.. This statement has a stronger validity if the impact load is acting above the floor level and there is a side door on the DC.

3. APPROACHING THE BASIC REQUIREMENTS

3.1. Standard accident situations.

To define appropriate accident situations – in which the protection of the driver shall be assured – is not too easy. The main mechanical parameters to be considered are the impact energy, the impact force and the belonging deformation. First of all it is necessary to emphasize that in the case of a dynamic partial frontal impact on the DC of a bus, having a certain impact speed, the total kinetic energy is not absorbed by the DC itself. The following situations and energy conditions could be considered as standard collisions:

a) Colliding a car, or van under a certain angle. The bus pushes this vehicle and the kinetic energy of the collision is absorbed - beyond the deformation of the DC – by the further motion of the vehicles (braking, friction work, etc.) and the deformation work of the car or van.
b) Having a frontal collision with another similar heavy vehicle (having a certain angle or offset in the collision) Both vehicles get structural deformations and have further motion with changed direction absorbing the kinetic energy of the collision.
c) Rushing offset into the loading platform of a truck from the back. Both vehicle get structural deformation and the truck is pushed away.
d) Hitting a rigid wall (or wall like object) under a certain angle. The bus is running away with a changed direction while the DC is deformed.
e) Hitting a pole-like object, the pole itself absorbs a certain energy and also the bus may have certain further motion when the pole breaks down.

The certain angle could be in the range of 0-45^o, meaning that the dynamic impact load is acting at the corner of the front wall. The conclusion of this brief analysis shows that although the energy absorbed by the DC depends on the masses of the vehicles (objects) being involved in the collision as well as on the relative impact speed, but this function is not a well defined equation. In the case “a” and “c” the impact on the DC is limited to a certain area according to the extension of the partner vehicle. In case “b” and “d” the impact force is distributed along a total height of the DC and it could be represented by a large rigid plane. In case “e” the impact force is acting along a vertical line.

3.2. Survival space

The concept of survival space is used in the ECE Reg.29. for the driver [7] and also in Regulation 66 (Required strength of bus superstructure in case of rollover accident). The definition, given in the revised version of Reg.66. is the following: “Survival space means a space to be preserved in the passenger’s and driver’s compartment to provide better survival possibility for passengers, driver and crew in case of rollover accident.” On the basis of this definition, considering the usual structural deformations in a rollover accident, the survival space has been geometrically specified. In the case of frontal collision, involving the DC, the definition of the survival space described above should be extended. The consideration of this extension is based on the fact that this survival space shall be preserved only for the driver, who is a key person in an accident, he can help to the passengers to avoid the panic, to help in evacuation, etc. So the definition could in this case: “Survival space means a space to be preserved in the driver’s compartment to provide high level survival probability for the driver (without serious injury) in case of standard frontal collision as well as to provide easy way to leave the DC after the collision.”. In other words it means that no structural parts may intrude into this space as consequence of the collision, and obstacles – caused by structural deformations – shall not prevent the driver in leaving the DC. Fig.7. shows modern, up to date DC arrangements with inner doors which could be blocked by structural deformations. It is clear that if these doors are blocked, it is very difficult to leave the DC, even if a certain survival space remains for the driver after the collision. The volume of the survival space depends on the extent of the driver’s body (e.g. 95% representation of the drivers population) and also on the restraint system (seat belt) which allows a certain, limited motion for the driver. The major difficulty when defining the survival space is caused by the steering column and wheel. These structural elements are already in every survival space before the collision, but their deformation and displacement can cause tragic injury to the driver. (This is illustrated on Fig.1., Fig2 and Fig.3.) Beyond the steering wheel and column, the dashboard, the instrument panel, the waistrail under the windscreen, the foot plate with the pedals may penetrate into the survival space. A certain proposal has been already presented for this survival space [3] but it should be developed because it does not fully cover the definition given above.

3.3. Restraint systems for the driver

To keep driver in the survival space in frontal collision needs the use of restraint system. This system to days is a 3pt seat belt which is fixed to the driver’s seat. Hopefully in the future airbag system will be developed for bus drivers, too. There is no international regulation for driver’s seat equipped with seat belt, no international requirements how to check the biomechanical limit loads on the driver. One solution could be the extension of ECE Reg.80 (Strength of bus passenger seats and their anchorages in case of frontal collision) to the driver’s seats, too. There are two different philosophies to protect the driver in the DC:

– to keep the driver in the survival space and develop a strong DC preventing large scale deformations and any structural intrusion into the survival space

Fig.7. Modern DC arrangements with inner side doors

– together with the structural deformation of DC, to pull out the driver from the deformed zone of the DC In this case the restraint system, the biomechanical loads shall be adjusted to this situation. This philosophy leads to the concept of the safety platform, which is a rigid in its plane. The driver seat and the steering column (together with the steering wheel) is fixed to this safety platform. When the dynamic impact force acts on the front wall causing structural deformation, the rigid safety platform is pushed back in the DC, together with the driver seat and the driver, providing the survival space. Dynamic pendulum tests proved that this construction works well [1].

