

# STUDY OF IMPROVED SAFETY FOR MINIBUSES BY BETTER SEAT AND OCCUPANT RETENTION

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## ABSTRACT

There is considerable interest in improving the crash safety of buses, minibuses and coaches despite their comparatively good safety record. Publicity given to accidents involving these vehicles has led to demand for safety measures, notably the installation of seatbelts in coaches and minibuses. This demand has been met to some extent in the UK by the recent requirement for all children, on journeys relating to school or other child activities, to be transported in vehicles fitted with seatbelts. Further UK legislation will require all new buses and coaches, apart from those specifically designed for urban use and standing passengers, to be fully equipped with seatbelts. However, the requirements for seatbelt anchorage strengths in these larger vehicles are less demanding than for cars. An evaluation of samples of seats, seatbelt systems and minibuses, the potential for improving their performance and the appropriateness of current regulations was undertaken. This paper describes: a study of the available UK national accident statistics, an in-depth analysis of the UK minibus accidents held in the TRL database of police files of fatal accidents, the selection of a suitable crash pulse for testing minibus seatbelt systems which represents the real life accident situation, tests of standard minibuses in order to establish the performance of current seatbelt systems, the development and testing of improved minibus seatbelt systems and suggestions for improved test methods for minibus seatbelt systems.

## INTRODUCTION

Buses, minibuses and coaches are some of the safest forms of road transport in the UK. However, when accidents do occur they can involve a relatively large number of people in a single incident and this gives rise to public concern. Publicity given to accidents involving these vehicles has led to demand for safety measures, notably the installation of seatbelts in coaches and minibuses. This demand has been met to some extent in the UK by the requirement for all children, on journeys relating to school or other child activities, to be transported in vehicles fitted with seatbelts. Further UK legislation will require all new buses and coaches, apart from those specifically designed for urban use and standing passengers, to be fully equipped with seatbelts. However, the

requirements for seatbelt anchorage strengths in these larger vehicles are less demanding than for cars. It was decided to focus on minibuses for this project. The first stage of this study was to determine from accident data the impact severity in terms of vehicle velocity change and acceleration, of minibus accidents that typically result in serious and fatal injury. Following this the performance of current minibus seatbelt systems was reviewed to determine their efficacy in that accident situation. Next, these minibuses seatbelt systems were improved where necessary and tested to determine and demonstrate whether it is practical to provide protection in accident situations which currently result in serious and fatal injuries. In addition, these results have been considered in order to provide guidance for the proposal of test methods that would result in higher standards of occupant protection through improved floor, seat and seatbelt anchorage performance.

## ANALYSIS OF ACCIDENTS TO AID SELECTION OF A CRASH PULSE

### Method (accident analysis)

Two databases were used as a basis for deciding on the test conditions appropriate for occupant protection provision in minibuses. The first, known as STATS 19 consists of computerised data provided by the Police on all injury road accidents occurring in Great Britain. When the Police report a road accident involving personal injury they fill in the form for STATS 19 but in the case of an accident involving a fatality they also compile a full report of the accident including witness statements, coroners' reports, results of Police accident investigations and often photographs. Fatal accident files, from co-operating Police Forces around the UK, forms the second database of road accidents. These databases were interrogated to provide information on typical accident situations that would be most demanding for the seat and seatbelt system. Full-scale crash test data were found which best matched this accident situation and a simplified crash pulse was derived that would be suitable for use in sled testing of minibus shells.

### Results (accident analysis)

UK National Accident data were used to find the most frequent types of minibus accident. Each

accident was classified by the most serious minibus occupant injury. The analyses showed that the most common minibus accidents resulting in passenger injuries were from impacts with other vehicles accounting for 75% of all injury minibus accidents. Of these accidents with other vehicles, 61% were due to the minibus colliding with a single vehicle. Of these accidents, impact with car type vehicles were the most common and accounted for 72% of injury accidents involving one vehicle.

However, accidents resulting in serious or fatal injuries to minibus occupants are thought to be more appropriate when considering seatbelt strength requirements. Again minibus accidents with other vehicles were found to be the most frequent accounting for 59% of all fatal or serious injuries accidents. Of these accidents with other vehicles, 57% were due to the minibus colliding with a single vehicle. Of these accidents, impact with car type vehicles were the most common and accounted for 67% of fatal or serious injury accidents involving one other vehicle. In these accidents with single car type vehicles the front of the minibus was the first point of contact in 64% of impacts with car types. Of these accidents involving the front of the minibus, 68% were with the front of the car.

Fatal or serious minibus accidents with heavy vehicles (trucks and buses) were less common (19% of all fatal or serious accidents) but resulted in a higher injury rate. The proportion of minibus accidents that resulted in fatal or serious occupant injuries was 29% for the heavy vehicles, compared with 6% for the car type vehicles. The minibus front was most often involved in accidents fatal or serious accidents with heavy vehicles (59% front, 25% side and 16% rear of the minibus). Of these fatal or serious minibus front accidents, 35% were to the front, 27% were to the side and 38% to the rear of the heavy vehicle.

The probability of fatal or serious injuries was found to be higher if the minibus overturned. For the impacts with the car type vehicles, the proportion of minibus accidents in the fatal or serious category is 31% for the minibus overturned compared with 6% for non-overturned (the numbers of overturned accidents with heavy vehicles was too small to make a similar comparison). As no information is given in this database on whether ejection occurred as a result of overturning it is not possible to know the exact cause of the injuries. However, it is likely that the wearing of seatbelts would reduce the risk of injuries within the vehicle and the risk of ejection. Ejection greatly increases the risk of serious or fatal injuries for occupants. Nevertheless, the frequency of minibus

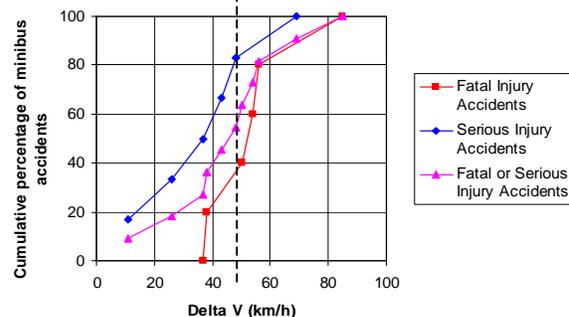
overturning accidents is low at 19% of all fatal or serious injury minibus accidents.

Speed limits on the roads where the fatal or serious accidents occurred were generally above 40 miles/hr. For accidents with the car type vehicles this speed limit accounts for 56% of fatal or serious minibus accidents while for the heavy vehicle type the figure is higher at 77%. However, the less serious accidents are more common on roads with lower speed limits.

