COACH PASSENGER INJURY RISK DURING ROLLOVER: INFLUENCE OF THE SEAT AND THE RESTRAINT SYSTEM

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ABSTRACT

In the last years the European Community funded several projects, whose general aim was to improve the safety of road users. Among them, the "Enhanced Coach and Bus Occupant Safety" (ECBOS) Project was set up in order to study improvements in current regulations and propose new standards for the development of safer buses and coaches.

For what concerns the rollover protection (ECE66 Regulation), one of the main suggestions, proposed by the partners of the ECBOS project [1], is to take into account the presence of the passengers on board both in the numerical and in the experimental homologation tests. An additional mass in the vehicle increases the energy assumed to be absorbed by the structure in order to pass the test. That could lead the bus manufacturers to increase the strength of the vehicle super-structure in order to obtain a deformation level below the limits stated in the ECE66 regulation.

A numerical study was performed to evaluate how an increment of the super-structure strength, that ensures the vehicle to pass the homologation test with the passengers onboard (i.e. to avoid intrusions into the residual space defined by the regulation), affects the injury risk for the passengers themselves. To perform such a kind of study, it is essential to model the interactions of the passengers with the coach inside environment accurately. One of the most important components that greatly influence the movement of the passengers inside the vehicle is the seat. For that reason, a detailed hybrid model (Mulibody – FE) of a seat was developed based of a real coach seat, whose data were provided by a seat manufacturer. Two configurations were analysed, changing the restraint system (two-point and three point belt). The injury risk for passengers was evaluated calculating the most significant injury parameters and criteria (HIC, TTI, VI, etc.).

INTRODUCTION

Passenger transport in terms of buses and coaches is very safe nowadays. Statistical comparisons with other means of transport show evidence for the high safety level of buses and coaches, which is much higher than that of cars, being comparable with that of trains or even airplanes. Despite the high safety rating, particular serious bus and coach accidents still occur and arouse public attention casting doubt on the positive safety image of these vehicles. In the European Community approximately 20000 (4%) buses and coaches are currently involved in accidents with personal injuries each year [2]. More than 30000 persons are injured due to those accidents and about 200 occupants suffer fatal injuries. Among the bus and coach accidents, one of the most dangerous is surely the rollover of the vehicle.

The ECBOS project, started on January 2000 and ended on June 2003, was sponsored by the European Community to suggest improvements in current regulations and propose new regulations and standards for the development of safer buses and coaches. Seven partners from six European countries were involved in the project. As outcome of the project a list of suggestions for new regulations and written standards were jointly proposed by the partners in order to decrease the incidence and the severity of occupant injuries and social suffering which occur as a result of bus and coach accidents.

ROLLOVER PROTECTION

Buses and coaches are transport means for which in Europe the regulation is not at the moment so strict as for cars. The high cost of the single vehicle makes the manufacturers unwilling to perform full vehicle tests like car crash-tests.

For what concerns the rollover of a bus or a coach, the point of reference is the UNECE regulation no. 66 (ECE66) [3]. The same requirements of this regulation are included in the European Directive 2001/85/EC [4]. The ECE66 applies to single decked vehicles constructed for the carriage of more than 16 passengers, whether seated or standing, in addition to the driver and crew. This regulation set the uniform provision concerning the approval of large passenger vehicles with regard to the strength of their super-structure. "Super-structure" means the parts of a vehicle structure which contribute to the strength of the vehicle in the event of a rollover accident.

In order to obtain the approval, the super-structure of the vehicle shall be of sufficient strength to ensure that during and after it has been subjected to one of the test methods:

- no displaced part of the vehicle intrudes into the residual space
- no part of the residual space projects outside the deformed structure

“Residual space” means the volume within the passenger compartment which is swept when the transverse vertical plane shown in figure 1 is moved in along the vehicle longitudinal axis.

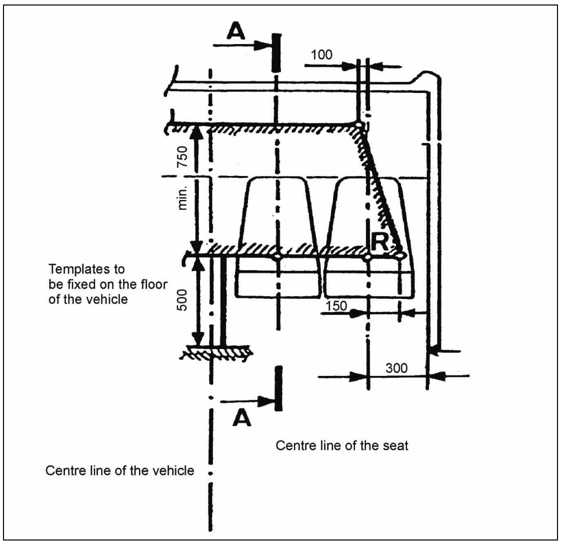

Figure 1. Residual space as defined in the ECE 66 Regulation.

Each type of vehicle can be verified according to one of the following methods at the discretion of the manufacturer or according to an alternative method approved by the competent authority:

- a rollover test on a complete vehicle
- a rollover test on a body section or sections representative of a complete vehicle
- a pendulum test on a body section or sections
- a verification of strength of super-structure by calculation

"Body section" means a section containing at least two identical vertical pillars on each side representative of a part or parts of the structure of the vehicle.

It is important to remark that in the homologation tests, proposed by the ECE66 regulation, the vehicle is verified without considering the presence of the passengers on board.

NUMERICAL MODEL

A numerical model able to describe the behaviour of an M3 vehicle structure during a rollover was developed [5-8] through the multibody (MB) approach using MADYMO software.

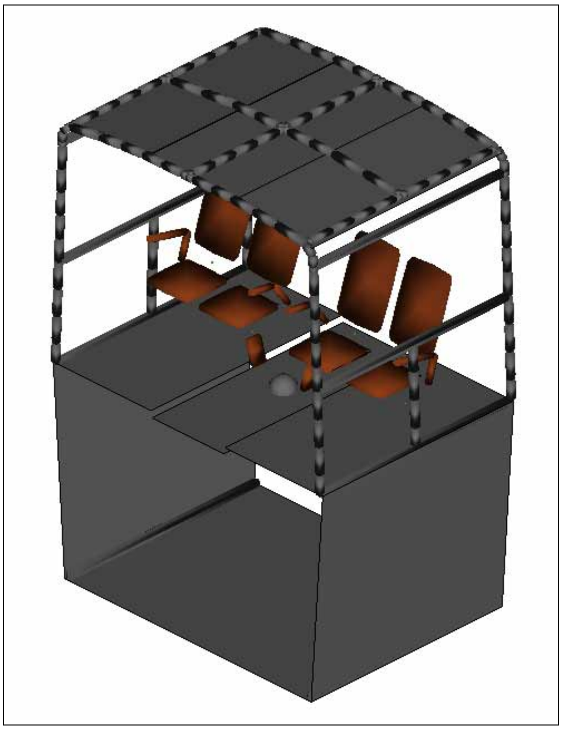

Figure 2. Bay section MB model.

