CHILD FRONTAL IMPACT SAFETY IN COACHES

Luis Martínez
Antonio García
Enrique Alcalá
Manuel Espantaleón
University Institute for Automobile Research, Polytechnic University of Madrid (UPM – INSIA)
Spain
Paper number 11-0383

ABSTRACT

This paper reviews the safety of children from 18 months to 10 years old at the coaches' frontal impact event. To meet this goal it has been made 5 frontal crash tests at 30 kph using 4 child dummies restrained each one with a different safety system in each test. The configurations chosen for the safety systems cover the withholding provided solely by the back of the seat back placed in front to the combined use of three-point belt with the proper child restraint seat according to the size and weight of each dummy. It have been checked the operation of both safety belts, the one with three points anchorages and with two anchor points for the latter is the most common configuration in Class II and Class III coaches. Also, have being verified the behavior of a three-point belt with automatic regulation of the shoulder height for the children or adults. In all cases the values measured by the dummies were used to calculate the injury criteria and compared with the IARV developed by EEVC working groups WG12 "Biomechanics" and WG18 "Child Safety", as well as the latest proposals of the informal working group of GRSP in child restraints.

INTRODUCTION

The growing interest of people to environmental issues is encouraging the transportation industry to reduce CO2 emissions and increase energy savings. As a result research activities to reduce fuel consumption of vehicles have been directed towards improving engine efficiency and other measures to assist in the reduction, for example by reducing vehicle weight. These research activities are identified as long-term solutions and are a danger that for the short term, other measures can be taken as has happened in Spain, which has reduced the roads speed limit with the intention of reducing fuel consumption.

In the Transport Policy requirements for 2010 of the EU White Paper, stressed the importance of developing public transport over private vehicles, paying particular attention to passenger safety and reducing pollution. This trend has accelerated in recent months due to rising cost of oil and its derivates as a result of political instability in the Gulf region.

During last years awareness has increased regarding the improvement of child safety in traffic accident in the different vehicle types. In this direction, during 2006 in 12 EU countries has come into force the European Directive 2003/20/CE that encourage the usage of child restrain systems and safety belts in all vehicle types including Class II and III buses.

In Spain, this directive has modified the "Reglamento General de Circulación" [1] (RGC, being September 6th 2006 the date to come into force). It defines that all passenger older than three years old in more than nine seats, including the driver, collective transport vehicles, should wear the safety belts, correctly fasten in urban transport as well as interurban one. It also indicates that reminder drawings should be included (consisting of a passenger with the seat belt fasten) and that, in every trip, passengers were requested to use the safety features incorporated in the vehicle.

Installation and safety testing on the coaches' seats and its safety belts are carried out taking only into account adult passengers [2], without any further verification for their suitability for children older than three years old.

The GRSP Informal Working Group on Child Restraint Systems is making an important activity in the development of future regulations for child restraint seats, however this intense activity is focusing the research resources to develop solutions tailored to the passenger cars as a first phase and were relegated for the future the normative development of requirements for systems adapted to the buses necessities.

Within these necessities it is necessary to take into account that in Europe there is not a school bus as it happens in the EEUU. The transportation of children to schools is done in Spain and Europe by buses that combine the use of the same seating place for adults and children in an unbroken chain of services without coming to be a period of adaptation of the vehicle. Given this situation, it is necessary to develop restraint systems to ensure the safety of all sizes, from the three years old child to the adult without increasing the operating time of vehicles.

While the operating characteristics of vehicles impose greater requirements for the design of the restraint systems, the larger buses size with respect to other vehicles have advantages, reducing the levels of acceleration that suffers when it collides with lower-mass vehicles. However, this advantage has to be taking in a rational way avoiding to fall into the temptation of developing child restraint systems with lower strength requirements for buses than for passenger cars. Start to think in previous differentiation for the CRS have necessary a real guarantee that the approved systems for buses could only be installed on buses and never may be installed in cars.

In tests conducted in this study has used an impact speed of 30 kph, set to the characteristics of the buses and in accordance with the provisions of Regulation 80. The child seats that have been used are approved under Regulation 44, after having passed a crash test at 50 kph.

METHODS – TEST CONFIGURATION

There were conducted a total of 5 sled tests for checking 20 different child restraint configurations. These tests have been performed as specified by the ECE R80 (i.e. 30-32 kph with a mean deceleration between 6.5 – 8.5 g). All the tests were performed at the same pitch between seats (750 mm) and all the seats tested were from the same manufacturer.

Four child impact dummies were used to carry out the sled tests. These dummies represent children of different ages: from 18 moths up to 10 years. Later shows the dummy-configuration (instrumentation and painting for checking contacts).

Test matrix

All dynamic tests were carried out simultaneously with four child dummies. These child dummies belong to the P-series (P1.5 and P10) or Q-series (Q3 and Q6), ie the child dummies used cover the rage of ages from 1.5 to 10 years old.

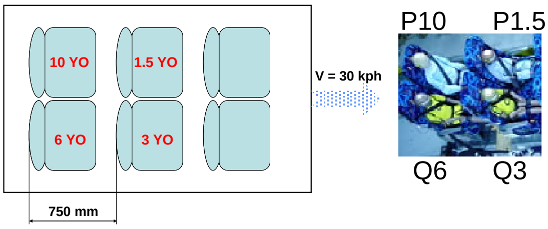


Figure 1. Sled test configuration.

The five configurations tested are explained:

- **FRONTAL_001**. Coach seats with three-point belt system with automatic regulation of the third point. This seat is in itself a CRS approved as 44R03 – groups II and III.
- **FRONTAL_002**. Coach seats with three-point belt system with CRS (infant carrier).
- **FRONTAL_003**. Coach seats with three-point belt system used as if they were adults (no additional device).
- **FRONTAL_004**. Coach seats with three-point belt system that it is not fastened (similar than compartmentalization).
- **FRONTAL_005**. Coach seats with two-point belt system used as if they were adults (no additional device).

