UNIVERSAL COACH SAFETY SEAT

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ABSTRACT

Bus and coach seats with 3-point seat belts, when properly designed, implemented and used, are safer than any current available seat and restraint option. However, they imply cost and weight penalties and can also be 'too rigid' for unbelted passenger sitting behind.

A universal coach safety seat has been developed and tested that meets the following requirements:-

(a) The seat carries a 3-point belt that adequately restrains two 50%ile dummies under the most extreme condition of UN-ECE Regulation 80 (R80), also when the seat simultaneously restrains unbelted or lap-belted 50%ile dummies seated behind.

(b) The R80 specified injury criteria of the unbelted or lap-belted dummies seated behind the test seat are met under condition (a) and also when the test seat is empty.

(c) The technical requirement (a) and (b) were met using conventional materials (low cost steel, plywood, foam and standard belts) and production methods, resulting in a twin seat of 36.3kg.

INTRODUCTION

Improved protection for a coach occupant is influenced by two main parameters. The first is the residual space (minimum space required to prevent occupant throughout the accident) within the vehicle. The excessive collapse of super structure (intrusion into residual space) generally results from vehicle rollover. This parameter has been studied resulting in Regulation 66 that specifies the extent of structural collapse without intruding into the defined space based on the seat geometry (Ref. ESV paper no. 216).

The second parameter concern occupant interaction with the boundary of the residual space. This could involve occupant body segments impact with the structure's interior surfaces or partial/total ejection from the vehicle. In either case the induced loads on the occupant's body segments are highly likely to exceed human tolerance loads. To prevent such a condition it is necessary to minimise the relative displacement of the body segments relative to the seat.

A number of serious coach accidents in UK and elsewhere in Europe generated a growing concern about the feasibility of improving coach safety by fitting seat belts. In the late 1994 the European Commission initiated a project to deal with the problem. The results have been presented in [1] and some of the main conclusions were:-

(a) Passenger ejection is a major cause of death and injury particularly in minibus and coach rollovers, but also in frontal and side impacts. All minibus and coach seats occupants are 'exposed' to danger in rollovers as well as other accidents.

(b) Seat belts can significantly reduce or prevent passenger ejection, but the whole system: seat, seat belts and all anchorages must be properly designed, manufactured, installed and used.

(c) Some of the R80 compatible seats approved with unbelted dummies can maintain acceptable injury levels even when dummies are lap-belted. However, lap belts increase the head strike exposure and the belt angles should be controlled to reduce danger of abdominal in juries.

(d) Seats with 3-point belts offer, in principle, the best protection to belted occupants, but can be 'too hard' to those sitting behind, particularly if they wear lap belts. This raises important questions whether 'hard' 3-point belt seats can be mixed with other types and whether the protection of un-belted occupants be considered.

(e) Combined loading, with lap or 3-point belted dummies in the test seat and unbelted dummies behind impose very much higher seat and anchorage loads and a significant geometry change in comparison with a standard R80 test. Combined loading should be considered, so that the unbelted occupants sitting behind do not compromise safety of belted occupants.

(f) Dynamic tests on seats, anchorages (and obstacles if any exist in front of a seat with lap-belts) ought to be applied to reflect the body dynamics in front impacts and particularly the head-strike.

(g) An 'ideal' solution would be a seat that can protect occupants under all conditions, i.e. unbelted, lap belted and 3-point belted, as well as any combination of these. These options were met with much scepticism in terms of their commercial feasibility (size, cost and weight).

PROJECT OBJECTIVES

The objective of the Project was to investigate the feasibility of an M3 coach twin seat that would meet the following requirements:-

(a) the current ECE R80 (empty) seat test with unrestrained dummies sitting behind;

(b) the proposed conditions combining the current ECE R80 (empty) seat test with lap-belted dummies behind (Draft Commission Directive lli/5l62/94/EN concerning the Directive 74/408/EEC);

(c) the combined loading, involving 3-point belted dummies in the seat and unbelted dummies behind;

(d) the combined loading, involving 3-point belted dummies in the seat and lap-belted dummies behind;

(e) weight and cost-related constraints that would make the seat commercially feasible; this feasibility may be justified even if such seat can be safely used (as regards rear passengers too) only in the 'exposed' seating positions ; however, the maximum possible benefit would arise from an 'all round', large quantity seat to which lap or 3-point belts can be retrofitted.

