ADULT AND CHILD DUMMIES TESTS FOR SAFETY ASSESSMENT OF SEATED OCCUPANTS IN URBAN BUS COLLISIONS

Luis Martínez
Manuel Espantaleón
Marta de Loma-Ossorio
Enrique Alcalá
Universidad Politécnica de Madrid
Spain

Christopher René Torres
Instituto Politécnico Nacional
México

Paper Number 17-0401

ABSTRACT

Currently, no passive safety regulatory requirements for passengers of urban buses exist, mainly based on its low operational speed. Nevertheless, crash reports at the city of Madrid show that even fatalities can occur amongst urban buses passengers.
The objective of this research is to assess the level of protection achieved on seated passengers on the current Madrid urban buses seats. Also, secondary aims are considered:

- Obtain a representative configuration of urban buses collision (acceleration pulse).
- Assess the seats' resistance (are seats able to withstand crash loads?).
- Evaluate the seats' restraint (compartmentalization).

To obtain a representative deceleration pulse for urban bus collisions, FE models have been used. The FE models validation process includes a sled crash with a mobile deformation barrier (EuroNCAP AE-MDB version), acting as bullet vehicle, and the frontal part of an urban bus (supported by load cells and including strain gauges for obtaining loads in five axis in three beams of the bus structure).
To analyse occupant safety, sled tests were performed with the acceleration pulse obtained. Adult (Hybrid III 50^{th} & 95^{th} male) and child impact dummies (Q1.5, Q3 & Q6) were used. The Hybrid III 50^{th} includes instrumentation at head, upper neck, chest, femurs, knees and tibias. Whereas Q-dummies at head, upper and lower neck, chest and pelvis.

A reliable crash pulse for urban buses was obtained for a better estimation of the protection requirements that urban buses could need in the future. Currently there are safety requirements for long distance buses (UNECE R80) with accelerations of 6.5-8.5 g and a delta-v of 30-32 kph. Nevertheless, the R80 crash severity has a higher severity than urban bus collisions.
The kinematics and the injury criteria obtained from the dummy readings are used to evaluate the protection capabilities of each tested configuration. Also, comparison of the dummy signals allows making recommendations.

The acceleration pulse representative of urban bus collisions has been developed using FE models. Based on the simulation results, it was taken the most severe acceleration pulse of the plausible configurations simulated. That configuration corresponds to the frontal collision (100% overlap) of an urban bus (12 t) at 50 kph impacting against a vehicle (2 t) at 50 kph. This configuration represents the invasion of the opposite lane of one vehicle when both vehicles are travelling at the maximum road speed.
The occupant analysis was performed using only one type/model of urban bus seat. There are configurations which were not tested such as bay seating, seats placed at different height or standing passengers.

To conclude, the acceleration pulse of a representative urban bus collision has been developed. The urban bus seats are able to withstand the crash load; the structural strength has been assessed with 95^{th} mass dummies.
The worst configuration for adult occupants has taken place in rearward projection due to the neck injuries. A large extension (moment and angle) has been observed.
The compartmentalization for child occupants has been deficient; dummies finish the test on the floor. For child dummies, the safest configuration is when they travel in rearward facing seats.

INTRODUCTION

The requirements of the EU Transport Politics exposed on the White Book, encourage the importance of using public transport instead of private transport, having special interest on the passengers safety and the decrease of the pollution. At urban environment, the main ways of public transport are buses. This fact is reflected by the Health World Organization in its report about the road safety situation in the world, where they urge governments to promote the use of safety, accessible and sustainable public transport, because it is necessary to increase the safety in urban areas where the traffic is becoming increasingly congested.

From the passengers' passive safety point of view, urban buses have fewer requirements than coaches, used for longer routes. Long routes coaches have incorporated seatbelts at its seats (2-points anchored), whereas urban buses do not use any restraint system. Children and adults safety has been previously studied [1-3].

The urban buses safety is based on the "compartmentalization" method, seats are placed very close and this does not allow the displacement of passengers inside the vehicle during a crash impact. This system is used by the school transport buses in the United States [4], having the premise of longitudinal configuration impacts, they do not consider high energy configurations like overturning. The compartmentalization method has been used to evaluate and define systems' requirements that help to improve the urban buses safety when children strollers are transported [5].

Although the energy levels of urban buses impacts are smaller than those of the coaches, its safety and evaluation should not be neglected fundamentally for two reasons:

- It is a way of transport that is being promoted in cities, so it is expected to increase the degree of use of this type of transport.
- The passengers' type at buses, because the majority are vulnerable users like children and elderly.

Through the Madrid-EMT (Empresa Municipal de Transportes) data, it has been found that there are three main configurations (of fifteen), where more than 75% of injuries are produced. These configurations are: impact against other vehicle, braking manoeuvre and falling inside the vehicle. According to this data, the most critical configuration is the impact against other vehicle (due to the higher decelerations of the vehicle). Therefore, to assess the passive safety of seated occupants on buses during crashes against other vehicles provides a safety framework which is able to obtain favourable results on the three configurations where injuries are produced.

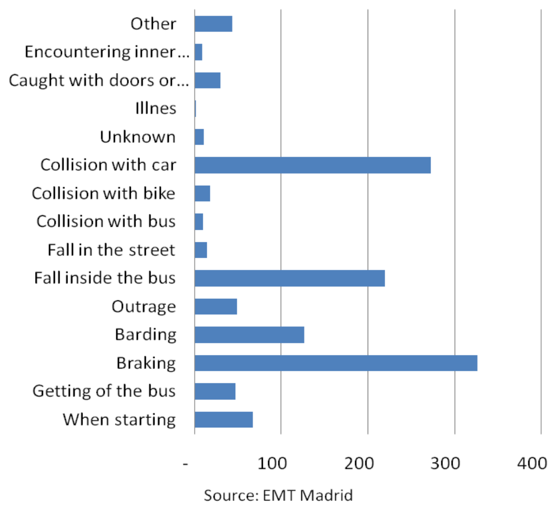


Figure 1. Causes of injuries in urban buses.