The aim of the configurations 1 and 2 is to obtain the best protection offered to children in coaches (it has been tested a seat approved by regulation No 44 as groups II and III and auxiliaries CRS appropriate to the size and weight of the child).

Configurations 3, 4 and 5 are representative of the coach park. Prior to the application of the Directive 2003/20 coaches did not incorporate seatbelt (tested configuration in FRONTAL_004). Once come into force, coaches should install seat belts that can be two points (FRONTAL_005) or three-point belt (FRONTAL_003), although the latter is less common (except local implementing regulations of each country).

It is relevant to highlight the following: according to the UNECE Regulation No 44, a child younger than 3 years old must use an integrated system, i.e. can not use a seat belt installed on the vehicle directly on his/her body. Therefore, the configuration used in dummy P1.5 is not allowed by that regulation. However, authors consider relevant to study what effects can have a child of 1.5 years old with the different safety systems tested. The P1.5 dummy could be representative of child who goes to daycare.

Sled configuration

As mentioned above, the sled test configuration fulfills the requirements of the Regulation No 80. The Table 1 shows the transducer installed in the sled for ensured the requirements.

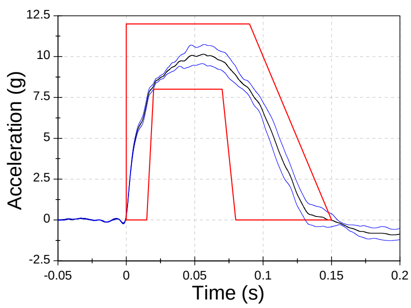
Table 1. Sled instrumentation.

Sled Instrumentation	
Acceleration (a_X)	X
Initial speed (v_X)	X
Displacement (d_X)	X
TOTAL:	**3**

The Table 2 shows the results of the tests (initial speed and mean acceleration) It also includes a graph with the mean acceleration pulse, along with the standard deviation (mean ± std). As can be seen, the repeatability of the deceleration pulse is good, so a direct comparison of the recorded signals is possible (if the deceleration pulses were significantly different, the signals recorded by the dummies could not be compared because the severity of impact is not the same).

Table 2. Initial speed and acceleration.

Ref.	**1**	**2**	**3**	**4**	**5**
Initial speed (kph)	31.32	30.78	30.78	30.78	30.78
Mean acceleration (g)	7.21	7.06	7.09	7.05	7.06



Each sled test was conducted with two high speed cameras (one on each side) with a sampling rate of 1000 fps. The use of high-speed cameras allows a more detailed analysis and understanding of test signals (e.g., an arm contact with the head produces peak acceleration, without video registration would be virtually impossible to establish this fact).

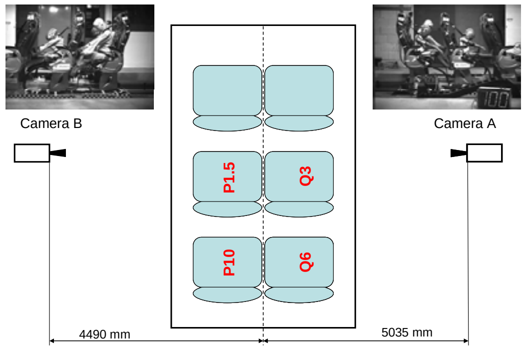


Figure 2. Cameras set up.

Dummies – instrumentation

Four child impact dummies were used to perform the sled tests. The instrumentation installed in each dummy are shown in the next table

If the seat belt is used, a load cell is installed in the belt (all tests except “FRONTAL_004”). Depending if the belt is 2 or 3 points, the load cell is installed at upper diagonal belt or at lap belt outside.

Table 3. Dummy instrumentation.

Dummy part		**P1.5**	**Q3**	**Q6**	**P10**
Head	a_X , a_Y , a_Z	X	X	X	X
Up Neck	F_X , F_Y , F_Z	F_X, F_Z	X	X	-
	M_X , M_Y , M_Z	M_Y	X	X	-
Chest	a_X , a_Y , a_Z	X	X	X	X
	d_X	-	X	X	-
Lumbar Spine	F_X , F_Z	-	X	X	-
	M_Y	-	X	X	-
Pelvis	a_X , a_Y , a_Z	X	X	X	-
Belt*	F	X	X	X	X
TOTAL:		**13**	**20**	**20**	**7**

* If the belt is used

Figure 3. Detail of the location of the belt load cell installed at three and two point safety belt.

Furthermore, to record potential contacts of the dummy's head with the back of the seat, different parts of the head have been identified (using the same color code as in Euro NCAP frontal impact).

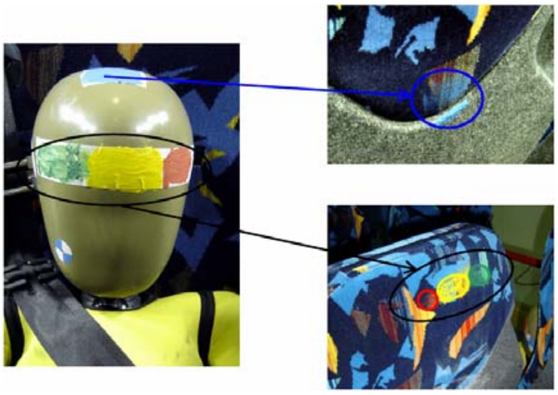


Figure 4. Color code for checking contacts.

RESULTS

The most relevant results concerning to their setup test, as well as the recorded signals are shown in the following paragraphs. Figure 6 shows the kinematics of the impact (filmed with the camera on the right side of the sled) for three configurations (compartmentalization, 2 point belt and 3 point belt). These three configurations are shown in order to make a direct comparison (same page). All tests using three-point belt (FRONTAL_001, 002 and 003) are almost the same kinematics.

