SAFER BUS FRONTS FOR PEDESTRIAN IMPACT PROTECTION IN BUS-PEDESTRIAN ACCIDENTS

A Preliminary Investigation

J. Kajzer and J.K. Yang
Dept. of Injury Prevention, Chalmers University of Technology
S-412 96 Gothenburg, Sweden

D. Mohan
Center for Biomedical Engineering, Indian Institute of Technology
110016 New Delhi, India

ABSTRACT

Investigations of pedestrian fatalities in vehicle-pedestrian accidents in less motorized countries (LMC) and highly motorized countries (HMC) indicate that the proportion of pedestrians killed in the former is much higher than that in the later. In the HMCs a majority of the accidents involve private cars, whereas in the LMCs trucks and buses are the vehicles which hit pedestrians more often. This paper contains a general review of traffic accidents in India and Sweden, and vehicle-pedestrian accidents in New Delhi and Gothenburg, with the main emphasis on the bus-pedestrian impact situation. Buses were involved in 193 (32%) out of a total of 602 pedestrian and bicyclist fatalities in Delhi in 1985 for which details are known. This indicates the importance of minimizing injuries due to bus impacts with this class of road users.

A preliminary investigation has been done to examine the possibilities of designing a safer bus front by using a mathematical model of the bus-pedestrian impact. To evaluate the effect of a protective structure, in the form of padding[1] on the front structures of the bus in bus-pedestrian accidents, a simulation of the impact has been performed using the MADYMO 3D program. The results from the computer simulation indicate that it should be possible to design safer bus fronts which will reduce the severity of injuries at impact speeds below 30 km/h.

1 INTRODUCTION

Pedestrians form a major group of traffic accident victims in many highly motorized countries (HMC) and less motorized countries (LMC). A statistical investigation of traffic accidents in European countries shows that approximately 13 - 33 % of all road users killed were pedestrians (EEVC/CEVE, 1982). However, the percentage of pedestrians killed in all road accidents is higher in LMCs than in HMCs. Malini and Victor (1990) observed that as many as 35 - 45 % of all road accident casualties were pedestrians in LMCs, and these accidents were particularly common in urban areas. In addition, most severe and critical injuries (AIS4 and AIS5) were seen in accidents in which either buses or trucks were involved.

The number of motor vehicles registered in India in 1988 was 13.5 million of which cars and jeeps accounted for 2 million (15%), buses for 0.3 million (2%), trucks for 1 million (7%), and motorized two-wheelers (MTW) for 8.5 million (63%) (ACMAI, 1989). Nationwide official statistics for road accidents are available for 1986 (TRD, 1987), showing 211,000 recorded accidents in which 40,380 persons were killed. The number of crashes recorded is a gross underestimate but the number killed would be closer to the actual number. This is

[1] In this paper the word "padding" is used to denote any deformable and energy-absorbing structure suitable for this purpose.

because a large number of non-fatal crashes are not reported to the police, but cases in which someone gets killed are difficult to ignore. The number of fatalities had increased to over 50,000 by 1991. Out of all recorded accidents for which details were known, buses were involved in 16%, trucks in 29%, and private cars in 2% of the crashes.

In Sweden, the total number of motor vehicles registered in 1988 was 4.348 million of which private cars accounted for 3.483 million (80%), buses for 0.014 million (0.3%), trucks for 0.267 million (6.1%), tractors for 0.330 million (7.6%), and motorcycles for 0.254 million (6%) (SCB, 1989). The official statistics for road traffic accidents in Sweden in 1988 show that there were 17,207 reported accidents in which 813 persons were killed, 5,869 persons severely injured, and 16,969 persons slightly injured. Buses were involved in about 3% of the reported accidents, and private cars in 77%.

During the past decade, the pedestrian safety problem for impacts with private cars in HMCs has been studied extensively using mathematical models, epidemiological studies, and impact tests with mechanical dummies and biological materials (Kajzer, 1991). Various recommendations for the front structure design of vehicles (mainly private cars), have been made. From the results of these studies, various methods have been suggested to reduce the severity of injuries to pedestrians in car-pedestrian accidents. Those include decreasing the aggressiveness of the fronts of cars. Only a few studies of the problems of bus-pedestrian impacts have been made.