The model (figure 2) was built according to a real bay section (figure 3) used by the Cranfield Impact Centre (CIC) to perform experimental tests within the ECBOS project [9].

Figure 3. CIC bay section (courtesy of CIC).

The general design of the bay section was taken from a typical existing ECE66 approved coach design. The bay section design used two complete body rings (i.e. one ring consists of two window pillars, roof cross beam and floor cross beams). These two rings were connected via longitudinal beams at floor, waist and roof level. The bay section had one row of seats. The data about the bay section geometry and the materials characteristics were provided by CIC, together with the results of two experimental rollover tests. These results were used to check the behaviour of the model and to validate it [5,6].

The seats were modelled thought a simplified structure made up of three bodies (seat base, seat back and head rest) [5,6].

MB SEAT MODEL

In order to study the consequences of a rollover on the passengers the movement of the occupants inside the vehicle must be described accurately. For this purpose it is necessary to set up a seat model able to represent the behaviour of a real seat during a rollover event properly. Therefore a detailed MB seat model was developed according to a real seat (figure 4) produced by Lazzerini, an Italian seat manufacturer of the Grammel group, one of the most important European seat producers. The information necessary to build the model was provided by the manufacturer itself.

Figure 4. Seat for M3 class coaches.

Seat frame

The manufacturer provided the data about the frame of a double seat usually mounted on M3 class vehicles. This frame is made up of three components:

1. The linking element between the seat and the side wall of the coach (figures 5 and 6)
2. The seat leg on the aisle side (figures 7 and 8)
3. The transversal rods supporting the seats (figures 9 and 10)

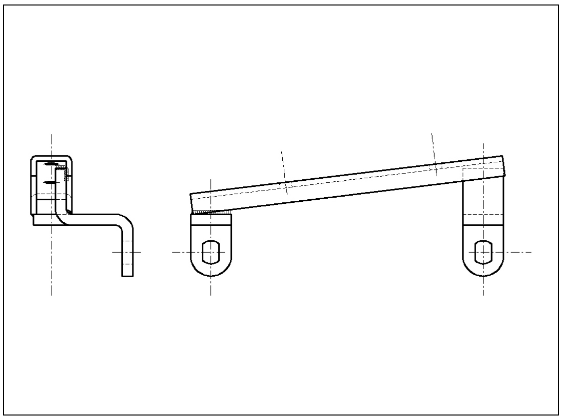

Figure 5. Linking element.

Figure 6. Linking element fitted.

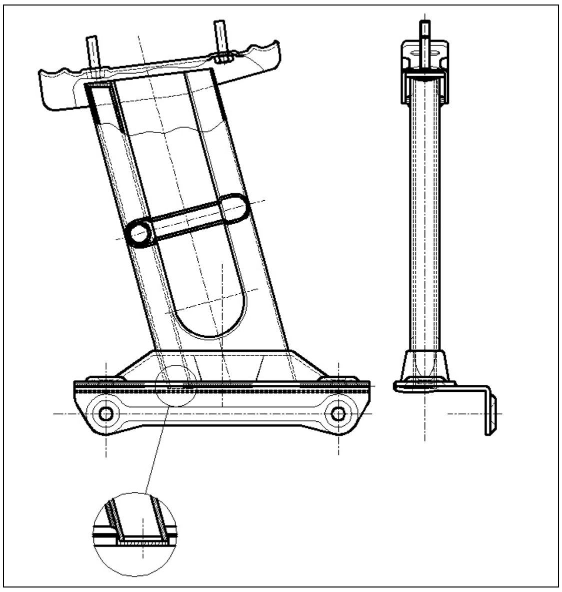

Figure 7. Seat leg.

Figure 8. Seat leg fitted.

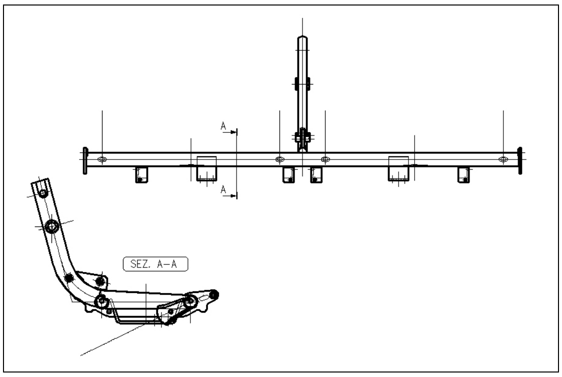

Figure 9. Transversal rods.

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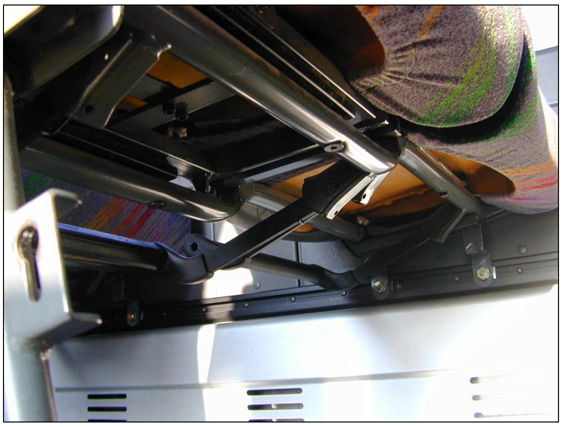

Figure 10. Transversal rods fitted.

The first component is made up of three parts welded together. The parts with holes connect the seat to the coach side wall through two bolts while the horizontal plate bears the seat frame. In the seat leg two bolts in the lower side plate connect the seat to the coach deck. A second welded plate holds the housing for the vertical column. A beam is positioned inside the column to increase the bending stiffness of the structure. The upper part of the seat leg is shaped properly to house the transversal rods of the frame, which bear the seat.

The two transversal rods are connected at the aisle side to the seat leg and at the window side to the horizontal plate of the linking element. The connection is made by two blocking plates clamped by bolts.

FE model of the seat frame

In a rollover the seat frame is usually deformed in the transversal direction beyond the elastic limit of the material.