Kinematics

The following table shows a sequence of images where you can check the kinematics of the impact. Since the kinematics obtained for configurations in which the occupants incorporate a three-point belt is very similar, a comparison is showed where the kinematics for tests in which the occupants traveling compartmentalization, using a two-point belt or using a three-points belt.

In the compartmentalization occupant’s configuration, the occupants slid along the seat impacting against the seatback precedent inevitably. The smallest occupants, impact his feet firstly, so they can’t restraint their body (bending the knees), and finally hit his head and chest in the previous seat. However, the older (ten years) has a very similar kinematics to an adult occupant, where firstly hit with the knees with acceptable levels of retention and then initiate a turn of the torso forward causing the impact of the head in the seatback (no contact with the chest) and traction the neck.

In the two-point belt configuration, the kinematics of the impact is quite different, because there is a pelvic retention (caused by the two-point belt). Then, there is a rotation of the torso forward until the impact of the head against the seat before.

Finally with the three-point belt, there is retention at the level of the pelvic area and chest. That prevents the contact of the head against the seatback in all occupants. In terms of kinematics, a three-point belt provides better retention than the two previous systems.

Frontal_001

The chair used incorporates a system to regulate automatically the height of the third point of the safety belt. This chair could be used by children as CRS approved by regulation 44 (groups II and III). Therefore, the dummy P1.5 (which represents a child 1.5 years old) can not legally use this device.

To improve the route of the belt, a booster cushion is used (this system is approved for groups II and III). Therefore, the configuration used in the P1.5 dummy would not be allowed by that regulation (as it is mentioned above).

Figure 5 shows a picture with the test setup for each of the dummies. The shoulder belt is adjusted correctly to each dummy (except P1.5) due to the system that automatically regulates the height of the third point.

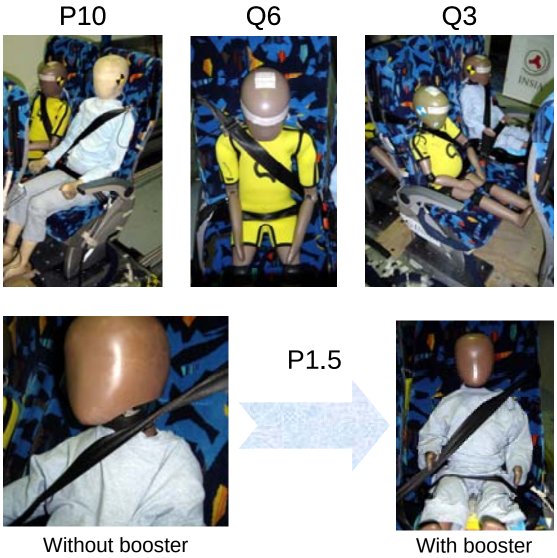


Figure 5. Seat belt path for each dummy.

Figure 6. Kinematics of impact of three different configurations.

Figure 7 shows the main data signals recorded by the dummy sensors. The color code of the graphs is maintained (P10 = black; Q6 = red; Q3 = green; P1.5 = blue). The graphs (eg head acceleration) show perfectly the main impact and the rebound phase (after 200 ms).

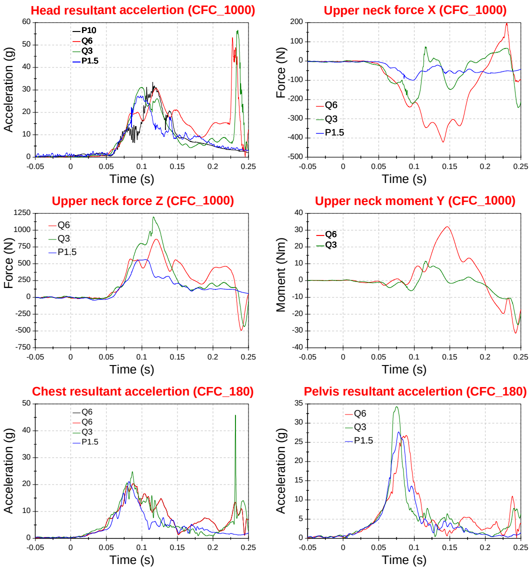


Figure 7. Data plots of FRONTAL_001.

No occupant hit his head on the front seat. Both Q3 as a Q6 obtain the maximum peak head resultant acceleration in the rebound phase. That is, the maximum acceleration is obtained when the nape hits against the anterior surface of the seatback.

The younger dummy (P1.5) was not properly retained. During the test, the shoulder belt is displaced to the outside down the arm. In the last phase of impact, the P1.5 dummy got a similar restraint to that offered by a two-point belt. Figure 8 shows a detail of how to escape a seat belt, and the final position of dummy (the chest has not been retained by the belt).

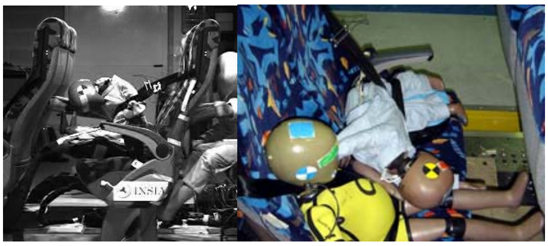


Figure 8. Time when the seat belt from slipping on the arm and final position of the P1.5 dummy.

Frontal_002

Dynamic test performed with three rows of coach seats. Impact dummies are in the last two rows of seats. The restraint system used is a three point seatbelt together with Child Restraint System (CRS) (approved by ECE R44). To facilitate transport and placement in the coach, a booster cushion has been chosen as CRS (approved for occupants of Group II and III). These devices can not be used for smaller size dummy (P1.5) because it belongs to Group I. For this dummy, a Group I CRS has been chosen. The CRS has its own seat belt for the retention of the child. The seat belts are used to retain the CRS.

