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Informal document No. **GRSG-96-19**
(96th GRSG, 4-8 May 2009
agenda item 4)

DRIVER AND CREW PRECTION IN FRONTAL COLLLISION OF BUSES.

This paper was presented on the "Science and Vehicle" Conference (Belgrade, 15-16 April, 2009) and gives some technical background, statistical information to the GRSG discussion in this subject. It supports the Hungarian proposals to the new draft regulation (ECE/TRANS/WP.29/GRSG/2007/33)

ABSTRACT

Statistical figures are analyzed about bus frontal collisions showing the severity of this accident type among all bus accidents. Based on in-depth accident analyses different types of frontal collision are specified and those are pointed out which are the most dangerous in respect of the driver's injury. The driver's injury risk – based on statistical evaluations – is very high, while the driver is the key person after the accident (to control the further motion of the bus, to help in the evacuation, to call the ambulance and police, to extinguish fire, etc.) There is no international regulation (requirements, test methods) for the driver's protection in frontal collision, the work just has been started in the ECE/WP.29/GRSG group (Geneva)
This paper tries to show the possible frame of an international regulation: to specify the groups of frontal collisions in which the driver should be protected, to specify a survival space into which no structural intrusions are allowed, (to keep the driver in the survival space during the accident, to limit the biomechanical loads on the driver) and to make it possible for the driver to live the driver's compartment after the accident. The drivers position in the different bus constructions and designs are different, that should be considered, too when thinking about a new regulation.

KEY WORDS: bus, front impact, regulation, driver, compartment, survival space

1. INTRODUCTION

The driver is a key person on a bus, responsible for the safety of the passengers and for the bus itself. This responsibility is expressly valid in the case of and accident: he is skilled for this situation, he can operate the exits, use the fire extinguisher help to the passengers, call for help, etc. The driver, sitting in the driver's compartment (DC) is in a extremely vulnerable position in case of a frontal collision. The driver must be protected in this case, international regulation is needed. This problem was recognized in Geneva, the ECE organization started to work on that field. When thinking about the driver protection, we have to consider the co-drivers on tourist and long-distance coaches as well as other crew members (e.g. tourist guide) sitting next to the driver, in the same row, in the very front of the vehicle. In other words beyond the DC we have to consider the crew's compartment (CC) as well. The reason of that is double: these persons are in the same vulnerable position as the driver and they are also key persons in respect of the passenger safety.
The DC, is well known and specified among the definitions of UN-ECE bus regulations (R.107, R.66) The CC is not so clear yet, a possible definition could be: "Crew's compartment means the space located alongside the driver intended for the exclusive use of the crew (co-driver, tourist guide) containing the crew seat(s)

and the belonging surroundings". There are different constructional solutions in the practice for CC. Fig.1. shows some examples which should be kept in our mind when thinking about this subject:

Fig.1. Different existing crew compartments in the practice

a) the crew seat(s) (folding seat) is located in the staircase of the front service door, fixed to the rear wall of the staircase, in front of the first row of passenger seats.

b) the crew seat (folding seat) is located in the staircase of the front service door, fixed to the front-wall of the staircase (or of the bus)

c) the two (three) seat positions are in the same compartment, same room, next to each other, in one row. this room is separated from the passenger compartment.

Thinking about an international safety regulation for driver's (crew's) protection in bus frontal collisions, the following questions should be analysed

- what is the technical meaning of driver's protection
- in which accident situations shall be the driver protected (standardized accident situations)
- requirement specification (e.g. survival space concept)
- application of the worst case concept or the rules of extension of an approval

Fig.2. Small and large buses

An interesting question should be mentioned at the beginning of the work: is it possible to cover both M2 and M3 vehicles by one safety regulation? Too many and significant differences are between the two categories (see Fig.2.): in mass ranges, main geometrical parameters, constructional features, (The small buses have front engine, the DC is located above or behind the front axle while large buses have rear engine and DC is in front of the front axle, etc.) Therefore a two steps approach seams to be adequate: first to regulate the large buses and as second step to extend the scope of this regulation to small buses, if it is possible. This paper discusses the questions of M3 category only, but all classes (city buses, intercity buses, tourist coaches, double deck and articulated vehicles)

There are two UN_ECE regulations which could be used as starting points to the new regulation:

- Reg.29 protection of the occupants of the cab of a vehicle. (Truck) This is a rather old regulation (1974), the latest amendments were made in 1998. It has to be underline that this regulation could be a starting point, but its extension to buses is not feasible.
- Reg.66 Strength of the superstructure of buses and coaches. The original regulation was also old (1986) but its Revision 1. is a very up to date (2005), good example to be followed.