In order to build the MB model of a structure submitted to an elastic-plastic collapse it is necessary to know in advance the deformed shape of the structure for the applied loads and its non linear stiffness characteristic. In this way it is possible to know the collapse points of the structure, in which the proper kinematic joints will be positioned, and the strength characteristic assigned to them [10]. Starting from the data provided by the manufacturer, the FE model of the seat frame was developed with the aim of studying how this structure collapses during the rollover of the vehicle. The three components of the seat were modelled with four nodes shell elements, while the welding was modelled with rigid beam elements connecting together the nodes of the components in the welded areas. For what concerns the connections between the three elements, due to the very high stiffness of the links, they were modelled as completely rigid.

Figure 11. Deformed seat frame.

FE simulations of the seat under-frame collapse

In the FE simulations, carried out through MADYMO, a displacement field reproducing what happens during a rollover was applied to the seat frame. Looking at the deformed shape of a bay section after a rollover test (figure 11), it is possible to notice that the displacement of the seat frame is caused by the rotation of the side wall around the plastic hinge which develops in the lower part of the window pillars. To reproduce that in the simulations the nodes around the holes of the side plate at the bottom of the seat leg (figure 12) were rigidly constrained to the inertial reference system.

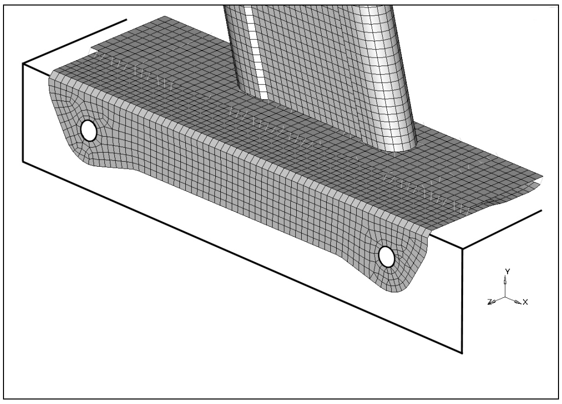

Figure 12. FE model boundary conditions: seat leg.

Furthermore the nodes belonging to the horizontal plate at the bottom of the leg (figure 12) were constrained so that they couldn't go down (negative Y direction) due to the presence of the vehicle floor.

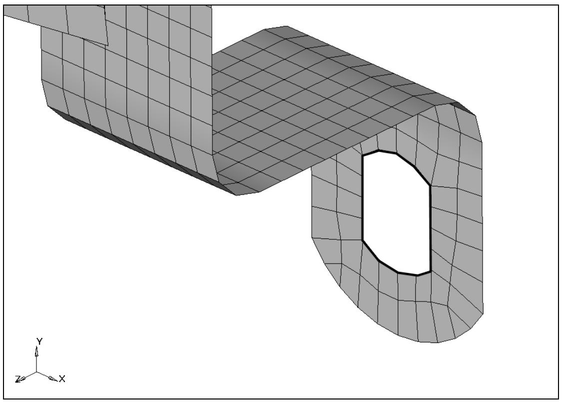

Figure 13. FE model boundary conditions: linking element.

The nodes around the holes in the linking element (figure 13) were constrained to a reference system rotating around the X axis.

Two different situations were simulated. A positive rotation (figure 24) to model what happens to the seat at the impact side and a negative rotation (figure 15) to simulate what happens to the seat opposite the impact side.

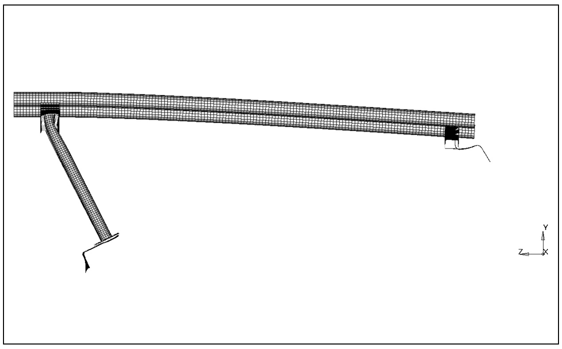

Figure 14. Deformed shape of the seat on the impact side.

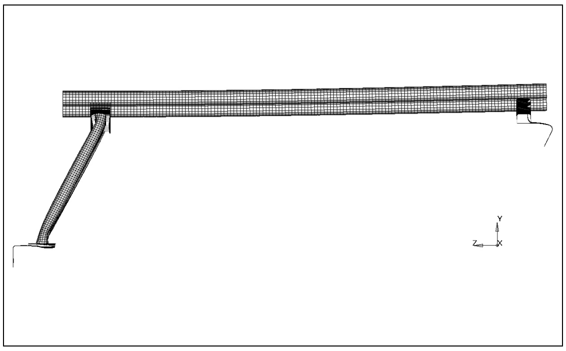

Figure 15. Deformed shape of the seat opposite the impact side.

For what concerns the seat on the impact side the deformed shapes obtained from the simulations are shown in figures from 16 to 18. It is possible to locate three collapse points. The first point is in the clamps of the linking element (figure 16) and the second one is at the top of the column in the seat leg (figure 17). The last point is in the side plate at the bottom of the seat leg (figure 18) which went up during the deformation process.

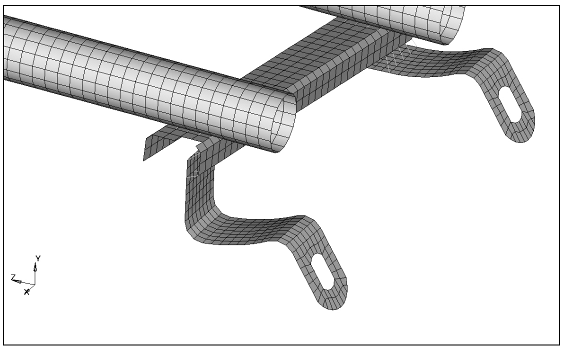

Figure 16. Deformed shape of the linking element on the impact side.

For the seat opposite the impact side the deformed shapes are shown in figures from 19 to 21. In this case too there are three collapse points.

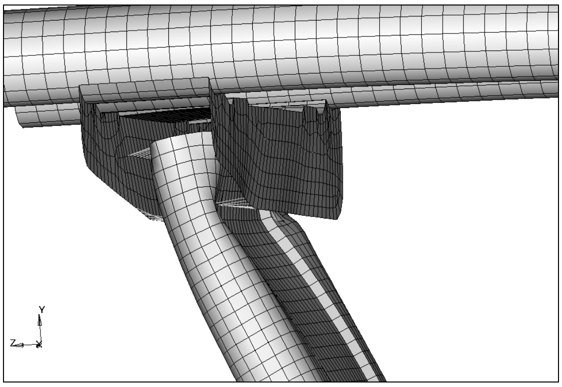

Figure 17. Deformed shape of the upper part of the seat leg on the impact side.