The booster also incorporates a “strap” that lowers the height of the effective third anchorage point. This system is used in the Q3 and Q6 dummies. The P10 dummy does not need a modification of the third point height.

P10 Q6 Q3

Figure 9. FRONTAL_002 configuration. Detail of the shoulder belt positioning.

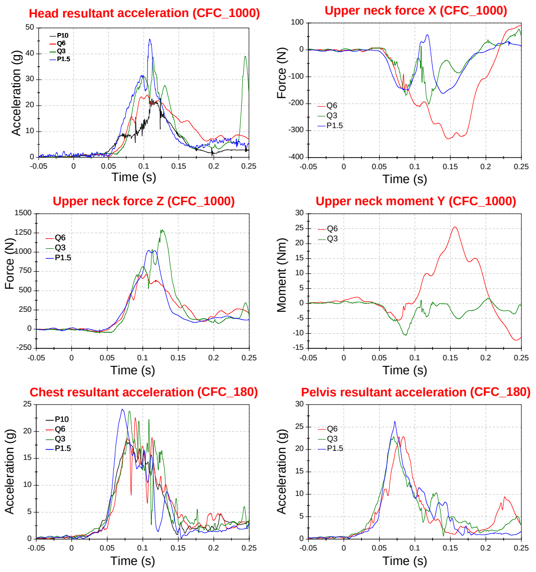


Figure 10. Data plots of FRONTAL_002.

Again, as in the previous test, the dummy Q3 and Q6 get the maximum head acceleration in the rebound phase.

The P1.5 dummy hit the top of his head in the front seat. In addition, the impact zone is produced on the border of a padded area and a stiffer one (grey) as it can be seen in the next figure.

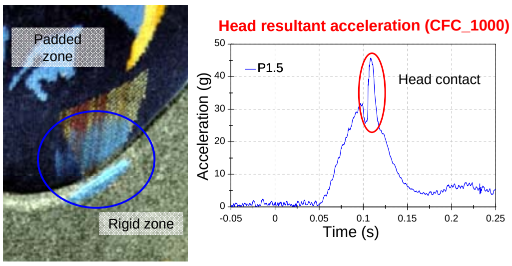


Figure 11. P1.5 head contact (FRONTAL_002).

Frontal_003

In this configuration, seats with three-point belt without any additional elements are used. That is, child dummies wear seat belts as adults.

Figure 12 shows the geometrical configuration of the seatbelts into the dummies. The P1.5 and Q3 dummies have a total incompatibility. The path of the belt does not provide proper installation of the shoulder belt. On the other hand, the P10 dummy can directly use the safety belt. Finally, the Q6 dummy has an intermediate situation. The path is not optimal but can provide a satisfactory retention.

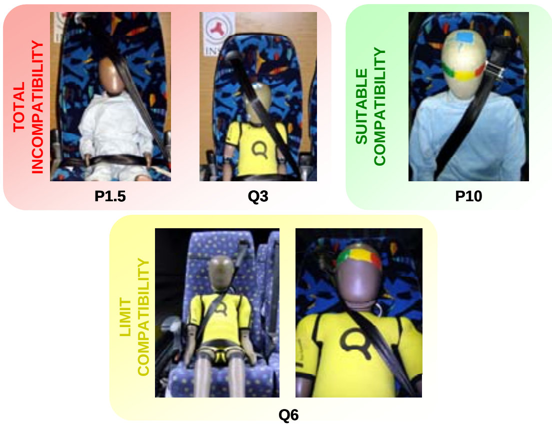


Figure 12. Geometrical configuration of the three-point seatbelts.

The belt positioning for the P1.5 and Q3 dummies are explained (Figure 12). As it is mentioned above, for the P1.5 and Q3 the location of the shoulder belt is very deficient. In both cases the band of the belt passes through the neck, but also its position is forced. The seat belt suddenly changes direction just past the neck of dummy (showing that the position of the belt is forced). This position of the belt is not recommended; in addition it is probable that the child refuses to take a trip in these conditions or misused of the belt passing the shoulder belt behind his back (being in a similar configuration of two point belt).

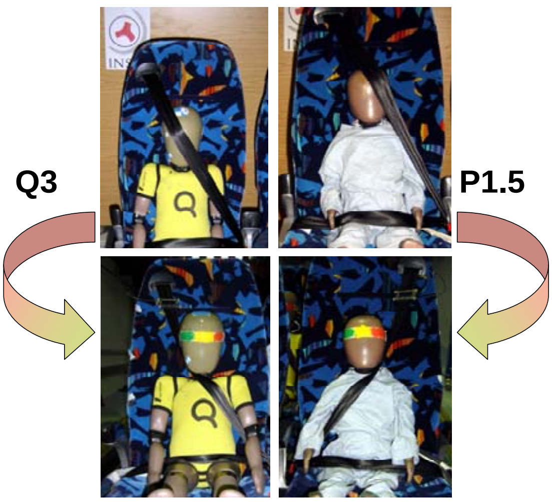


Figure 13. Seat belt installation for P1.5 and Q3 dummies.

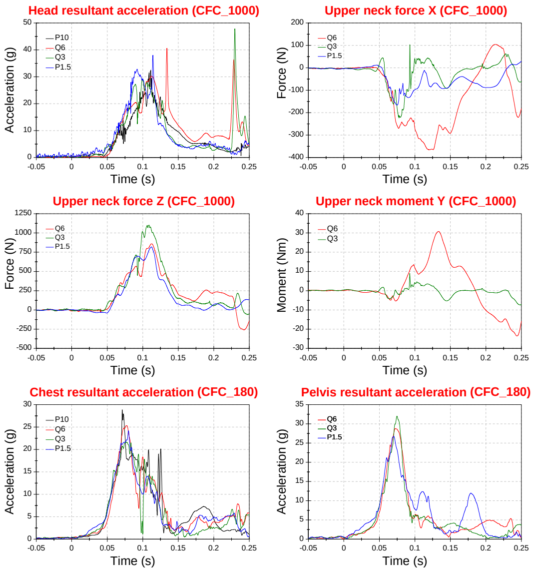


Figure 14. Data plots of FRONTAL_003.