DRIVER (CREW) PROTECTION

The driver (crew) protection in frontal collisions has many aspects:

a) To assure a certain survival space (SP) into which there is no structural intrusion
b) To keep the driver in this survival space
c) To reduce the biomechanical loads (forces, decelerations, etc.)
d) To ensure for the driver a leave the DC after the frontal collision (for helping the passengers and for other needed activities)

In the light of the structure of UN-ECE regulations it is clear that to regulate these four major aspects listed above can not be done in one regulation, because different standard accidents, therefore different test methods, different type of requirement and measuring methods are needed.

To keep the driver in the SP ("b") belongs to Reg.80 which regulates the strength of seats and seat anchorages using seat belts as well. In this case the standard accident is to hit a rigid wall with a speed $v \approx 30$ km/h and the deceleration pulls is derived from this situation.

To reduce the biomechanical loads acting on the driver (crew) belongs to the safety belt and airbag system's requirement ("c") and the standard accident situation is similar to the previous one. (High speed, deceleration plus). In this case Reg.14, Reg.16 and Reg.114 could be considered as basis documents.

This paper concentrates on the structural aspects of the driver (crew) protection: the integrity of DC and CC, their strength and energy absorbing capability. The general requirements may be formulated, saying that in specified, standardized accident situations no structural parts, components shall intrude into the SP (a) and appropriate exit shall be provided from the DC after the accident ("d")

It has to be mentioned that some other, very important issues are belonging to the frontal accidents and collisions of buses, like:

- protection of vulnerable road users (pedestrians cyclists, motorcyclist, etc.)
- protection of small cars, as partners (front underrun protection)
- protection of main control systems of the bus (e.g. brake, steering, electrical) etc.

but these problems are not directly related to the driver's protection

STATISTICAL BACKGROUND

Analysing bus accident statistics collected from different countries, different sources [1], [2] the frontal collisions or run over type accidents – in which somebody has been injured – are in the range of 55-60 %. The different statistics represent certain scatter, therefore only certain ranges can be given to show the rate of partners in bus frontal collisions:

- 30-50 %% with vulnerable partners (pedestrians, bicyclist, motorcyclist, moped, etc.) This accident is not dangerous for the bus occupants
- 30-50 % with cars, vans, light trucks, which are weaker than the bus. They represent also low level danger for the bus occupants, accept the driver and the crew if they are sitting in low position compartment (see Fig.1/c and 13/a)
- 10-30 % with heavy vehicles and stable objects, which are very dangerous for the bus occupants, especially for the drivers and crew. These are the severe frontal impacts.

Among the severe frontal collisions 20-40 % the full frontal impacts and 60-80 % are the partial ones, roughly half of them on the DC side and the other half on the other side (service door side, or CC side)

Table I. compares the driver/passenger (D/P) injury rates in bus accidents in which bus occupants were injured based on different accident statistics. To determine the D/P injury rates from the statistics, it was assumed – as an average – that the buses had 50 passengers on board when the accident happened, so one driver belonged to 50 passengers. Comparing the average injury probability (IP) of the driver and passenger in different accident situation it may be said:

Table I.

D/P injury rate	All type of bus accidents					Frontal impact only
Type of injury	Japanese	Spanish	German	U.K.	Hungarian	Japanese
Fatality	83:1	6:1	8:1	5:1	5:1	125:1
Serious injury	13:1	} 2:1	10:1	4:1	} 3:1	18:1
Light injury	7:1		6:1	3:1		4:1
Total number of casualties	4800	2400	4500	234,616	4300	3200
Time of observation	1992-94	1984-88	1979	1971-92	1987-92	1992-94

- in side impact the driver has lower IP
- in rear impact the driver has equal or lower IP
- in rollover the IP is equal for driver and passengers
- in fire the IP is equal for driver and passengers
- in frontal collision the driver has higher IP

It means that the high D/P injury rates considering all types of bus accidents are due to the frontal collisions. Analysing the ECBOS data [3], similar tendencies may be found in Table II.