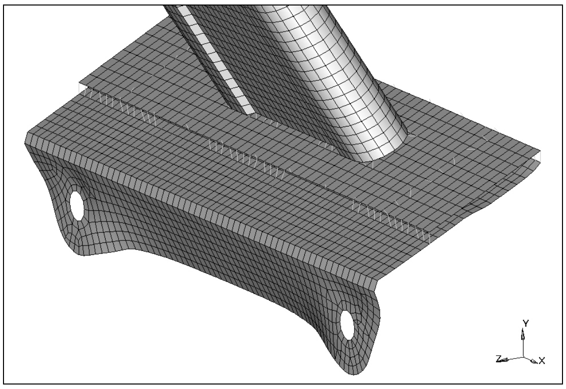

Figure 18. Deformed shape of the lower part of the seat leg on the impact side.

The first two points are similar to the ones of the seat on the impact side, i.e. in the clamps of the linking element (figure 19) and at the top of the column in the seat leg frame (figure 20). The third point developed in a different location than in the previous case. As the seat leg can't go down due to the presence of the vehicle floor, the structure collapsed in the lower part of the vertical column (figure 21).

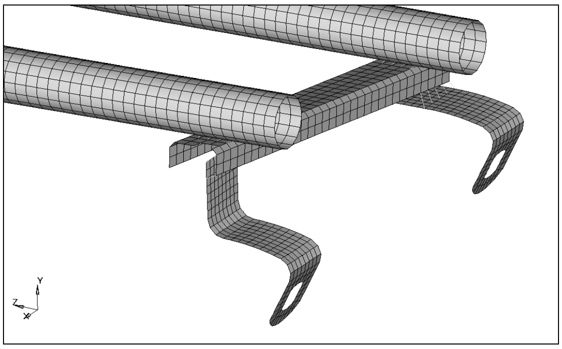

Figure 19. Deformed shape of the linking element opposite the impact side.

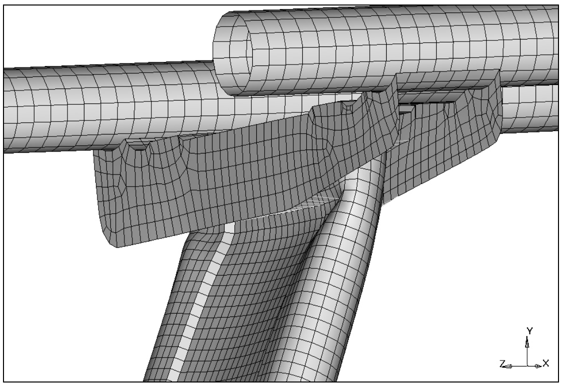

Figure 20. Deformed shape of the upper part of the seat leg opposite the impact side.

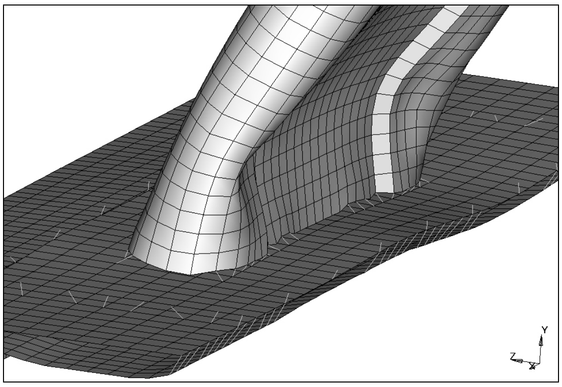

Figure 21. Deformed shape of the lower part of the seat leg opposite the impact side.

As a consequence the global behaviour of the seat frame can be described by concentrating the deformations of the structure in three points (figure 22) where the plastic hinges develop while the remaining parts of the structure can be represented as two rigid members. The non-linear strength characteristic of the seat frame in terms of resistant moment versus relative rotation of the two rigid members around point 2 is shown in figure 23. This curve was calculated from the FE simulations by an energy balance.

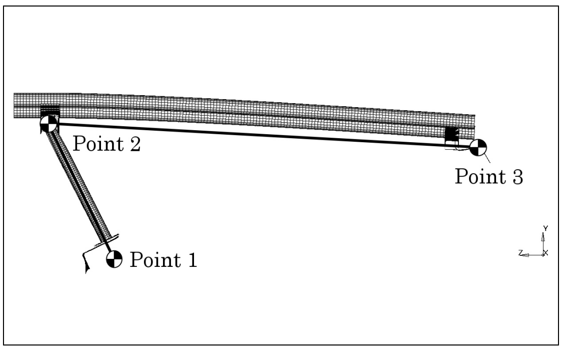

Figure 22. Deformation points of the seat frame.

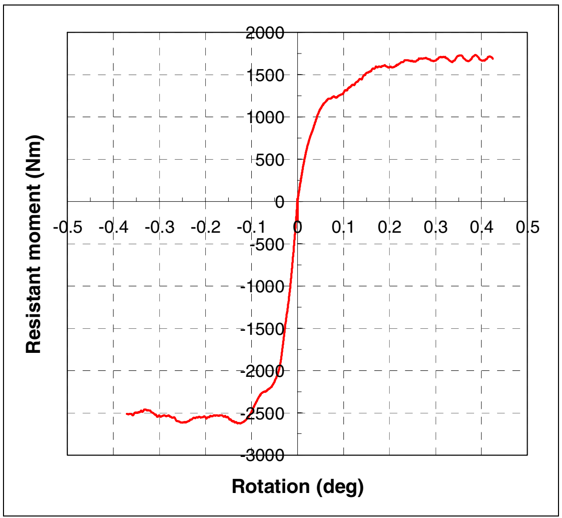

Figure 23. Seat frame non-linear characteristic.

Seat MB model

In the seat model development both techniques, MB and FE, were used. With the FE it was possible to describe the geometry of the seat in a more accurate way than with simple MB surfaces like planes, ellipsoids and cylinders. In particular the seat cushion, the seat back, the armrests, the footrests, the plastic parts in the seat back and the seat leg were modelled by shell elements (figure 24). The material used to model these components was a rigid one (NULL MATERIAL in MADYMO) without inertial properties.

Figure 24. MB seat model with FE contact surfaces.