2 VEHICLE-PEDESTRIAN ACCIDENTS

Two towns were chosen for an analysis of vehicle-pedestrian accidents: New Delhi and Gothenburg. Delhi is the capital of India with over 8 million residents. In 1990, Delhi had a population of 1.8 million vehicles, 22% of which were cars, 67% MTWs, 6% trucks and 1% buses (ARC, 1991). In 1990, there were 1,559 fatal accidents. In these crashes, vehicles considered by the Delhi police to be "at fault" comprised 14% cars, 35% trucks and 32% buses. In these accidents 1,670 persons were killed, 43% of whom were pedestrians, 12% cyclists, 21% MTW riders, and 21% occupants of all other motor vehicles including bus commuters. These data show that buses and trucks are involved in the vast majority of crashes and that cyclists and pedestrians made up the majority of the fatalities. In other Indian cities the percentage of cyclist fatalities would be higher and motor vehicle occupants lower.

Table 1
Distribution of road fatalities in Delhi (1985) by road user type
and striking vehicle or object.

Victim	Ped	Struck by								Total(%)
		Bic	MTW*	TSR*	Car	Bus	Tru	Oth	Unk	
Pedestrian	-	-	29	19	35	154	99	22	110	468 (42)
Bicycle	-	1	6	1	6	39	50	13	18	134 (12)
MTW	2	2	15	1	20	88	67	30	27	256 (23)
TSR	-	-	-	4	1	13	8	2	1	29 (3)
Car	-	-	-	-	3	3	8	3	-	17 (1)
Bus	2	-	1	-	-	3	10	47	-	107 (10)
Truck	-	-	-	-	1	47	15	11	-	31 (3)
Others	-	-	-	1	3	12	29	12	5	62 (5)
Unknown	-	-	-	1	-	2	-	1	10	14 (1)
Total (%)	4 (0.4)	3 (0.3)	50 (5)	27 (2)	69 (6)	362 (32)	286 (26)	142 (13)	174 (16)	1118 (100)

* MTW = Motorized two-wheelers, TSR = Three-wheeler scooter-rickshaw(Taxi).

Table 1 shows the distribution of fatalities in Delhi by victim and impacting vehicle type in 1985 (at present data about distribution of road accidents were not available). This shows that out of the cases for which details were known, 154 pedestrians were hit by buses, 99 by trucks and only 35 by cars. The pedestrian fatalities comprise 42% of all fatalities, and buses are involved in 43% of the crashes where impacting vehicle details were recorded. If we take all the vulnerable road users (pedestrians, bicyclists and MTWs) we see that they comprise 77% of all the fatalities and that buses are involved in 40% of these crashes for which details are known.

Table 2
Distribution of road accidents in Gothenburg (1990) after category of primary element 1 involved in accident (CPE1) and category of primary element 2 involved in accident (CPE2).[2]

CPE1	CPE2														
	Si*	PCar	Tru	Bus	MC	MP	Unk	Bic	Ped	Trc	Trs	Tri	Tr	An	Total
Private Car	694	1603													2297
Truck	84	425	40												549
Buss	12	108	14	1											135
Motorcycle	36	50	-	-	1										87
Moped**	19	44	2	-	1	6									72
Unk. veh.*	12	7	2	-	-	-	-								21
Bicycle	42	99	8	2	3	10	1	10							175
Pedestrian	-	124	10	10	-	8	-	8	-						160
Tractor	4	19	5	2	-	1	-	1	1	-					33
Tram	-	75	5	3	-	-	-	3	21	-	2				109
Train	-	1	1	-	-	-	-	-	-	1	-	-			3
Trailer	-	8	1	-	-	-	-	1	-	-	-	-	1		11
Animal	-	151	4	2	-	-	-	-	-	-	-	-	-	-	157
Total	903	2713	93	20	5	25	1	23	22	1	2	-	1	-	3809

* Si = Single vehicle accident, Unk. veh. = Unknown vehicle.
** Moped is a vehicle with engine up to 50 cc and top speed up to 30 km/h.

Gothenburg, with 0.726 million residents (including suburban areas), is the second biggest town in Sweden. In 1990, 0.321 million vehicles (not including motorcycles) were registered in the Gothenburg area, 0.295 million (91.9%) of which were private cars, 0.001 million (0.3%) were buses , and 0.025 million (7.8%) were trucks (BIS, 1990).

Table 3
Distribution of pedestrian fatalities by age* and location on the road in bus-pedestrian accidents in New Delhi (1985).