Table II.

Among the 8 participating countries	D/P fatality rate	D/P injury rate
Minimum value	3:1	4:1
Average value	9:1	8:1
Maximum value	20:1	20:1

The accident statistics do not mention the crew members separately, so there is no direct information about them, but considering their position it may be assumed that their injury rate is similar to the driver.

STANDARDIZED ACCIDENT SITUATIONS

Studying carefully the accident statistics and the deformation mechanism of the different types of frontal collisions, it is evident that the full frontal collision – when the whole front wall of the bus is involved into the collision – is much less dangerous for the driver (and crew) than the partial collisions having the same energy input (same mass ratio, same impact speed). Fig.3. gives a clear example with two full scale frontal impact tests with a bus type IKARUS 250. The impact speed was 35 km/h in both cases against a concrete wall [1]:

a) the wall was perpendicular to the motion of the bus (full frontal collision). The whole front wall of the bus was hit and deformed, the whole impact energy was absorbed by the front part of the bus. The driver seat-steering wheel position seems to be a normal one (Fig.3/a)

b) 45^o wall on the DC side (partial frontal impacts) Only the DC was deformed, the other parts of the front wall remained intact, the front service door (other side) was openable and the driver seat – steering wheel position because unacceptable (Fig.3/b). It has to be mentioned that only – roughly – the half of the impact energy caused this unacceptable deformation, because the bus “slipped away” on the 45^o wall and stopped by a fence in a 12-15 m distance.