However, the regulation R80 [6] only describes the impact conditions for coaches in frontal impact configuration (the coach impact against a rigid wall at 30 km/h). This impact type is more severe than the situations described before for the urban buses. Therefore is necessary to define properly the decelerations suffered by this type of vehicle, which must be in an intermediate severity between those defined in Regulation 80R03 and those of the emergency manoeuvres (limited by the road adherence).

AIMS

The main objective of the research is to assess the passive safety of seated passengers on city buses. To achieve this objective, the following secondary aims will be considered. Those will be monitored during the performance of the dynamic tests.

- To assess the resistance of the seats and their anchorages (using adult crash test dummies of 95th percentile male, i.e. 100 kg). As mentioned before, there are not requirements for assessing the passive safety of urban buses. One of the premises of passive safety is the ability of all elements to resist the impact without any detachments or breaks that may endanger the integrity of the occupants.
- The restraint ability (compartmentalization) offered. Especially for children, because due to their lower weight they may not be adequately restrained.
- Problems of geometric incompatibility. It is assessed if there is any incompatibility on the current systems, especially for the infant population due to their different dimensions because of their growth.
- Improvement proposals. These proposals could be aimed at new designs, the improvement of the current designs, geometric modifications, etc.

MATERIALS AND METHODS

To evaluate the passive safety of urban buses seated occupants during crash impacts, dynamic tests have been performed at natural scale using impact dummies, both adults as children. However, first of all is necessary to define dynamic conditions for tests. For this, finite element models (FEM) have been developed of buses and vehicles (frontal and side) representing by average properties of all vehicles [7, 8]. These models have been used for the definition of the acceleration pulses in urban bus – vehicle collisions.

Among the scenarios of plausible crashes in urban environment (with buses involved), it has been identified as the worst (from the point of view of the bus deceleration) as follows: “urban bus with very few occupants (mass of the bus 12 t) travelling at 50 km/h that crashes frontally against other vehicle (mass of 2 t) also travelling at 50 km/h with full overlap” (see figure 2).

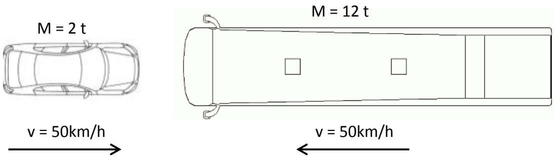


Figure 2. Urban collision scenario considered.

FEMs of city buses and vehicles (frontal and lateral representative) have been used to obtain the deceleration pulse. The city bus FEM has been validated with crash tests against AEMDB.

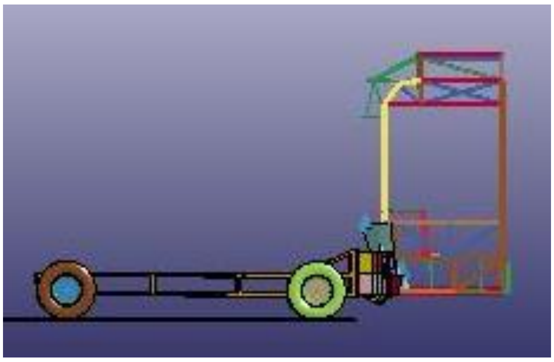


Figure 3. CAD city bus.

Figure 4. Crash test configuration.

As a result of the worst plausible crash, it has been obtained a ΔV of 15 km/h on the bus with a peak deceleration of 12 g.

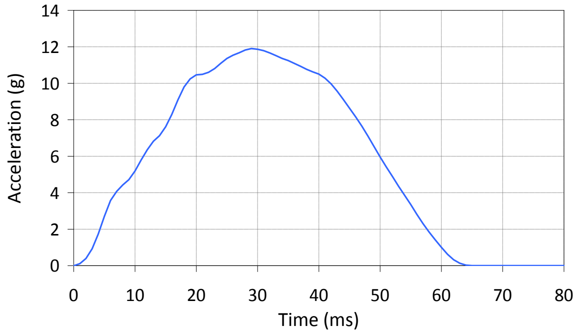


Figure 5. City bus acceleration.

Test configuration

Seven crash impact tests on a sled platform, varying occupancy degree and seat orientation have been performed at the Passive Safety Laboratory of the Instituto Universitario de Investigación del Automóvil (INSIA) with crash dummies. The table **1** shows the summary of the tests performed and the dummies used in each crash test. It has been used three adult dummies and three infant dummies.

Table 1. Tests performed.

Test Ref.	Configuration	Dummy					
		Adult			Child		
		H3-95th	H3-50th+23kg	H3-50th	Q6	Q3	Q1.5
#1	Frontal	X	X				
#2	Frontal			X	X		
#3	Frontal				X		
#4	Frontal					X	
#5	Rear					X	
#6	Rear			X		X	
#7	Frontal						X

#2

#7

The adult occupants have been represented by the Hybrid III family. The Hybrid III 95th corresponds with a dummy representing the 95% male percentile (weighting 101kg). Due to it is not possible to seat properly two dummies of this characteristics, it has been used an intermediate

version, the Hybrid III 50th dummy with a ballast of 23 kg at the pelvic area to increase the overall mass up to 101 kg. The 101 kg dummies have been used to assess the structural strength of the seats and their attachment to the bus structure (because there are not regulatory requirements to perform this verification). Finally, the Hybrid III 50th dummy represents the 50% percentile male anthropometry (78 kg); this dummy incorporates more instrumentation than the 101 kg dummies.
The infant occupants are represented by the dummies of the Q-series (which are the child dummies with more biofidelity that exist nowadays [9]). The Q1.5, Q3 and Q6 have been used in the crash tests (the number indicates the approximate age of the child that is being represented).

Test – instrumentation

Dummies are equipped during the impact tests with the following instrumentation. The parameters collected during the impacts are accelerations on head, chest and pelvis using accelerometers; and forces and moments using load cells on neck and lumbar spine. Adult dummies have also collected forces on the lower limbs (femurs and tibias).
The table 2 summarizes the instrumentation installed in each dummy and the filter applied during the signals analysis.

Table 2. Dummy instrumentation.