Location	Age group						Total(%)
	0-4	5-14	15-24	25-44	45-60	>60	
Straight section	7	23	17	21	11	5	84 (77)
Intersection	3	2	-	6	2	-	13 (12)
Unknown	-	2	2	6	2	-	12 (11)
Total (%)	10 (9)	27 (25)	19 (17)	33 (30)	15 (14)	5 (5)	109 (100)

* Pedestrians whose ages are not known are not included in this table.

Table 2 shows the distribution of road accidents in Gothenburg in 1990 after category of primary element 1 and element 2 (CPE1 and CPE2) involved in the accident (Ericsson, 1991). The pedestrian is struck by a private car in 68% of the reported vehicle-pedestrian accidents, by a bus in 5.5%, by a tram in 11.5%, and by a truck in 5.5%. In most European countries, private cars are the most common impactor in vehicle-pedestrian accidents, followed by tram/bus and truck. Ericsson (1991) showed that in these accidents, 18 persons

2 Primary element 1 & primary element 2 involved in accident are these road users which are involved in the first collision during the accident. These terms are not equal to "Victim" and "Struck by" in Table 1.

were killed (9 pedestrians), 475 severely injured (180 pedestrians) and 1008 slightly injured (71 pedestrians).

Table 3 shows the distribution by age of fatal pedestrian crashes and the location of the road where the crash with the bus took place. This shows that the vast majority of the crashes took place away from intersections. The pedestrian can be hit from behind while walking on the road or from the side while crossing. Children (0 - 14 years) accounted for 34% of the fatal accidents.

Table 4
Distribution of pedestrian injuries by age and severity of injuries in vehicle-pedestrian accidents in Gothenburg (1990).

Severity	Age group							Total(%)
	0-4	5-14	15-24	25-44	45-59	>60	unknown	
Killed	-	1	-	-	1	7		9 (5)
Severely injured	4	14	16	24	16	34		108 (57)
Slightly injured	1	5	13	24	15	12	1	71 (38)
Total (%)	5 (2.7)	20 (10.6)	29 (15.4)	48 (25.5)	32 (17)	53 (28.2)	1 (0.6)	188 (100)

Table 4 shows the distribution by age and severity of injuries in vehicle-pedestrian accidents in Gothenburg in 1990. Children (0 - 14 years) are involved in 13.3% of all accidents and elderly people in about 28%. Elderly people are overrepresented in pedestrian fatalities (78% of the total number of pedestrian fatalities).

A study (IRT, 1990) of bus accidents involving buses owned by the Pallavan Transport Corporation of the city of Madras in India shows that their buses were involved in 35 fatal and 179 injury-producing crashes with pedestrians in 1989. The fleet of the corporation in 1989 was 2,309 buses, covering a distance of 171,400,000 km. This gives 1.5 pedestrian fatalities and 7.8 pedestrian injuries per 100 buses per year, with each bus travelling about 200 km per day. The number of pedestrians killed and injured per 10 million bus km per year are 2.0 and 10.4, respectively.

The tables cited above do not allow for a direct comparison, due to differences in statistics, definitions, and terminologies, but it is not difficult to find general differences in the distribution of accident types. The data presented above indicate that the vehicle population and the pattern of vehicle involvement in crashes in a LMC like India is very different from that in HMCs. In the former private cars constitute a much smaller proportion of all vehicles than buses and trucks which hit pedestrians in particular and vulnerable road users in general. The pattern of the crashes and the incidence of bus-pedestrian impacts makes this a significant problem in LMCs.

3. MATHEMATICAL SIMULATION

A protective structure, in the form of padding on the front of the bus, can reduce the forces acting on the pedestrian. The MADYMO 3D Crash Victim Simulation package was used to evaluate the protective effect of a padded bus front in bus-pedestrian impacts. Mathematical models have a perfect repeatability and enable assessment of the influence of the modifications made to a vehicle. It is also possible to use them before the vehicle is actually produced or modified.