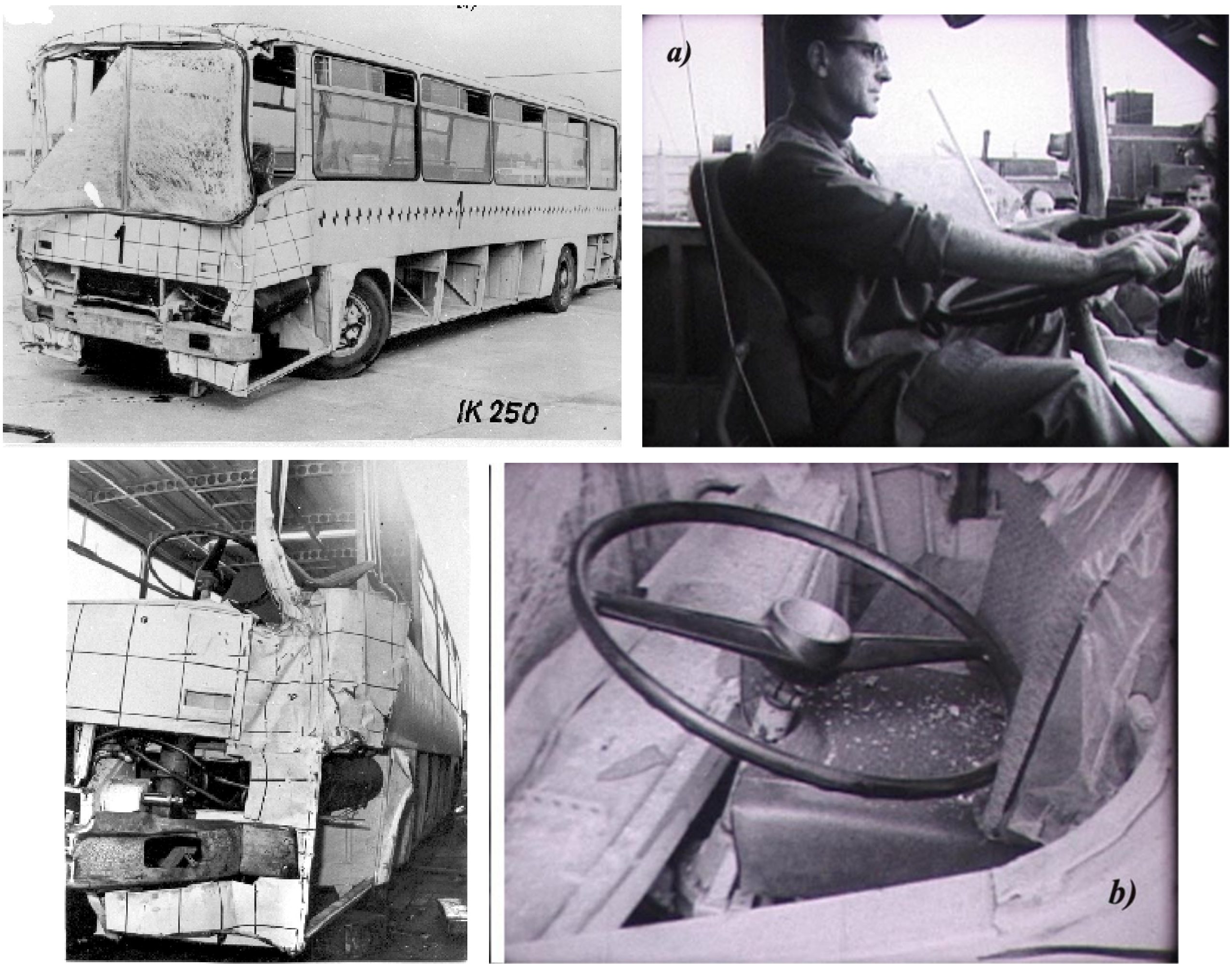

Fig.3. Full scale frontal collision tests with the same bus type:

a) full frontal impact *b) 45^o impact on the DC side*

In the full frontal collision the two longitudinal beams of the underframe structure is rigid enough to take the dynamic forces and distribute them into the whole frame structure. The stiffness of these longitudinal beams is higher with two or three order than the other parts, frame of the front wall, of the DC.

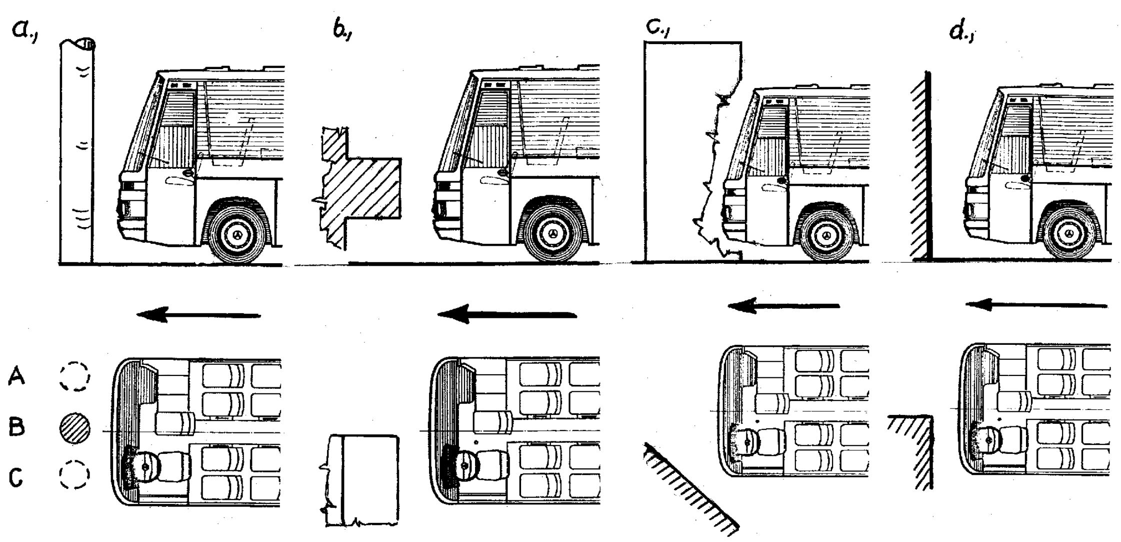

Fig.4. Typical partial frontal impacts on DC side

Therefore when protecting the driver we should concentrate on the partial frontal impacts. Fig.4. shows some typical partial impacts on the DC side and symmetrically similar cases may be considered for the CC:

a) to hit a pole like object (these are generally stable obstacles, see Fig.5.)

b) running into a truck platform (it could be full width or offset, see Fig.6.)

c) - d) offset collision with large, wall like object (see Fig.7.) The direction of the dynamic impact force can be parallel to the central vertical plane of the bus or angular to it.