Reference	Orientation	Filter [10]	Dummies					
			Adults			Child		
			H3-95th	H3-50th +23kg	H3-50th	Q6	Q3	Q1.5
Head	$Acc_{(X, Y, Z)}$	1000	X	X	X	X	X	X
Upper neck	$F_{(X, Z)}$	1000*	X		X	X	X	X
	$M_{(Y)}$	600	X		X	X	X	X
Lower neck	$F_{(X, Z)}$	1000				X	X	
	$M_{(Y)}$	600				X	X	
Chest	$Acc_{(X, Y, Z)}$	180		X	X	X	X	X
	$D_{(X)}$	180		X	X	X	X	X
Lumbar spine	$F_{(X, Z)}$	600				X	X	X
	$M_{(Y)}$	600				X	X	X
Pelvis	$Acc_{(X, Y, Z)}$	1000				X	X	X
Femur	$F_{(Z)}$	600		X	X			
Knee	$Ligaments_{(X)}$	180		X	X			
Tibia	$F_{(X, Z)}$	600			X			
	$M_{(Y)}$	600			X			

* When the force is multiplied by an arm to get a moment, CFC_600 is used.

In addition, to record potential contacts of the dummy's head and lower limbs with the back of the front seat, different parts of the head and lower limbs have been identified using colours.

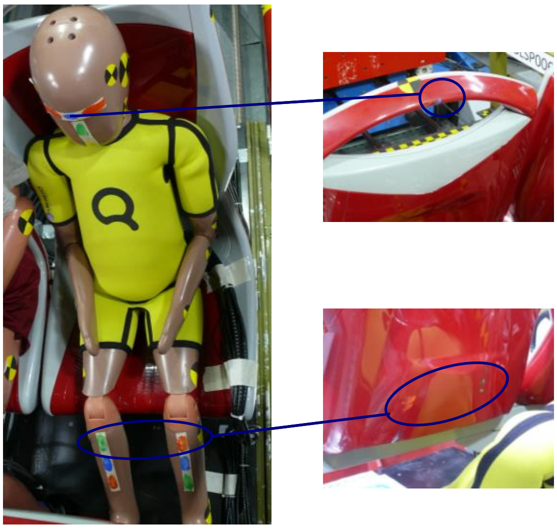


Figure 6. Colours for checking contacts.

Furthermore, the crash tests have been recorded using four high speed cameras. These cameras allow assessing the kinematics behaviour and tracking of targets to obtain displacements (such as the head excursion). All cameras have a sampling rate of 1,000 fps. The figure 7 shows the sketch of the cameras configuration.
Two of them (in colour) are placed on both sides of the test bench, another camera record an overhead view, and the fourth camera is located in an oblique point of view in order to have a higher detail of the kinematics and more information about contacts of the dummy against the seat (the location of the last camera is variable depending on the test configuration, rearward or frontal).

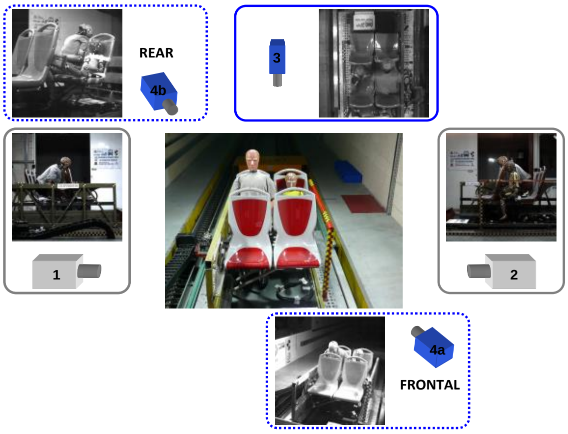


Figure 7. High speed cameras configuration.

Injury Assessment Reference Values (IARV)

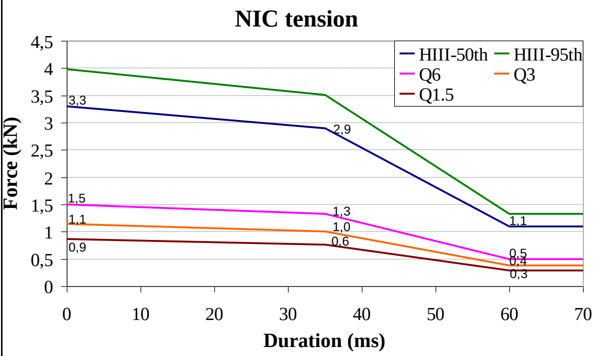
Thanks to the measurements capabilities of dummies, it is possible to establish a baseline or boundaries to determine whether there is a likelihood of injury.
The reference values taken in this paper are shown in the table 3. The values on blue, green and orange are those obtained from regulations 80, 94 and 129 respectively. Other values are obtained from by Mertz et al. [13].

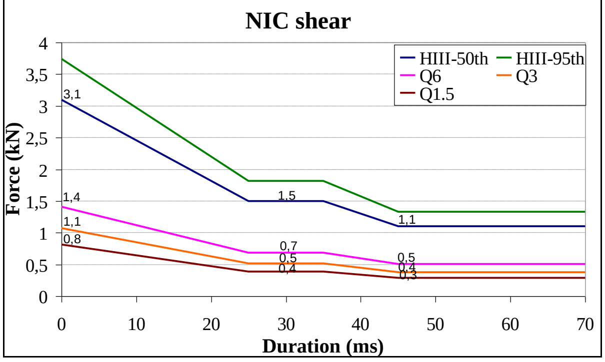
Therefore, reference values are defined in this table for assessing each configuration tested and to know when injuries are produced. These IARV values are based on the following hypotheses:

- The IARV obtained from three sources: ECE R129 [11] (for child restraint systems used on vehicles), ECE R94 [12] (for adult safety in frontal collision) and ECE R80 (for the approval of seats of large passenger vehicles), represent a large set of IARV.
- HIC criteria used in R80 has been selected instead of R94, because there is a direct impact of the face during this tests.

Table 3. IARV.