There are two main injury-related parameters in bus-pedestrian impacts. The first one is the velocity of the bus at the time of the impact with the pedestrian. The second parameter is related to the undeformable bus front. The pedestrian is subjected to a great load at impact with a stiff bus front. Safer bus fronts should be optimized for head, chest, pelvis and lower limb impacts. Details of impact velocities are not known but traffic surveys from various

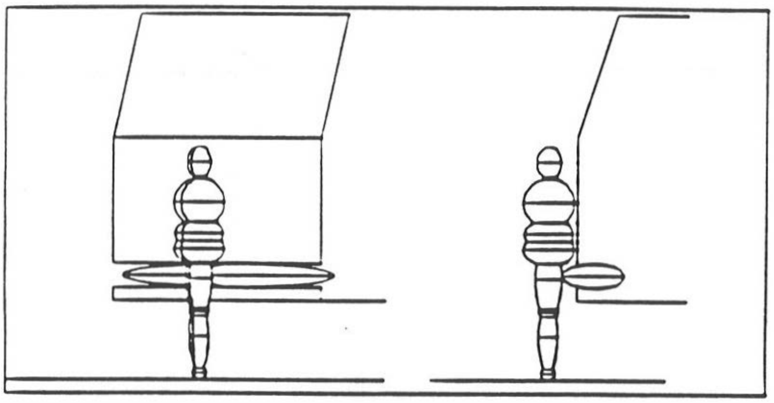
Indian studies indicate that urban bus speeds vary between 15-45 km/h. In the absence of further data, a velocity of 20 km/h was chosen for the bus-pedestrian impact simulation.

3.1 Model Setup

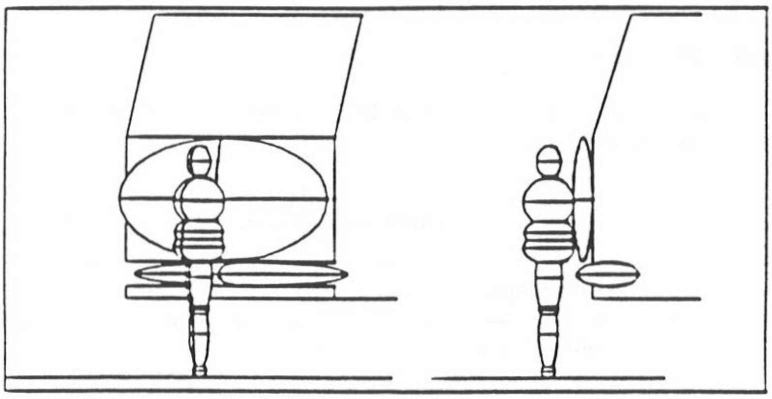
The model setup in this study represents a pedestrian dummy impacted from the side by a bus front, as shown in Figure 1. The model can be divided into two separate systems: one for the pedestrian dummy and one for the bus. The dummy model consists of 8 rigid ellipsoids connected to each other by joints. The vehicle is modeled by a separate one-body system. Five planes and two hyperellipsoids are connected to the system and defined by different force-deformation characteristics. Two simulation tests were conducted with this setup.

3.1.1 The dummy model

The same dummy model was used to represent the pedestrian in two simulation tests. The dummy model was based on the information supplied in both TNO (1990-b) and Kajzer (1991). For this specific application a number of modifications were made.



(a) simulation with unpadded bus front



(b) simulation with padded bus front

Figure 1. Bus-pedestrian impact 3D model

Earlier mathematical and experimental studies have shown that small changes to the initial arm position have a relatively small effect on the test results for the body. For this reason, arms were not included in this model. The arm mass was partly assigned to the upper torso.

The representation of the lower limb was based on a rotationally symmetrical pedestrian dummy (RSPD) developed at the Chalmers University of Technology (Chalmers) and the French National Institute for Transport and Safety Research (INRETS) (Kajzer 1991). To obtain a good repeatability in simulations, the model was made symmetrical about its vertical axis and given only one leg.

As a consequence, the dummy model has eight segments: head, neck, upper torso, central torso, lower torso, thigh, leg and foot. The mass distribution is based on a recommendation dataset of the Part 572 dummy and RSPD model.

3.1.2 The bus model

The bus is a separate one-body system. Five planes and one hyperellipsoid are connected to this system to represent the bus front. The geometrical description is adjusted to a typical bus front from Delhi, India. Five finite planes are used for the grill, windshield, top-hood and chassis, respectively, while the bumper is represented by a hyperellipsoid. In addition, a hyperellipsoid was defined to model the padding on the front of the bus. The bus mass is 930 kg which is the same as a standard vehicle mass in the MADYMO vehicle-pedestrian impact example. The bus has an initial velocity of 20 km/h and a 0.5 g deceleration field is assumed to simulate braking. The simulated padding material has characteristics as shown in Figure 2. The thickness of the padding material is 160 mm.

