In-depth investigation and reconstruction of bus accidents: lessons from a 17 fatalities accident

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Abstract

Bus accidents involving rollover are rare but may lead to severe consequences. On the 15th November 2007, at late afternoon, a major accident involving a passenger car and an interurban bus occurred in a motorway in Portugal, resulting in 17 fatalities and 23 serious injuries. Public interest in this accident was magnified and social consequences were aggravated due to the fact that the bus was carrying a study tour of students from a senior university.

Following a careful at scene data collection by enforcement agents, the Public Attorney-General decided to establish a multidisciplinary team in charge of reconstructing the accident, finding the manoeuvres involved and explain the contribution of road elements, vehicles and each driver in the mechanisms that produced both the accident and its injuries. This team involved participants from the BT-GNR, (the highway police), the Technical University of Lisbon (IDMEC-IST) and the Portuguese National Laboratory of Civil Engineering (LNEC).

It was concluded that the accident started with the car loss of control, followed by its side collision twice with the bus (first with the rear axle, and secondly with the front axle); then, both vehicles ran-off-the-road to the right side of the carriageway, crossed the existing guardrail at the end of the paved shoulder and invaded the steep slope embankment; the car stopped at the bottom of the slope in the ditch. While travelling in the roadside; the bus overturned, resulting in its body failure and the projection of several passengers.

Computational simulation tools such as PC-Crash were used to reconstruct the accident. Also Madymo is used to analyse the behaviour of the occupants and to evaluate the injuries of the unbelted passengers as compared with what would have happened if they were effectively restrained by two point belts. Also simulations with three point belts were carried out to evaluate the effect of this improved restraint system under rollover conditions.

No serious offences by any driver were detected, as the car was travelling at 120 km/h (the bus at 90 km/h) and both vehicles were in their respective lanes. A definitive explanation for the car driver's loss was not obtained, due to lack of evidence and inconclusiveness of participant testimonies.

As a result of the study carried out, a comprehensive set of factors was identified, that played a role in the transport system failure resulting in the analyzed accident

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Keywords: Bus Rollover, Accident Reconstruction, Biomechanics, Multidisciplinary in-depth accident investigation,

Introduction

Road safety is a major global health problem and an important issue in European Union's transport agenda. According to a World Health Organization (WHO), 1.2 million persons lose their life every year and over 18 million are hospitalized worldwide, as a result of traffic accidents [1]. Forecasts by WHO state that road traffic will be the third leading cause of life years lost. Road deaths in the European Union (EU) decreased by 36% between 2001 and 2009; nevertheless, in this last year 34900 persons lost their lives. In Portugal, the number of traffic fatalities declined by 50%, from 1670, in 2001, to 839, in 2009.

Accidents involving buses are rare events in the EU and the resulting victims are a low percentage of the total number of victims. According to the CARE accident database, bus and coach fatalities are less than 0.5% (992 fatalities) of all fatal victims in the five year period from 2004 to 2009 [2]. Recent developments in the yearly number of fatalities in the European Union are illustrated in Figure 1. Bus and coach occupant fatalities show a steeper decreasing trend (-16% yearly, on average) than the one for road fatalities in general (-4%, on average).

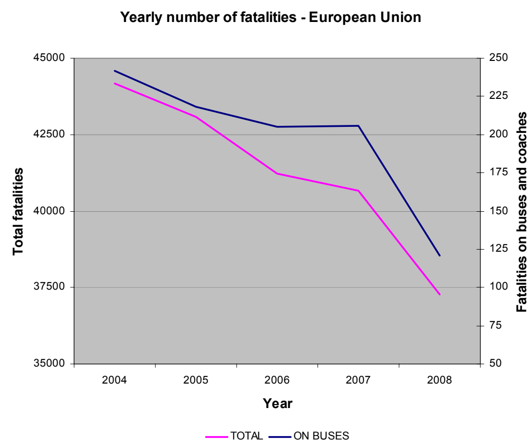


Figure 1 – Developments in the annual number of fatalities in the EU (2004-2008)

Bus accidents on high speed roads and motorways have the potential to be severe, especially in case of a rollover situation, as the risk of fatal casualties is five times higher than the risk of victims in any other type of accident [3]. The risk of death in a frontal impact is of 2.3%, against 9.6% in a rollover situation, as referred by Martinez *et al* [3] in a study carried out in Spain between 1995 and 1999. The rollover situation determines that the occupants are more probably ejected from their seat when compared with any other type of accident [4].