The layout of the MB part of the seat model is shown in figure 25. Each seat component (seat cushion, seat back, etc.) is described by one rigid body whose inertial properties were calculated from the data provided by the seat manufacturer. The bodies are connected together by kinematic joints in an open branch chain. Joints 1 are revolute joints which allow the rotation of the seat back around the transversal axis of the seat (Y axis). The strength characteristic of these joints were experimentally measured and provided by one the ECBOS project partners [11]. Joint 2 is a revolute joint, with the rotation axis parallel to the X direction, allowing the deformation of the seat structure in the transversal direction (Y direction). The strength characteristic of this joint was extracted from the FE simulations described in the previous section (figure 23). Each FE surface (seat cushion, seat back, etc.) is rigidly connected to the corresponding body.

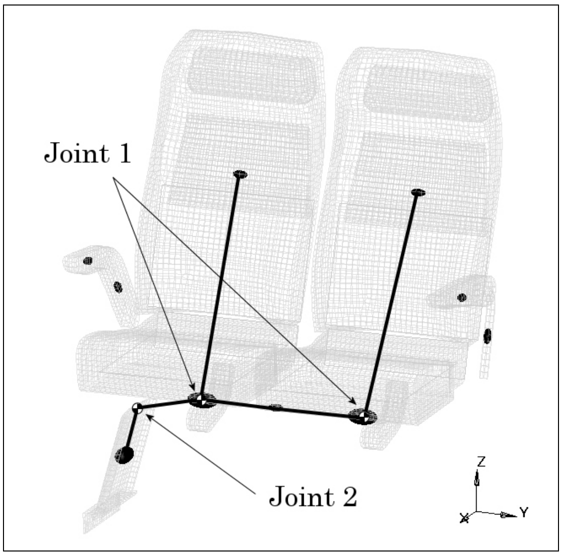

Figure 25. Layout of the MB seat model.

Therefore the FE components act as rigid surfaces whose role is to define the geometry for the contact interaction of the seat with other bodies like dummies, pillars, etc. The mass and the stiffness properties were described by the MB parts.

The links between the seat and the bay section structure were modelled by four point restraints, two at the window side and two at the aisle side (figures 26 and 27).

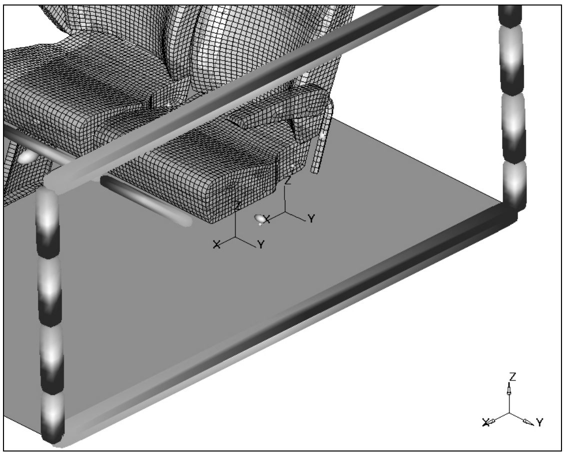

Figure 26. Link between the seat model and the bay section mode: window side.

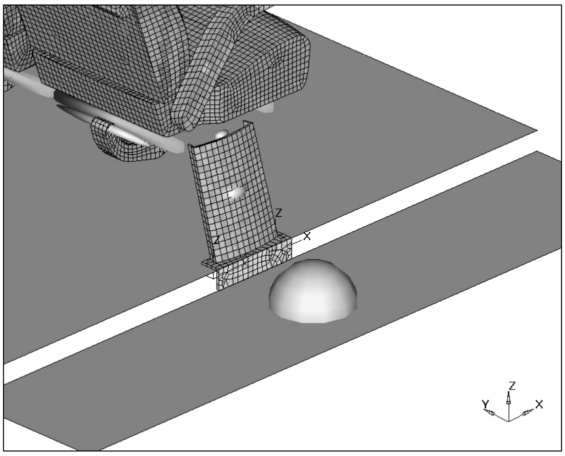

Figure 27. Link between the seat model and the bay section mode: aisle side.

The point restrain is a link between two points belonging to different bodies with a strength characteristic (linear or non- linear) in each principal direction (X, Y and Z). For what concern the window side (figure 26), the point restraints connect the body representing the external cushion to a body in each window pillar, while on the aisle side (figure 27) they connect the body of the seat leg to the central body of the bay section.

The strength characteristic in the X direction, corresponding to the forward and backward movement of the seat, was experimentally measured and provided by one of the ECBOS project partner [11]. In the other two directions very high strength characteristics were assigned in order to avoid, in those directions, the movement of the seat relative to the bay section structure. The values of these strength characteristics were calibrated after some test simulations.

INTERIORS MODEL

In order to perform a realistic evaluation of the injury risk for passengers in a rollover event it is very important to correctly model the interactions between the passengers and the internal component of the vehicle. From statistical study performed within the ECBOS project the main interior components, which are cause of injury for the passengers, are the window pillar, the side window, the luggage rack and the seat [12]. For this reason, in addition to an improved seat model, in the MB bay section model some plane were added to represent the luggage racks and the side windows. To describe the contact interaction between the passengers and the interior components the following contact characteristics were assigned to the internal surface of the bay section:

- Dummy head – side window
- Dummy head – window pillar
- Dummy head – luggage rack
- Dummy – seat back
- Dummy – seat cushion

These characteristics were obtained from experimental tests carried out within the ECBOS project [11,13].

INFLUENCE OF THE SEAT

As described above, a detailed new seat model was introduced in the MB bay section model in order to obtain a better description of the interactions between the passengers and the interior environment during the rollover.

A study was performed to evaluate how an improved description of the seat behaviour affects the results of the simulations in term of loads acting on the body of the passengers and injury parameters. To that end two rollover simulations with an EUROSID-1 dummy model seated in position 3 (near the aisle on the impact side) were carried out using the MB bay section model equipped with the improved seat model. In the first simulation the dummy was restrained with a two-point belt, while in the second one it was restrained with a three-point belt (figure 28).