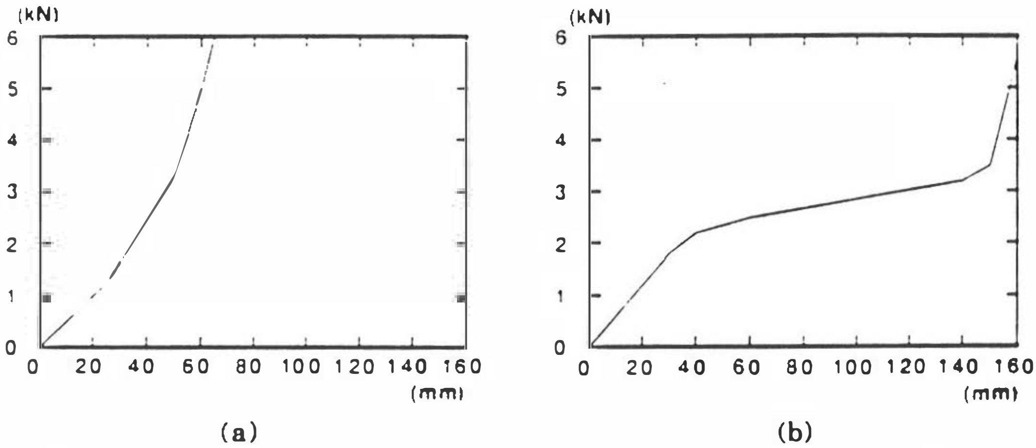


Figure 2. Force deformation characteristics: (a) the bus front; (b) the padding material

3.1.3 Contact interactions

The various contact interactions for the bus-pedestrian impact simulation with a stiff front are defined and listed in Table 5.

Table 5
The contact interactions with a stiff bus front

Interaction	Identifier
Plane - ellipsoid	
1	grill - head
2	grill - upper torso
3	grill - lower torso
4	grill - thigh
5	ground - foot
Ellipsoid - ellipsoid	
1	thigh - bumper

The contact interactions between the padded bus front and pedestrian are defined and listed in Table 6.

Table 6
The contact interactions with padding

Interaction	Identifier
Plane - ellipsoid	
1	ground - foot
Ellipsoid - ellipsoid	
1	head - pad
2	upper torso - pad
3	lower torso - pad
4	thigh - pad
5	thigh - bumper

The simulation tests were made with the contact interactions listed above. The contact forces and accelerations of the impact to main regions of the human body were studied.

3.1.4 Model validation

Since mathematical modelling is unable to give an overall assessment of the vehicle-pedestrian impact, full-scale experiment verification is necessary. The simulations in this work were conducted without experimental verification of the whole model. The reliability of the mathematical model is considered adequate and the model results presented here are considered to be realistic, at least in a qualitative sense.

It should be mentioned here that a MADYMO 3D pedestrian dummy model is based on a Part 572 dummy, which is not a realistic pedestrian substitute for this type of impact. Some effort has been made to modify the MADYMO 3D pedestrian model. A new mathematical one-legged pedestrian model was made as described in Section 3.1.1, as a combination of the part 572 description and the RSPD description.

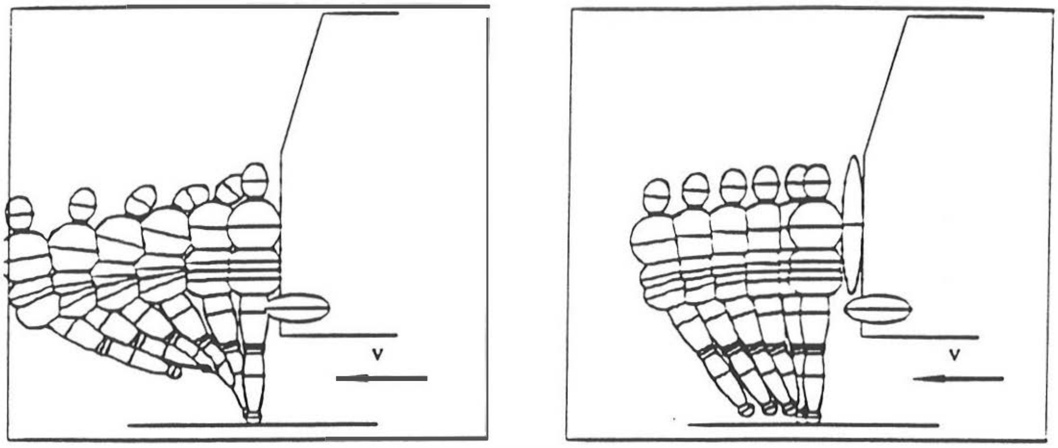
The design of the RSPD mechanical model was based on a number of investigations (Kajzer, 1991), with the main emphasis on the lower limb, especially the knee joint. For this mechanical model, a number of tests were previously performed in different parameter series as follows:

- bumper material and shape;
- impact speed (20 km/h to 32 km/h);
- bumper level above the ground (180 mm to 450 mm).