**Results of Analyses of Police Fatal Accident Files**

identified a total of 74 minibus accidents. It should be noted that an accident is classified by the police as fatal if one of the occupants in either/any vehicle involved or a person outside the vehicle is killed. Therefore not all fatal minibus accidents cases found involve a fatal minibus occupant injury. Classifying the 74 accidents by the most serious injury to minibus occupant, 15 were fatal, 6 serious and 53 slight. In 20 of the 21 fatal or serious minibus accidents it was possible to identify which part of the minibus made contact with the vehicle or object hit. In 13 of these 20 accidents (65%) the impact to the minibus was essentially frontal. It was also possible to find the degree of overlap in these 13 frontal minibus accidents and 6 cases (46%) involved the full width of the front of the minibus. A further 5 cases (38%) involved at least half the width. The remaining 2 cases (15%) involved about one third of the minibus front. It can therefore be concluded that a large overlap was the most frequent accident situation. Also out of the total of 13 frontal minibus accidents, it was possible to make a “best estimate” of the speed of each vehicle at contact and the mass of the vehicles involved in 11 cases. From this an estimate of the change in minibus speed at first contact (delta V) was calculated, using the equation of conservation of momentum and assuming no rebound. Details of the injuries sustained by the minibus occupants were also available for these cases.

These data have been used to plot the cumulative percentage of minibus accident according to the most serious occupant injury severity against the change in



**Figure 1. Cumulative percentage of accident severity by change in minibus speed**

minibus speed at first contact (delta V), see Figure 1.

From this figure a test speed can be selected for a sled test of minibuses or minibus components to cover a chosen proportion of accidents. The figure shows that a test speed of about 48 km/h would cover at least 50% of all accidents in which a minibus occupant was fatally or seriously injured.

Severe impacts with heavy vehicles were found to result in a large extent of crush within the minibus, causing serious injury to the occupants within these areas. Any normal style restraint system is unlikely to be of worthwhile benefit to the minibus occupants within the crushed cell. However, the restraint system would still benefit occupants in positions within the area of the minibus that was not crushed.

Rollover accidents often result in the ejection of occupants, who thereby suffer fatal or serious injury. A seatbelt system would help to retain the occupants within the vehicle during rollover. However, a seatbelt test based on rollover requirements would be less demanding than one for frontal impacts. It will, however, be necessary for the sensors of any emergency locking retractors to operate under an overturning mode.

Although it might be expected that accidents involving heavy vehicles would result in larger values of minibus delta V, due to the heavy vehicles having a larger mass, this was not found to be the case in the fatal accident database. The values of delta V for accidents with heavy vehicles were found to be of a similar magnitude to those of car type impacts because the heavy vehicle accidents occurred at lower speeds. This finding was despite the UK national statistics showing that accidents with heavy vehicle most frequently occurred on roads with higher speed limits.

## **CRASH PULSE FOR SLED TESTING OF MINIBUSES**

### **Crash Test Data**

One full-scale minibus crash test was found which matched the most common impact condition, identified above, of 100% overlap. This was a Ford Transit minibus crash test conducted at TRL. The vehicle, a 1983, 12 seat Ford Transit (line built), was subjected to a perpendicular impact into a large concrete block, with full overlap at a speed of 49.5 km/h (30.9 mph). Figure 2 shows the time history for that test from the fore and aft accelerometer mounted on the B post.

The change in velocity seen by the minibus during the main phase of this impact (delta V) is equal to the test velocity.

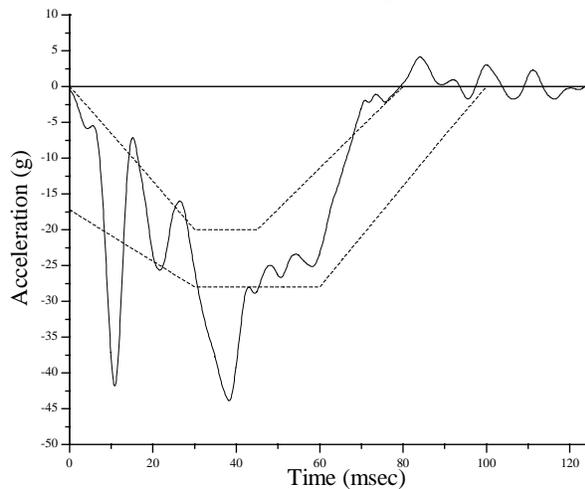
## **Selection of a Crash Pulse**

**Discussion (Crash Pulse)** The two main properties needed to specify a crash pulse for a sled test are the test velocity and the sled acceleration time-history. The velocity can be selected from the accident data and the acceleration should be one typical for all types of minibus.

It is difficult to provide strong seatbelt fixings in minibuses because, unlike cars, for some seats there is no adjacent vehicle structure to which they can be attached. Therefore, minibus seatbelt anchorages are normally built into the seat. Consequently it is important that a crash pulse is carefully selected to provide the optimum reduction of injuries without being over demanding. A test for minibus seatbelt systems should be based on the loadings that occur in accidents. However, it would be unreasonable to expect them to withstand the most severe accidents. Indeed, anchorage of excessive strengths would provide little or no additional protection because in very violent accidents they would induce belt loadings in excess of the strength of the human frame. In these cases some additional protection may be provided through deformation of the seatbelt system on overload (e.g. bending of the seat back). Because of the above considerations it is concluded that a target of a seatbelt system strong enough to withstand the loadings in a minimum of 50% of fatal and serious injury accidents, would be reasonable. As has already been discussed, this target would result in a sled test speed (delta V) of about 48 km/h. However, it should be noted that the data are drawn from a sample of fatal accidents. Because of this it is likely that a number of lower speed accidents resulting in minor or serious injuries are not included. The bias from this means that a test velocity selected from this graph is likely to represent in real life a larger proportion of all fatal and serious minibus accidents. There were no accident data available for minibus accidents that would enable this degree of bias to be estimated. Therefore it should be noted that the estimate of 50 percent of the severe minibus accidents included in a 48 km/h test has to be considered as conservative.

The accident data discussed above indicate that the most common impact is minibus to car, front to front, with 100 per cent overlap. However, accidents with heavy vehicles, although less common, result in a higher injury severity. The impact conditions in the TRL full-scale Ford Transit test would be broadly similar to the most common minibus front to car front, or minibus front to front or rear of heavy vehicle accidents with a delta V of about 49 km/h. However, it will be slightly more demanding because the concrete block would have caused slightly higher minibus

accelerations due to it forcing all the stiffest frontal structures to deform. In a minibus to other vehicle impact these stiff structures are likely to deform slightly less because they are likely to penetrate the other vehicle. Taking these considerations into account it was concluded that the acceleration time history from this full-scale test would be suitable for developing a crash pulse. Ideally it would be preferable to test a range of different makes of minibus against cars and heavy vehicles to select an average or a worst case acceleration time history. However, taking into account the accuracy with which the delta V value could be established from accident data the results from this one vehicle model are thought to be acceptable. Therefore, the sled crash pulse for tests of minibus shells in this project was based around the acceleration performance of the Ford Transit to concrete block tests illustrated in Figure 2.



**Figure 2. Full scale crash test results overlaid with ECE Regulation 44 crash pulse**

For a sled test some simplification of the acceleration pulse is acceptable to take account of the nature of sled arresting systems and the frequency response of seatbelt systems. In addition, a tolerance is required to make reasonable allowances for the test to test variations common to sled test systems. Both of these requirements are normally taken into account by providing "a crash pulse corridor." Sled test regulations were examined for guidance on this and it was noted that the ECE Regulation 44 pulse (Economic Commission for Europe, 1998) (for testing child restraint systems) has the same test velocity, and an acceleration history similar to, but slightly lower than, the average level of acceleration found in the Transit test. Figure 2 shows the Regulation 44 crash pulse corridor overlaid on the full-scale crash test result. It was decided to use this corridor for minibus sled tests in this research programme.