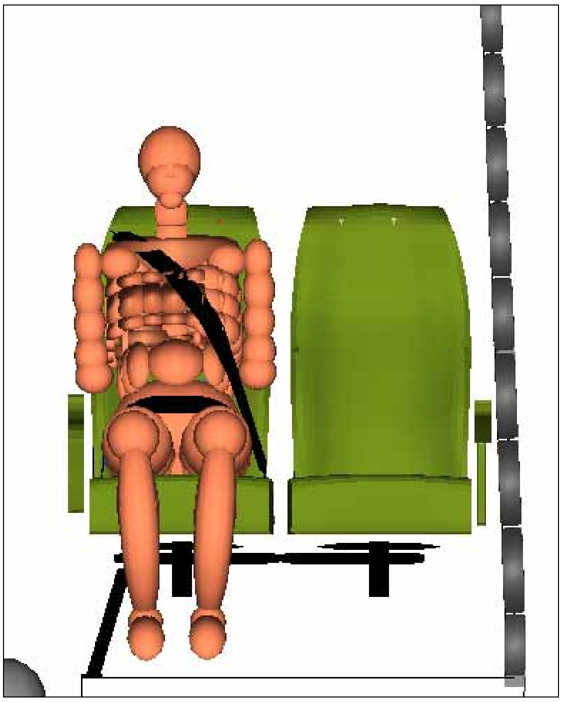

Figure 28. Dummy model with 3-point belt.

The loads and the injury parameters calculated in such simulations were compared with the ones obtained through the same MB bay section model equipped with a simplified seat model [5]. The comparison is reported in table 1 for a passenger restrained with a two point belt and in table 2 for a passenger restrained with a three point belt.

Table 1.

Comparison of the body loads and injury parameters for a two-point belted passenger with different seat models.

	Simplified seat model	Detailed seat model
Head acceleration (m/s^2) (CFC1000)	1841	2619
HIC (CFC1000)	1701	2751
Force lower neck (N)	4187	5750
Moment lower neck (Nm)	142	151
Force lower lumbar (N)	7285	5340
Moment lower lumbar (Nm)	254	177
Force pubic symphysis N)	7285	3701
Femur Left force (N)	1457	1129
Femur Right force (N)	1475	640

Table 2.

Comparison of the body loads and injury parameters for a three-point belted passenger with different seat models

	Simplified seat model	Detailed seat model
Head acceleration (m/s^2) (CFC1000)	339	567
HIC (CFC1000)	78	319
Force lower neck (N)	1776	1811
Moment lower neck (Nm)	113	135
Force lower lumbar (N)	4089	3433
Moment lower lumbar (Nm)	216	198
Force pubic symphysis N)	4089	2500
Femur Left force (N)	1695	939
Femur Right force (N)	1624	694

The comparison of the results shows that the improved description of the seat deformation during the rollover makes it possible to simulate in a more detailed way the load distributions on the passenger. In particular the loads, and the injury parameters consequently, in the lower part of the body (lumbar, pubic symphysis and legs) are lower with the detailed seat model than with the simplified seat model. On the contrary the loads and injury parameters on the higher part (head and neck) of the body are higher with the detailed seat model than with the simplified seat model. Furthermore with the improved seat model the loads acting on the legs are quite different while with the simplified model the loads are nearly the same. As the impact is on the left side it is reasonable to expect higher loads on the left femur as happens with the improved seat model.

ECE66 ROLLOVER TEST WITH PASSENGERS

Effect of the additional mass

As remarked previously, in the tests of the ECE66 regulation the presence of the passengers on board is not taken into account. As in this regulation no prescriptions are stated about restraint systems to be used on buses and coaches, the assumption behind this document is that unbelted passengers do not affect the energy absorbed by the structure during a rollover.

During a rollover only a part of the total passengers mass is coupled to the structure, this part depends on the kind of restraint system that constrains the passengers. Within the ECBOS project some studies [9] were performed to assess the mass of the occupant that is effectively coupled to the structure during the ECE66 rollover test. The results of such studies are reported in table 3.

Table 3.

Mass of the occupant coupled to the structure during an ECE66 rollover test

	mass coupled to the structure
Unrestrained passenger	20 %
2-pint belted passenger	70 %
3-point belted passenger	90 %

A study was performed to evaluate how the presence of the passengers onboard affects the deformation of a bus structure in a rollover event. Using the MB bay section model, four different rollover test simulations were carried out:

- Rollover test without passengers
- Rollover test with four unrestrained passengers onboard
- Rollover test with four lap-belted passengers onboard
- Rollover test with four 3 point-belted passengers onboard

In order to simulate the presence of the passengers onboard, a ballast mass was placed on each seat and rigidly connected to it as shown in figure 29. Taking as reference a 50%ile EuroSID-1 dummy, the inertial properties of the ballast masses were assigned according to the percentage reported in table 3, while the centre of gravity of the mass was positioned in the same location of the centre of gravity of the dummy positioned on the seat.

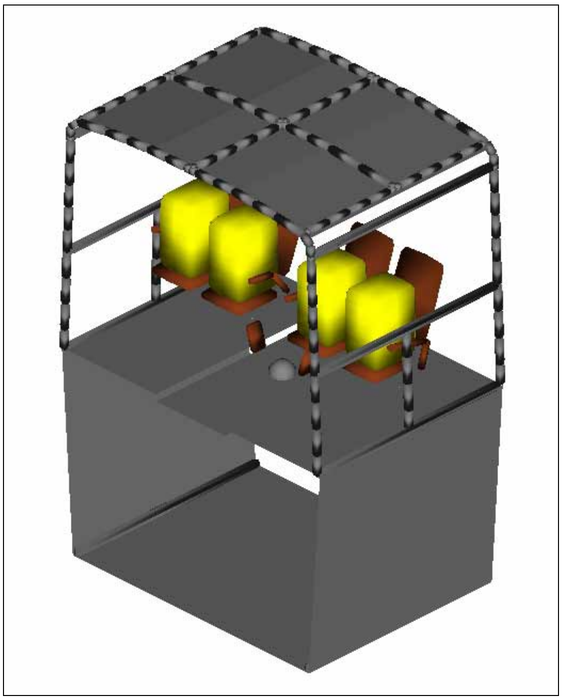

Figure 29. MB bay section model with ballast masses.

The rollover tests were carried out following exactly what stated in the ECE 66 regulation.

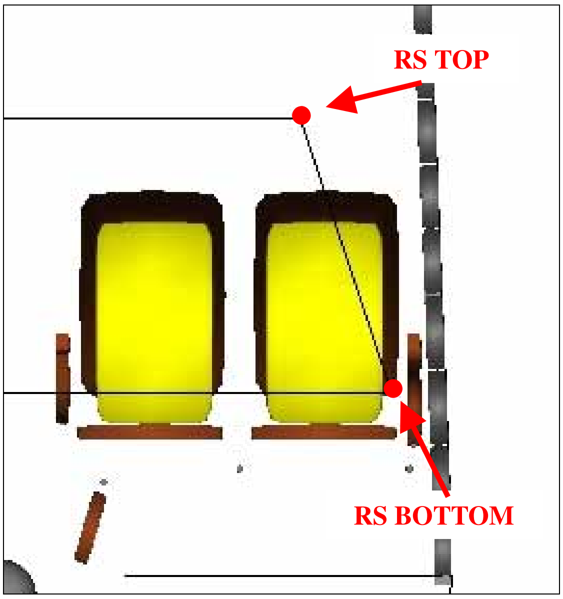

Figure 30. Measurement points of the residual space intrusion

During the simulations the distance between the structure and the residual space, defined as prescribed by the ECE 66 regulation, was measured in order to check if any displaced part of the structure intruded into the survival space. This distance was evaluated with respect to two different points of the residual space as shown in figure 30. The time histories of the distance between the structure and the above mentioned points of the residual space for the four tests are shown in figures 31 and 32.