To validate the representation of the lower limb in the mathematical pedestrian model with the RSPD mechanical model, the mathematical model has been used for simulation of these previous car-pedestrian impact tests. A soft bumper, placed 450 mm above the ground, was used in the simulation, and the impact speed was 20 km/h. The gross kinematics appear to be in agreement with observations from the high-speed films from the laboratory experiment. For instance, the bending deformation between the thigh and the leg in mathematical simulations and experiments with RSPD was well comparable. An agreement between the simulated and the experimental results can also be found for parameters such as contact force and acceleration. Although the mathematical model needs further modification and verificaton, this is no obstacle to its application in this study.

4. RESULTS

Two tests were made with the same dummy model and different bus models. The results presented from the simulations are the kinematics, some of the contact forces and the linear accelerations. The kinematics are shown in Figure 3. The peak values of the linear accelerations and the contact forces are listed in Table 7 and 8, respectively. The time history of the contact forces and the accelerations for the main impact regions of the body are shown in Figure 4 and 5, respectively.



(a) with unpadded bus front (b) with padded bus front

Figure 3. Kinematics of bus-pedestrian impact: v = 5.6 m/s, Δt = 30 ms.

Table 7
The results of peak linear acceleration (g)

	Without padding	With padding
Head	61	43
Upper torso	50	18
Lower torso	62	21
Thigh	74	20
Leg	48	13

Table 8
Results of peak contact forces (kN)

	Without padding	With padding
Head	2.3	2.2
Upper torso	11.0	3.3
Lower torso	7.8	3.1
Thigh	10.0	1.9

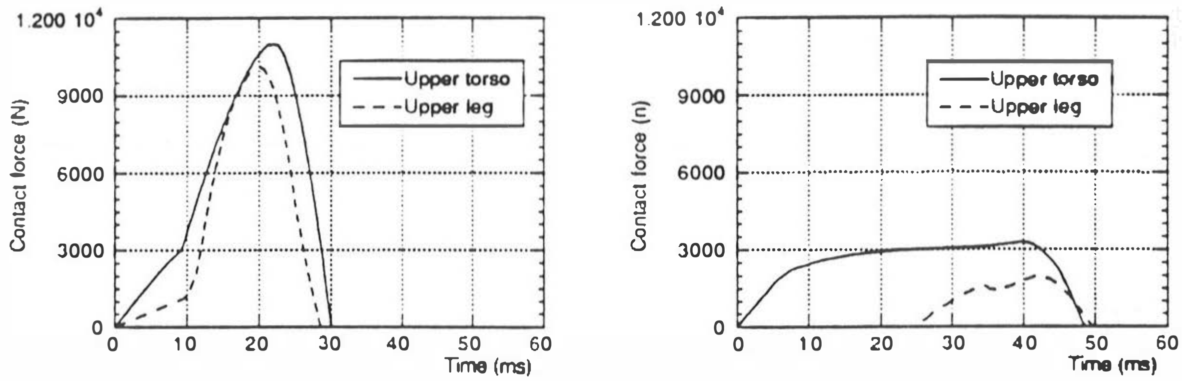
5. DISCUSSION

Bus-pedestrian accidents are a very serious problem in LMCs. This problem is shown by an example from New Delhi, India. The population of New Delhi is 11 times that of Gothenburg, and the number of pedestrians killed in bus-pedestrian accidents in New Delhi is about 52 times greater than in Gothenburg. This difference may be related to various factors, including legislation, road and traffic environment, education and training, road user protection, as well as the design and construction of vehicles. From the statistics in the preceding section, we find that the ratio of buses to private cars is about 14 times higher in Delhi than in Gothenburg and about 36 times higher in India than in Sweden. Obviously, this is one of the main reasons for this problem.