Usually, fatal and serious injury accidents involving buses draw considerable public attention due to the high number of occupants involved. Bus accidents may have serious social impact, especially when their occupants and victims belong to a unique small community or to a homogeneous group – such as school class. Such was the case of the accident described in this paper, whose occupants were students of the *Senior University of Castelo Branco* attending a study visit.

Characteristics of the bus accident at km 77 of motorway A23

The accident occurred on the 15th November 2007, at late afternoon, near km 77.200 of the Portuguese A23 motorway (Figure 2). The weather and visibility conditions were good; the wind was not strong.

Figure 2 – Overall aspect of A23, on the approach to the accident site

The accident involved a Ford Fiesta 1.1 passenger car (with four occupants) and a MAN model 13.230 HOCLA 206 bus (37 occupants); injuries (17 fatalities and 20 serious injuries) were produced in the bus only. Figure 3 presents the vehicles in their final rest positions.

Figure 3 – Overall aspect of the vehicles involved in the accident

Following careful at scene evidence collection by officers from the Traffic Brigade of the Republican National Guard (BT-GNR, the highway police), the Public Attorney-General decided to establish a multidisciplinary team in charge of reconstructing the accident, finding the manoeuvres involved and explain the contribution of driver, vehicle and road in the mechanisms that produced both the accident and its injuries. This team comprised participants from Traffic Police (BT-GNR), the Institute of Mechanics at IST-Technical University of Lisbon (IDMEC-IST) and the Portuguese National Laboratory of Civil Engineering (LNEC). In addition experts from legal medicine have investigated the injuries of the victims, and their work is used by the team especially concerning the questions related with seat bes uses and its effectiveness.

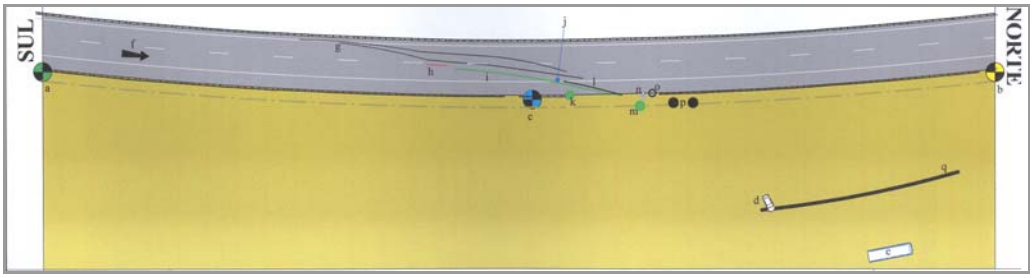


Figure 4 – Tire marks in the pavement surface and map of reported evidence on the road environment

Main characteristics of the road

Road characteristics were measured, regarding the geometric layout, pavement surface characteristics – International Friction Index (IFI) and International Roughness Index (IRI) – and roadside geometry and elements, including road restraint system features. Special care was dedicated to the friction properties of road markings, as yaw marks preceding the first collision marks were collected on the left guideline. Collected data enabled the construction of a three dimensional model of the road and its roadsides, that was used in the PC-Crash reconstruction of the accident.

The accident occurred in the circular part of a left curve (900 m radius, and 475 m length) with 7% superelevation. All these parameters comply with Portuguese motorway design standards.