4. POSSIBLE APPROVAL TEST METHODS

The international passive safety regulations are based on the approval test(s) and the belonging requirements. Therefore it is interesting to consider the possible test methods, their geometrical arrangements and the belonging questions.

4.1. Static or dynamic test?

First of all it shall be said that both kind of tests are used in different passive safety regulations.
The statistic tests are much simpler, less expensive and they are applicable mainly when components, structural parts or units are tested. Static test is used e.g. for the approval of front underrun protective devices of heavy trucks. [6] Fig.8./a shows a static test of a waist rail under the windscreen of a bus, simulating a pole type intrusion. The position of this element in the DC structure can be seen on Fig.9/b. (after a pendulum impact test) Fig.8/b shows this waistrail part after a real frontal collision with a pole.
The dynamic test of the DC may have different versions:

- Collision test with complete vehicle against a fixed, rigid barrier having a prescribed geometry
- Hitting the DC by a moving trolley with a prescribed geometry
- Hitting the DC by a pendulum with a prescribed geometry

In these last two cases theoretically the DC can be hit on complete vehicle, too, but considering the cost and repeatability requirements the test of a fixed DC seems to be more appropriate. The pendulum test is already used in the international practice to approve the strength of truck cabs [7]. Fig.9/a shows the arrangement of a pendulum impact test of a bus DC, which is fixed to the ground. Fig.10 gives the geometry of this pendulum test.

4.2. The position and direction of the impact

If the goal is to specify approval test for all kind of buses, including minibuses, too (see Fig.5) different pendulum tests should be specified:

- For small buses (minibuses) saying that if the total width of the bus is smaller than e.g. 1,8 m, the pendulum impact test shall be extended to the whole front wall (see Fig.11) if the impact direction is parallel to the longitudinal centre plane of the bus.
- For bigger buses only a partial impact test could be used as specified on Fig.9 and Fig.10.

The direction of the impact, the angle of the impact force should be the responsibility of the Technical Service, (TC) they can decide this impact parameter. TC may study the structure of the DC, the construction as a whole and choose the most dangerous impact angle. On the other side it means that only one impact approval test is needed. Fig.12 shows the arrangement of a pendulum impact test having an angle of 45^o.

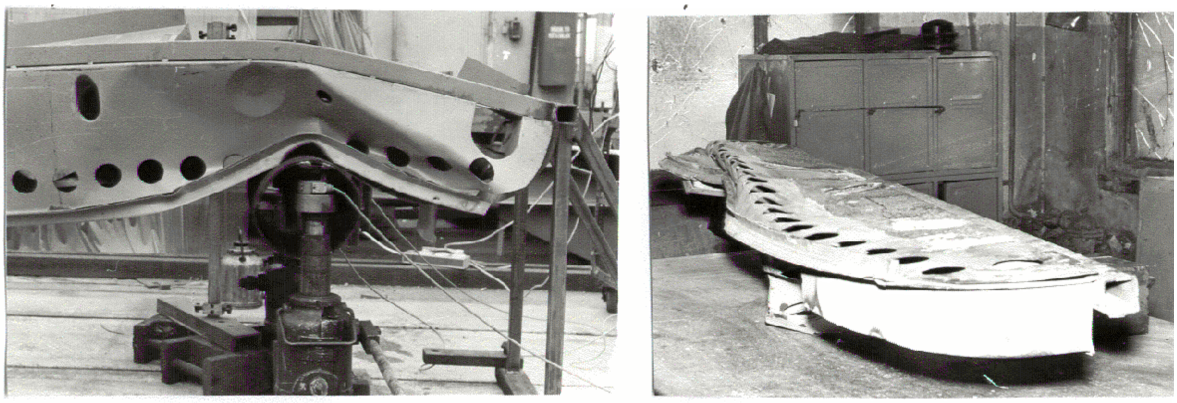

Fig.8. Static test of the waistrail of a DC under the windscreen

Fig.9.Pendulum impact test of DC

The impacting surface of the pendulum shall be a rigid plane. The dimensions of this plate as a minimum could be 700*700 mm, but as a maximum 1000*1800 mm may be also considered. The height position of the impacting surface is a sensitive question. There are three major possibilities to determine the height position of the impacting surface (the position of its lower edge):

– related to the nominal ground level on which the bus stands. The DC also has a height position above the ground level so their relative position is unambiguously determined
– related to the R point of the driver seat.
– related to the floor level of the passenger compartment at the front door (or in the front overhang)