We also found some differeces in the definitions and terminologies used in accident statistics in HMCs and LMCs. These differences betweeen countries may give rise to additional difficulties when making direct comparisons between the pedestrian situation in the two countries and in-depth accident studies. These disparities seem to be small in European countries due to the coordination work caaried out in the EEVC for many years.

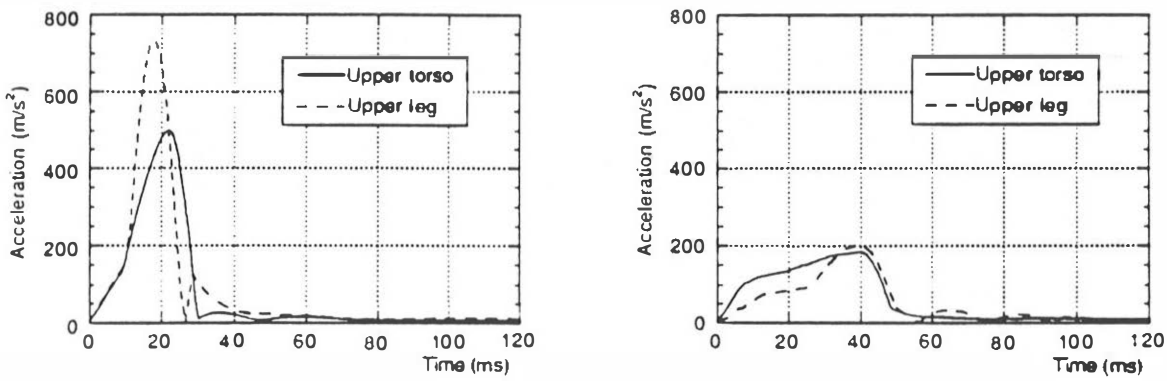
The purpose of the mathematical modelling was to simulate the effect of padding on the front of the bus. The results from the simulations clearly show a reduction of the impact load to the pedestrian. The reason for this change is the soft characteristics of the padding material and a certain degree of energy absorption. In a bus-pedestrian crash, it appears reasonable to assume that a "softer" bus front should reduce injuries. However, the extent of reduction possible is not entirely clear as we have not taken into account the pedestrian-road impact in this paper.

The contact force-time history curves, as shown in Figure 4, show that the initial contact between the grill or bumper of the bus and the main regions of the body occurred at almost the same time. In this one-legged mathematical model, with a simplified lower limb section, the contact between the lower limb and the bumper takes place a little bit later than would be the case with a two-legged model.



(a) without padding (b) with padding

Figure 4. Time history of the contact forces from the bus-pedestrian impact simulation test



(a) without pading (b) with padding

Figure 5. Time history of the accelerations from the bus-pedestrian impact simulation test

Figure 5 shows a comparison between the acceleration time histories of padded and unpadded bus fronts. Results are presented for the upper torso and thigh. All parts of body experienced lower accelerations in crashes with padded fronts as compared to unpadded fornts.

Injury prevention research concerned with pedestrian safety has focussed mainly on head and leg injuries, as these regions of the body are most frequently injured in traffic accidents with private cars. In bus-pedestrian collisions, it has been reported that there were fewer serious pelvic and leg injuries and more serious chest, arm and head injuries than pedestrians struck by fronts of private cars (Ashton et al., 1979). Our modeling results also show that upper parts of the body are likely to sustain more serious injuries.

The bus model used in these simulation tests was based on a bus front structure from Delhi, India. It should be noted that this bus front structure is highly aggressive to pedestrians. For the protection of pedestrians it is essential to improve the design of new bus front structures, including bumper systems, whenever possible.

6. CONCLUSIONS

Investigation of vehicle-pedestrian accidents shows differences between LMCs and HMCs in the pattern of vehicle involvement in accidents. With the accident data currently available it was difficult to make detailed analyses of problems concerning traffic accidents. For further research in this field, it is necessary to use the same or more similar criteria and terminologies in the accident statistics of different countries.

The data presented in this paper clearly indicate that designing safer bus fronts should be given a much higher priority than it has got in the past. This is of great importance for the LMCs, and relevant for the HMCs also because buses and trams do hit a significant number of vulnerable road users. With the trend toward pedestrianization and greater use of bicycles all over the world, development of safer bus fronts (and safer tram fronts) will become increasingly more important.

