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Spanish frontal accidents of buses & coaches. Injury mechanism analysis

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Abstract

The buses and coaches are the safest means of transportation. Nevertheless, several severe accidents occur creating a high public concern.

During the last years, the international community has developed a spectacular activity related to the definition of new regulations for improving the passive safety in buses and coaches. The effectiveness of these regulations will be based on their influence in real accidents, and especially on the reduction of injuries. It can be demonstrated that the implementation of R66 has reduced significantly the severity of rollover accidents of buses and coaches in Spain. Nevertheless, and instead of all above mentioned, there is still not any regulation about frontal collision safety on these vehicles.

The aim of the study presented in this paper is to identify the main injury mechanisms in buses and coaches frontal collisions that have occurred in Spain over the last years.

The study is based on an in-depth analysis using a buses and coaches accident database including highly detailed information, retrospective investigation, reconstruction, police reports and medical records with injury description and mechanisms. Real-world accidents were considered, in depth-analyzed by the Accident Research Unit of INSIA and investigated in collaboration with the Police Forces, Paramedics and Hospitals.

Finally, conclusions are proposed about the protection provided by the current regulations in the accidents considered (frontal collisions); and recommendations for improving these regulations according to the reduction of injuries in this type of accidents.

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1. Introduction

Buses and coaches are rarely involved in road accidents compared in proportion to other vehicles. The casualties registered each year in these accidents are quite few; making buses and coaches one of the safest means of mass transportation. In Europe, bus and coach accidents represent less than 1% of all traffic fatalities (Niewöhner et al., 2004), whilst in the United States an average of 200 occupants are killed in a year from which 40 are occupants of the bus (Olivares et al., 2007). The ratio of these fatalities by the number of passengers and travelled kilometers is often compared to the one obtained in trains and planes (Australian Transport Safety Bureau, 2005). Nevertheless, the media impact when a bus or coach accident occurs is stunning. The outcomes in terms of injury severity for occupants of both the bus and its collision partners, when involved, suggest that issues like compatibility and occupant protection, in certain accident configurations, still have a large potential of enhancement.

Substantial efforts have been undertaken as regards the rollover protections for occupants of buses and coaches. In Europe, real accident data are proving the effectiveness of the Regulations enforced over the last years on the enhancement of secondary safety of buses and coaches. However, there is still a potential to reduce furthermore the casualties, especially on compatibility issues when head-on collisions are considered.

The present research study, based on real-world accident data of accidents involving at least one bus/coach in a frontal collisions with an obstacle or other vehicles, aims to identify the main injury mechanisms in buses and coaches frontal collisions that have occurred in Spain over the last years, which could serve to find new efficient protections measures.

2. Sources and methods

This study uses fully detailed information of real-world accidents to identify the main characteristics of frontal collision involving buses and coaches. Only M3 category vehicles have been analyzed during this phase.

The aim was to depict the injury mechanisms and to study the frontal damage of the buses/coaches and the collision partner in head-on impacts.

Representative cases were selected from an in-depth survey of real-world bus and coach accidents (SIRABUS database), which are gathered in a dataset of 28 accidents. These are serious accidents with killed or severely injured occupants as consequence, collected between 1996 and 2009. Detailed information from scene, vehicle and human records is available in the dataset.

The SIRABUS database was commissioned to INSIA by the DGT and includes retrospective investigations, accident reconstructions through computer simulations, police reports and medical records with injury descriptions and mechanisms.

Kinematic parameters were estimated from the in-depth analysis and derived from the simulations, all presented in the next section. The analyzed cases have been reconstructed by means of computer simulation in order to identify the main relevant accident conditions and data such as impact velocities of the involved vehicle(s), principle direction of force (PDOF), change of velocity Δ-v due to collision, vehicle deformations, road contacts, and the three dimensional bus movement pre- during and after collision (kinematics).

From the SIRABUS database, a sample configured with 12 accidents according to the following characteristics:

- Severe accident for the occupants of the Bus or Coach.
- With vehicle front structural damage.