Conditions (c) and (d) go much beyond the proposed conditions under (b), not only in terms of the level of loading, but also as regards the geometry change of the tested seat occupied by belted dummies.

The current R80 compatible seats are designed to protect unbelted occupants only and the Australian Design Rule 68/00 (first approved in October 1992) concerns safety of the 3-point belted occupants only. To the best knowledge of all people involved in this Project, a seat meeting criteria above neither existed, nor has a similar attempt been made in the past.

GENERAL APPROACH TO THE PROBLEM

The work programme included:-

(a) Engineering background study,

(b) Component tests,

(c) Occupant and structural simulation studies,

(d) Concept selection and parametric studies,

(e) Proposal for the main deforming and non-deforming components,

(f) Blending the safety features with the other functional and manufacturing constraints of an assumed 'production seat',

(g) Production of seat test prototypes,

(h) Dynamic tests on a HyGe reverse accelerator rig,

(i) Static test on anchorages according to the Directive 76/115/EEC.

ENGINEERING BACKGROUND AND DEFINITION OF TEST CONDITIONS

The first step involved investigation of the conclusions arising from the EC seat belt project [1], past CIC projects on aircraft, railway and coach seats and from literature. This resulted in the framework within which the concept solution was found and identified priority issues in the theoretical and experimental work. Decisions reached at this stage were, for example, to:-

(a) Achieve the solution by a controlled and progressive collapse of the seatback and underframe structures;

(b) Interpret the 'seat pitch' as 'seat spacing' in the ECE Regulation 36 (i.e. measured between the front of the seat back of the auxiliary seat and the rear of the seat back of the seat tested), which increases the distance between the 'equivalent' points on the auxiliary and test seats by approximately 50 to 60 rnrn and creates a more severe test scenario;

(c) Make the test conditions as severe as possible while still within the bounds of ECE R80 on acceleration and total velocity change. The test pulse was therefore tailored to be very close to 12g over approximately 30 ms of acceleration, with a total velocity change of 30 kph - this has brought the seat as close as was possible to the M2 minibus category too.

The parameters of interest are shown in Figure. 1.

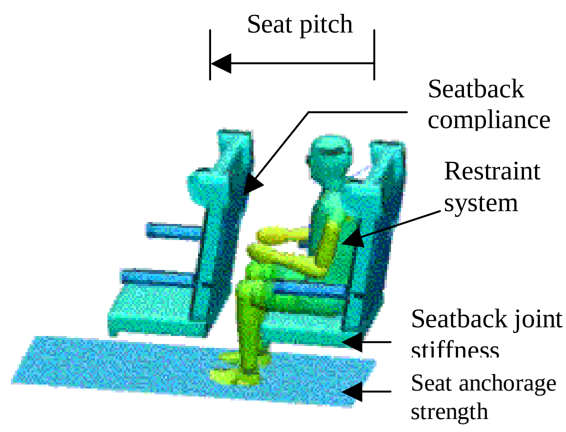


Figure. 1. Seat structure and main features of relevance.

COMPONENT TESTS

Component tests comprised:-

(a) Static bending collapse tests on a selection of mild steel tubes used within the seat structure to establish the reference material properties. These were used to predict bending moment-rotation curves and section optimisation using an in-house computer program.

(b) Static compression tests on the seat cushions and backs to enable correct dummy positioning in the dynamic occupant / seat simulations using program MADYMO.

(c) Dynamic pendulum tests on the energy absorbing materials to estimate the impact response of different combinations of materials and geometries and generate MADYMO input data. Typical of the tests carried out is that using a pendulum (Figure 2.), made of aluminium carrying a mahogany head former sculptured to represent closely the face of the HYBRID III dummy.

In this test an accelerometer was mounted centrally immediately behind and in line with the head-to-seat-back contact. The seat back test specimens with different padding of the head impact zone were mounted on a frame with a seat-back like geometry. The angle of impact was adjusted to approximate the relative kinematics of the head-strike of a lap belted occupant against an empty seat in front. Test results included the impact velocity, deceleration signal, visual inspection and photography.