## SELECTION OF REPRESENTATIVE MINIBUS SHELLS FOR SLED TESTING

A study was made of the methods used to produce minibuses in the UK. It was found that there were three different methods of construction:

- i) Line built - A standard delivery van is normally used as the base for line built minibuses. However, the extra features required for a minibus are built into the vehicle as they are made. These features include purpose made floor reinforcements, seat attachment anchorages and factory fitted windows.
- ii) Van conversions - The modifications made to the basic vans by the various converters visited vary widely. In some cases the van roof is removed and replaced by a raised glass-fibre roof. Window apertures are cut in the side structure of the van and this sometimes requires the removal of stiffening struts. Often a welded steel strengthening frame is fitted around the window aperture in an attempt to replace the strength removed when the aperture was cut.
- iii) Coach built vehicles - The coach built vehicles are normally built on the rear of a chassis-cab produced by a major vehicle manufacturer. The coach built vehicles examined under construction were all being built directly onto the vehicle chassis, not pre-assembled and then mounted to the chassis. Typically, longitudinal galvanised steel members were attached to the top of the vehicle main chassis members. Cross members were then fixed to these and a side structure attached in turn. The vehicles were clad in either stainless steel sheet or aluminium. Seats or tracking fixings were normally located on the longitudinal and cross members of the floor.

Minibus body shells were obtained which represented the three types of construction. Vehicles were chosen from the larger manufacturers or converters who were willing to co-operate in the research programme. A total of seven minibus shells were purchased for the initial phase of testing current standards of construction; one line built from manufacturer A, two coach built from manufacturers F and G and four van conversions. The van conversions selected were based on three different makes and models of van. Van conversions B and C used the same model of large long-wheel base van as a basis and were converted by the same converting company. Van conversions D and E were based on different models and converted by different converting companies. Four of these, (one coach built by company G and three van conversions vans C, D and E) were then selected for improvement. With the exception of one of the van conversions (van

C), which was improved solely by TRL, the manufacturer or converter and seat manufacturers made these improvements with various degrees of assistance and collaboration from TRL.

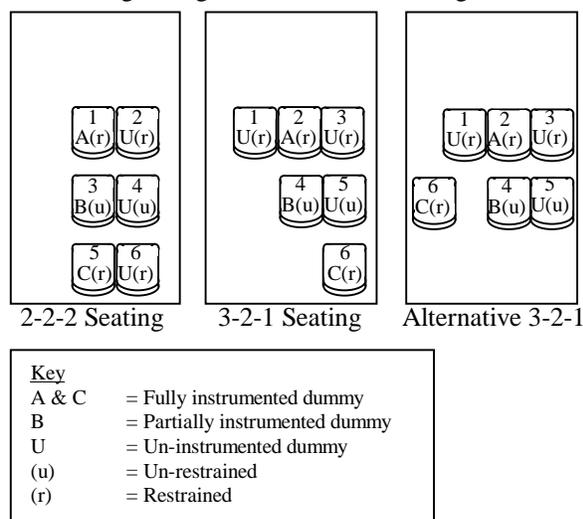
## TESTING OF CURRENT AND IMPROVED MINIBUS SHELLS

### Method

The front and back of the main longitudinal members of each of the minibus shells were attached to the test sled. These attachments were arranged to cause the minimum of interference (strengthening) to the floor structure of the vehicle.

These shells with six crash test dummies as passengers were then dynamically tested to the ECE Regulation 44 crash pulse.

In each of the sled tests performed, a total of six passenger seats were fitted into the minibus shell in two or three rows. The seat rows were made up of single, double and triple seat units. The exact seat arrangement depended on the seat plan of the minibus concerned. For the vehicles tested there were three basic seating configurations as shown in Figure 3.



**Figure 3. Plan view of the seating arrangements used in the sled tests**

In the tests dummies, with or without the seatbelts in use, occupied all the seats. As all of these vehicles had the seatbelt anchorages attached to the seats, these arrangements produce a combination of seat loading conditions that enabled the maximum information to be obtained from each test. These arrangements provided:

i) double loading, where the front seats were subjected to the loading of their restrained occupants and also the loading from un-restrained occupants behind.

ii) rear loading only, where the middle row of seats initially had un-restrained occupants and were later loaded by the knees and head of the restrained occupant behind. The seat plan of vehicle ALB<sub>s</sub> was such that the unrestrained seats had no rear loading (alternative 3-2-1 seating plan).

iii) single loading only, where the seat is only loaded by its restrained occupant. However, for all but vehicle ALB<sub>s</sub> with the alternative 3-2-1 seating plan, the restrained occupant also contacted the back of the seat in front, thereby reducing the loading on the seat and restraint to somewhat less than full single loading.

The instrumented dummies used for these tests are as follows: Dummies A and C (both restrained) were Hybrid III dummies with head and thorax triaxial accelerometers, chest compression potentiometers and neck and femur force transducers. Dummy B (un-restrained) was a Hybrid II dummy with head and thorax triaxial accelerometers, and femur force transducers.

## DESCRIPTION OF THE STANDARD MINIBUS SHELLS TESTED

All of the vehicles tested had the seatbelts attached to the seats.

### The line built or factory made minibus

The factory-produced minibus (vehicle ALB<sub>s</sub>) was unusual because the seatbelt anchorages had been designed to meet the more demanding strength requirements for a car (M1) rather than those of a minibus (M2 or M3). The anchorages were therefore at least twice as strong as the current minimum required for a minibus. The seating arrangement, with some seats removed, was in the Alternative 3-2-1 configuration, (see Figure 3). The seat, made by supplier  $\alpha$ , had legs that were integral to the seat and consisted of heavy steel tubes with substantial diagonal braces and large strong flat plate feet to which the lower seatbelt anchorages were attached. The large flat 'feet' were bolted to threaded anchorages in the floor pan. The floor pan was heavily reinforced with longitudinal and transverse under-floor box members. In addition the sides of the seat backs that were against the side wall of the vehicle, (numbers 3, 5, and 6), were also attached to the minibus side rail by means of short straps made from seatbelt webbing. The seatbelts had the reel attached to the foot of the seat, with a pivoted guide and upper mounting on an 'extender' on the side of each seat.

### The van conversion minibuses

**The first van conversion** tested (vehicle BVC<sub>s</sub> had seats made by supplier  $\beta$ . These seats were bolted in

place in a 2-2-2 pattern. The conversion consisted of a wooden floor placed on top of the steel floor of the van and the feet of the seats were bolted through both the wood and steel floors with square-load spreader plates underneath. Two pairs of legs were used for each double seat unit.

**The second van conversion** tested (vehicle CVC<sub>s</sub>) again had seats made by supplier β. However, the seats were attached to a low-cost tracking system in a 2-2-2 pattern. The conversion consisted of a wooden floor placed on top of the steel floor of the van and the tracking was attached to the floor with bolts through both the wood and steel floors with penny washers (washers with a large outside diameter) to spread the load underneath. In addition, wood-screws were used between the bolts to fix the tracking to the wooden floor. Two pairs of legs were used for each double seat unit.