Measured mean texture depth values ranged between 0.42 mm and 0.54 mm. Skidding resistance was measured with a *Griptester* apparatus at 50 km/h with 0.25 mm water film depth. The resulting F60 ranged between 0.52 and 0.57 in the left lane; 0.48 e 0.52 in the right lane; and 0.32 e 0.37 on the left guideline. Roughness measurements were made with a laser profilometer in 50 km/h running. The IRI is an indicator of the longitudinal roughness of a road surface, being related with 500 mm and above wave lengths; functionally, the IRI is related to rolling resistance, rider comfort, vehicle wear and road safety [7]. In the accident section, the IRI corresponds to a high quality surface for high speed roads, as the measured values ranged between 0.96 and 1.53 m/km on the left lane; and 1.16 m/km and 2.12 m/km on the right lane.

Restraint systems are installed in the roadside area. The same type of system is used in both sides of the road, their containment level class being N2, according to EN 1317 [8]. This class of restraint system can redirect a colliding passenger car (1500 kg) at 110 km/h under a 20º impact angle.

On the right side of the carriageway there is a steep (v/h = 2/3) 13 metres high embankment slope, at which bottom there is a paved ditch.

Aspects related to drivers and passengers

Both drivers were experienced, with more than 5 years of practice, and familiar with both their vehicle and the motorway. No alcohol or other psychoactive substances were found in any driver. The passenger car driver had been driving for less than one hour. The bus driver had been driving intermittently, for the whole day: the journey consisted of three legs, the first between 07:00 and 10:00h (150 km), the second with approximate length of 50 km (by 13:30h) and the return trip, that started by 17:00h. The accident happened shortly after a 20 minute break, in a rest area. There is no evidence that fatigue affected the driving performance of any involved driver. Analysis of testimony produced by passenger car and bus occupants proved to be of limited use in the accident reconstruction, as conflicts with evidence were detected in all cases; for example, only one passenger car occupant (out of four) remembered hearing the sound produced by tires on the rumble guideline. Medical and forensic reports were examined, to identify injury production mechanisms.

Examination of the vehicles

Vehicles were inspected to measure deformations and to detect defects that might have contributed to the accident and to its consequences. Data so collected in both vehicles was used to generate and validate alternative accident scenarios. The passenger car's direction, suspension and braking systems were thoroughly inspected, trying to find deficiencies that might explain its uncontrolled trajectory prior to the initial collision with the bus; as regards the bus, special interest was put on the condition of both its tires and the material of the body structure. No mechanical defects were detected in both vehicles. However, evidence of failure in several bus occupant restraint systems was found.

The analysis of the bus tacograph made possible to determine its pre-impact speed as 94 ± 3 km/h. Through energy and dynamic analysis the car pre-impact speed was calculated as 114 ± 6 km/h. These values were used as input in PC-Crash runs.

Accident reconstruction results

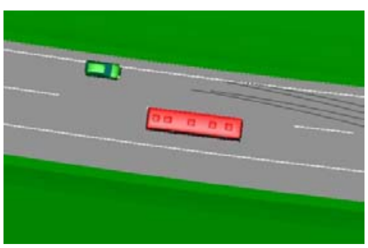
The collected information allowed for the definition of a set of accident scenarios that were validated using the PC-Crash program [9].

The accident scenario that fits al the tyre evidences on the road and vehicles, the sequence of events stared with a passing manoeuvre by the passenger car, in which the driver lost control of its vehicle when passing over the left rumble guideline, due to the combined actuation of the steering wheel and the brakes; the car skidded to its right, towards the centre of the carriageway and collided with the bus rear left panel, hitting in the process the outer left rear tire, which deflated suddenly. At the time of this impact the bus was in the right lane, almost on top of the carriageway centre, smoothly leaning to the right side of its lane. Then the passenger car rebounded and for a few metres travelled sideways with the bus, until it collided again with the bus, this time with the left front wheel. Afterwards, both vehicles slipped to the right roadside, where the bus crushed the lateral restraint system; at the same time, the car passed over the barrier. Both vehicles run over the embankment slope where the bus overturned laterally, hitting the ditch and crushing the rear body structure; the passenger car stopped after colliding with the ditch.