ANALYTICAL STUDIES

The analysis activities were carried out broadly in parallel with the component tests, with some additions after the first full scale tests. For more efficient use of time, where ever possible, the sin1ulation was carried out applying quasi-static structural analysis method, linked in an iterative loop with a dynamic occupant / seat interaction analysis applying MADYMO code. The main role of the static analysis was to:-

(a) 'translate' the general collapse properties of the seat structure indicated as favourable by the dynamic simulations into design recommendations on the main deforming and non-deforming members at the levels of the overall layout and component collapse properties.

(b) feed input data back to the dynamic analysis after assuming a certain design and generating the component and overall collapse properties.

(c) control the compatibility of the MADYMO and structural collapse modes and identify design problems and favourable collapse modes.

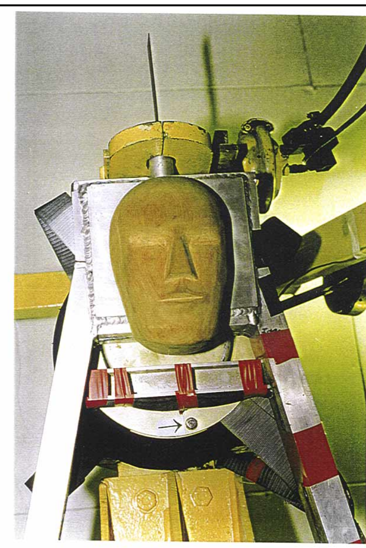


Photo 4 Close-up view of Photo 2 with pendulum arm horizontal

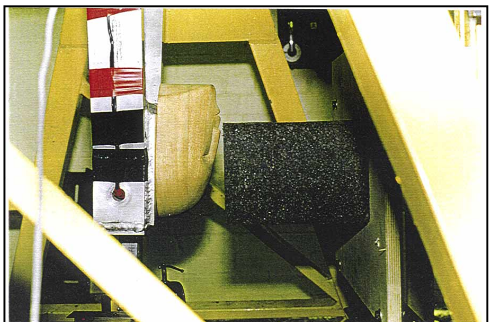


Photo 3 Close-up side view of Photo 1 with pendulum arm vertical

Figure 2. Testing various materials for required compliance properties

Component moment-rotation curves at plastic hinges were generated using program to facilitate the analysis of the complete structure. The loads were applied in two or three directions at seat belt anchorage points, knee, torso and head contact region using axially collapsible beams whose load-deflection curves reflected the loading sequence observed in earlier tests [1], or dynamic analysis.

However, static analysis has serious limitations in identifying the truly dynamic effects of the interaction between the dummy and deforming seat, represented by highly oscillating time histories with shifts between different contact regions.

Dynamic analysis was carried out to:-

(a) investigate different concept solutions, both in qualitative and quantitative terms,

(b) investigate the chosen concept as regards the effect of the collapse properties of the structure and contact regions on the occupant kinematics and injury criteria.

The main difficulties concerned reliability of the input data and the potentially high sensitivity of the injury criteria to relatively small variations of input parameters (both affected by quasi-static analysis and pendulum tests).

The seats were studied in the four configurations shown in Figure 3, each implying different conditions for both the seat and dummies (al1 50 %ile male):-

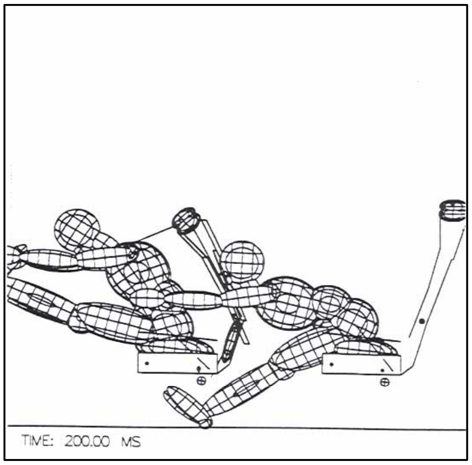


Figure 3(a) Front dummies 3-point belted, rear lap-belted.

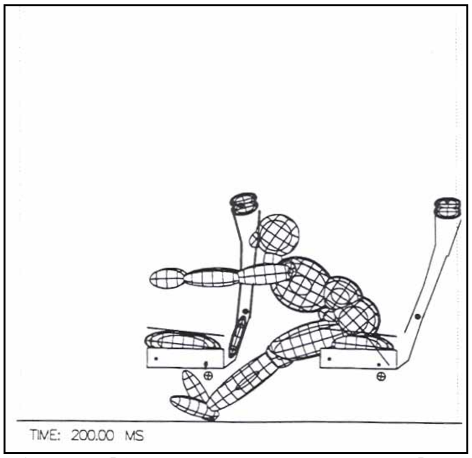


Figure 3(b) Front seat empty, rear dummies lap-belted.