Fig.5. Collision with pole like object

Fig.6. Running into a truck platform

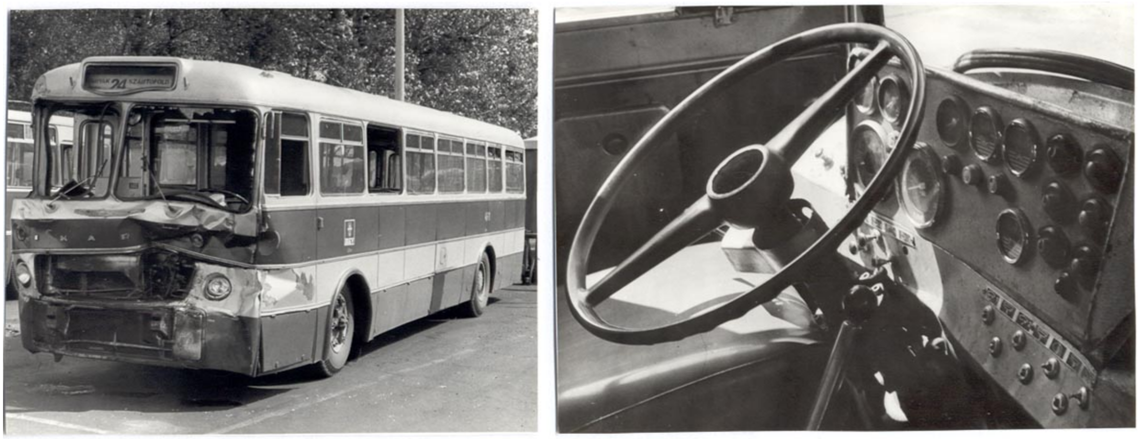

Fig.7. Offset collision with large, wall like object

Important question is the impact energy to be introduced into the structure of the DC, absorbed by this structure having a limited deformation. The impact energy, if a vehicle having a mass m hits the bus DC with a relative impact speed v is:

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

where ***c*** is an energy factor showing the energy dissipation (energy absorbed by the impacting vehicle, by further motion of the two vehicles, etc.) Fig.8. gives the order of the energy impute:

a) when the bus is hit by three different mass categories of vehicles (m = 3,5 t; 5 t; 10 t) with a relative impact speed v and the energy factor is ***c*** = 0,5. The example (red lines and point) shows that m= 5t (small bus) hits our bus with a speed v=20 km/h, the impact energy to be absorbed by the DC of the bus is 40 KJ.

b) If the large bus (M = 16t) hit a rigid, concrete wall, where the energy dissipation is negligible and the energy absorption by the DC is assumed as the same value (40 kJ) the impact speed of the bus should be ≈ 8 km/h.

c) If the impacting vehicle is more rigid (so ***c*** is decreasing) the energy to be absorbed by the DC structure is increasing. As Fig.8/c shows the absolute rigid (c = 0) impacting vehicles doubles the energy input into the DC (from 40 kJ to 80 kJ)