There has been no contact between the head and the anterior seatback.

Figure 15 shows the Q6 head acceleration components. The resultant acceleration (blue) has three peaks. The first one is caused mainly by the acceleration Z (green) and is the predominant peak in the test. At 134 ms, another peak is produced mainly caused by the acceleration Y (red). This second peak is produced by a left-arm contact with the head. Finally is produced a third peak which is produced by the contact against his chair (as has happened in previous tests).

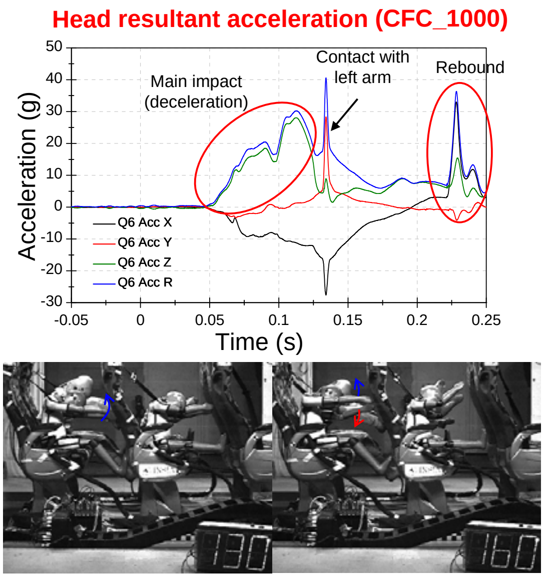


Figure 15. Q6 head acceleration – explanation.

The figure also shows two images obtained from high speed cameras. The Q6 arms are parallel at 130 ms. In this moment, the arms are running an upward movement over the head. Subsequently, at 160 ms it is found that the left arm is in a lower position (running a downward movement), while the right arm continues its upward movement. This fact also occurs in Q3 and P1.5 dummies (although with less quantification).

Frontal_004

This configuration using seats with three-point belt, but the belts are not fastened (using the compartmentalization as a restraint system). A priori, the back of the chair with three-point belt is stiffer than the seat with two-point belt or no belt (due to it is the own back of the chair that should withstand the seat belt loads).

The following picture shows de test setup.

Figure 16. Test setup of FRONTAL_004.

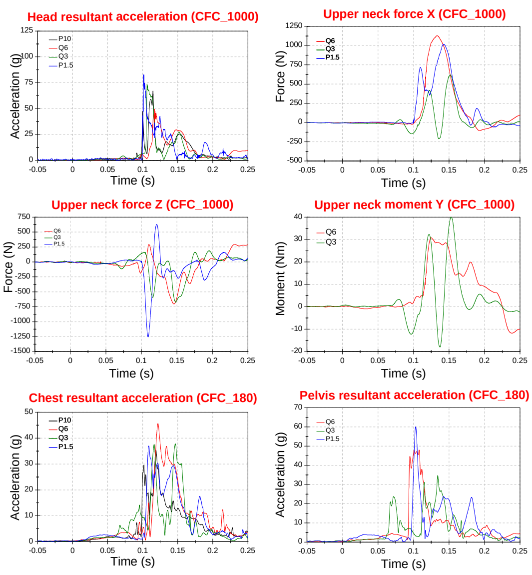


Figure 17. Data plots of FRONTAL_004.

In this test, the Q3 dummy neck had a break. For this reason, the readings of the upper neck load cell may not be reliable.

Occupant retention has not been fully achieved. All occupants have been stopped by the foregoing seats as intended. However, the P15 has finished on the ground so that the occupant protection against possible second impact is not done. In this test configuration, evidently, there have been contacts with the respective head in front seats. Figure 18 shows the location of head contacts against the previous seats for each occupant.

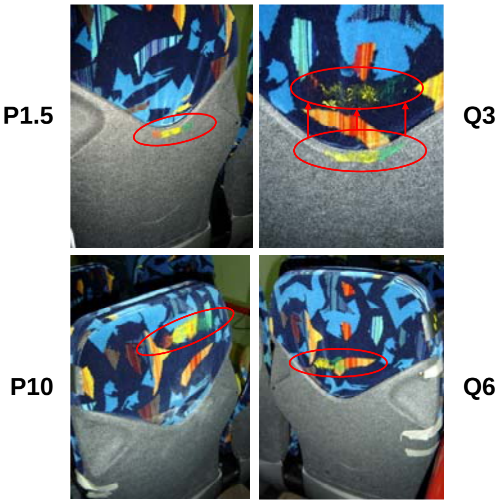


Figure 18. Head contact location (Frontal_004).

Frontal_005

The restraint used are two-point belts, the safety offered by the coaches with seats two points without any additional element is tested. The next figure shows the configuration of the two-point safety belt. As in previous tests, the P1.5 dummy could not use a seat belt installed on the vehicle following the guidelines of regulation No 44.

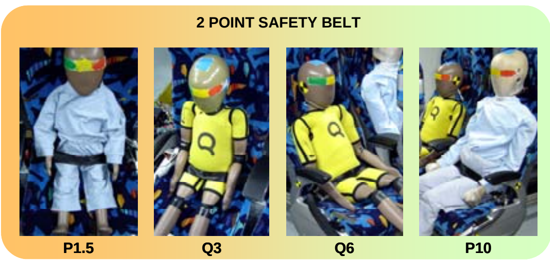


Figure 19. Geometrical configuration of the two-point seatbelts.