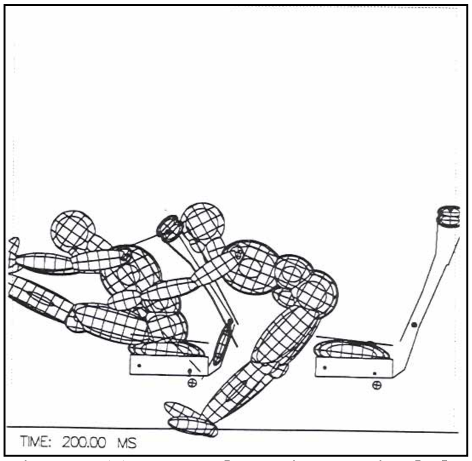


Figure3 (c) Front dummies 3-point belted, rear unbelted.

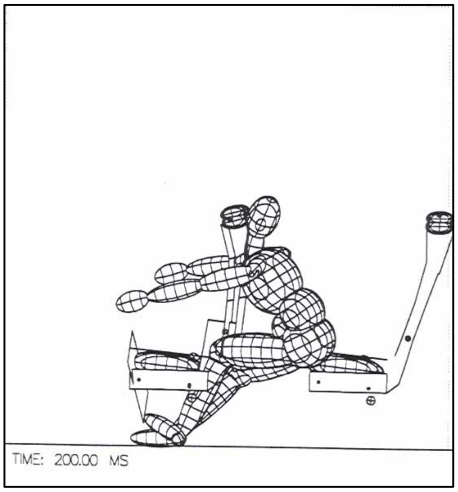


Figure 3(d) Front seat empty, rear dummies unbelted.

The parameters considered in the dynamic study were the head and knee contact stiffness, seatback structure strength, underframe stiffness and strength (in a 'macro' sense, i.e. not including individual structural elements) and seat belt stiffness. Table 1 (overleaf) shows the dummy results obtained with a 'recommended' design used in the first test on each scenario in Figure 3. Results correspond to the rear seat dummies with top figures predicted by analysis and the bottom two corresponding to the test results (first the "window" side occupant (50 %ile Hybrid II), then, after the'/’ sign, the "aisle" side (50 %ile Hybrid III)).

Table 1.

Table 1

Front seat	Rear seat	HAC theory/test limit 500	Chest acc. (g's) theory/test limit 30 g	Femur load (kN) theory/test limit 10 kN
Vacant	Not belted	264 213/359	18.3 29.2/21.2	7.34 4.5/4.7
Vacant	Lap belted	803 436/356	18.3 29.8/19.0	4.89 3.7/4.0
3-point belted occupant	Not belted	457 567/302	9.7 21.2/12.3	5.53 5.1/4.3
3-point belted occupant	Lap belted	482 871/633	23.8 22.6/14.1	2.35 3.6/2.8

Table 1 is illustrative not only as regards the agreement between the theoretical and the first experiments, but also in terms of the scatter of the test results. Further 'fine' tuning of the seat was necessary, mainly based on additional pendulum tests.

THE BASIC DESCRIPTION OF THE NEW SEAT

The concept of the new seat was based on the desire to achieve both the safety and commercial viability. This immediately led to a decision to aim for:-

(a) utilisation of conventional materials and production methods, typical for the bus and coach seat manufacturing industry,

(b) a design that would, ideally, be suitable as a standard seat for all seating positions, resulting in the following benefits:

  (b1) high number of units, hence lower unit cost,

  (b2) possibility to offer lap or 3-point belts as options on the same seat,

  (b3) possibility to retrofit lap or 3-point belts after the original purchase.

The same requirements also enhanced the need to minimise the weight of the seat. Weight minimisation often implies use of advanced materials, such as aluminium and composites. However, it was only practical (and fully justifiable) to go for the same basic materials used in other seats, i.e. steel tubes, plywood, low-cost foams (meeting the Directives on the burning behaviour of interior materials used in buses in coaches - which is not yet in force). This was also the case for range of brackets, joints, etc. also made of steel and using conventional production procedures. The total weight with one leg and anchorages was 36.3 kg.