3. Results

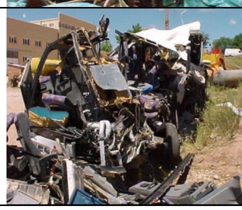
The vehicle type and the collision partner or struck obstacles for the 12 frontal accidents selected from SIRABUS are listed in (Table 1). There is only one bus (vehicle designed for urban transport) included in the list, the rest been different sort of coaches (vehicles designed for interurban transport). This is due to the high seriousness of the accidents, according to the sampling criteria of SIRABUS, which come about more often out of urban areas, where the driving speed is higher and more suitable for coaches rather than buses.

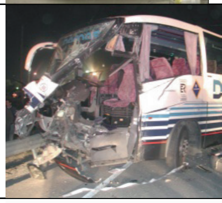
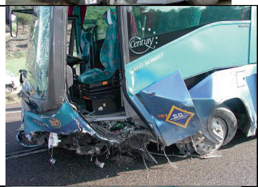
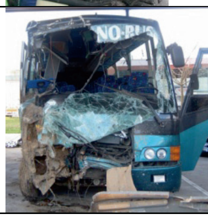
Table 1. Vehicle type and collision partner or stroke object.

Accident ID	Type of bus/coach	Collision partner/obstacle
IN1001	Coach	Car
IN1002	Double Decker coach	Mountain wall
IN1004	Scholar coach	Lorry
IN1007	Coach	Lorry
IN1008	Coach	Lorry
IN1010	Coach	Articulated lorry
IN1013	Coach	Lorry
IN1014	Scholar Coach	Car
IN1016	Coach	Bridge pillar
IN1017	Coach	Car
IN1018	Coach	Articulated lorry
IN1019	Coach	Sewer siphon

3.1. Buses and coaches damages

Table 2. Structural damages in buses and coaches involved in frontal accidents from SIRABUS.

ID	Description	
IN1002	• All front area, spread to all the height, damaged. • Intrusions in the front up to the front axle. • Front rows have been destroyed up to the front axle. • Driver compartment damaged.	
IN1003	• Front left corner, spread to all the height, damaged. • Low intrusions in the front left corner. • Driver compartment partially damaged.	
IN1004	• Front left corner, spread to all the height, damaged. • High intrusions in the left side up to the rear axle. • Left rows have been partially destroyed up to the rear axle. • Driver compartment partially damaged.	
IN1007	• Left side, spread to all the height, damaged. • High intrusions in the left side up to the rear axle. • Left rows have been totally destroyed up to the rear axle. • Driver compartment totally collided.	

ID	Description	
IN1008	• Right side, spread to all the height, damaged. • Intrusions in the right side up to the front axle. • Right rows have been damaged up to the front axle. • Driver compartment partially damaged.	
IN1010	• Front left corner, spread to all the height, damaged. • Low intrusions in the front left corner. • Driver compartment partially damaged.	
IN1013	• Front left corner, spread to all the height, damaged. • Low intrusions in the front left corner. • Driver compartment partially damaged.	
IN1014	• Front left corner, below the floor, damaged. • Driver compartment slight damaged.	
IN1016	• Right side, spread to all the height, damaged. • High intrusions in the right side up to the rear axle. • Right rows have been totally destroyed up to the rear axle. • Driver compartment partially collided.	
IN1017	• Front left corner, below the floor, damaged. • Driver compartment undamaged.	
IN1018	• All front area, spread to all the height, damaged. • Intrusions in the front up to the front axle. • Front rows have been partially destroyed up to the front axle. • Driver compartment damaged	
IN1019	• Front right corner, spread to all the height, damaged. • Intrusions in the front right corner up to the front axle. • Driver compartment slight damaged.	

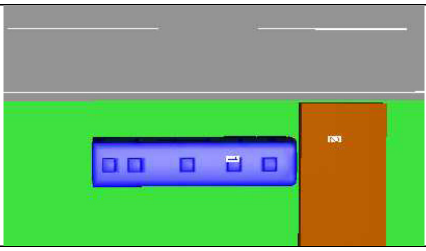
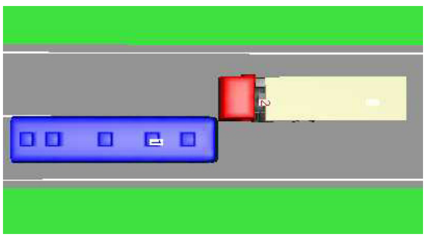
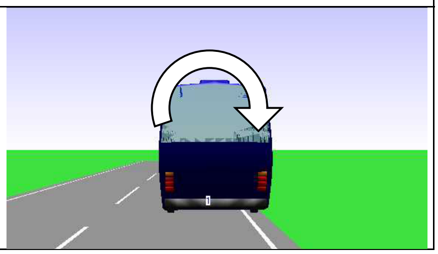
3.2. Collision configuration