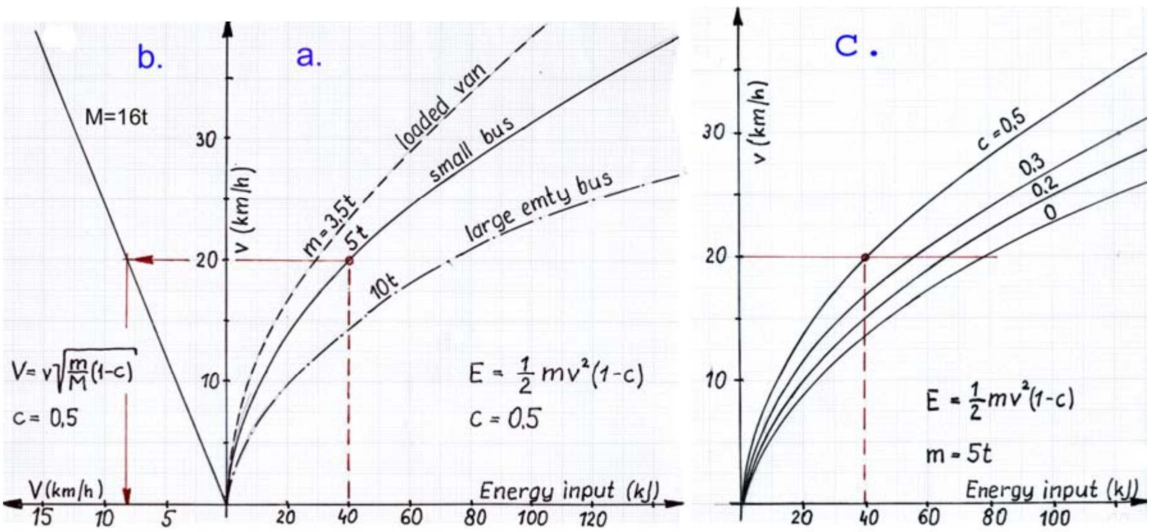

Fig. 8. Energy impute diagrams

It is interesting to mention that the kinetic energy of a 16t bus running with a speed v=35 km/h into a rigid wall (see the results of these tests on Fig.3) is 756 kJ, which is higher with one orders than the values discussed above. This extremely high energy input did not endangered the SP in full frontal impact (see Fig.3/a) Based on the measured impact forces in the full scale tests (shown on Fig.3.) a rough calculation was made two estimate the energy distribution in the 45^o impact test. It may be said that roughly 28-30% of the kinetic energy was absorbed by the DC and 70-72% went into the further motion of the bus (12 m) absorbed by friction, side wall local deformations, later impacting a fence, etc. So the energy input deforming the DC was around 210-220 kJ.

SURVIVAL SPACE (SP)

The SP is an essential tool in the driver (crew) protection when the structural integrity of the DC is in question. The specification of the SP should meet certain general requirements:

a) It shall belong to the driver (crew) seat, it shall be specified in relation to this seat.

b) It shall be large enough to provide a safe room even for a small or big driver (5% 95% male body)

c) It shall be specified by a very simple geometrical configuration

d) The steering wheel and column shall be considered.

e) a plastic foam interpretation of this geometrical form shall be producible easily

Two ways are known in UN-ECE regulations to specify SP:

- In Reg.29 a human body like manikin is specified based on 50% male body with movable, adjustable limbs. (see Fig.9.) It meets only the requirement “a”.
- Reg.66 is using a pure geometrical formula not directly related to a human body like figure. It meets all the requirements listed above, expect “d”.

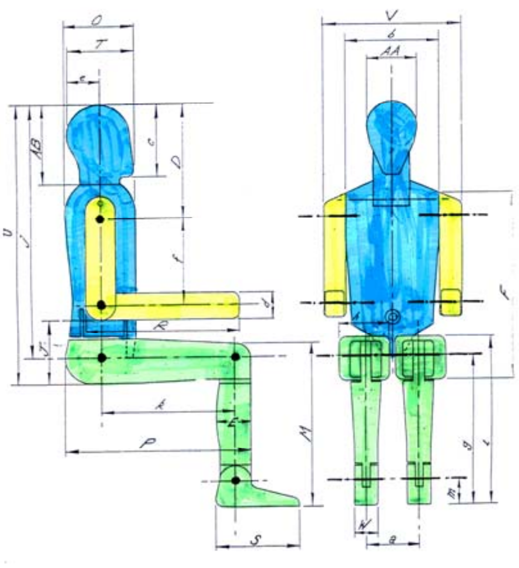

Fig.9. Manikin used in Reg.29.

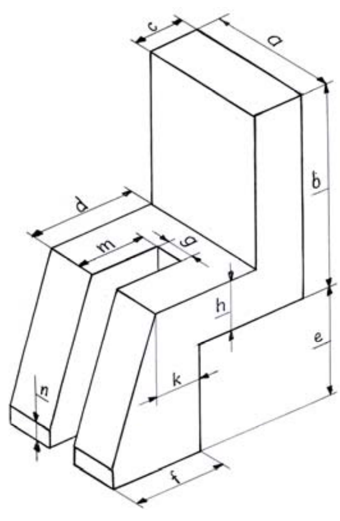

Fig.10. Possible survival space for the driver

Now we need a combination of these two ways, in principle closer to Reg.66, formally liken to Reg.29. Fig.10 shows a possible solution. The symbols, used in this figure need certain explanation: “a” represents the body width with the arms, “b” is the upper trunk height including the head, too; “c” considers the pot-belly in the depth of the trunk. The leg space includes different possible shin positions of the driver (“e” and ”f”) and the width of the gap (“g”) shall be determined assuming symmetrical, comfortable legs position when one of the legs is just touching a pedal. In the DC both the steering column and wheel and the driver seat is adjustable to provide comfortable position for small or big drivers. This has to be considered when specifying the approval test method.