The 3-point belt was of standard configuration. Both shoulder belt slots were in the middle of the seat, to remove them from the aisle and have a common seat for the left and right side of the coach. The retractors were under the cushions. The seat design, which is patent pending, was chosen to combine:-

(a) compatibility with all the geometry/installation requirements for M3 vehicles;

(b) stiff and strong seat leg and all anchorages, attached to standard vehicle rails;

(c) deformable seat underframe;

(d) deformable and detachable seat back, for production/fit consideration;

(e) provision for the reclining mechanism (which was however reinforced and blocked in all tests, except for one rear seating position in Test 6);

(f) contact properties in the knee, head and chest contact regions.

FULL SCALE DYNAMIC TESTS

Full scale dynamic tests were carried on a HyGe reverse accelerator sled rig, with test conditions adjusted to be as severe as possible for the M3 vehicles, as described above. The auxiliary (launch) seats were standard production seats and compatible with ECE Regulation 80. In view of the geometric similarity of the front face of the standard and the new seats and since the R80 seats with lap-belted dummies did not appear to deform permanently, it is argued that the test conditions reasonably represented the case where all seats are of the new type.

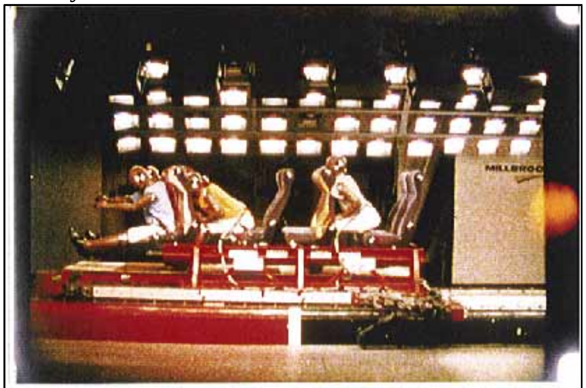
All seats were mounted on rails identical to those used in standard reference coaches.

All the tests (except Test 5 which involved seat rows 1 and 2 only) examined two scenarios using a single firing of the HyGe sled rig (examples are shown in Figures 4 and 5).

Where in Figure 4:-

- Row 1 (new seat) - 3-point belted with uninstrumented Hybrid II dummies in both seats,
- Row 2 (R80 seat) -lap belted, instrumented dummies, near (window seat), Hybrid II, next to Hybrid III,
- Row 3 (new seat) – empty,

- Row 4 (R80 seat) - unbelted, instrumented dummies, near (window) seat Hybrid II, next to Hybrid III.

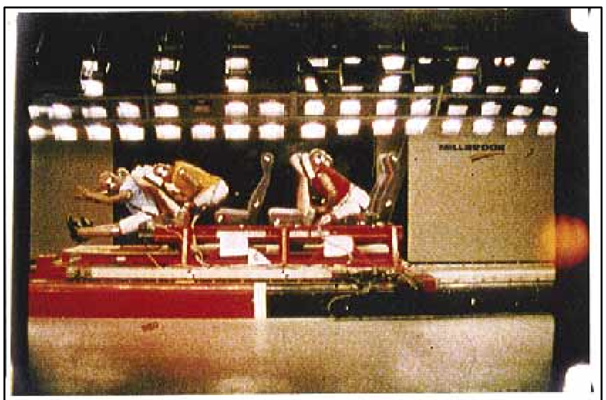


(d) Front dummy head contact

Figure 4. HyGe sled test of the universal coach safety seat with 50 %ile male dummies .

The test arrangement for Figure 5 was:-

- Row 1 (new seat) - 3-point belted, uninstrumented Hybrid II in both seats,
- Row 2 (R80 seat) - unbelted, instrumented dummies, near (window) seat Hybrid ll, next to Hybrid III,
- Row 3 (new seat) – empty,
- Row 4 (R80 seat) - lap-belted, instrumented dummies, near (window) seat Hybrid ll, next to Hybrid III.



(d) front dummy head contact

Figure 5 HyGe sled test of the universal coach safety seat with 50 %ile male dummies.