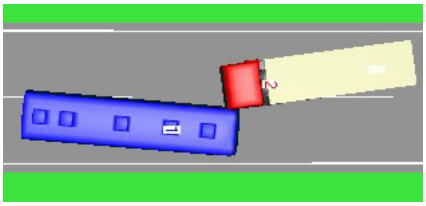
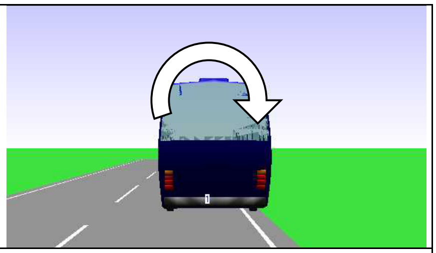
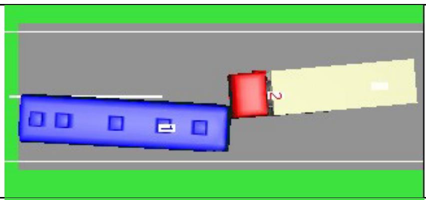
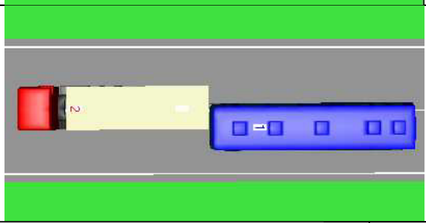
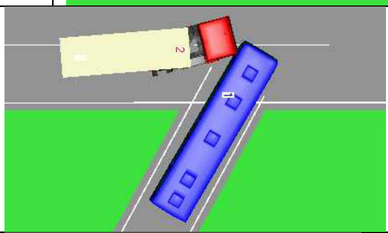
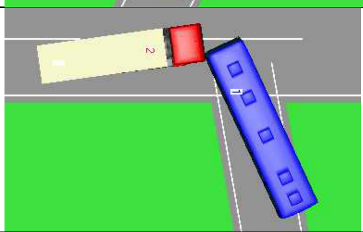
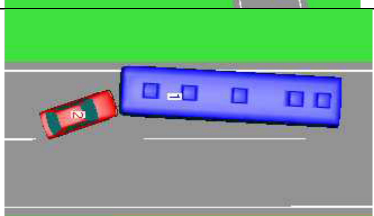
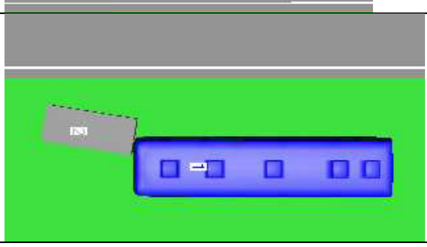
To define the accident it have been considered two types of collision, Type 1 and 2 corresponding to the two most important events on the collision ordered in a chronological way. The next tables (Table 3 and Table 4) summarize the collision types of the 12 studied accidents.

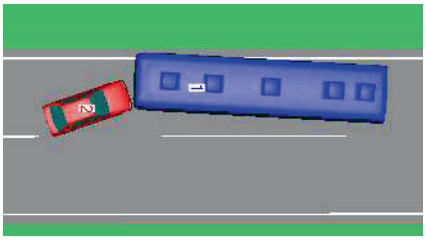
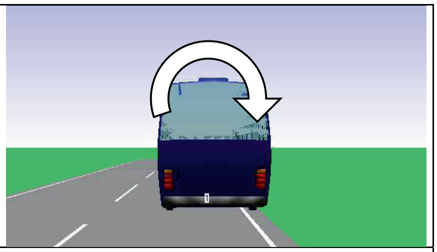
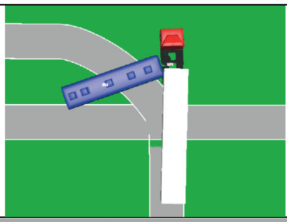
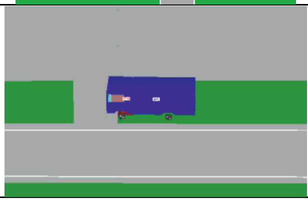
Table 3. Collision configuration in the in-depth sample.