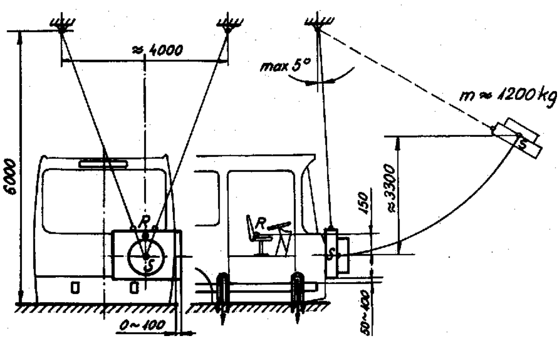

Fig.10. Geometrical arrangement of the pendulum impact test

The basic question to be studied and decided: which part of DC'-s front wall shall have a certain strength and energy absorbing capability? The whole structure below the windscreen, or only its "soft part": below the windscreen but above the floor level of the passenger compartment in the front of the bus. The answer may be derived from the standard accident accepted for the safety evaluation of the DC. If the standard accident (offset or angled) involves collisions with:

a) rigid walls, wall like objects (fences), bigger cars, vans, front wall of other heavy vehicles
b) trucks, lorries running into the rear part of their loading platform
c) both cases "a" and "b"
d) pole like object

the solution should be different. Simulating case "a" the pendulum shall impact the whole DC structure below the windscreen, in case "b" only the "soft part" of the front wall shall be tested. The most general solution – see case "c" – could be a combination of an impact test on the whole DC structure together with an additional static test on the "soft part". Case "d" needs a special test, it can be either dynamic or static. This analysis shows that the optimum solution needs three different, independent approval tests to protect the driver in the case of a partial head on impact: a pendulum impact test and two additional static test. The position of the loading devices and the direction of the loads

Fig.11. Pendulum impact test on small buses

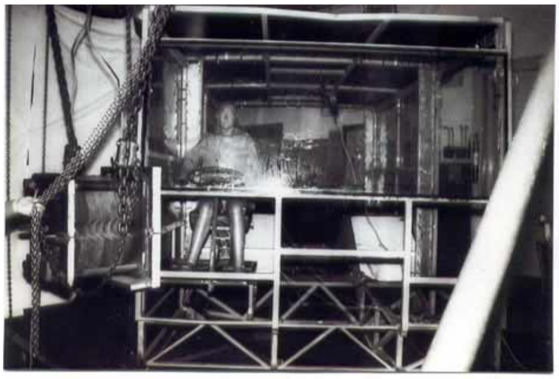

Fig.12. Pendulum impact test with an angle of 45°

shall be determined by the Technical Service conducting the approval tests.

4.3. Energy conditions

Let us consider two kind of bus frontal collisions.

If a smaller vehicle (car, van, limousine, etc.) hits the DC of a standing bus, the energy to be absorbed by the DC (without damaging the survival space) is:

$$E = \frac{1}{2} m v^2 (1-c) \qquad \ldots 1$$

where: *m* is the mass of the impacting (smaller) vehicle, *v* is its impacting speed and *c* is an energy factor showing the ratio of the energy dissipation (energy absorbed by the distortion of the smaller vehicle, by the further motion of both vehicles, by oscillations in both vehicles, by elastic deformations in both vehicles, etc.)

If a bus having a mass *M* hits a rigid wall with a speed *V*, assuming that there is no energy dissipation, all the kinetic energy is absorbed by the DC structure, we can determine an equivalent impact speed, assuming the same energy absorption expressed in Equ.1.

$$V = v\sqrt{\frac{m}{M}(1-c)} \qquad \ldots 2$$

Assuming that c=0,5, Fig.13/a shows the equivalent bus impact speeds for different mass ratios. Table II. gives some ideas about the possible masses. The mass ratio m/M=0,19 on Fig12/a represents the situation when we compare a loaded van to a loaded large bus. Fig.13/b gives an idea about the order of the energy to be absorbed by the DC if it is hit by a loaded van, having different impact speeds, and assuming again that c=0,5. The pendulum impact test described on Fig.10. represents an energy input of 40 kJ. This energy was used only for testing the "soft part" of the DC. The required pendulum energy in the approval test of truck driver's cab is 30-45 kJ depending on the total mass of the truck. [7]. These considerations and figures are good milestones to specify in the future the pendulum impact tests of bus DC.

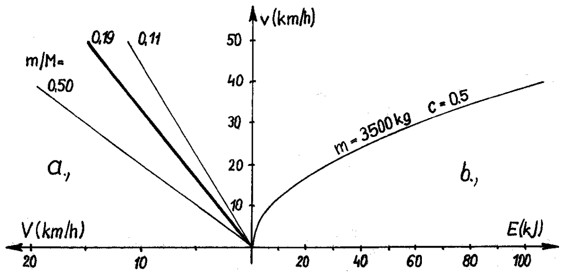

Fig.13. Energy conditions of DC impact

Vehicle masses **Table II**

m[kg]		M[kg]	
Light, small car	1000	loaded minibus	2.500
Heavy, big car	2000	loaded small bus	5.000
Loaded van	3500	empty large bus	10.000
Small, loaded lorry	5000	loaded large bus	18.000

5. CONCLUSIONS

- The bus drivers have a vulnerable position in the DC, when the bus is involved in a partial head on impact. International regulation is needed to protect the seriously endangered drivers.
- The first step on the way to prepare an international regulation is to determine standard accidents and to find good definition for the survival space in which the drivers have to be protected.
- The approval tests may be derived from the standard accident situations. Three kind of (independent) approval tests seem to be needed to solve this problem: one general pendulum impact test, one pole-like intrusion test and one test on the "soft part" of the DC. These last two tests could be static loading test.
- The energy conditions of the approval tests (e.g. energy input, produced by the pendulum, energy to be absorbed by the DC, etc.) may be also derived from the accepted standard accidents.

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