One scenario was tested using rows 1 and 2 and the other with rows 3 and 4. The general test arrangement was as follows:-

Row 1: tested seat - new seat in Tests 1 to 6, loaded with uninstrumented, 3-point belted Hybrid II dummies,

Row 2: launch seat - R80 seat in all tests, loaded with instrumented Hybrid II (window seat) and Hybrid III (aisle seat) dummies (50 %ile in tests 1 to 5, and 95 %ile (aisle) and 5 %ile (window) in Test 6) , dummies were unbelted in Tests 1 and 2, or lap-belted in Tests 3 to 6,

Row 3: tested seat - empty in all tests,

Row 4: launch seat - standard R80 seat in all tests, with instrumented Hybrid II (window) and 50%ile Hybrid III dummies, unbelted in Test 3, otherwise lap-belted.

The 'pitch' (i.e. seat spacing) between the test and launch seats was 750 mm in all tests, apart from rows 3 and 4 in Test 6, which had a spacing of 650 mm. The gap between the seat back in row 2 and cushion in row 3 was approximately 150 mm, so that there was no interaction between the seats in rows 2 and 3. The reference injury criteria required by the ECE Regulation 80 and the new draft amendments to the 76/115/EEC Directive were:-

(a) the head injury/acceptance criterion (HAC): 500.

(b) the chest (thorax) acceleration acceptance criterion (HAC): 30 9 for up to 3 ms.

(c) the femur force acceptance criterion (FAC): 10kN (8kN for more than 20 ms).

Although not part of any safety legislation, the neck injury criteria in most Hybrid III dummies were also measured to investigate an important injury mechanism. These are based on the comparison of the processed time histories (level - duration) of the neck loads with a 'tolerance corridor' and expressed in percents of the tolerance limit. An 'acceptable' result reads less than 100 %.

The main test conditions and results are summarised in Table 2. Extracts from the high speed films from each test scenario are shown in Figs 4 and 5.

Test 1 was to be preceded by a static seat belt anchorage test to investigate whether joint separation may occur. Unfortunately, this could not be done and indeed the seat back in the first row fractured at the reclining mechanism and had to be re-designed.

Test 2 and all subsequent test had an identical main structure. The seat met all the structural, dummy kinematics and injury criteria, including the extra neck- related data, with the exception of the unbelted Hybrid II dummy in the second row whose HAC was just above the limit (567). There was no damage to anchorages and all seats stayed firmly anchored after test. This demonstrated that the same seat can carry

3-point belted occupants and also restrain the unbelted passengers behind. When empty, it also protects the rear lap-belted passengers.

Table 2. Summery of the dynamic test configurations, crash pulses and injury details from 6 test batches.

Seat	Seating spacing	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
1st	All seat spacing 750mm, except between rows 3 & 4 in test 6	New seat	New seat	New seat	New seat	New seat	New seat
2nd		R80	R80	R80	R80	R80	R80
3rd		New	New	New	New	New	New
4th		R80	R80	R80	R80	R80	R80
	Dummies						
1st	All dummies Hybrid II (50%ile)	3-point belted	3-point belted	3-point belted	3-point belted	3-point belted	3-point belted
2nd	Window, Hybrid II (50%ile) Aisle, Hybrid III (50%ile) Exception, 5%ile (Window) and 95%ile (aisle) in test 6	Unbelted	Unbelted	Unbelted	Unbelted	Unbelted	Unbelted
3rd		Vacant	Vacant	Vacant	Vacant	Vacant	Vacant
4th		Lap Belted	Lap Belted	Lap Belted	Lap Belted	Lap Belted	Lap Belted
Dummy	**Parameters**						
2nd row window	Head HAC	397	567	871	697	413	587
	Chest 3ms max (g)	11.1	21.1	22.6	24.9	21.6	23.6
	Max. left femur load (kN),(compressive +ev)	5.4	5.1	3.6	3.4	4.0	-1.7
	Max. right femur load (kN),(compressive +ev)	1.5	2.9	0.7	0.4	1.0	-1.3
2nd row aisle	Head HAC	Corrupt data	305	633	604	439	421
	Fore/aft neck criterion (%)			39.9/24.3	14.6/76.7	59.3/11.9	
	Tension/compression neck criterion			56.3/5.3	54.7/5.1	79.4/57.5	
	Chest 3ms max (g)	10.0	12.3	14.1	12.8	12.6	15.1
	Max. left femur load (kN),(compression +ev)	1.7	4.3	2.8	2.7	2.8	3.4
	Max. right femur load (kn),(compression +ev)	3.9	3.4	2.5	2.3	2.8	3.0
Rear Row window	Head HAC	240	436	213	347		257
	Chest 3ms max (g)	25.8	29.8	29.2	24.5		22.8
	Max. left femur load (kn),(compression +ev)	5.4	3.7	4.5	4.1		4.9
	Max. right femur load (kN),(compression +ev)	2.6	3.3	3.8	2.6		3.2
Rear row aisle	Head HAC	307	356	359	575		177
	Fore/aft neck criterion (%)	48.3/16.6	15.4/65.9	10.4/110	12.1/86.8		
	Tension/compression neck criterion (%)	3.5/93.1	95.1/2.7	91.8/9.6	71.6/4.6		
	Chest 3ms max (g)	18.1	19	21..2	15.5		11.7
	Chest deflection (mm)			3.7			
	Max. left femur load (kN),(compression +ev)	3.1	3.4	4.7	4.9		3.5
	Maxi. right femur load (kN),(compression +ev)	3.8	4.0	3.7	3.5		3.1
Pulse details	Max. Deceleration (g)	11.9	11.9	12.0	11.9	11.2	12.1
	Max. velocity	30.6	29.9	29.9	29.9	30.6	30.2
	Average decel. (g)	7.54	7.73	7.69	7.16	7.19	