ID	**DATE**	**TYPE 1**	**TYPE 2**
IN1002	26th April, 1998	Exit of the road, right side. Collision with an obstacle.	Not applies.
IN1003	3rd June, 1998	Ride on vehicle collision. Lateral collision.	Exit of the road, right side with rollover.
IN1004	17th November, 1998	Ride on vehicle collision. Front-lateral collision.	Exit of the road, right side with rollover.
IN1007	6th July, 2000	Ride on vehicle collision. Frontal collision.	Going off the right side of the road.
IN1008	14th October, 2002	Ride on vehicle collision. Head-on collision.	Not applies.
IN1010	14th January, 2003	Ride on vehicle collision. Front-lateral collision.	Not applies.
IN1013	17th March, 2003	Ride on vehicle collision. Front-lateral collision.	Not applies.
IN1014	31st March, 2003	Ride on vehicle collision. Frontal collision.	Not applies.
IN1016	28th April, 2003	Exit of the road, left side. Collision with an obstacle.	Not applies.
IN1017	18th May, 2003	Ride on vehicle collision. Frontal collision.	Rollover on the road.
IN1018	13th October, 2003	Ride on vehicle collision. Front-lateral collision.	Not applies.
IN1019	2nd November, 2003	Exit of the road, right side. Collision with an obstacle.	Not applies.

Table 4. Sketches of the collision configuration in the in-depth sample.

IN1002 (C1)			
IN1003 (C1)		IN1003 (C2)	

IN1004 (C1)		IN1004 (C2)	
IN1007 (C1)			
IN1008 (C1)			
IN1010 (C1)			
IN1013 (C1)			
IN1014 (C1)			
IN1016 (C1)			

IN1017 (C1)		IN1017 (C2)	
IN1018 (C1)			
IN1019 (C1)			

3.3. Reconstruction outputs

Table 5. Reconstruction outputs.

ID	Opposite/Obstacle	Collision type (bus)	Bus Category	Bus pre-impact long. velocity	Front overlap (%)	PDoF (º)	Delta-V (kph)	Rollov. Delta-H (m)	Rollov. Angle (º)
IN1002 (C1)	Mountain	Frontal	M3 Double-decker	50	100	0	50	-	-
IN1003 (C1)	Truck	Frontal	M3 Double-decker	95	5	0	4	-	-
IN1003 (C2)	Ground	Rollover		0	-	-	-	2,0	120
IN1004 (C1)	Truck	Side	M3	80	-	-24	20	-	-
IN1004 (C2)	Ground	Rollover		30	-	-	-	0,5	180
IN1007 (C1)	Truck	Frontal	M3	100	15	-18	32	-	-
IN1008 (C1)	Truck	Frontal	M3	85	65	3	31	-	-
IN1010 (C1)	Truck	Side	M3	8	-	-108	15	-	-
IN1013 (C1)	Truck	Side	M3	19	-	-60	22	-	-
IN1014 (C1)	Car	Frontal	M3	90	25	-16	12	-	-
IN1014 (C2)		Side		77	-	-45	1	-	-
IN1016 (C1)	Pole	Frontal	M3	80	20	0	80	-	-
IN1017 (C1)	Car	Frontal	M3	100	10	-47	3	-	-
IN1017 (C2)	Road	Rollover		60	-	-	-	0	90

ID	Opposite/Obstacle	Collision type (bus)	Bus Category	Bus pre-impact long. velocity	Front overlap (%)	PDoF (º)	Delta-V (kph)	Rollov. Delta-H (m)	Rollov. Angle (º)
IN1018 (C1)	Truck	Frontal	M3	44	100	20	11	-	-
IN1019 (C1)	Wall	Frontal	M3	65	45	0	65	-	-

3.4. Injury Mechanisms analysis

Table 6. Injury Mechanisms.