Dummies	H3-95th	H3-50th +23kg	H3-50th	Q6	Q3	Q1.5
HIC_{15ms}	500	500	500	492	356	262
Head Acc_{3ms} (g)	78	78	80	80	80	75
NIC	See graph					
Up neck extension (Nm)	76	76	57	28	19	15
Up neck flexion (Nm)	252	252	190	94	63	49
Lo neck extension (Nm)	206	206	156	77	52	40
Lo neck flexion (Nm)	504	504	380	188	127	97
Chest deflection (mm)	46	46	42	26	23	21
Chest Acc. (g)	27	27	30	55	55	55





- Reference values of R94 and R80 are defined for the 50th percentile. Those values are scaled using the work done by Mertz et al. [13] and the work done by the EEVC [14]. Both, scales the IARV to a dummy target size using its geometric data and using as a reference the 50th percentile adult dummy for the 95th percentile and for Q dummies.

RESULTS AND DISCUSSION

The most relevant results concerning their configuration, as well as the recorded signals are described in the following paragraphs.

Firstly, kinematics assessment is done thanks to the tested scenarios. Figures 9 and 10 show the impact kinematics of forward and rearward projections respectively. Eight images have been selected from each impact configuration (each picture includes the time in milliseconds from the beginning of the crash). At the first level of each figure is found the child dummy (Q3 and Q6 in rear and forward projection respectively) and at the background plane it is found a midsize adult occupant (Hybrid III 50th male).

The seats used in urban buses do not have headrest and the maximum height of the seat backrest is not high (although it depends on each type of seat or manufacturer, the backrest height is approximately 620 mm from the bench or seat cushion). This fact produces that the head of adult occupants has not got any restraint due the lack of support, however, children (because of their lower stature), have support in their back for the head. For the tested seat, the limit for the head support is among the dummy that represents a child with 10 years old and the adult 5th percentile female, i.e. occupants with a height between 140 and 150 cm (the sitting height of these dummies are 734 and 787 cm respectively).

Forward projection kinematics

During the forward projection impact, both dummies have a movement toward the front seat due to the lack of a restraint system (like a seatbelt) to maintain their position on their respective seats.

For the adult dummy, the first contact occurs on the knees that impact against the front seat at 56 ms (reaching an axial compression force of 5.2 kN in femurs).

This impact situation causes the restraint of the lower part of the occupant body. However, the upper part is not restraint yet and a forward and descendent movement of the head takes place. This movement stops when the head makes contact against the handle of the front seat at 146 ms, reaching a resultant acceleration of 47.6 g.

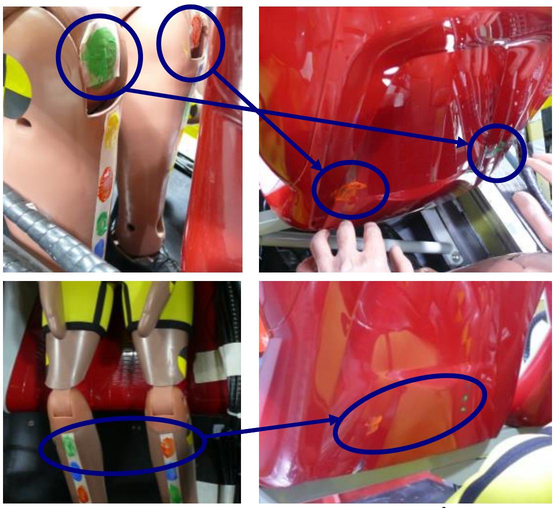


Figure 8. Knees contact. Hybrid III 50th and Q6.

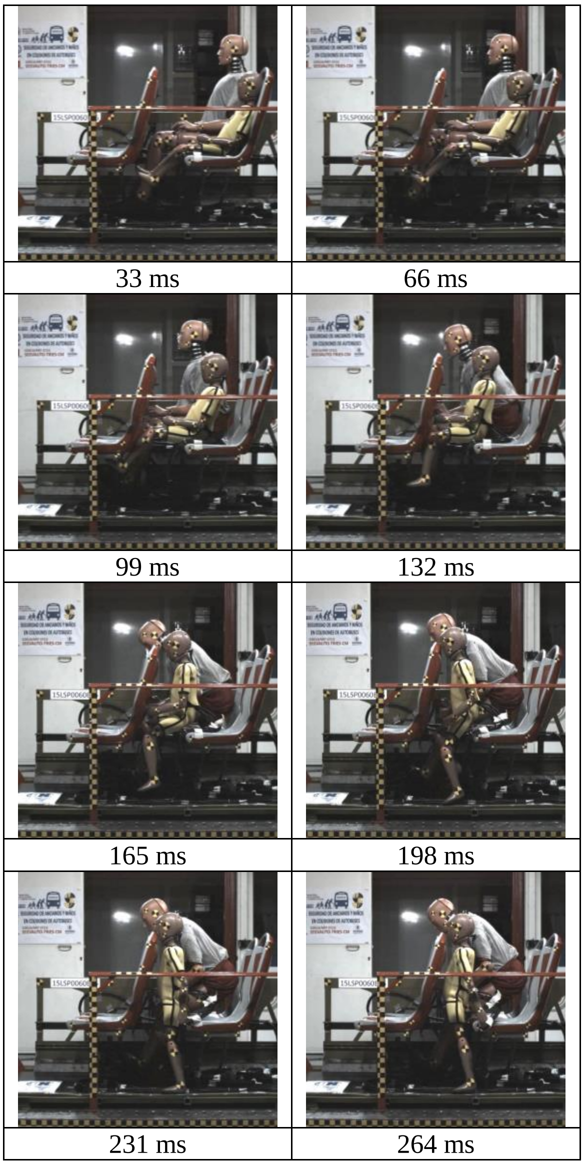


Figure 9. Frontal impact kinematics. First plane: Q6. Second plane: Hybrid III 50th male.

Adult dummy head's impact do not produce a high neck extension, on the other hand, this impact is produced with the occupant nose with an estimated impact force of 2.5 kN. After that, (due to the elasticity of the front seat) the dummy starts a rearward movement to return to its own seat, until the dummy is finally seated (final test position).