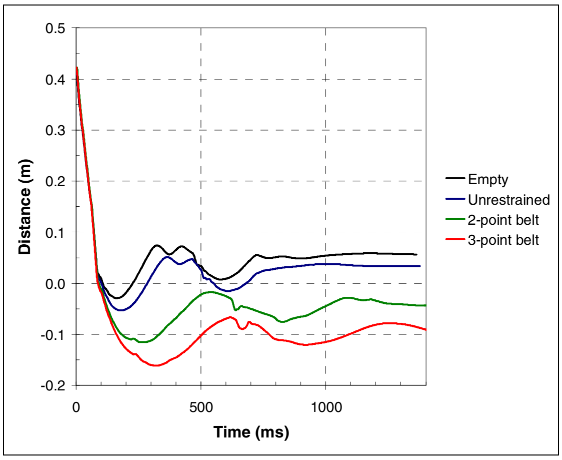

Figure 31. RS top distance.

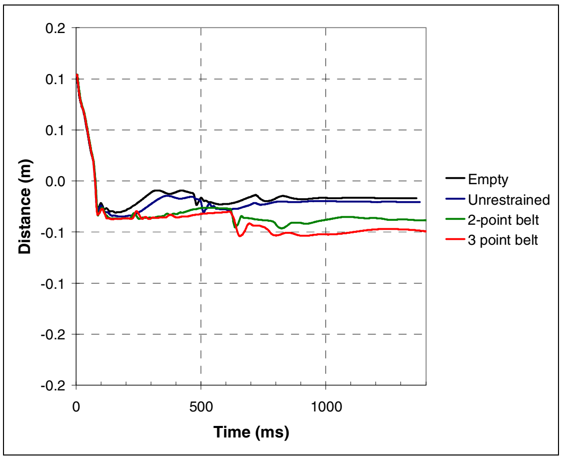

Figure 32. RS bottom distance.

The results reported in the figures show that the presence of the passengers on board affects the deformation level of the structure in a rollover. As expected the deformation raises by increasing the percentage of the passenger mass coupled to the structure. Even in case of unrestrained passengers, it was calculated an increment of the structural deformation.

Increment of the structural strength

Increasing the mass in the vehicle causes an increment of the structural deformation in the rollover test. Therefore, if the presence of the passengers on board is considered in the homologation test, the energy assumed to be absorbed by the structure in order to pass the test increases. As a consequence a structure that fulfils the ECE66 rollover test requirements with no passengers on board, may not pass the same test if the presence of passengers is taken into account.

Taking as reference the rollover test carried out without passengers ('empty' plot in figures 31 an 32), the strength of the super-structure was incremented up to obtain with the passengers on board (ballast masses) the same minimum distance between the structure and the residual space as in the reference condition. To achieve an increment of the super-structure strength the window pillar strength characteristic in the MB model was multiplied by a factor greater than one.

The time history of the distance between the structure and the residual space for the three tests, empty (reference condition), belted passengers in a structure with reference strength and belted passengers in a structure with increased strength, are shown in figures 33 and 34.

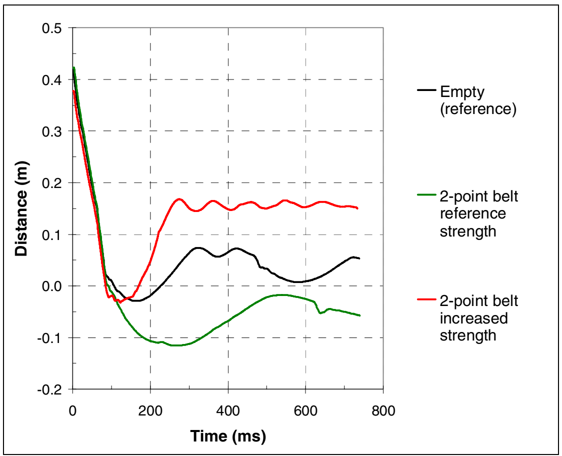

Figure 33. Structure-residual space distance for 2-point belted passengers.

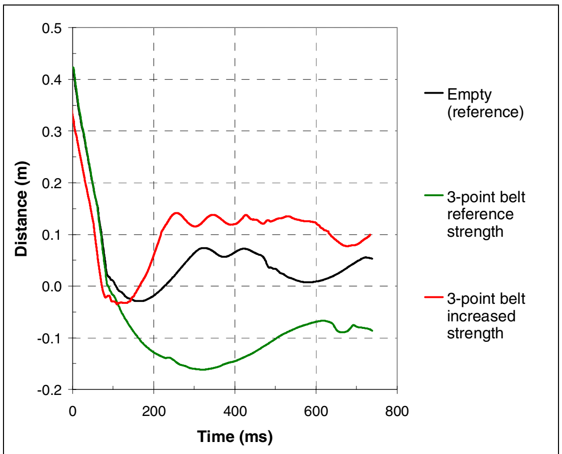

Figure 34. Structure-residual space distance for 3-point belted passengers.

INJURY RISK FOR PASSENGERS

As discussed previously, if the presence of passengers on board is taken into account, it is necessary to increase the structure strength in order to obtain the same level of deformation as in the condition without passengers. Therefore a structure that fulfil the ECE66 rollover test requirements with no passengers on board, may need to be reinforced by increasing the strength characteristic of the window pillars to pass the a test with passengers on board. However a stronger structure often means a greater level of accelerations and forces on passengers. In order to evaluate the influence on the injury risk for passengers of an increment of structure strength, some simulations of an ECE66 rollover test with a passenger model on board were performed. In such simulations the ballast mass in position number 3 (near the aisle on the impact side) was replaced by the numerical model of a EUROSID-1 dummy while the other seats were still occupied by ballast masses. For each restraint system (two-point belt or three-point belt) used for the dummy, two different configurations were analysed (table 4).

Table 4.