THE OUTLINE OF AN APPROVAL TEST

Specifying an approval test for an UN-ECE passive safety regulation, the following viewpoints shall be considered:

- it shall be a standardized, repeatable, reproducible test.
- the requirements shall be checked by measurable, well specified parameters, measures.
- the test method shall represent a certain group of real accidents (standard accidents)
- the test method shall be applicable to all vehicle categories covered by the scope of the regulation.

From the accident statistics and real world accident analysis it became clear that partial frontal collisions (instead of the full front wall collisions) shall be considered, and both sides of the front wall (DC and CC) have similar accident rate. The partial frontal impact is a dynamic process, therefore the approval test, representing the standard accident situations shall be also dynamic test. Both pendulum impact test and moving trolley impact test can be used with a rigid impacting plate having prescribed dimensions and mass (range) Taking an example from our earlier research activity [5] a possible arrangement of a pendulum impact test on a bus DC is shown on Fig.11.

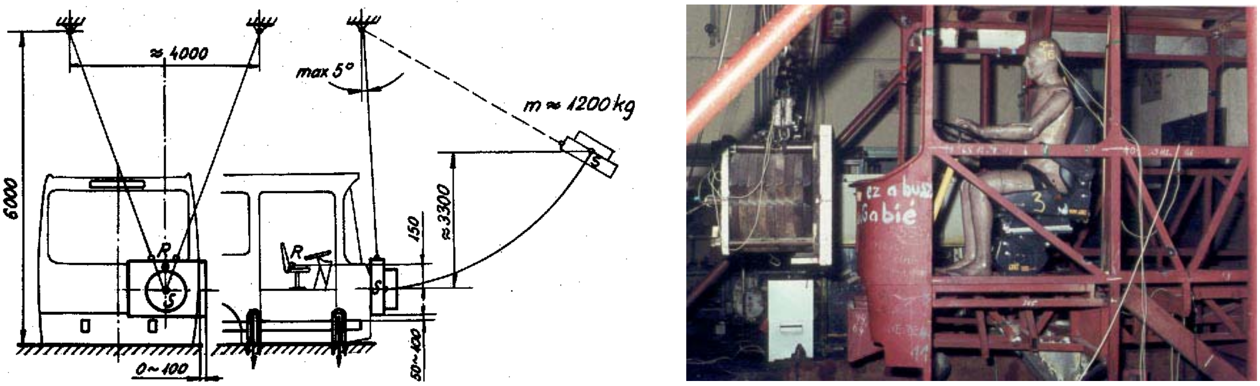

Fig.11. General arrangement of a pendulum impact test on a DC

Accepting this dynamic approval test(s) seven important questions shall be cleared and specified:

a) The dimensions of the impacting plate. The width of this plate (w) shall be less than the half width of the vehicle and the height (h) shall be more than the measure between the DC floor and the lower lane of the windscreen (Possible dimensions ≈ 1000 x 700 mm)

b) Direction of the impact. The accident analysis showed that the direction of the impact has an almost equal distribution between the parallel ($\alpha_{min} = 0^o$) and angular ($\alpha_{max} = 45^o$) impact related to the central vertical longitudinal plane of the bus. The question is: which could be more dangerous for the DC in respect of the SP. There is no general rule every individual bus construction shall be analysed in details, so this decision should be made by the competent authority (Technical Service) with the cooperation of the manufacturer. An example is shown on Fig.12. about an $\alpha = 45^o$ pendulum impact test.

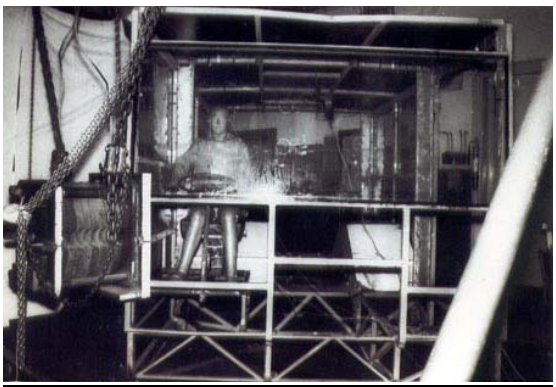

Fig.12. Pendulum impact test on DC with an angle $\alpha = 45^o$

c) Position of the impacting plate shall be specified in relation to the DC, to the driver seat. Fig.13. gives two extreme DC position related to the road level. The floor level of the DC is ≈ 400 mm above the road in the first case and ≈ 1300 mm in the second case. Below the floor of the DC different structures, parts and components are located, but the dynamic test should concentrate on the integrity of the front wall structure in front of the driver. It may be proposed: the centre of gravity of the impacting plate shall be above the floor level of the DC with a measure of h/2.