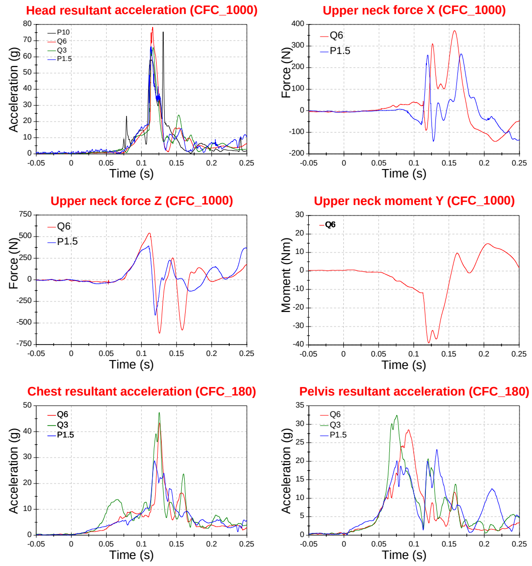


Figure 20. Data plots of FRONTAL_005.

The restraint used (two-point belt) has worked successfully, since all the occupants have been retained in their seats. In this test configuration, all occupants have had direct head contact with the previous seat. The P1.5 and Q3 have not left traces of paint on the front seats. There is a scraping area in the seat (which is marked with a marker that becomes more apparent contact area) that corresponds to the forehead contact.

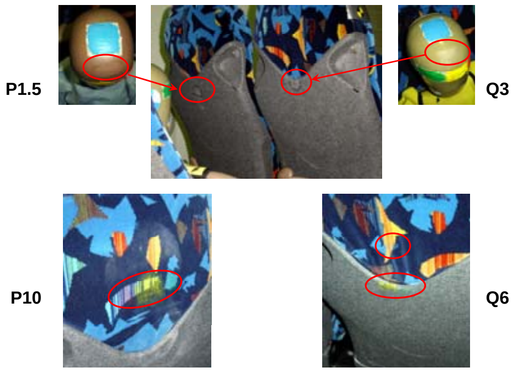


Figure 21. Head contact location (Frontal_005).

The Q3 dummy hits with the soles of the feet and legs straight, being unable to get bend knees but has produced a hyperextension of their knees (Figure 22). The recorded signals (pelvic acceleration) have not significantly detected this fact, due to the retention provided by the seat belt that has also helped to prevent a possible rupture of the knees.

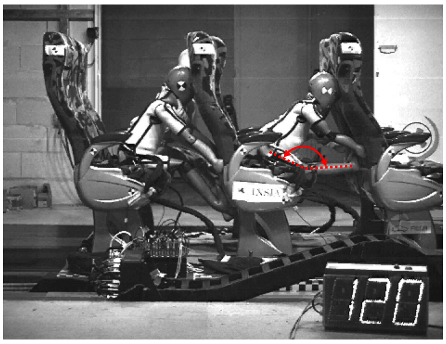


Figure 22. Knee hyperextension.

INJURY ASSESSMENT REFERENCE VALUES (IARV)

The tests performed allow realizing a comparative analysis to determine (quantitatively and qualitatively) the safety of the different configurations tested. However, it is necessary to know a reference value to establish the injury risk. I.e., without reference values are not known if any configuration is damaging or it is not. Therefore, reference values need to be established to evaluate each configuration tested and know when injuries occur (probabilistically) and know the area of the body more vulnerable.

Hypothesis

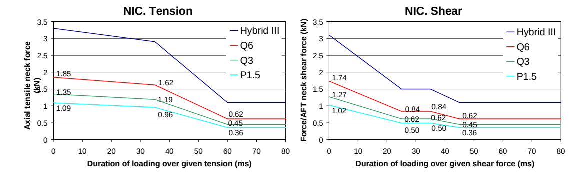
The hypotheses used to obtaining the IARF are shown below:

- The IARV are obtained from two sources: ECE R44 ("child restraint systems") and ECE R94 ("frontal impact").
- Reference values of R44 are taken directly (due to they are for child dummies). The values are: resultant chest acceleration (3ms) < 55 g; vertical component (3ms) < 30 g.
- Reference values of R94 are scaled using the work done in the EEVC [3], [4] is used as a basis to obtain IARV (using the scaling technique).
    - The P1.5 reference values are obtained as if it were a Q1.5.
    - The P10 dummy uses the geometric data of a child 10 years old (50th percentile) [5], [6] for the head acceleration. The HIC value are taken equal than

Table 4. IARV obtained from ECE R94.

	HIC	Head Acc_{3ms} (g)	NIC	Up neck extension (Nm)	Up neck flexion (Nm)
P1.5 (*)	530	70	See graph	(***)	
Q3	710	75		19	63
Q6	980	82		29	95
P10 (**)	1000	84	-	-	-

(*) Obtained like a Q1.5.
(**) HIC of Hybrid III 10YO. Head acceleration scaling.
(***) Not considered. The Up neck LC has a pin (allows rotation around Y axis)



The current regulation 44 is being reviewed [7], for example the new dummies used are Q series. The requirements purposed are:

Table 5. Injury assessment criteria for frontal and rear impact (Purposed R44 – Draft).

	HIC(15)	Head Acc_{3ms} (g)	Up neck tension force (N)	Up neck flexion moment (Nm)	Chest Acc_{3ms} (g)
Q0	600	75	For monitoring purpose	For monitoring purpose	55
Q1	600	75			55
Q1.5	600	75			55
Q3	800	80			55
Q6	800	80			55

Therefore, the reference values taken in this paper are stricter than the proposed (draft) in regulation 44. Consequently, the conclusions of this study are based on safety levels stricter than those proposed in the new regulation 44.

ANALYSIS

The comparison of different retention systems tested is shown below. The main signals recorded in the tests are represented in bar char. The utilization of a bar char allows to analyze qualitatively and quantitatively the evolution for each restraint systems tested. Below is the analysis of the four areas of the body (head, neck, chest and pelvis). For the pelvis IARV not available, i.e. it is not possible to determine what the probability of an injury is.