ID	Occu. (bus)	Fatal. (bus)	Sev. (bus)	Slight (bus)	Driver Injury	Intrusion	Projection	Partial ejection	Total ejection	Driver mechanisms
IN1002 (C1)	48	11	31	6	Severe	4	40	4	0	Intrusion
IN1003 (C1)	55	0	0	1	Slight	1	0	0	0	Intrusion
IN1004 (C1)	46	7	13	6	Severe	10	16	0	0	Intrusion
IN1007 (C1)	38	27	11	0	Fatal	14	18	5	1	Intrusion
IN1008 (C1)	30	0	1	27	Severe	1	27	0	0	Intrusion
IN1010 (C1)	18	1	5	8	Severe	2	11	0	1	Intrusion
IN1013 (C1)	23	1	5	15	Severe	1	19	0	1	Intrusion
IN1014 (C1)	15	0	0	7	Slight	0	7	0	0	Projection
IN1016 (C1)	43	6	18	17	Severe	20	21	0	0	Projection
IN1017 (C1)	46	0	0	0	-	0	0	0	0	-
IN1018 (C1)	32	0	4	25	Severe	1	28	0	0	Intrusion
IN1019 (C1)	12	2	5	4	Uninjured	0	11	0	0	-
Total	406	55	93	116	-	54	198	9	3	-

If the occupants do not wear the fitted lap seatbelt, most injuries are associated with the occupant moving forward into the seat back in front, causing injuries to the face, neck and legs (especially the knees). The seatbacks in front provided some restraint by deforming. The severity of the casualties increases if the seat anchorages break as a consequence of the deceleration.

Other important cause of injuries for the bus occupants is the impact against sharp edges (television box,...) or rigid elements (luggage compartment, handle,...), caused by the projection of the occupants.

The most common mechanism of fatal or critical injury in frontal accidents has been found to be direct intrusion. Many of the cases feature large amounts of intrusion and structure deformation, with impacts with trucks being a particular problem. In these cases, it is very difficult to suggest simple prevention, due to the collapse of the bus structure in the area of the impact caused by the high energy involved.

Two seats in the bus are specially exposed in frontal collisions: the driver seat and the tour guide seat. In case of occupants ejected through the front windscreen (from the driver seat, the guide seat and the first row seats), it is expected multiple fractures. This would be prevented if a seat belt had been worn in this forward facing exposed seating position. Besides, special safety devices should be designed for these positions.

The seats and their anchorages should tolerate the more typical efforts which appear in real accidents. The use of seat belts combined with an adequate behavior of the seats and their anchorages would reduce drastically the severity of the injuries, especially in the case of occupants projected or ejected.

4. Conclusions

The representativeness of the data included in this study and thus the results and conclusions are limited due the number of cases for the in-depth analysis.

Accidents involving buses and coaches do not happen very often in the Spanish roads in comparison to other vehicles. However, the media impact generated around them motivates the interest of having a clear picture of the issue.

The results obtained about the injury mechanism indicate that there are a lot of subjects about buses and coaches safety that need to be studied and it is possible to have suggestions for improving them:

- Use of seat belts is strongly recommended. A part of the injuries in accidents is caused by the projection of the occupants, by collisions with other occupants, and by partial or total ejection. The number of the injured occupants and the injury severity of the casualties is less if the bus is equipped with a seat restrains system.
- Partial ejection out of the bus (side window / windscreen) should be avoided. The analysis of accidents indicates that the partial or total ejection is a severe injury mechanism. The injury severity or the casualties is less if the bus is equipped with a seat restraint system and with laminated glasses. Besides, a side airbag especially developed for rollover movement could prevent from the ejection of occupants.
- Research for driver/co-driver frontal impact safety. The special risk of the driver's workplace in a lot kind of accidents, like frontal collisions, can be higher than the passenger's one. On the other hand, if the drivers were correctly protected, in such way that they remained conscious and were not seriously injured, they would keep the control of vehicle in maneuvers after the accidents and would make easy the evacuation. Special protection devices should be designed for the driver protection in the frontal of the coach because the driver's safety it is not adequately contemplated in current regulations.
- Compatibility. The proposals that must be studied about the driver's workplace must be walk at time the study on the compatibility with other vehicles (industrial and cars). First it is needed to guarantee the security of the driver in the bus or in the coach against very different obstacles (at different heights and with different energy to be taken into account). On the other hand to guarantee the security of the occupants in the vehicles that could impact against the bus or the coach.

Acknowledgements

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