**The third van conversion** tested (vehicle DVC<sub>s</sub>) had the seats made by manufacturer γ, fitted in a 3-2-1 pattern. The front triple seat unit had three pairs of legs, one pair at each end and one pair in the middle. Their front and back feet rested on a sub-frame with bolts through the foot, the sub-frame and the steel floor of the van. The sub-frame was made of rectangle steel tube and was fitted on top of the steel floor. Load-spreading washers were used beneath the floor. The sub-frame was only attached to the floor by the bolts of the seat feet, despite the frame extending some distance beyond the seats. Wooden in-fill was used between the sub-frame members to create a flat floor area. Behind the front row of seats a continuous sheet of wood was placed on top of the steel floor of the van. The middle seats and the rear seat had a combination of floor mounted legs, bolted through the wood and steel floor, and side mountings on to the vehicle side structure (two pairs of legs and a side mount for the middle double seat unit, one pair of legs and a side mount for the single rear seat). The front and rear seat legs were joined by a continuous “U” shaped foot.

**The fourth van conversion** tested (vehicle EVC<sub>s</sub>) had the seats, made by manufacturer δ, fitted in a 2-2-2 pattern. This conversion was intended to be especially robust and the van shell had been heavily reinforced with a full safety cage which was made from rectangular steel tube and included roll-over protection. Each double seat unit had one pair of floor-mounted legs, on the inboard end, with the feet bolted through a strip of high-strength steel on the floor. Each side of the strip had been seam welded to the floor. The outboard side of each double seat unit of seats was attached to the side rail of the reinforcement cage at the front and back of the seat.

## **The coach built minibuses**

**The first coach-built minibus** tested (vehicle FCB<sub>s</sub>) was made from a series of modules joined to make up the selected length. (This modular system enabled the manufacturer to tailor the length of the coach built section to fit both long and short chassis.) A wooden floor was mounted on top of multiple longitudinal members joined by crossbeams. This assembly was in turn attached to longitudinal members of the chassis. The seats, made by manufacturer β, were fitted in a 2-2-2 pattern and were bolted through both the wooden floor and the underlying longitudinal members. Two pairs of legs were used for each double seat unit.

**The second coach built minibus** tested (vehicle GCB<sub>s</sub>) was made up from a series of cross-members attached to two longitudinal members beneath, which in turn sat on the chassis rails of the chassis cab vehicle. The seats, made by manufacturer ε, were fitted in a 2-2-2 pattern. Each double seat unit had a pair of legs at each end with the feet attached to two lengths of tracking, which ran the full length of the shell, one for each end of the seats. The tracking assembly consisted of an aluminium extrusion on top of a steel “top-hat” shaped section. This assembly had been designed by the coach builder to transfer the seat loads directly to the top of the floor cross-members. In addition, the sides of the aluminium track were shaped to provide support and location for wooden floor sections used to in-fill between the tracks.

It was intended to test the “standard” minibus shells without any modification that would affect their occupant protection performance. However, for this minibus the method used to attach the cross-members to the longitudinal members appeared to be inadequate to withstand the test loads. These joints effectively hold the complete coach-built shell to the chassis of the chassis-cab or in this case to the test sled. TRL considered that there was a high risk of the entire coach built shell detaching during the dynamic test. Samples of these joints were made and dynamically tested. These tests confirmed that the joint was inadequate. A modification to the joint was devised which proved effective in similar component tests. Therefore, all the ten joints on the test shell were strengthened using the same method before it was tested.

## **RESULTS OF TESTS TO STANDARD MINIBUS SHELLS**

The results of the tests of the standard minibus shells are summarised in the first part of Table 1. These results show that all but one of the standard vehicles tested suffered serious failures of the front seats and/or the vehicle structure at the seat attachment points. This

is not surprising as the crash pulse and double loading for this seat row was more than twice as demanding as that currently required for M2 vehicles. The only standard vehicle not suffering serious failure was the line built minibus, which had been designed to exceed current regulations by a large margin. However, one aspect of the performance of this vehicle gave rise to concern about the construction of the seat back. The seat backs inside the metal frame were filled with only fabric, fibre padding and wire. This provided little resistance or load spreading when the knees of the unrestrained rear occupants struck the back of the front seats. The knees penetrated the seat back and tore the ribs from the spine of the dummy in the front seat (seat number 2). Although this dummy was not instrumented to record this type of injury, the mechanical parts are strong and this damage indicating that a significant concentrated force was applied to the dummy, indicating a risk of serious or fatal spine injury in a human. This emphasises the importance of wearing seatbelts in the rear of passenger vehicles, both to protect the rear seat occupant and the occupant immediately in front.

Many of the outputs from the instrumented dummies were within safe limits where the tests were meaningful. Test results were the seats failed completely, where there were no seats in front or where dummies were ejected are not reported. Consequently, only the HIC values from the rear “restrained” dummies are reported in Table 1.

## **IMPROVEMENTS OF MINIBUS SHELLS AND SEATS**

It was decided to improve and test three of the van conversions and one of the coach-built shells.

### **Method**

Modifications to improve the strength of the seat attachments and floor reinforcements were devised to overcome the deficiencies seen in the current vehicle tests. For the seat assemblies, dynamic tests, again to the ECE Regulation 44 crash pulse, were carried out with modified seats mounted to a solid floor fitted to the sled. A second double seat unit was positioned behind the modified seats so that two or four un-instrumented dummies could be used to produce either single or double loading in the seats under test. Further seat modifications were carried out in the light of the failures, until the results were considered satisfactory.

Mathematical simulations were run in order to determine the likely foot to floor forces of the improved seats. A combination of component tests, calculations and engineering judgement was used to

decide if and how a vehicle needed strengthening and, if so, how to improve it.

### **Modifications to the seats, seat legs and seat side mounts**

The standard versions of the four vehicles selected for improvement each had seats from a different manufacturer. TRL collaborated with these manufacturers to develop improved seats and carried out seat sled tests to determine their performance. The design target selected for these improved seats were:

- i) For the seat to be restrained to the floor under both double and single loading without excessive movement of the seat base.
- ii) A small movement of the seat back in single loading.
- iii) A small to medium movement of the seat back in double loading to help reduce the injuries of the unrestrained rear occupant.
- iv) A deformation mode for the seat back that was unlikely to result in it rupturing or separating leaving jagged stumps under more severe loading than the ECE Regulation 44 crash pulse.
- v) A system that prevented excessive penetration of seat back by the knees of unrestrained rear occupants.
- vi) Improved protection for the head impact of restrained occupants with the seat in front.

### **Results and discussion of sled tests of improved seats**

For three out of the four seat manufacturers who supplied the original seats for these vehicles ( $\gamma$ ,  $\delta$  and  $\epsilon$ ) an acceptable solution was found which met targets (i) to (iv) and some also achieved to some extent targets (v & vi).

Many modifications were made to the seats from the fourth manufacturer (manufacturer  $\beta$ ) and methods of producing controlled energy absorption through bending of the back and of controlling rear occupant knee penetration were found with this seat. However, ultimately the seat frame was found to be too weak for the required strengthening to be practical, so these seats were not used in the improved vehicle tests.

As can be seen from the results of tests to standard shells, there were a number of failures found with the seats and their attachments. The improvements developed for each seat were specific to each design. Nevertheless, certain generic problems and solutions emerged which are summarised below.