Tested configurations

Dummy restraint system	Super-structure strength
Two-point belt	Reference
	Increased
Three-point belt	Reference
	Increased

In the first one, the reference (not reinforced) super-structure was tested, while in the second one the super-structure was reinforced so that the same maximum deformation (minimum distance between the structure and the residual space) was obtained as in the rollover test of the empty bay section.

For each simulation the most significant accelerations and loads on the passenger and injury parameters level were calculated. The results are shown in table 5 for the two-point belt condition and table 6 for the three-point belt condition

For a passenger seated in position 3 restrained with two-point belt the increment of structure strength, necessary to obtain with the passengers on board a level of deformation similar to the one of an empty bay section, yields a significant increment of the accelerations and loads on the passenger and leads to higher levels of injury parameters. The risk of injuries to head, thorax and pubic symphysis injuries rises considerably. On the other hand, for the same passenger restrained with a three-point belt the accelerations, the loads and the injury parameters are quite the same even if the strength of structure was increased. This happens because the three-point belt better restrains the occupant to the seat avoiding, during the rollover, the impact of the passenger with the structure as discussed in [5].

Table 5.

Body loads and injury parameters for a two-point belted passenger

	Reference strength	Increased strength
Head acceleration (m/s^2) (CFC1000)	1841	**2873**
HIC (CFC1000)	1701	**2886**
Force lower neck (N)	4187	**7074**
Moment lower neck (Nm)	142	**175**
Upper rib acceleration (m/s^2) (CFC180)	650	**795**
Middle rib acceleration (m/s^2) (CFC180)	658	**777**
Lower rib acceleration (m/s^2) (CFC180)	676	**773**
TTI (FIR100)	44	43
Force lower lumbar (N)	7285	**8337**
Moment lower lumbar (Nm)	254	276
Force pubic symphysis (N)	7285	**8337**

Table 6.

Body loads and injury parameters for a three-point belted passenger

	Reference strength	Increased strength
Head acceleration (m/s^2) (CFC1000)	339	342
HIC (CFC1000)	78	91
Force lower neck (N)	1776	1745
Moment lower neck (Nm)	113	118
Upper rib acceleration (m/s^2) (CFC180)	417	375
Middle rib acceleration (m/s^2) (CFC180)	315	319
Lower rib acceleration (m/s^2) (CFC180)	294	295
TTI (FIR100)	31	32
Force lower lumbar (N)	4089	3750
Moment lower lumbar (Nm)	216	193
Force pubic symphysis (N)	4089	3750

CONCLUSIONS

The work performed within the ECBOS project showed that the current regulation about passenger safety in the rollover an M3 class coach should be improved. The presence of passengers on board should be taken into account in the regulation. Moreover it is necessary to describe accurately the structural behaviour of the seat during the rollover as the correct description of the seat deformation is fundamental in order to evaluate properly the movement of the passenger inside the vehicle. A correct assessment of the passenger movement is necessary to evaluate properly the loads and the injury risk for passengers.

The performed simulations showed that an increment of the mass in the vehicle causes greater deformations in case of rollover. Therefore a structure that fulfils the ECE 66 rollover test requirements with no passengers on board, may not pass the same test if the presence of passengers is taken into account. That may lead to build stronger structures to fulfil the requirement of no intrusion into the survival space stated in the regulation.

The calculations showed that a more rigid structure may cause higher levels of injury on passengers if an inadequate restraint system is adopted. For this reason an improved regulation about safety in the rollover of a M3 class coach should include the adoption of restraint systems on board together with homologation tests in which the additional mass of passengers is taken into account. In particular three-point belts should be prescribed as such kind of restraint system offers, on the average, a good level of protection in rollover events.

As general outcome of this work and of the work performed within the ECBOS project, it is very important to highlight the necessity to update the safety levels of coaches and buses to the ones reached in the automotive field. Therefore, also for buses and coaches, dynamic tests with dummies on board should adopted to evaluate the safety level of the vehicles. Moreover, not only a limit to the structure deformations (survival space), but also restrictions to the loads and the accelerations (injury parameters) on occupants should be prescribed to obtain the vehicle homologation

REFERENCES

[1] F. Aparicio, A. Garcia, T. Vicente, V. Martinez, J. Paez, L. Martines, G. Fernandez, ECBOS Workpackage 4 Task 4.1 “Suggestion for new regulations and written standards” Final Report, European Union, June 2003.

[2] [1] A. Kirk, R. Grant, ECBOS Workpackage 1 Task 1.1 “Statistical collection” Final Report, European Union, 2001.

[3] ECE 66 Regulation "Uniform provisions concerning the approval of large passenger vehicles with regard to the strength of their super-structure" Economic Commission for Europe, Geneva 1986.

[4] Directive 2001/85/EC "Special provisions for vehicles used for the carriage of passengers comprising more than eight seats in addition to the driver's seat", Euroepan Union, 2001

[5] G. Belingardi, D. Gastaldin, P. Martella, L. Peroni, "Multibody analysis of M3 bus rollover: structural behaviour and passenger injury risk" Proceeding of 18th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Nagoya (Japan), 2003.

[6] P. Martella, "The multibody approach in crash analysis. Study of the passive safety in the rollover of an M3 coash" Ph.D Thesys, April 2004

[7] M. Matolcsy "Plastic hinge theory to analyse the structural strength and energy absorption of bus structures", Proc. Int. Conf. Science and Motor Vehicles, Belgrade, 1987.

[8] J.C. Anderson, "Rollover crashworthiness of a new coach structure", Cranfield impact centre Ltd., Truk and Bus Meeting and Exposition, Portland (Oregon), 4-6 December 2000.

[9] J.C. Anderson, ECBOS Workpackage 3 Task 3.3.1 "Full-scale test methods; extened rollover test" Final Report, European Union, 2002.

[10] J. Ambròsio, M. Pereira, "Multibody Dynamics Tools for crashworthiness and impact", Crashworthiness of transportation systems: structural impact and occupant protection, NATO Advanced Study Institute, vol. 1, pp. 437-484, Tròia (Portugal), 7th-19th July 1996

[11] D. Twisk, C.G. Huijskens, ECBOS Workpackage 2 Task 2.1 "Seat Component and Frontal Impact Baseline Testing" Final Report, European Union, 2001.

[12] ECBOS Workpackage 2 Task 2.5 "Cause of injury summary" Final Report, European Union, 2002.

[13] J.C. Anderson, ECBOS Workpackage 2 Task 2.1 "Free Motion Headform Testing on Interior Components of Coaches, City-buses and Minibuses " Final Report, European Union, 2001.