Head

Figure 23 shows the results registered in the head (3ms acceleration and HIC). The red line in the graph indicates the reference value defined in Table 5. The HIC graph does not contain the red line, due to the values are lower than the reference value.

No dummy exceeds the reference values, although the dummy P1.5 is closer to the limits than the others dummies. The configurations more severe are with two-point belt and compartmentalization. The values obtained in the last settings double those obtained with three-point belt. In the configuration with three-point belt does not hit the head of the dummies (except the P1.5 in the Frontal_002 test due to the less distance between the head and the seatback).

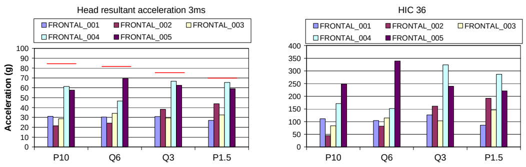
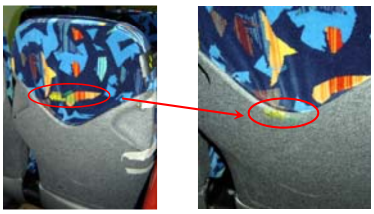


Figure 23. Head acceleration 3ms & HIC

The acceleration value of the Q6 dummy (Frontal_004) are lower than expected. This is because the head hits in a higher position of the seat (padded) than the two-point belt (Figure 24). The Q3 and P1.5 dummies always hit in the stiffer area (Frontal_004 and Frontal_005). Previously in Figure 18 and Figure 21 it can be seen the head contact location of these tests.



FRONTAL_004 FRONTAL_005

Figure 24. Q6 head contact comparison.

Neck

Figure 23 shows the results registered in the upper neck load cell (axial and shear forces and the flexion-extension moment).

The flexion moment does not exceed the reference value. The highest value is for Q3 in the test “frontal_004”. As it is mentioned above, this value is not reliable due to the neck of the Q3 has been broken.

The maximum extension moment values obtained for the three-point belt configuration was obtained in the rebound phase, while the others are obtained when the head hits against the seatback. In this case (extension moment) the limits have been exceeded in several tests (“Frontal_001” and “Frontal_004”). These tests correspond with the adjustable third point safety belt and two-point belt.

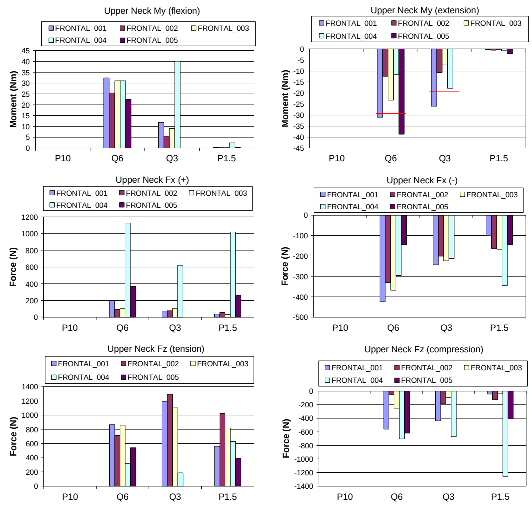


Figure 25. Upper neck loads (Fx, Fz, My)

For the shear neck force, only the test Frontal_004 (compartmentalization) gives high values. This force is caused in the head contact with the backrest. The graph of the NIC (scaled) is shown below (only for “Frontal_004” and for P1.5 and Q6 dummies).

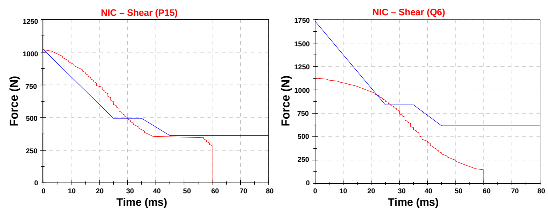
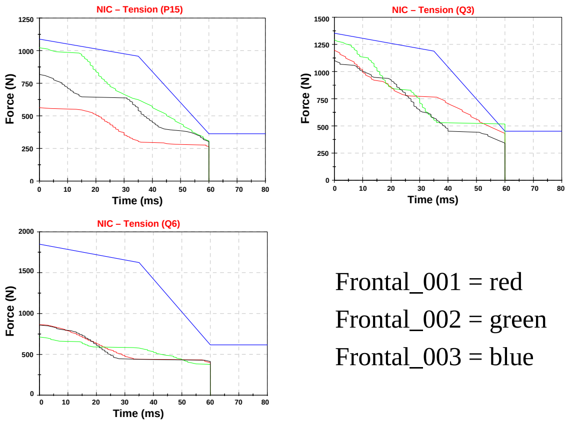


Figure 26. P1.5 and Q6 Shear–NIC (Frontal_004).

Finally, the axial neck force is explained. Tensile values are higher than the compression and the highest values are achieved in the three-point belt configurations due to the shoulder belt restraint the chest of the dummies and the head consequently.

Only the P1.5 obtained a high value in neck compression in the "Frontal_004" test. This fact is because there is a slight tilt of the head before the hitting against the seatback chair, providing compression force.



Frontal_001 = red
Frontal_002 = green
Frontal_003 = blue

Figure 27. P1.5, Q3 and Q6 Tension-NIC.

Chest

The Figure 28 shows the chest acceleration and the reference values of the current regulation No 44. The vertical acceleration is significantly below the limit (because the coach seat is in a more vertical position than in tourism and because of the speed test which is lower). With respect to the resultant acceleration, it is also below the limit of regulation 44. The most severe configurations are the last two tested (compartmentalization and two-point belt).

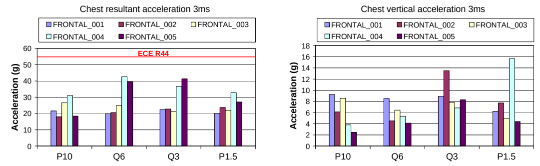


Figure 28. Chest acceleration (3ms).