The front and rear legs were too close together creating high leg and feet to floor forces. Angling back the rear leg increased this distance and was more effective at resisting the combination of shear and moments caused by the inertia of the seat and occupant(s).

The front feet were too small to spread their loads directly into the floor. (Under-floor washers commonly used by converters are ineffective for compressive front foot loads). Larger feet, more feet or stronger floors are required.

Cantilevered feet were used by all manufacturers to provide room for the fixing bolts, but the feet bent and reinforcing gussets often split, foot attachment welds failed. The bolt heads were also found to pull through the feet. It was also noted that some failure modes of cantilevered feet were such that floor and bolt forces could be considerably magnified by a levering action. A combination of thicker metal in the bolt area and bigger and stronger gussets were used for the feet of the improved seats.

The clamp arrangements used to attach the legs to the seat base were weak points. This option gives converters the freedom to select the positions of pairs of legs across the width of the seat to match fitting requirements. As well as introducing a weak joint the practice of adjusting leg positions can reduce the installed strength of the system if the legs are too close together, leaving parts of the double or triple seat unit cantilevered. Heavy external clamps were found to be effective in holding the legs to the front and rear cross-members of the seat base with one design. An alternative solution found with a second seat manufacturer consisted of replacing the open section cross members at the front and rear seat base with box members and locally packing the interior of the cross members in the vicinity of the legs with well fitting (aluminium) blocks. These blocks were positioned so that the legs could be attached by bolting through the box and packing. A third solution found was to fit stronger box section seat base cross-members and to weld the legs permanently in place to them. Welding the legs to the seat base results in a loss of fitting flexibility, however, it has the advantage that it would fix leg positions to those tested by the seat manufacturer.

Current regulations, for anchorages attached to seats, place restrictions on deformation but this encourages rigid structures that are more likely to snap off when subjected to higher loads, leaving dangerous stumps. Designs that are initially rigid but then fail progressively on overload would be safer. This has been achieved with these experimental seats by using frame sections (tubes, etc.) for the seat backs that are stronger in tension than compression. This promoted

progressive buckling of the front compression parts on overload. Alternatively, seat back corner gussets, designed to buckle progressively on overload, were found to be effective.

Experimental seat backs, made from approximately 0.5 mm thick sheet steel attached by spot welds to the frame, were found to prevent excessive knee penetration from unrestrained and restrained rear occupants and were found to be effective in strengthening the joint between the seat back and seat base. Seat rows are normally so close in minibuses that knee and head contact with the seat in front is very likely for adults, even when restrained.

Heavy seat reinforcement was found in the seat back in the area likely to be hit by the head of rear restrained occupants. Solutions to this problem were not fully explored but it was found that reinforcement could be moved further forward and covered on both sides with padding. Alternatively, parts above the upper seatbelt anchorage could be designed to be lightweight and to bend on rear impact.

Details of the final seat modifications used for each vehicle are given in the following section.

### **Modifications to improve the van conversions**

**The first van conversion** selected for improvement, vehicle EVC<sub>s</sub>, fitted with the reinforcing safety cage, was considered to have sufficient strength in its original floor and side mountings to withstand the loads of improved seats, so a second, similar example was obtained. This was fitted with seats that had been improved by the seat manufacturer (manufacturer  $\delta$ ) based on the results in the TRL seat sled tests. The seats were again arranged in a 2-2-2 pattern. The improved vehicle is referred to as vehicle EVC<sub>M</sub>. The seats had heavier front and rear seat base cross-members to which a stronger outboard pair of legs and an improved side mounting had been welded instead of the original clamping system. The design of the seat back to seat base joint was revised to improve the transfer of the seat back bending moments to the front and rear seat legs. The rear foot of the improved pair of legs was reinforced to resist pull-through of the head of the bolt.

**The second improved van conversion** was considered to require strengthening of the seat mountings. Vehicle CVC<sub>s</sub>, a long wheel-base van shell, was essentially undamaged from its first test when the tracking failed. It was therefore improved and re-used. It was modified by TRL to make improved vehicle CVC<sub>M</sub>. The modifications made were to strengthen and provide additional seat mounting points on the shell. Originally the floor was supported by a combination of heavy and light cross-members. Firstly the light

cross-members were replaced by heavy ones. Then two strips of steel, running the length of the floor, were seam-welded on top of it. These strips were positioned to take the middle and outboard pairs of seat legs. Finally a heavy “U” shaped reinforcement was fabricated to fit inside an existing stiffening channel in the inner side panel of the van to provide an additional side mounting point. The standard version of this vehicle had been fitted with seats from manufacturer  $\beta$ . As it had been found impractical to strengthen these to the required standard, alternative seats were fitted to the improved shell. These seats were modified seats made by manufacturer  $\delta$  and were similar to those used in the improved van conversion vehicle  $EVC_M$  described above, but they also had:

- a thin sheet-steel back to prevent excessive knee penetration.
- the seat back reinforcement in the region of rear head impact, which was originally only covered by cloth, was moved 25mm forwards and covered at the back with a 25mm layer of dense energy absorbing foam and at the front with the original seat upholstery foam.
- a second pair of legs welded to the seat base close to the middle of the double seat unit, aligned with the floor reinforcing strip.

Each double seat unit was therefore retained by a total of two pairs of legs and a side mounting. The seats were again arranged in a 2-2-2 pattern.

**The third improved van conversion** (vehicle  $DVC_M$ ) was produced by the converters following discussions with TRL. The seats, again from manufacturer  $\gamma$ , were fitted in a 3-2-1 pattern as before with the front set of three mounted on a sub frame. However, the front triple-seat unit was now fitted with five pairs of legs and a side mounting instead of the original three pairs of legs. The sub-frame mounted on the floor for the front set of three seats had two additional fore/aft members to take the extra seat legs. The sub-frame also had additional fixings to the floor where it extended beyond the seats.

The vehicle mountings for the middle double-seat unit and the rear single seat were unchanged as they were considered satisfactory for the purposes of this test programme and had not suffered failures in the original tests.

Other modifications to the seat had been made in addition to the extra legs and side mount for the front set of three seats. The legs themselves were stronger with a more robust clamp arrangement to attach them to the seat base. The rear cantilevered feet were also modified with a triangular gusset arrangement

replacing the original “U” section. The original junction of the seat and seat-back had been reinforced by welding straps along the underside of the seat and up the back of the seat side members to reinforce the parts subjected to tension. Sled tests had shown that this had the effect of forcing the seat back corner gusset plates to buckle and absorb energy on overload rather than snapping-off, when tested in conjunction with strengthened legs. The seat backs were made from 0.5 mm sheet steel welded to the seat frame, to control penetration of the knees of rear occupants, and were faced with cloth covered hardboard.