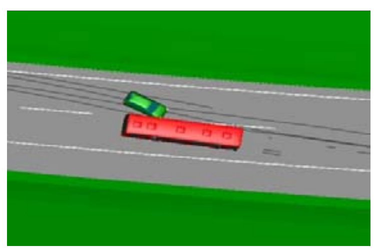
Bus passengers were thrown out of the vehicle during the rollover movement, as a result of seat belt malfunction, due to belt and seat failure. This was the prevailing mechanism for injury production in this accident.

The collected evidence was not sufficient to reach a unique scenario and a conclusive explanation for the drivers' manoeuvres prior to the car driver's loss of control.

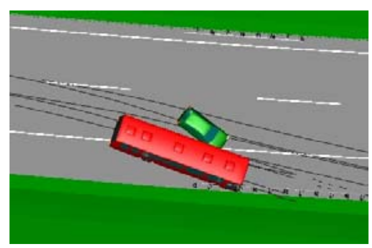
The sequence of events is presented in Figure 6.



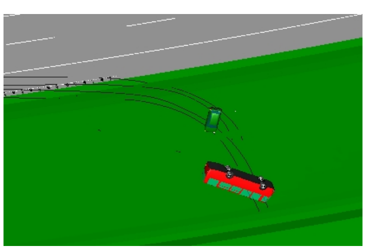
T = 0.00 s Approaching positions



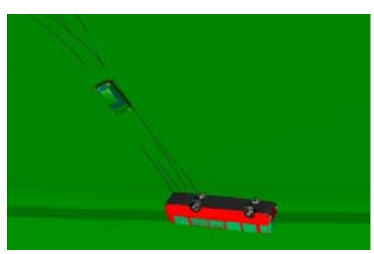
T = 1.10 s First Impact



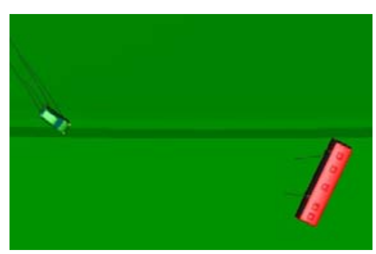
T = 2.12 s Vehicles leaving the road



T = 5.01 s – Heavy passenger vehicle rollover



T = 5.76 s – Roof contact with the ground



T = 8.45 s Final positions

Figure 5 – Computer simulation of side impact followed by rollover.

Lessons learned from the accident investigation

Because of the study carried out, several factors were identified, that might have played an active role in the prevention of this accident or in the mitigation of the severity of its consequences

Current road design policies do not differentiate criteria for the selection of road restraint systems according to roadside characteristics and the presence and characteristics of dangerous obstacles in it. Due to this fact, *W-beam* metallic safety barriers are usually used on motorways; according to EN 1317, their containment level class is N2 and they are suitable to passenger cars only. The lone exception is the application of concrete barriers at sites where there is not enough space to accommodate the *W-beam* working width. The use of higher containment levels in critical sections, such as in the vicinity of high and steep embankment slopes (for instance above 7 m), would have prevented the bus from invading a dangerous slope. In fact, the bus, weighting 12.1 t, impacted the safety barrier at 78 km/h with a 12º impact angle. Since restraint systems of class H1 are able to contain a 10 t impacting rigid body heavy vehicle at 70 km/h with a 15º angle and class H2 systems may contain a 13 t bus at 70 km/h with a 20º angle, it is likely that application of such systems would have been sufficient to redirect the bus in this accident, preventing its exposure to rollover conditions in the steep slope.

Another roadside issue concerns the absence of a smooth transition zone between the steep slope and the paved ditch or the natural terrain, which contributed to increase the angular acceleration of the bus rollover.