Fig.13. Low and high DC position related to the road level.

d) Energy input, the impact energy. The impact energy in Reg.29. for heavy trucks (total mass more than 7 t) is 45 kJ. As it may be seen from our previous energy analysis this is a very low level requirement: 40 kJ is produced by a 5t vehicle impacting the bus with 20 km/h (***c*** = 0,5, half of the energy is absorbed by the impacting vehicle!) or when the bus impacts a rigid wall with a speed of 8 km/h. On the other hand more tests proved that practically all the existing bus constructions can meet this requirement, so accepting this energy input value we would have an expensive approval test for nothing (not increasing the safety). More realistic energy input value would be in the range of 75-80 kJ. This would mean an impact speed v= 25 km/h of a 5t vehicle, or a 10 t impacting vehicle having 20 km/h speed.

e) Specification of the SP. A simple geometrical form was proposed above. The question is, which driver category shall be considered when specifying the parameters of the SP and its position: a small male driver (5%) or a big one (95%). In the DC the pedal's positions are fixed, the driver seat and the steering column/wheel positions are adjustable at least with two degrees of freedom. The small driver (with smaller required SP) puts forward the driver seat and steering column, while the big driver (with much bigger required SP) pushes backwards the seat and the steering wheel. Both arrangements in the same DC. It shall be carefully studied which test arrangement could increase generally the safety.

f) The structure to be tested. To use a complete bus for the approval tests theoretically is acceptable, but practically is not usable way (the "test specimen" would be too expensive) The test specimen should be the front part of the bodywork, but its completion shall be determined by the manufacturer, specifying the superstructure (the load bearing and energy absorbing parts and structural elements) The definition and specification of the superstructure is an essential element of the approval process. The superstructure – according to the decision of the manufacturer – provides the required safety for the driver (crew) it has to be tested and approved. If there is any change in the superstructure (e.g. in a future development) the modified or new vehicle type shall be approved again. If there is no change, no new approval is needed. The superstructure is a basic idea in determining the worst case, too. Very simple example: if the manufacturer nominates only the most important front wall frame elements as superstructure, the face lifting of the outside frontwall, or a new styling inside the DC can be done without a new approval.(This kind of front wall specimens are shown on Fig.11. and 12.) If the manufacturer nominates the complete front part of the bodywork as superstructure, it means that all the outside sheets, windscreen, inside covering elements, instrument panel, etc. are part of the superstructure, they are assumed to participate in the energy absorption and load bearing, therefore any change of them may require a new approval.

g) Possibility of leaving the DC. After the accident the driver shall have the opportunity to leave easily the DC. (e.g. to help to the passenger, to start to extinguish a fire, to call for outside help, etc.) That means at least one way shall provide him this capability:

- if there are two doors on the DC (one outside and one inside door) both shall be part of the approval test and one of the shall be easily operating after the impact test.
- if the DC is separated from the passenger compartment at it has only one outside door, this door shall be part of the test and easily operating after the test
- if the DC is not separated from the passenger compartment, it has a free access to it, to the gangway or to the front service door, the requirement is met, the test shall not cover this issue.

SUMMARY AND CONCLUSIONS

The bus driver (crew) protection in frontal collision against structural intrusions shall be regulated on international level. Working on that regulation the following issues shall be considered:

1. The requirements and approval tests shall be based on detailed accident analysis, specifying a "group of standard accidents." It is proposed to accept a partial impact in angular range of 0^o-45^o
2. A simple geometry is proposed for the survival space considering the steering column/wheel presence in the DC.
3. Dynamic pendulum and or trolley test is proposed providing an energy input of 75-80 kJ.
4. The basic problems to be studied and solved when specifying the approval test are: the dimensions and position of the impacting plate: the parameters and position of the survival space, the direction of the impact and the test specimen (part of the bodywork) to be tested.
5. At least one way shall be assured for the driver to leave the DC after the approval test. It could be an operating door or a free access to the passenger compartment.

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