For the child dummy, its kinematics is completely different. The dummy has a movement toward the front seat until the first contact takes place with its knees at 106 ms. This contact has been delayed 50 ms with respect to the adult dummy, therefore it produces a relative impact speed of the child dummy higher than the adult dummy.

In addition, during this time period the child dummy is practically out of its seat, being complicated the return of the dummy to its own seat once the crash finishes. The knees impact cannot stop in the same way the child dummy as the adult dummy, it occurs because the child dummy's feet do not rest on the floor such as the adult occupant do. The upper part of the child occupant continues its forward movement, while the angle between femurs and the torso is increasing until the dummy is almost fully upright. Subsequently, a head contact against the front seat is produced. This contact occurs usually with the forehead, but the location of the impact varies with the size of the dummy due to the height differences. After this contact, the dummy do not have speed enough and falls down to the vehicle floor. Accelerations collected during the dummy falling sometimes reach the half value collected during the impact against the seat.

Rearward projection kinematics

For the rearward projection, masking tapes have been used on the upper part of the dummies torso to prevent movements during the acceleration phase of the sled (the sled accelerates up to the target speed and subsequently the main deceleration or crash is produced). These tapes do not avoid the main impact and it can be seen its break during the rebound phase.

For the adult occupants, as mentioned before, there is not head support, which produces a backwards movement of the head and consequently a neck extension. Using tracking motion analysis, it is recorded a neck extension angle of 98º and this movement is limited by the contact of the occiput (occipital part of the skull) against its own seatback (at 134 ms), which increases the head acceleration up to 34 g. The neck extension moment has reached 62 Nm (exceeding the criteria established by the UNECE regulation for the protection of occupants during a frontal collision [12], where the crash takes place at 56 km/h). The restraint of the rest of the body, in general terms, is satisfactory. The seat and its anchorages withstand the impact loads

without breaks or strains that may cause a risk to the passengers of the urban bus.
For the child dummy (Q3), the safety performance offered by the seat in the rearward projection is correct, because there is a large support of the back and head of the dummy with its own seat. It is observed as well a small upward movement of the occupant due to the inclination of the backrest. This vertical movement increases the risk of the neck extension for older children because facilitates the lack of head support. Peak accelerations of the dummy are between 15-21 g, taking into account that the peak deceleration of the sled (that represents the urban bus) is 11.6 g, so there has been a small increase in the peak values thanks to the good support of the dummy. Finally, because of the elasticity of the seat (partly by the load of the adult occupant), the child dummy acquires a rebound speed and finally ends on the floor. This fact produces peak acceleration values close to 15 g (similar to the main impact, but in this case with a shorter time duration).

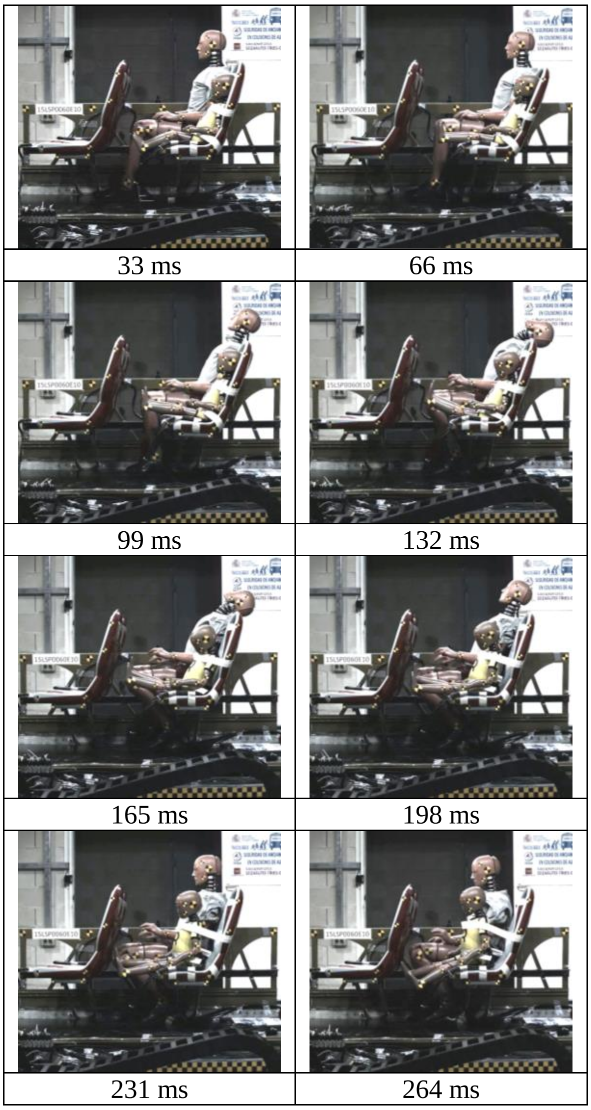


Figure 10. Rear impact kinematics. First plane: Q3. Second plane: Hybrid III 50th male.

Peak values and IARV

The tests performed allow assessing and analysing to determine (quantitatively and qualitatively) the safety of the different configurations tested.
Figures 11 and 12 show a graphical representation of the main %IARV of each dummy in the forward and rearward projection. Blue colours palette represents the adult dummies while the palette transition from red to yellow represents the child dummies. Graph units are the percentage according to the limits described in table 3.
On the other hand, in the table 4 it is shown the maximum values collected by the dummies' instrumentation. In red is remarked those parameters that exceed the limits established and in brown those that exceed the 50%.
In the rear impact configuration the peak values collected are lower than in the forward impact configuration, except the tension on the neck and its extension moment in both adult and child dummies. For the adult it is caused by the lack of head support described previously. In absolute terms, all other values are kept at low values.
In the frontal impact, it is not observed a clear trend on the child dummy signals due to the increasing of the stature. This fact is caused by the legs reaction which changes the way of loading the upper part of the body. The Q1.5 is the dummy which strikes with greater relative speed and obtains greater decelerations in the chest (part of greater mass concentration); furthermore the Q1.5 head strikes in the most rigid part of the seat backrest.