Taking into account the smoothness of the swerving and braking manoeuvres of the passenger car in the early stages of its yawing it is likely that an ABS and ESP equipped car driver would not have lost the vehicle control, thus preventing its collision with the bus.

Three major factors contributed to the severity of the consequences of the accident: the bus rollover, the structural failure of the vehicle body structure (especially at the rear) and the deficient functioning of the occupant restraint (due to seat integrity and seat belt material problems.

A question remained, concerning the suitability of two point seat belts to restrain the occupants in the current rollover crash. To analyse the effect of changes in seat belt type further simulations were made using PC-Crash and MADYMO, which are described in the following chapter.

Biomechanics and many-body dynamics

In order to evaluate the severity of injuries faced by the passenger heavy vehicles' occupants at the rollover moment with origin in the failure of the safety belts, a computer model using *Madymo* [10] program was built, with support of many-body theory. Three tests were made in result:

- 1) Passengers using malfunctioning of the two-point belts;
- 2) Passengers using two-point safety belt;
- 3) Passengers using three-point safety belts.

Anthropomorphic models

In what concerns the technical designation of the models in use, it must be stressed the 50th percentile adult male *EuroSid1* and *Hybrid III* [11] belonging to the group of models prepared by ellipsoids. *EuroSid1* model was used in order to simulate an event with loosen of the belts in the passenger level. Also was simulated an event using a two-point belt due to its strength when suffering side impacts. *Hybrid III* model was used to simulate an event connected to a three-point belt, once the *EuroSid1* model does not include defined contact features in the thorax, shoulders and clavicles.

Criteria of injury severity

AIS Criteria (Abbreviature Injury Scale)

This criteria is based on anatomic scale, enabling injury classification in terms of its anatomic placement, kind of injury and respective severity level. In fact the scale is divided in eight different levels being that each one of them presents a respective severity code for each part of the human body.

Head injuries

For the head injuries evaluation of anthropomorphic models was used HIC (*Head Injury Criteria*) parameter. The goal was to evaluate head injury potential at the moment of contact with rigid bodies (equation 2).

$$HIC = \left[\frac{1}{t_2 - t_1} \cdot \int_{t_1}^{t_2} a(t) \cdot dt \right]^{2.5} \cdot (t_2 - t_1) \qquad (2)$$

In what concerns the HIC maximum values admitted, the gap for maximum limit is 1000 [12], resulting that from this value on injuries expected are severe and permanent.

3.2.3 Neck injuries

The neck in anthropomorphic models was tested through tension forces measurement, pressure, cut and bending moment resulting from these. Also they were compared with maximum values admitted.

Torso injuries

To evaluate the torso injuries were used the TTI (Tórax Trauma Index) criteria. This is based on the measures speed at thorax level which is fundamental for evaluating injuries in the thorax region resulting from side impact. It was also used VC criteria to quantify the movements connected to internal organs of the chest, that was only used in the model validation. The VC limit is calculated in 1,0 m/s [13].

Pelvic injuries

To evaluate the influence of using the belt system were measured the maximum resulting force intensity to conclude if the injuries induced by belt system are significants. The maximum resulting force limit is caculated in 3000 N [13].

Computer model of passenger heavy vehicles

A study at three dimensional sections, departed from the ends of the vehicle, as represented on figure 3a was carried out. This kind of section is commonly used in simulations with passenger heavy vehicles, on one hand because it allows an important economy of processing time and on the other hand because it achieves precise results.

The positions are numbered from 1 to 4 in order to identify the anthropomorphic models easily. Regarding launching position the model was placed on the beginning of the higher altitude of the slope with an initial rotation velocity of 0.6 rad/s (figure 3b).

a) Computer model

b) Launching position

Figure 6 – Computer model of passenger heavy vehicle.

Computer validation of the model

The validation of the computer model was made through the support of the european standard ECE R66. It was used for the effect of the anthropomorphic model *EuroSid1*, placed at position 3, with no retention system support, comparing the results obtained by Martinez *et al* [3]. The test used a velocity of the tipping platform of 1º/second.