Pelvis

Finally the pelvis resultant acceleration is shown in Figure 29. There is no reference value for this measure. The most severe configuration is "Frontal_004" (where the dummies do not used the safety belts). In this configuration, the Q3 dummy has lower value than it can be expected. The reason is shown in Figure 30. The Q3 dummy has a primarily retention through his leg. The other dummies have enough distance (P1.5 or P10) or the retention of the feet (Q6) does not provided retention. Subsequently, the Q3 knees are flexed, decreasing the pelvic acceleration. Finally (120 ms) all the dummies impact against the previous seat where the main pelvic acceleration is obtained. The Q3 dummy has a dual phase of ride down, first with his feet and later with all over the body (see Figure 17).

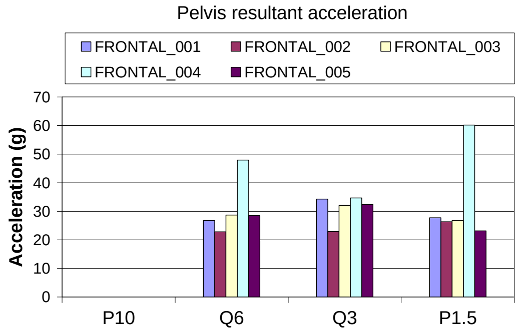


Figure 29. Pelvis acceleration (peak).

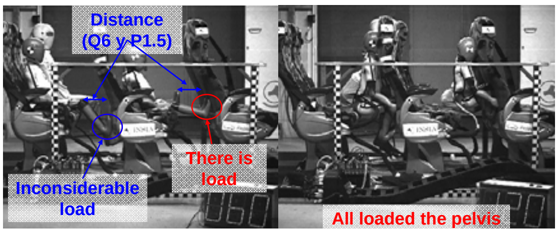


Figure 30. Q3 pelvis acceleration explanation.

CONCLUSIONS

The test configurations have been evaluated differences. The worst configuration in frontal impact has been on the occupants to travel unbelted. The values recorded in the head, neck and chest have been high (above the reference values establish in this paper). Additionally, this configuration has not been able to retain all occupants in their seats (existing therefore a risk of injury in secondary impacts).

The use of two-point safety belt has obtained more satisfactory levels than those obtained by the previous configuration. This configuration achieves that all passengers remain seated. The head and neck are the areas with the highest levels. In the tests performed, the two-point belt restraint system is preferable to the previous configuration (compartmentalization), though the neck extension moment have been exceeded the reference values (risk of injury).

Finally, the best results have been obtained by configurations with three-point belt (used as an adult occupant, together with a CRS or a seat with the third point belt adjustable in height). These three configurations have obtained similar safety levels. The use of seat belts by children without any additional element (ie, as an adult) causes the shoulder belt is not placed satisfactorily for all ages, and there is a geometric incompatibility in some age ranges (especially up to six years old).

The adjustable belt system has failed to properly retain the occupant of 18 months (although the system is not approved for this age). This system has been successful for other ages (from 3 years old) in the forward impact phase, while in the rebound phase had values above the reference values established for the neck of the dummies that represent children of 3 and 6 years old.

The joint use of a coach seat with three-point belt in conjunction with a CRS has been the only system capable to retain to all occupants properly.

However, using this combination of CRS plus three-point belt, presents serious logistical problems for the operation of buses. The weight of the buses, as well as space needs to carry the CRS when not in use by children is increased.

The adjustable belt system can be improved by a review of backrest design and is a good candidate for protecting children from three to 10 years. The results obtained by the two-point belt can be improved significantly if the backrest is designed with greater energy absorption capabilities.

Previous configurations need to be demonstrated in a future study.

Children under three have special needs, i.e. smaller width of the strap, belt with four or five anchor points, also it is necessary to place the CRS in a rearward facing configuration. To ensure the safety of children less than three years seems necessary to use CRS derived from cars. However it will be necessary to verify in this case the spacing between rows of seats, and the necessities of space for the CRS placed in rearward facing with respect to the minimum distance set in the current Regulation 36.

ACKNOWLEDGEMENTS

This work has been carried out within the EMSITRAC ("Evaluación y Mejora de la Seguridad Infantil en Vehículos de Transporte Colectivo") project (TRA2007-67765) founded by Ministerio Ciencia e Innovación (MICINN). Authors would also reflect that the Community of Madrid has contributed to support this work through the SEGVAUTO programme (S2009/DPI-1509).

REFERENCES

[1] Spanish "Real Decreto" 965/2006 that upgrade the Spanish "General Traffic Regulation", Spanish Official Journal September the 5th of 2006.

[2] Directive 2005/40/EC of the European Parliament and of the Council of 7 September 2005 that upgrade the Council Directive 77/541/EEC related to safety belts and restraint systems of motor vehicles.

[3] EEVC WG12-18. "Q-dummies Report: Advanced Child Dummies and Injury Criteria for Frontal Impact". Document No. 514. April 2008.

[4] Palisson et al. "Estimating Q3 Dummy Injury Criteria for Frontal Impact Using the CHILD Project Results and Scaling Reference Values", IRCOBI Conference. September 2007.

[5] Annette L. Irwin, Harold J. Mertz, Ali M. Elhagediab, Steve Moss. "Guidelines for Assessing the Biofidelity of Side Impact Dummies of Various Sizes and Ages" SAE Technical Paper. 2002-22-0016.

[6] Richard G. Snyder et al. "Anthropometry of infants, children and youths to age 18 for Product Safety Design". UM-HSRI-77-17.

[7] UNECE WP29. "Draft new Regulation on uniform provisions concerning the approval of enhanced Child Restraint Systems used onboard of motor vehicles". December 2010.