Test 3 included some improvement of the head strike region and met all the structural, dummy kinematics and injury criteria (Table 2) for the unbelted occupants sitting behind the empty seat. The fore and aft neck criterion was, however, marginally above the limit (110%). The head strike region had to be improved again also because both lap belted dummies in the second row failed the HAC (871 and 633), but passed other requirements.

Test 4 confirmed that the worst case scenario (at least with this particular seat) when the seat loaded with 3-point belted passengers also had to protect lap-belted occupants behind.

Test 5 showed full compliance with all the injury criteria in the last remaining case of the seat protecting both the 3-point belted 50 %ile dummies and simultaneously, the lap-belted 50 %ile dummies behind.

Test 6 was organised to investigate how the seat in Test 5 would perform with the arrangement involving:-

- Row 1 - loaded with 3-point belted 50 %ile dummies
- Row 2 - lap belted dummies: 5 %ile small female dummy in the window seat next to 95 %ile (large male)
- Row 3 - empty
- Row 4, at 650 rnm pitch lap belted dummies : 500/oile Hybrid II (window seat) next to a 50 %ile Hybrid III.

All the injury criteria were below the limit (Table 2), except the HAC of the small (5 %ile) dummy in the second row, which read 587. This dummy hit the lower edge of the foam block that was, at that point only, stiffened to blend the padding with the back of the seat. This may have raised the HAC and confirmed the higher sensitivity of the smaller dummies as observed in the earlier EC project by the same team. The lower injury readings with 650 rnm pitch confirmed the earlier findings that the smaller pitch benefits the safety of occupants.

STATIC TEST ON BELT ANCHORAGES TO THE 76/115/EEC DIRECTIVE

The static test of the seat belt anchorages to the Directive 76/1l5/EEC, as amended in 9O/629/EEC was carried out on one seat after completion of the dynamic tests. The M3 specification required 450 daN for each torso belt and for each lap belt 450 daN plus 6.6 times half of the seat weight (i.e. a total of 567 daN). The requirement was met with the seat top moving forward to a maximum of approximately 200 mm and without any material separation.

Figure 6 show the analysis and Figure 7 the testing of various seat orientations to ensure effectiveness of the seat design when subjected to different loading conditions.