Results and discussion

Dynamic of anthropomorphic models with the malfunction of the two-point safety belt

This test has the particularity of permitting the analysis of anthropomorphic models dynamic in the rollover event and where the operation of the two-point safety belt was considered inefficient. It should be remarked that it is within this test that the passengers most interfere in one another injuries. (Figure 4).

Figure 7 – Simulation dynamic photogram's.

In what concerns the biomechanical index measured in models' head it is registered that the passengers more probably injured in the head are the ones placed at position 1 and 3, as shown by the measured HIC values (table 1). This is due to the position of the model 1 which has established a direct contact of the torso with the surface of the slope registering a maximum acceleration value of 115 g. Following the model was placed at position 3 for a lateral head crash in the seat of position 2. Positions 1 and 3 are the most significant with high probability of severe torso fracture.

Regarding the neck area it is at the level of the anthropomorphic model placed in position 1 that are shown the highest values of tension and pressure force, cut force and bending moment when directly hitting the ground (table 1).

In what concerns thorax injuries, the higher TTI values were registered on the model placed in position 1 and position 4. In position 1 the highest value is presented when contacting the ground rigid surface while position 4 results of the high intensity impact of the dorsal region at the hand baggage compartment (table 1).

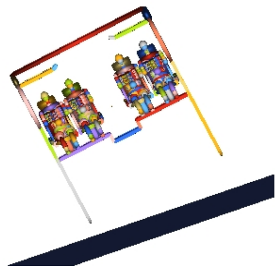
Regarding the pelvic region the maximum strength value resulting is registered at model 2 in the moment of impact placed at position 1 and when reaching the ground. At this time is presents a maximum of 3350 N higher than the admitted limit.

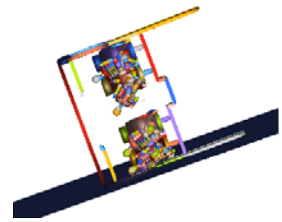
Table 1 – Biomechanical index resulting from computer simulations.

		Model in position 1	**Model in position 2**	**Model in position 3**	**Model in position 4**	**Limits**
Head	HIC36	1320	557	812	632	1000
	Maximum acceleration (g)	115	57	84	62	-
	AIS	3,4	1,8	2,8	2	6
Neck	Maximum tension forces (N)	1791	1274	428	275	4170
	Maximum pressure force (N)	4573	3270	863	439	4000
	Maximum shear force (N)	2925	1286	358	180	3100
	Maximum bending moment (Nm)	241	132	157	87	190
Thorax	TTI (g)	314	115	175	217	-
Pelvis	Maximum resulting force intensity (N)	1287	3350	2450	2774	-

Dynamics of anthropomorphic models with two-point safety belts

This test enables to observe the anthropomorphic models in the rollover event with a proper use of the two-point safety belt by the passengers. In this case one can notice that any of the models left their seat place. (Figure 5).





T = 0.0 s – Launching position   T = 2,5 s – Final position

Figure 8 – Photogram's of simulation dynamics.

On the topic of severity of head injuries it is shown that the anthropomorphic model placed in position 1 is the one presenting a higher HIC value due to the fact that the use of a two-point safety belt does not prevent head from hitting the ground. The model placed at position 2 presents a higher HIC second value once it registered a hit of the head with the clavicle of anthropomorphic model 1 (table 2).

Concerning the neck it is important to highlight that the value of the forces and registered moments is generally significantly lower than the admitted limits. With a call of attention to cut forces that indicate high values in the model placed at position 1 and 2, this is due to the contact of the first with the head on the ground and from the contact of the second with the clavicle of the model placed at position 1.

Regarding the measures made on the thorax the higher TTI (table 2) value occurred in the model placed at position 1, because it is the nearest positioned to ground impact, and also because it is exposed to the interaction with the anthropomorphic model of position 2. Note that the proper operation of the two-point safety belt enables the level of acceleration on the thorax (TTI) to be lightly reduced if compared with the previous test.