### **Modifications to improve the coach-built shell**

The coach-built shell selected for improvement was vehicle  $GCB_s$ . In the original test the failures had all been with the seats and not the vehicle or tracking. However, mathematical simulation of improved seats predicted that a tensile load of about 60 kN on the rear leg, and a compressive load of about 50 kN on the front leg would be caused by double seat loading in the test. This was well in excess of the minimum strength that is typically required of this type of tracking when used with seats with M2 anchorages. Therefore, a tracking pull test was devised to assess the strength of the tracking. The track was mounted to a solid base and a static load, developed by a hydraulic ram attached through a cantilever, was applied to the “seat mounting plate” locked into the track. The first static tensile loading test resulted in failure of the bolts holding the tracking at a force of about 40 kN. A repeat test using higher grade bolts resulted in a catastrophic failure of the system, with the “seat mounting plate” bursting out of the tracking at a load just below 50 kN. It was concluded from these results that the strength of the original two track seat fixings would probably be inadequate. A coach-built shell was therefore obtained fitted with three lengths of tracking. The new shell, referred to here as Vehicle  $GCB_M$ , also had the improved joint, between the floor cross-members and the underlying longitudinal members, that was used in the tests to the standard shell. Additional floor support was provided in the modified shell in the vicinity of the rear wheels to bridge the gap left for the tyres. Two equally spaced cross-members were used, thus avoiding contact with the tyres.

The modified shell was again fitted with seats from manufacturer  $\epsilon$  in a 2-2-2 pattern. In addition to the extra middle pair of legs fitted to each double seat unit to accommodate the third length of tracking, other modifications had been made to the seats. The legs themselves were stronger and were attached to the cross-members of the seat base by both welding and bolting through the box member. The front and rear box cross-members of the seats were also packed with

an aluminium block at each leg position to further reinforce it and to prevent crushing due to the leg bolt. The original foot, which had linked the front and back legs, was replaced with a twin rear foot and a single front foot all reinforced with triangular gussets. The fore/aft seat-base members were reinforced with lengths of steel angle to help them withstand the bending moments from the seat back. The original junction of the seat base and seat back had also been reinforced by welding steel strips along the underside of the seat and up the back of the seat side members to reinforce the parts subjected to tension. Sled tests had again shown that this had the effect of forcing the seat-back corner gusset-plates to buckle and absorb energy on overload rather than snapping-off when tested with strengthened legs. The seat backs were again made from 0.5 mm sheet steel welded to the seat frame to control penetration of the knees of rear occupants. The top area of the seat back had been modified to improve rear occupant head protection. The box cross-members at the top of the seat back were replaced with an upper and lower steel strip designed to bend on head contact. The headrest fixing sockets were also attached to these strips.

## **RESULTS AND DISCUSSION OF TESTS TO IMPROVED MINIBUS SHELLS**

The results of the tests to the improved minibus shells are summarised in the second half of Table 1. Out of the four modified vehicles tested two had no failures of the seats, the seat to vehicle attachments or the seatbelts. One, vehicle EVC<sub>M</sub>, the first of the improved van conversions tested, suffered a seat failure due to a poor quality weld. On this vehicle the double loaded front seat double unit suffered a partial failure when the foot of the inboard rear leg pulled-off at the start of the impact. Examination of the foot welds showed that they had very poor penetration. Despite this failure the seat was still retained by the remaining front leg and side mounting. Seats to the same design had shown no distress when subjected to double loading in the seat development sled tests. The floor and side mountings of this vehicle were also considered adequate, so it was concluded that the seat in the full vehicle test would not have failed had the welds been of good quality.

The second improved van conversion tested, vehicle CVC<sub>M</sub>, the long wheel-base van shell, suffered a failure of both the seatbelts on the rear double seat unit. The mounting of the seatbelt reel was such that belt forces caused the belt mounting to distort and bend the “U” shaped seatbelt reel frame causing it to spring open and allow the reels to pull out. This failure was due to a combination of poor reel and mounting design. This problem had not been identified in the seat development tests because the seat manufacturer had

made subsequent modifications to the reel mounting. However, it was concluded that minor changes to the design of the reel, the reel mounting on the seat or to both would eliminate this problem. It may seem surprising that the reels of the front double-loaded seats did not fail as double loading in cars normally increases seatbelt loads. However, when the upper anchorage is attached to the seat back, as in this case, double loading will reduce seatbelt forces as the seat back and anchorage is pushed forwards. The high-speed film of this test showed that the seatbelts of the rear double-seat unit offered some restraint in the initial stage of the impact before failing. The HIC<sub>36</sub> of the rear seat “restrained” dummy on impact with the back of the middle seat row was 1102. These seats had been modified to improve the rear head impact area. The top of the seat back had deformed as intended, therefore, the HIC<sub>36</sub> would probably have been below 1000 had the seatbelts not failed. Apart from this, it was not possible to compare the effects of improving rear head contact with the standard vehicle because of its tracking and seat failures. However, the improved design appeared to be a practical and effective solution.

The improved seat back head impact area for the improved coach-built minibus appeared to be effective with the HIC<sub>36</sub> falling from 1298 to 761. However, again it is difficult to compare with the standard results where the rear and middle seats both moved.

No significant movement of the seats or seat backs was seen in the middle or rear seat rows in any of the tests to the modified vehicles. The front seats of all the modified vehicles were seen to bend forward when impacted by the unrestrained dummies behind. However, the seat back movement was controlled, absorbed energy, and restrained or partially restrained the rear occupants.

The fitting of thin sheet metal backs appeared to be effective in preventing excessive knee penetration. The femur forces of the restrained and unrestrained dummies were also low with this design of seat back. It was not possible in these tests to determine the injury risk to the front occupant from knee penetration.

It was concluded, in the seat development tests, that seat backs, that bent forwards and absorbed energy when overloaded, were beneficial (in the case of double loaded seats). If this is accepted then it can be concluded from the results of the tests to the standard line-built vehicle and the modified vehicles that it is possible to make minibuses, seats and seatbelt systems capable of withstanding a ECE Regulation 44 crash pulse. This conclusion applies to the three manufacturing methods (line-built, van conversion or coach-built) and all combinations of occupant loading. As the methods used to improve the seats and vehicles

were comparatively inexpensive and used conventional technologies, it was also considered reasonable to require minibuses to meet the test conditions used here.

The methods used in this project to improve the seats and vehicles have been shown to be effective and should be of help in designing improved systems.

### **IMPLICATIONS FOR IMPROVED REGULATIONS**

The analysis of fatal minibus accident data when combined with full-scale crash data indicates that the current requirements for minibus seatbelt anchorages are insufficient to provide protection in some of the more severe accidents. Vehicles with seat and seatbelt systems that can withstand ECE Regulation 44 loading would provide protection for more than 50% of serious minibus accidents, taking into account the bias towards serious accidents in the fatal accident database. Improved regulations based on the loading caused by a Regulation 44 crash pulse would require anchorages of approximately twice the strength currently required for M2 vehicles. As it has been shown that it is necessary and practical to provide improved seatbelt systems it is recommended that seatbelt anchorage regulations for these vehicles be revised to require a higher standard.

Improved standards for seatbelt systems should take into account many factors, including:

- i) the direction and magnitude of forces within the seat and vehicle mountings.
- ii) the need to confirm that there are no weak links in the load path from seatbelt anchorages to vehicle structure.

Two options are proposed below that would improve minibus safety. A third possible option could be based on the method used in Australia for coaches, however, this method has some disadvantages which are also discussed below.