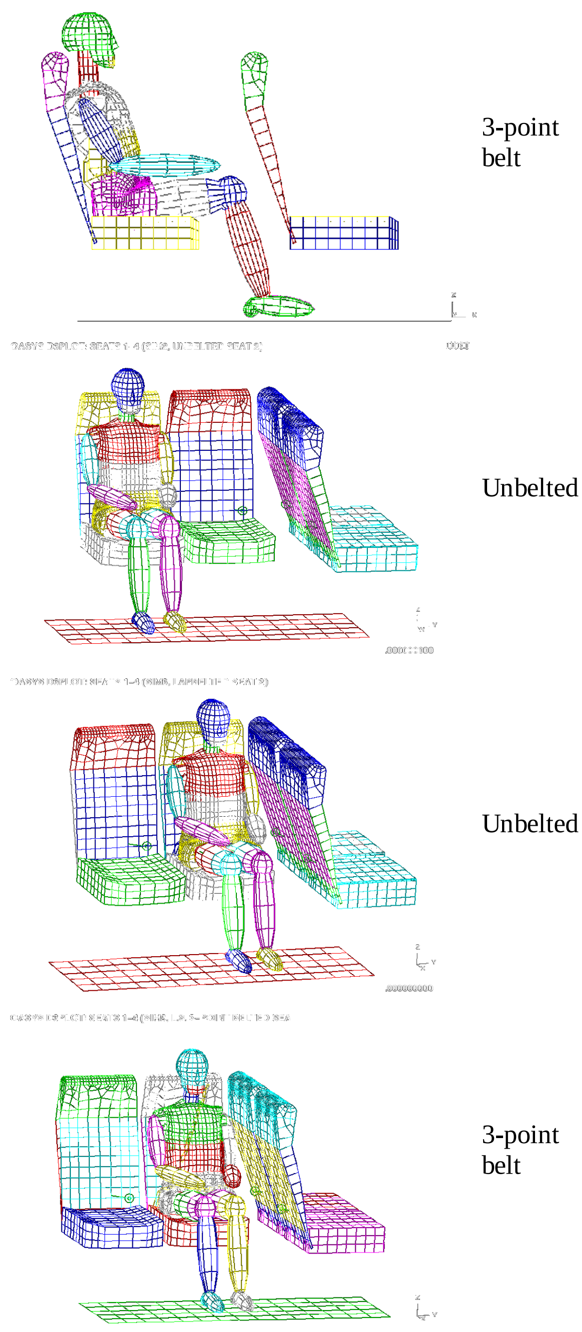


Figure 6. Numerical simulations of different seat configurations.

(a) The belted dummy locations before test

(a) Before test.

(b) The belted dummy locations after test

(b) After test.

Figure 7. Different seating configurations of occupants inside frontal impact test of M2 vehicle.

CONCLUSIONS

A prototype twin coach seat with three- point belts has met all the ECE Regulation 80 injury criteria under the 'worst' acceleration and seat pitch conditions for the M3 coaches. Effective occupant protection was shown to exist under the following scenarios:-

- empty seat hit by unbelted dummies,
- empty seat hit by lap-belted dummies,
- fully loaded seat hit by unbelted dummies,
- fully loaded seat hit by lap-belted dummies

The seat also performed well when fully loaded seat was impacted by lap-belted 95 %ile male and 5 %ile female dummy, as well as when seat spacing of 650 mm was applied between an empty seat and seat carrying lap- belted 50 %ile dummies. The seat also passed the 76/115/EEC Directive on seat belt anchorage loads, although this requirement was not seen as essential after the whole system seat/ belt/anchorages met the dynamic test conditions.

The seat thus passed all the conditions of the current proposal for the new EEC Draft Directives on seats and seatbelts (50 %ile unbelted or lap-belted dummies impacting an empty seat in front), but also all the conditions of the combined loading where unbelted or lap belted dummies impact the seat in front which also carries 3-point belted dummies.

The seat is no bigger than a typical current European production seat and is made using conventional materials and production methods. The mass of the new twin seat of 36.3 kg compares well with some in current use. The seat was tested with standard mounting rails on the coach body . All these provide a sound basis for the production development of a commercial seat that would be suitable for all seating positions, with the following possibilities:

(a) high number of units, hence lower unit cost,

(b) possibility to offer lap or 3-point belts as options on the same seat as well as retrofit. The new seat also provides a sound basis for resolving all of the main outstanding issues regarding the safety of coach seats (i.e. protection of all passengers, 'mixed mode operation', etc.).

ACKNOWLEDGEMENTS

The Project was initiated and funded by the Department for Transport (UK) and supported by Plaxton Coach and Bus (UK). Full-scale dynamic tests were carried out at Millbrook Proving Ground (UK).

The author wishes to remember the late Dr. Dusan Kecman, a great engineer and close friend whose contributions to bus and coach secondary safety has been recognised world-wide.

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