For the pelvic region the value for resulting maximum force is obtained at position 3 and 4.This is due to the fact that these are positions under higher angular speed in the rotation moment.

Table 2 – Resulting biomechanical index from computer simulations.

		Model in position 1	**Model in position 2**	**Model in position 3**	**Model in position 4**	**Limits**
Head	HIC36	281	183	15	22	1000
	Maximum acceleration (g)	86	82	13	41	-
	AIS	1,3	0,8	≅ 0	≅ 0	6
Neck	Maximum tension forces (N)	126	170	87	132	4170
	Maximum pressure force (N)	103	634	96	125	4000
	Maximum shear force (N)	1366	1387	144	502	3100
	Maximum bending moment (Nm)	13	21	11	15	190
Thorax	TTI (g)	472	24	93	35	-
Pelvis	Maximum resulting force intensity (N)	1969	2560	3854	4611	-

Anthropomorphic model dynamics with the three-point safety belt

In what concerns this test and similarly with the test of the two-point safety belt it was possible to determine that any of the anthropomorphic models were not ejected from the occupied position (figure 6). The advantage in using the three-point safety belt lies in the possibility of retention of the chest region. It should be highlighted that in this case were used the anthropomorphic models *Hybrid III* because they include defined contact features for the thorax.

T = 0.0 s – Launching position T = 2,5 s – Final position

Figure 6 – Photogram's of simulation dynamics.

Giving emphasis to the model placed at position 1 and despite the placement of the three-point safety belt one cannot prevent the head contact with the ground. It is identified a light reduction from HIC (table 3) regarding the test with two-point safety belts in reason that the head movement is limited due to a higher retention of the torso. In general a decrease of HIC value is detected for all the models. Concerning the intensity of forces specially the bending moment on the model's neck it was registered a light increase if compared to the values of the two-point safety belt test. This is due to the fact that the three-point safety belt holds the thorax region and therefore the neck is more exposed in head accelerations and decelerations.

The thorax in *Hybrid III* model does not allow the measurement of TTI values reason why only the values in the middle thorax region were measured. It is important to highlight that the peak acceleration values were reached at the impact moment of the structure with the slope. The maximum value was reached in the model placed at position 4 due to a higher value of the angular speed. It is equally in this context that the model placed at position 4 registers the maximum value of acceleration in the pelvic region. These values cannot be compared with the ones from the previous tests because the model *Hybrid III* does not allow the force measurement in the region studied.

Table 3 – Resulting biomechanical index of computer simulations.

		Model in position 1	**Model in position 2**	**Model in position 3**	**Model in position 4**	**Limits**
Head	HIC36	205	14	31	52	1000
	Maximum acceleration (g)	105	12	19	26	-
	AIS	1,1	≅ 0	0,1	0,3	6
Neck	Maximum tension forces (N)	115	99	321	256	4170
	Maximum pressure force (N)	121	150	363	390	4000
	Maximum shear force (N)	851	452	374	508	3100
	Maximum bending moment (Nm)	83	25	36	23	190
Thorax	TTI (g)	42	17	23	43	-
Pelvis	Maximum resulting force intensity (N)	19	21	16	36	-

Conclusions and future developments

The last decades have registered a decrease of road accidents involving passenger heavy vehicles due to the implementation of standards by the competent authorities. Even so the satisfactory levels have not been reached yet.

From the survey results one can conclude that the major part of drivers has not a detailed knowledge about the questions brought up and sometimes they were answering but uncertain that was the most adequate for the question. The professional driver plays a fundamental role in the prevention and respect of safety rules.

The accident scientific reconstitution allowed verifying that side impact can cause a vehicle going out of the track and running line with subsequent rollover of a passenger heavy vehicle. Wit this accident reconstruction performed with Pc-Crash the accident is explained because only fro testimonies and evidences was not possible to explain the accident.