#### **Adaptation of current seatbelt anchorage requirements for minibuses**

The analysis of minibus accident data and the full-scale minibus crash test have shown that minibus seatbelt anchorages should ideally be able to withstand the forces generated by the ECE Regulation 44 crash pulse. It can be calculated that for single loading this is approximately equal to the ECE Regulation 14 seatbelt anchorage requirement for M1 vehicles (Economic Commission for Europe, 1994). However, currently the anchorage strength requirements for M2 and M3 vehicles (minibuses) are half and one third respectively of that required for M1 vehicles. An improved seatbelt regulation for M2 and M3 vehicles could simply be to require them to withstand the same anchorage strength

requirements as M1 vehicles. The fact that the factory-produced minibus, with anchorages to M1 requirements (vehicle ALB<sub>s</sub>), performed well in the sled tests supports this argument. It could be argued that M1 anchorage requirements would be over demanding for M3 vehicles which, due to their high mass, are less likely to suffer high accelerations when impacting other vehicles. However, it was found practical to improve the larger coach-built shells to meet the Regulation 44 loading. A further possible criticism of the ECE Regulation 14 anchorage pull tests is that it is quasi-static and produces longer duration anchorage loading than those in a crash. However, this will only have the effect of introducing a small additional factor of safety. As the pull test is far simpler, easier to interpret and less expensive than a dynamic test it has many advantages.

Therefore, requiring minibuses to meet the M1 anchorage standard may well be sufficient to ensure improved anchorage strength.

#### **Sled tests of the complete shell using the ECE Regulation 44 crash pulse**

A sled test of complete shells or representative sub-systems could be used evaluate seatbelt anchorage strength. The Regulation 44 crash pulse could be used or, if considered necessary, a crash pulse could be derived by carrying out a programme of crash tests of representative minibus models. Sled tests would have the advantage of producing more realistic dynamic loading of the complete system and could provide information on knee and rear head-impact protection. However, a large capacity sled would be required to take a full minibus shell fully equipped with seats and occupant dummies.

#### **The Australian coach floor/seat regulation**

The essence of the Australian ADR68 (Federal Office of Road Safety, 1994) is that the performance of three rows of double seats, with restrained dummies in the middle row and unrestrained dummies in the rear row, is first assessed on a sled. The seats are mounted on a sled and subjected to a 20 g deceleration pulse. The test assesses the performance of the seats with regard to withstanding double loading and protecting the heads of the restrained dummies if they contact the seat in front. In addition to this, by mounting the double-loaded seat to the sled by a separate force frame, the foot to floor forces and moments for the seats under assessment are found. Also the seat mounting points, in the floor of the coach that the seats are intended for, are subjected to similar forces and moments to those found in the sled tests.

This method would have some advantages for minibus manufacturers. It would probably help to share test

costs with the seat manufacturers and alternative seats could be fitted to one floor design if they generated a force no larger than that with which the floor was tested and had similar foot fixing geometry. However, it was clear from the modes of failure seen in the testing of standard minibuses, and the component tests of seat and tracking, that local distortions of the seat and floor will normally occur when seats are tested fitted in a minibus. These could result in significant additional stress concentrations in the seat and floor that could precipitate failures that would not have been observed when the seats and floor were tested separately. This is because:

- For the sled test the seat must be attached to a rigid frame to measure accurately the force transfer and it would not be practical to mimic any deformation of the real vehicle floor in the test procedure. Fixing the seat to a rigid floor would effectively strengthen the seat, particularly the feet.
- For the floor, it would be difficult first to establish and then mimic on the floor, the distortions and/or partial failures seen in seats tested on a flexible floor.
- Overall, floor and seat distortion would reduce seat and floor stress by allowing some movement, which would reduce peak acceleration. However, local floor distortion could increase the local stresses in seat joints such as those between the seat feet and the seat leg. This could precipitate failures in the feet gussets, which in turn could increase local floor stress. Failure modes of feet side gussets were observed in seat tests, which increased local floor stress by acting as a lever.

Although this test method has virtues, separate testing of the floor and seats also has the above disadvantages, however, these disadvantages are comparatively insignificant.

#### **Other considerations for an improved minibus seatbelt anchorage test**

Other considerations for an improved regulatory test should include the following:

- i) the small-scale of production of minibuses, seats and seatbelts when compared with car manufacture.
- ii) the methods used to manufacture minibuses.
- iii) the tailoring of each vehicle to match the customer requirements for seat location plan, seat quality and seat to floor fixing options (direct bolting to the floor or via tracking).

Some flexibility in the requirement for testing of all seating options is recommended. This could be

achieved if the approval authority is allowed to use engineering judgement to only test the worst cases. Worst-case testing could, for instance, allow families of seat plans and seats types, for a particular vehicle model, to be approved with one or two tests for a particular manufacturer or converter.

**A further cause for concern** was the failures or potential failures seen in the test programme. The failure of the poor quality foot-to-leg weld highlighted a similar problem also found during the seat development tests where welds of standard components were also found to be faulty due to poor weld penetration. Weld quality is difficult to control for the small-scale simplified seat construction methods used by minibus seat manufacturers. However, methods should be devised to ensure the consistent quality of critical welded joints.

The failure of the seatbelt reels in the test to the improved van conversion, vehicle CVC<sub>M</sub>, could have been prevented by improvements to the reel frame or to the reel mounting on the seat. The seatbelts used for minibus seats are normally seatbelt reels for cars, adapted by fitting different lengths of webbing. The limited buying power of minibus seat manufacturers may make it difficult for them to require improvements such as riveted bars to close the open end of the “U” frame. Therefore, improvements to the mounting are the most practical option. In the test to improved vehicle CVC<sub>M</sub> it was only obvious after failure had occurred that the design of the reel mounting could cause the reel to fail. However, once alerted, a test authority would be able to reject this type of design by visual inspection. Due to the compact nature of minibus seating, many seat manufacturers make use of unusual belt routing and additional guides and brackets. These can suffer local distortions, which can affect the performance of the whole seatbelt system. In a sled test for approval of the whole minibus the standard belts and reels would be tested on the standard seat. For seat-anchorage pull tests heavier webbing is often used attached directly to the reel anchorage point. This method will not detect the effect of minor local distortions of the anchorage on the seatbelt reel assembly. Therefore it recommended that for pull tests on minibuses with seat mounted anchorages the actual belt installation that will finally be used should be tested with the reel lock activated.

#### **FURTHER ASPECTS THAT COULD BE CONSIDERED BY MINIBUS CONSTRUCTORS**

As already concluded, it would be beneficial to have seat backs that:

- i) bent forward and absorbed energy rather than breaking off when subjected to overloading from

impacts of unrestrained occupants or in more severe accidents.

- ii) protected the seat occupant when the seat back is impacted by the knees of restrained and unrestrained occupants behind.
- iii) protected the head of restrained and unrestrained occupants when they make contact with the back of the seat in front.

The seat back overload behaviour could be found by a pull test using an adaptation of the M1 anchorage test equipment. The following features would be beneficial.

- i) The seat back should not deform significantly under the normal M1 loads.
- ii) Once the seat back starts to deform, it should have a reasonably high and constant stiffness so that it absorbs energy.
- iii) The seat back should not fail catastrophically.
- iv) The initial load at which bending starts should be set to limit the seatbelt force on the occupant or to limit the force on an unrestrained occupant behind.