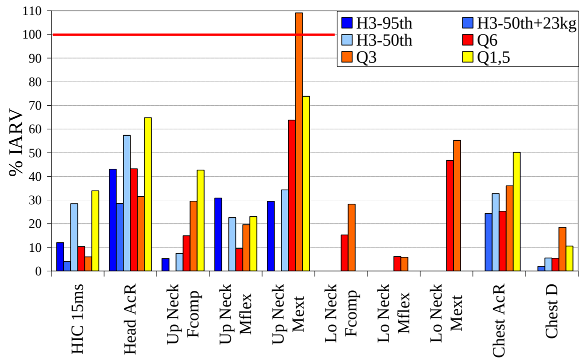


Figure 11. % IARV in forward projection.

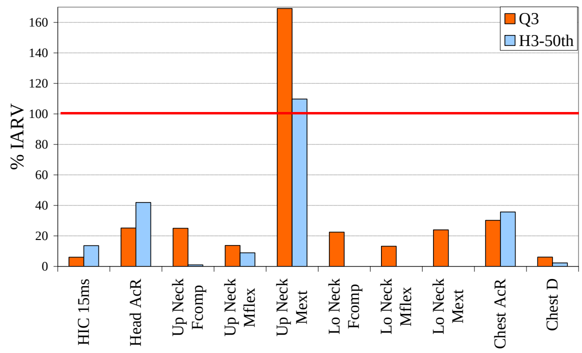


Figure 12. % IARV in rearward projection.

Table 4. Peak and injury criteria results.

Dummy part	Parameter	Peak Values							
		Forward projection						Rearward projection	
		H3-95th	H3-50th+23kg	H3-50th	Q6	Q3	Q1.5	H3-50th	Q3
Head	HIC_{15ms}	59.8	20.3	142.2	50.9	21.3	88.9	68.0	21.5
	$Acceleration_{3ms}$ (g)	33.4	22.1	**45.9**	34.5	25.2	**48.6**	33.5	20.1
Upper neck	Tension $+F_z$ (N)	501.5	-	944.4	219.6	290.0	218.8	1,228.4	224.9
	Compression $-F_z$ (N)	255.6	-	297.8	333.8	490.6	571.3	40.0	415.6
	Shear force F_x (N)	521.5	-	559.0	383.1	283.8	296.2	336.2	325.2
	Flex. moment $+M_y$ (Nm)	77.7	-	42.9	8.9	12.4	11.2	16.9	8.7
	Ext. moment $-M_y$ (Nm)	22.3	-	19.5	**18.0**	**20.7**	**10.8**	**62.5**	**32.1**
Lower neck	Tension $+F_z$ (N)	-	-	-	283.2	271.6	-	-	244.2
	Compression $-F_z$ (N)	-	-	-	341.6	469.7	-	-	373.1
	Shear force F_x (N)	-	-	-	251.6	325.9	-	-	364.7
	Flex. moment $+M_y$ (Nm)	-	-	-	11.6	7.4	-	-	16.7
	Ext. moment $-M_y$ (Nm)	-	-	-	36.1	**28.7**	-	-	12.5
Chest	Deflection D_x (mm)	-	0.9	2.3	1.4	4.2	2.2	1.0	1.4
	$Acceleration_{3ms}$ (g)	-	6.6	9.8	13.9	19.8	**27.6**	10.7	16.6
Pelvis	Acceleration (g)	-	-	-	22.4	18.5	19.5	-	17.9
Femur L	Compression F_z (N)	-	4,155.2	5,258.3	-	-	-	540.0	-
Femur R	Compression F_z (N)	-	5,510.4	5,148.8	-	-	-	576.5	-

As it can be seen in the figures, the extension moment of the neck has values that exceed the IARV and the 50% of the limit, especially on the child dummies in forward projection and in rearward projection. On the other hand, parameters of acceleration 3 ms on the head and the chest have obtained values around the 50% of the limits described before. Highlight a compression force of the upper part of the neck around the 50% of the limit for the Q1.5 dummy.
The rest of the parameters have not got values potentially injurious.

Head

No dummy exceeds the reference values defined, although the Hybrid-III 50th and the Q1.5 dummies have an acceleration (3ms) that exceeds the 50% of the head injury criteria. In frontal impact configuration all dummies hit against the frontal seat, although the HIC is very low for each dummy. The Q1.5 has higher values on the head compared with the other child dummies because its head hits in a lower position of the seat. Whereas, both Q3 as Q6 strike with the handle of the seat that has a greater elasticity, decreasing the accelerations recorded.
Highlight, that the HIC limit used for the head is that defined in the Regulation 80 and correspondingly scaled to the child dummies. This limit is used because of the impact of the face against the front seat and because it is more restrictive than those defined in the Regulation 94 and 129.

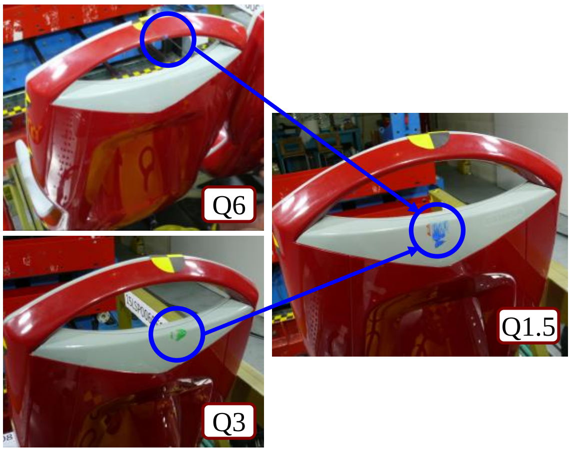


Figure 13. Q-dummies head contact comparison.

Neck

In rearward projections the Hybrid-III 50th and the Q3 dummies exceed the reference value of the extension moment due to the lack of head support in the adult's situation. In the Q3 occurs together with higher values of the shear and compression forces during the impact against the backrest. As the Q3 is the unique child dummy that has been tested in the rearward configuration, no conclusion could be obtained about the performance of the seat backrest for these high values.
This greater extension moment is also high on the child dummies in a forward projection due to the impact of its backs against the seat which produces a greater extension of its necks. This parameter is higher on the Q3 because it has a direct impact against its seat with the back (this fact causes a greater extension of the neck), whereas the other child dummies slide through the seat with its back.