The multidisciplinary team proved to be a crucial factor to investigate this complex accident Only with the knowledge of different areas is possible reconstruct and explain such complex accident.

Through *Madymo* software the severity of injuries on passengers from the studied section was measured. The most severe corresponds to the test of passengers without safety belt. The results have sown that the initial position of the passengers is extremely important in the level of injuries suffered. Therefore the positions on the rollover side inflict more serious injuries.

It was possible to verify that the correct operating of the two-point safety belt allows a decrease of injuries severity that occur when the passengers do not use the safety belt or due to any other reason it is not operating correctly. Despite its use, the passenger positioned in the near side of the rollover cannot prevent the contact of the head, neck and thorax with the ground at the impact moment. It is in this context that the three-point belt is used, as it enables trunk retention and allows in this position the reduction of the head contact with the ground.

Even so through the use of the three-point belt there is an increase of the acceleration levels in the thorax region, if compared with the two-point belt. This is due to the fact that the model is under a higher constraint and later during the impact of the higher forces applied in the ribs and lumbar region. Concerning the legs the use of the three-point belt did not indicate advantages connected to the two-point belt.

In a general way the use of retention system prevents injuries caused by the contact between passengers, reason why in a near future there there will be a generalisation of the three-point safety belts in passenger heavy vehicles because of its gain in preserving the integrity of its occupants.

In the scope of future developments it would be of great interest to perform a computer development of the contact features at the level of thorax, shoulders and clavicles of *EuroSid1* model in order to enable its use in events with three-point safety belt.

The anthropomorphic model *EuroSid1* is strong enough to be used in side impacts and *Hybrid III* in frontal impact. The rollover event demonstrated, especially in the test with no retention system, a mix of side and frontal contacts when models fall. In this context there are reasons to develop specific anthropomorphic models for rollover events allowing similarly the evaluation of neck torsion forces.

To prevent head, neck and thorax contact from the occupant of the nearest position of rollover with the ground it would be of great interest to develop curtain and side airbags models.

The lessons from this accident show that id the car is equipped with ESP(Stability Control) the accident is avoidable. The regulations for guardrails are not adequate for heavy passenger vehicles, and training of drivers especially emergency reactions also can contribute to avoid the accident.

References

1. WHO, http://www.unece.org/trans/roadsafe/docs/GA_R_57-309e.pdf , acceded in 2005-03-01.
2. EC, http://ec.europa.eu/transport/road_safety/specialist/statistics/care_reports_graphics/ , acceded in 2010-09-01.
3. Martinez L., Aparício F., Garcia A., Páez J., Ferichola G.,Improving occupant safety in coach rollover, International Journal of Crashworthiness, Vol 8, pp 121-132, 2003.
4. Subic A., He J.,Improving Bus Rollover Designs Through Modal Analysis, International Journal of Crashworthiness, Vol 2, pp 132-152, 1997.
5. ASTM (2003). E 1926-98. Standard practice for computing International Roughness Index of roads from longitudinal profile measurements. ASTM, USA.
6. ASTM (2003). E 1960-03. Standard practice for calculating International Friction Index of a pavement surface. ASTM, USA.
7. Cardoso, J.L. (2008). The influence of road surface characteristics on road safety. Some results from observational studies. Presented at the 5th Portuguese Road Congress, Estoril.
8. CEN (2003). EN 1317. Road restraint systems. Comité Européen de Normalisation, Paris.
9. S. Datentechnik, PC-Crash version 7.3, Road Accident reconstitution software.
10. TNO, Madymo v6.2 Theory Manual, Delft, Junho 2004.
11. TNO, Madymo v6.2 Model Manual, Delft, Junho 2004.
12. Prasad P., Mertz H., The position of the Us delegation to the ISO Working Group 6 on the use of HIC in the automotive environment, SAE Paper, 1985.
13. European New Car Assessment, Protocol and Biomechanics limits, Euro NCAP 2008.