Regulations on compulsory wearing of seatbelts would obviously have implications for the need to consider seat back overload. Compulsory wearing of seatbelts is already required in the UK, for all occupants of minibuses with an un-laden weight of less than 2540 kg. For these vehicles an overload test may be thought unnecessary if high wearing rates can be achieved. However, seat-mounted-anchorage are used almost exclusively in minibuses and it is difficult with these to provide upper anchorage strengths much in excess of the M1 requirement. Therefore, improved minibus upper anchorages will probably have less overload capacity than normally found in cars, where it is easier to provide strength in excess of the minimum requirements because the upper anchorages are normally part of the car structure. Consequently, for minibuses, even if compulsory seatbelt wearing is required, an energy absorbing seat back would provide additional protection in more serious accidents.

The concerns about seat-back behaviour when impacted by the head and knees of passengers sitting behind could be addressed by additional sub-systems tests to the seat back. The area of the seat back likely to be struck by the head could be tested using an adaptation of the European Enhanced Vehicle-safety Committee WG17 pedestrian headform tests (EEVC Committee, 1998). Appropriate adult and possibly child head zones, impact velocity and trajectory could be found from mathematical simulations or full-scale tests and the pass criterion of  $HIC_{36}$  1000 could be

used. Similarly a knee impactor could be developed to test for rear knee impact. The protection criteria could be aimed at reducing seat penetration to protect the seat occupants from injury or to protect both the occupant and the impacting knee from injury.

Alternatively, sled based tests could be used to explore the impact with the seat back. A combination of restrained and unrestrained test dummies could to some extent be used to explore seat-back overload performance due to double loading. However, dummies of different statures would be required to fully explore the head impact area with the seat back. Alternatively, seat-back safety could be explored by a combination of sled test and sub-system tests.

## CONCLUSIONS

- 1) Accident data have been used to identify the most common types of minibus accidents. These have also been used to establish the relationship between the proportion of serious and fatal accidents and the velocity change seen by the minibus. This relationship has been used to determine an appropriate velocity change for sled tests of minibus seatbelt systems, if the more serious accidents are to be catered for.
- 2) Suitable data from a full scale minibus crash test have been located and used in conjunction with the accident data to define an acceleration pulse for sled tests of minibus seatbelt systems.
- 3) The ECE Regulation 44 frontal "crash pulse corridor" was selected for sled testing of minibus shells, seats and occupant restraints because it matched the velocity and acceleration pulse selected and provided suitable simplification and tolerances for this type of test.
- 4) The test conditions selected here, from accident data, are at least twice as demanding as the current anchorage strength requirements for minibuses.
- 5) The standard minibus shells (made to current standards) suffered serious failures of the front double-loaded seats and/or the vehicle structure at the seat attachment points when subjected to the ECE Regulation 44 crash pulse. Some also suffered failures of the less heavily loaded seats.
- 6) Methods used to improve minibus seats and vehicle structure have been described.
- 7) The tests of the improved minibuses and the "line-built" minibus designed to exceed current standards showed that it was possible to make vehicles, seats and seatbelts systems to withstand the test conditions used here. Because the methods used to improve the seats and vehicles were comparatively

inexpensive and used conventional technologies, it was also considered reasonable to require minibuses to meet higher standards in future. Therefore it is recommended that seatbelt anchorage regulations for these vehicles be revised to require a higher standard, possibly in line with existing M1 'car' standards.

- 8) The implications of these results for improved design standards for minibus seats and seatbelt anchorages have been discussed and possible improvements to approval methods have been outlined.

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**Table 1. Summary of results of sled tests to standard and modified minibus shells**

Vehicle code	Seat code & fitting plan	Rear seats (single loaded)				Middle seats (no occupant loading)			Front seats (double loaded)		
		Floor failure?	Seat failure?	Seat detached?	HIC <sub>36</sub>	Floor failure?	Seat failure?	Seat detached?	Floor failure?	Seat failure?	Seat detached?
<b>Standard minibus shells</b>											
ALB <sub>S</sub> line built	α Alt. 3-2-1 #	No	No	No	453	No	No	No	No but distorted	Yes back penetrated by knees from behind	No
BVC <sub>S</sub> van conversion	β2-2-2 (2L) (2L) (2L)	No but distorted	No but backs bent	No	843	No but slight distortion	No but backs bent forward	No	Yes front feet and legs went through	No	No but seats tipped forwards a long way
CVC <sub>S</sub> van conversion	β2-2-2 (2LT) (2LT) (2LT)	Yes rear part of tracking ripped off floor	No	No but tipped and moved forwards a long way	N/A	Yes rear seat feet ripped out of track	No	No but seats tipped forwards a long way	Yes front and back feet ripped out of track	No	Yes completely detached at beginning of impact
DVC <sub>S</sub> van conversion	γ3-2-1 (3L) (2L+S) (1L+S)	No	No but back bent forwards	No	1133	No	No	No	No	Yes rear feet pulled off bolt heads	No but seats tipped forwards a long way
EVC <sub>S</sub> van conversion	δ2-2-2 (1L+S) (1L+S) (1L+S)	No	Yes rear side mounting pulled off seat base	No but seat tipped forward late due to side mount failure	730	No	No	No	No	Yes rear foot pulled off bolt & rear seat side mount pulled off	Yes seat tipped forwards then front foot and side mount failed
FCB <sub>S</sub> Coach built	β2-2-2 (2LT) (2LT) (2LT)	Partial light distortion front & moderate at rear	No	No but floor caused moderate seat tipping forward	1356	Partial moderate distortion front feet & light at rear	No	No but floor caused some seat tipping forward	Partial heavy distortion front & moderate at rear	Yes rear leg to seat base joint failed	No but seats tipped forwards a long way
GCB <sub>S</sub> Coach built	ε2-2-2 (2LT) (2LT) (2LT)	No	Partial failure at rear leg to seat base & rear feet bent	No but tipped and moved forwards a long way	1298	No	No	No	No feet tore off track fixing plate	Yes outer legs pulled off track, inner legs pulled off seat base	Yes seat tipped forwards then front legs failed
<b>Modified minibus shells</b>											
CVC <sub>M</sub> van conversion	δ2-2-2 (2L+S) (2L+S) (2L+S)	No	Yes bent seatbelt mounting caused reels to fail	No	1102 (improved back)*	No	No	No	No	No	No
DVC <sub>M</sub> van conversion	γ3-2-1 (5L) (2L+S) (1L+S)	No	No	No	2099*	No	No	No	No	No	No
EVC <sub>M</sub> van conversion	δ2-2-2 (1L+S) (1L+S) (1L+S)	No	No	No	1506*	No	No	No	No	Yes rear foot pulled off due to poor weld	No remaining attachments retained seat relatively well
GCB <sub>M</sub> Coach built	ε2-2-2 (3LT) (3LT) (3LT)	No	No	No	761* (improved back)	No	No	No	No	No	No

Notes: (S) = Seat with side mounting on one end. (T) = Seats attached to floor by tracking. (nL) = Seat with pair/s of legs attached to the seat base, “n” indicates number of pairs of legs per seat row. Leg type “n L” consisted of one front and one rear leg per pair, some with and some without diagonal braces etc.

# These seats had legs that were integral with the seat construction, all had large feet plates and multiple diagonal braces. The triple seat unit had four front and four rear legs. The rear double seat unit had three front legs and two rear legs with one rear side mounting and the single rear seat had two front legs, one rear leg and one rear side mounting.

\* Modified results cannot be compared with the standard results where the rear and middle seats both moved.