Figures 14 and 15 show the neck injury corridor (NIC) result from the tests performed (Q3 in rearward and forward projections) and them illustrate how the shear and tension force in the neck (upper and lower) do not exceed the limits calculated. This fact occurs for the NIC of every dummy tested; none of them exceed the limits calculated.

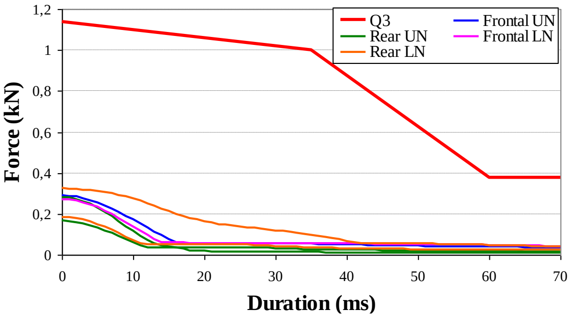


Figure 14. Q3 – NIC tension force.

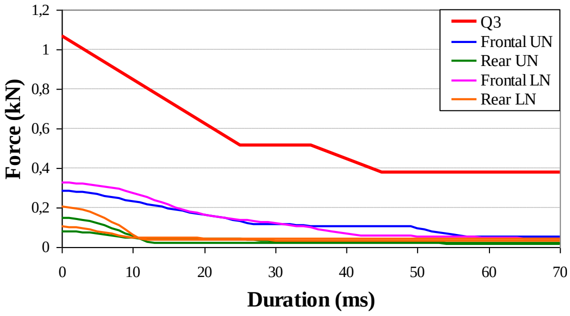


Figure 15. Q3 – NIC shear force.

Chest

The resultant acceleration is significantly below the limit because the test speed is lower than those specified in Regulations 94 and 129. The Q1.5 is the dummy which strikes with greater relative speed and obtains greater decelerations in the chest (part of greater mass concentration); furthermore the Q1.5 head strikes in the most rigid part of the seat backrest, more close to the seat anchorages.

On the other hand, the chest deflection is also bellow the limit of the regulations mentioned before, because the dummies do not have any restraint in the seat and its chest does not hit directly against the front seat.

Pelvis

Finally, the pelvis acceleration is shown in table 4. There is not reference value for this parameter for the child dummies or scaling procedure for frontal impact. The Q1.5 and the Q3 dummy have lower accelerations in forward projection, it is caused by a primarily retention through its legs. Subsequently, its knees are flexed decreasing the pelvic acceleration.

Figure 16. Q-dummies pelvis acceleration explanation.

Elderly IARV

The Hybrid III 50th has also been analyzed, comparing it with elderly injury criteria. There is not IARV for dummies representing older people except for the thoracic area, therefore the HIC and the neck parameters are calculated using the EEVC method [14] with the mechanical properties of Yamada [15]. The femurs' limit force is calculated through a FE model by Schoell et al. [16], these values will be used to evaluate its injury likelihood for the 65 years reference.

The following figures show the results of the Hybrid III 50th comparing with the calculated aged injury limits. The injury limits in the graphs are in colour red. The reference values for the head are those defined by the R80 when the face impacts against the front seat (forward projection).

As it can be observed in figure 17, the extension moment of the neck exceeds the limit established in rearward configuration. It is caused by the lack of headrest in the seat. This fact was also observed whit the standard limits.

On the other hand, the femurs' forces are in the limit in forward projections, it occurs when the knees hit against the front seat. This fact can produce a fracture on the femur of an elder adult.

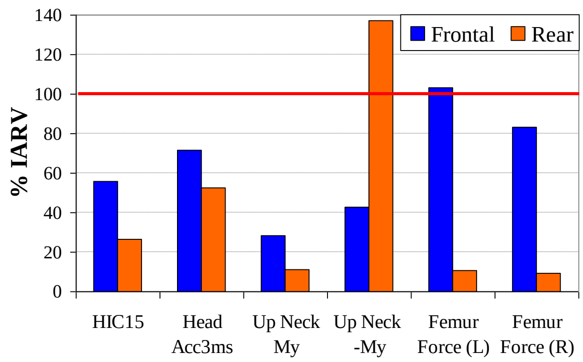


Figure 17. Forward and rearward configuration – Adult 65YO IARV results.

Figures 19 and 20 show the NIC results of the Hybrid III 50th. Both of them illustrate that the shear and tension forces are below the limits calculated for elder adults in both configurations.

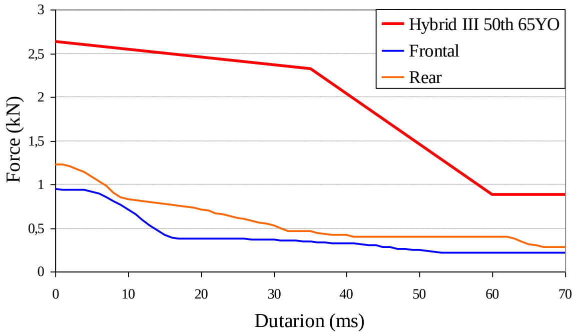


Figure 18. NIC-Tension Hybrid 50th 65YO:

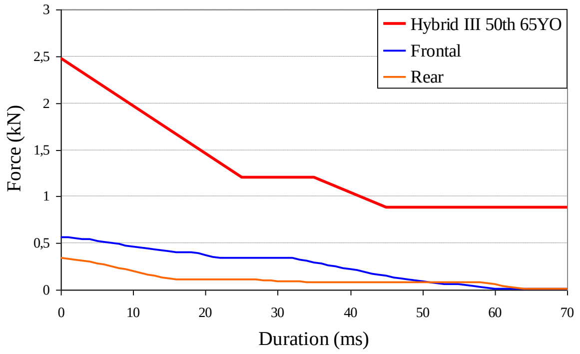


Figure 19. NIC-Shear Hybrid 50th 65YO.