The bus-pedestrian impact simulations presented in this paper indicate that it is possible to reduce impact forces on the pedestrian by making the front surface of the bus "softer". These preliminary simulations show that the torso experiences the highest impact forces in impacts with both the hard and soft fronts. This part of the body was usually the first area of impact. In the case of the hard front the chest peak forces and accelerations were unacceptable, but in the case of the softer front these were reduced to an "acceptable" level (Cesari et al., 1981 and Cesari et al., 1983).

These simulations have been done mainly with the intention of investigating whether it is possible to reduce the severity of injuries by designing a softer impact surface. These simulations indicate that it should be possible to do so. However, this study has the following shortcomings:

- The second impact of the pedestrian with the road surface has not been investigated;
- The biomechanical properties of the pedestrian have not been optimized for impacts with all body segments;
- Impacts in different positions of the body have not been modeled;
- Effect of impacts on different age groups has not been considered;
- The properties of the impact attenuation bus front have not been optimized for all segments of the body;
- Effects of using different thicknesses of the impact attenuation material have not been simulated;
- Cost benefit analysis of different impact attenuation structures has not been done.

The above shortcomings will have to be taken into account in future studies. Development of safer bus fronts has been neglected both by manufacturers and researchers upto now. This preliminary study shows that there is an urgent need to develop safer bus (and truck) fronts and that it is technically feasible to do so. In addition, similar designs could be incorporated in trams. Such safer fronts will not only protect pedestrians but also bicyclists and motorcyclists.

REFERENCES

ACMAI Automotive Component Manufacturers Association of India (1989): *Automotive Industry of India: Facts and Figures 1988.* Bombay, India.

ARC Accident Research Cell, Delhi Police (1991): *Report on Road Accidents in Delhi 1990.* New Delhi, India.

Ashton, S.J., Bimson, S., and Driscoll, C. (1979): *Patterns of Injury in Pedestrian Accidents.* Proceedings Twenty-Third Conference of the American Association for Automotive Medicine, pp. 185-202. AAAM, Des Plaines, IL, USA.

BIS Bilstatistik AB (1990): *Bilismen i Sverige 1990.* Bilindustriföreningen, Stockholm, Sweden.

Cesari, D., Ramet, M., and Bloch, J. (1981): *Influence of Arm Position on Thoracic Injuries in Side Impact.* Proc. 25th Stapp Car Crash Conference, pp. 271-297. Society of Automotive Engineers, Warrendale, Pa.

Cesari, D., Ramet, M., and Bouquet, R. (1983): *Tolerance of Human Pelvis to Fracture and Proposed Pelvic Protection Criterion to Be Measured on Side Impact Dummies.* Proc. 9th International Technical Conference on Experimental Safety Vehicles, pp. 261-269. U.S. Department of Transportation, NHTSA, Washington, D.C.

EEVC/CEVE (1982): *Pedestrian Injury Accidents.* Proc. of the 9th ESV Conference, Kyoto.

Ericsson L., (1991): *Trafikolyckor i Goteborg 1990.* Stadsbyggnadskontoret Informerar, Rapport 4:91. Trafikkontoret, Box 2403, 403 16 Göteborg, Sweden.

IRT The Institute of Road Transport, Taramani, Madras (1990): *Bus Accident Analysis 1989: Pallavan Transport Corporation Ltd., Madras.* Research Report No. 117, Madras, India.

Kajzer, J. (1991): *Impact Biomechanics of Knee Injuries.* Thesis, Department of Injury Prevention, Chalmers University of Technology, Göteborg, Sweden.

Malini, E. & Victor, D.J. (1990): *Measures to Improve Pedestrian Safety: Lessons from Experience in Madras.* ICOTS 91, New Delhi, India, Journal of Traffic Medicine, Vol. 18, No. 4, p. 266.

SCB Statistiska Centralbyrån (1989): *Trafikskador 1988*, Sverige Officiella Statistik. Stockholm, Sweden.

TNO Road-Vehicles Research Institute (1990-a): *MADYMO User's Manual 3D.* Version 4.3, Delft, The Netherlands.

TNO Road-Vehicles Research Institute (1990-b): *MADYMO Applications.* Version 4.3, Delft, The Netherlands.

TNO Road-Vehicles Research Institute (1990-c): *MADYMO Databases.* Version 4.3, Delft, The Netherlands.

TRD Transport Research Division, Ministry of Surface Transport, Government of India (1987): *Special Issue on Motor Vehicle Accident Statistics in India 1986.* New Delhi, India.