CONCLUSIONS

This research has allowed increasing the knowledge of the dummies' behaviour during urban bus collisions. According to the tests' results, the following conclusions are obtained:

- Urban bus seats have withstood the dynamic loads without fractures or breaks that could cause injuries on the occupants. Over 5 kN forces have been recorded on femurs of adult dummies. This value could be useful if resistance requirements are defined on seats or elements which are inside urban buses.
- The most dangerous configuration has been obtained for adult occupants in rearward projections. There is not headrest and it produces an extension movement in the neck over 90º, it causes a high injury risk (it is over the limits defined in the regulation). This movement has been limited by the contact between the occipital region of the head and its own seatback. Improvements are needed to prevent neck injuries on seats oriented rearward facing in the vehicle (like higher seats, place the seats oriented rearward facing against separator panels or other measures).
- In forward facing projection, the worst injury for the adult dummy takes place during the impact of its face against the front seat. High impact forces have been collected during this situation, therefore nasal septum fracture is likely to be produced.
- The restraint provided to children (compartmentalization) when they travel in forward facing direction is poor, all infant dummies end on the floor (not in their original seat). The parameters collected have not been high in absolute terms. However, when they travel oriented rearward facing, the parameters collected are drastically reduced and significantly improvements in the child restraint are produced (although in some test the child dummy ends on the floor too).
- For child safety, the protection in rearward facing projection is greater than in forward facing projection. However, if there is not head support (depending on the sitting height); the rearward configuration is more dangerous than forward facing.
- The tests performed do not collect any interaction between occupants; therefore, the contact between occupants of double seats does not affect the safety benefits provided (regardless of whether the occupants are adults or an adult and a child). There are not big differences between the behaviour of simple and double seats.
- According to the IARVs calculated (table 3), the dummies have values bellow the limits established, except the extension moment of the neck upper part. In rearward projections the upper part of the seat should be modified to avoid this situation. In the case of forward projections the falling to the floor of the child dummies should be avoided, if possible.
- For elder adults, the IARVs should be developed with more deeply research. According to the calculated values, the extension moment in rearward configuration and the femurs' forces in forward projection exceed the limits. Therefore, elder adults would have an injury risk higher than standard adults, especially on femurs (45% higher) in forward configuration and on the neck during its extension (extension moment 30% higher).

During the development of the study, the following limitations have been identified:

- A particular urban bus seat model has been tested. Although current designs are similar between manufacturers, the dynamic results could be different.
- There are seat configurations that have not been tested, such as: the bay configuration (where occupants look at each other, that is, some oriented in forward facing and others in the opposite direction), seats located at different heights and standing occupants.

ACKNOWLEDGEMENTS

This research has been held with the support of the Spanish Ministry of Science and Innovation who funded the project *Children and Elderly Safety in Bus Accidents. CESBA/SANCA (TRA2011-26313)*, in the 2008-2011 National Research Program (Basic Research). The CESBA/SANCA activities are included in the SEGVAUTO-TRIES program (S2013/MIT-2713) funded by the Comunidad de Madrid.

The Q-dummies used in the present study have been partially funded by the Spanish Ministry of Economy and Competitiveness through the *"Adquisición de Maniquíes Instrumentados Serie Q" (UNPM13-4E-1722)* with the FEDER funds.

Presentation of this paper is supported by the Spanish Ministry of Economy, Industry and Competitiveness through the TRA2016-77979-R, Research Project.

Authors also would like to acknowledge to the Public Transportation Operator of Madrid (EMT) for their contribution and collaboration in the development of this research.

REFERENCES

[1] Martínez L, García A, Alcalá E, Espantaleón M. Child frontal impact safety in coaches. 22nd ESV (2011) 11-0383.

[2] Martínez L, Vicente T, García A, Alcalá E, Aparicio F. Analysis of coaches rows seats distance influence on the passengers comfort and safety. 21st ESV (2009) 09-0197.

[3] Martínez L, García A. Estudio de prescripciones técnicas para la mejora de la seguridad infantil en vehículos de transporte colectivo. IX Congreso de Ingeniería del Transporte (2010).

[4] Elias JC, Sullivan LK, McCray LB. Large school bus safety restraint evaluation – Phase II. 18th ESV (2003) 313.

[5] Martínez L, García A, Espantaleón M, Alcalá E, Dols J. Analysis of children strollers and prams safety in urban buses. 24th ESV (2015) 15-0175.

[6] UNECE WP29 (2016). Regulation 80R03 – Uniform provisions concerning the approval of seats of large passenger vehicles and of these vehicles with regard to the strength of the seats and their anchorages.

[7] Sánchez M, Abellán D. Development of new deformable barriers for testing vehicle performance in different crash configurations. International Journal of Crashworthiness (2015), 20(4): 370-386.

[8] Alcalá E, Arribas D, Martín A, Martínez L, García A. Modelos de colisión de autobuses urbanos. Congreso Iberoamericano de Ingeniería Mecánica, ciudad de La Plata (2013).

[9] EEVC. Q-dummies Report. Working Group 12 and 18 Report, Document No. 514 (2008).

[10] SAE J211 – Part1. Instrumentation for impact test – Part 1 – Electronic instrumentations.

[11] UNECE WP29. Regulation ECE R129R00 – Uniform provisions concerning the approval of ECRS used on board of motor vehicles.

[12] UNECE WP29 (2016). Regulation 94R03 – Uniform provisions concerning the approval of vehicles with regards to the protection of the occupants in the event of a frontal collision.

[13] Mertz HJ, Irwin AL, Prasad P. Biomechanical and scaling basis for frontal and side impact injury assessment reference values. Stapp Car Crash Journal (2016), 60: 625-657.

[14] EEVC WG12-18. Q-dummies Report: Advanced child dummies and injury criteria for frontal impact. Document No. 514 (2008).

[15] Yamada, H. Strength of biological materials. The Williams and Wilkins Company (1970).

[16] Schoell SL, Weaver AA, Urban JE, Jones DA, Stitzel JD, Hwang E, Reed MP, Rupp JD. Development and validation of an older occupant finite element model of a mid-sized male for investigation of age-related injury risk. Stapp Car Crash Journal (2015), 59: 359-383.