A LOW-COST METHOD OF EVALUATING SEATBELT ANCHORAGES FOR LOW-VOLUME VEHICLES (M1, M2 AND M3) – FINAL REPORT

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Executive summary

The public’s attitude towards seatbelts and other vehicle safety systems has become more positive as the savings from compulsory seatbelt wearing in cars have become obvious, however, it is still a challenge to get some age groups to wear appropriate restraints. Because of both this and recent changes in safety legislation many large passenger-carrying road vehicles such as minibuses, buses and coaches are now fitted with seatbelts.

Manufacturers of minibuses, coaches and other vehicles produced in small numbers have been required to comply with the regulatory strength requirements for seatbelt anchorages for many years. However, the regulatory tests are very expensive for vehicles produced in small numbers because the costs are not spread over a large number of vehicles. Indeed, in some cases, vehicles like minibuses and coaches have tailor-made seating arrangements, so for every vehicle on the road one vehicle shell would have had been destroyed in testing if the regulations were strictly applied. Because of these problems, manufacturers of low-volume vehicles in the UK have not necessarily been required to prove by testing that their anchorages meet the strength requirements.

The methods used to show that untested anchorages would probably meet the strength standard have become increasingly demanding. Recently, changes have been made to the UK Construction and Use Regulations which require any seatbelt anchorage used in buses, coaches or minibuses first registered since October 2001 to meet the technical requirements of the EU anchorage Directive 2003/20/EC. This has lead to changes in the UK procedure for obtaining a Certificate Of Initial Fitness (COIF) for Public Service Vehicles (PSVs). Manufacturers of PSVs are now required to satisfy the Certifying Officer as far as possible that all of the anchorages on new vehicles meet the strength requirements. To do this a sample of each new type or model of low-volume vehicle must be subjected to the regulatory destructive test to gain anchorage approval. However, because of the low number of severe accidents that occur with these types of vehicle and a lack of evidence from accidents that untested anchorages have a high failure rate, there is a reluctance to force low-volume manufacturers to carry out these expensive tests. Therefore, as an interim measure, simple low-cost approval methods have been introduced for some types of vehicles produced in low volumes. These measures require pragmatic simplified design rules to be followed, often resulting in a high factor of safety; however, they have a number of limitations. Because of this the UK Department for Transport has contracted TRL Limited to develop effective low-cost approval methods for seatbelt anchorages in vehicles produced in low volumes. This report describes and discusses the findings of the study.

The conclusions from this work were:

Vehicles produced in low volumes are predominantly minibuses, buses or coaches. Analysis of GB accident data has shown that there are few casualties found within this low-volume vehicle group. This supports the use of low-cost approval methods for these vehicles. The GB data also showed that for injured bus or coach passengers more than half were seated and so might have benefited from wearing seatbelts.

Information has been obtained from various sources on the construction methods used to make large passenger-carrying vehicles in low volumes. Although there were only two main construction methods being used to make large passenger carrying vehicles in low volumes, significant differences were found between vehicles of different sizes, vehicles made for different purposes and vehicles made by different scales of production.

Information has been obtained on some of the current approval methods used for seatbelt anchorages in vehicles made in low volumes and TRL has also proposed further methods, including an improved design rule method. The advantages and disadvantages of and options to improve existing and new test methods have been discussed.

It was concluded that a number of different low-cost approval options were needed to reflect the range of vehicles and design solutions found. However this conflicts with the need for a simple, easy to administer, low-cost approval method. In order to achieve the best compromise between these two requirements TRL suggests that the options be discussed with all the stakeholders before the approval methods are finalised.
Proposals have been produced for a multi-path low-cost approval route method that could be used to obtain a high level of confidence that seatbelt anchorages meet regulatory strength requirements. These have been used to produce proposed low-cost multi-path approval methods for each of the main types of vehicles produced in small numbers:

- Minibuses and taxis made by converting delivery vans
- Coach-built vehicles with low floors (buses and low-floor coaches)
- Coach-built vehicles with ‘high floors’
- Special cars, kit cars, etc.

The proposals for a multi-path low-cost approval method are intended to be suitable for incorporation in some form of approval procedure. Although this study has gone some of the way towards developing the proposals into a form suitable for use in an approval procedure, further work will be required to produce a complete solution.

It was decided to carry out a limited programme of validation of two of the proposed approval methods. The first was the use of structural over-floor reinforcement conversion kits for use in delivery vans similar to, but not identical, to that in which it had been tested. The second was a TRL adaptation of the VOSA visual inspection rules (design rules) for coach-built vehicles to allow savings in weight through the use of high strength materials and beams with their cross-sections (shape) selected to give a high strength to weight ratio.

The validation tests to a delivery van, fitted with tracking intended to meet the M2 seatbelt anchorage strength requirements, showed that it met all pull test requirements for an M2 vehicle. The seats selected for the more demanding M1 test also passed, indicating that the tracking and floor assembly had a large safety margin. It was therefore concluded that in this case the tests showed that the method of approving a large family of similar vans, by testing just the two vans in the family that were thought to be the weakest, worked well.

The validation tests of the light-weight M2 coach-built floor, designed to a less conservative version of the TRL enhanced coach-built design rules than would ultimately be recommended, showed that it passed all of the M2 pull test requirements. However, when it was subjected to the more demanding M1 tests it failed before it met the required load. It can therefore be concluded that it has a small margin of safety. It also showed that applying the TRL design principles produced a satisfactory design at relatively low cost. The savings of such lightweight structures could be considerable in reduced fuel consumption and a reduced risk of accidents from improved stability, by reducing mass and the height of the centre of gravity. However, care is needed in proposing suitable section moduli and in developing rules to prevent buckling and tearing failures.

Data on the design of delivery van floors have been obtained from several manufacturers and have been summarised. These could be used to design a generic van floor and side-wall module which approximately represents any delivery van and which could be used in sub-systems seat tests.

A number of observations have been made that might help to improve large passenger vehicles produced in low volumes. It has been concluded that having anchorages that meet the strength requirements does not guarantee integrity of the complete vehicle in an accident. Although an integrity test is outside the scope of the current study, it is considered so important that TRL recommends that, at the very least, designers of vehicles with ‘high floors’ (coaches) should be required to calculate the forces on the floor structure and show that the suitability of members carrying these forces to the chassis have been considered. For mechanical attachments with implications for safety, such as the attachment of seat tracking to the underlying floor structure, TRL recommends that appropriate bolts (size and grade) and washers (size and thickness) be used along with the normal engineering practice of requiring a minimum thread engagement equal to about one bolt diameter. Obviously, approval tests are of less use if some of the seats actually fitted to vehicles on the road have sub-standard welds or other defects at critical locations. TRL recommends that conformity of production procedures be added for all seats with integral anchorages intended for use in vehicles produced in low-volumes, for both regulatory and low-cost anchorage approval (it has been assumed that large volume car manufacturers already insist on this).
Abstract

The public’s attitude towards seatbelts and other vehicle safety systems has become more positive as the savings from compulsory seatbelt wearing in cars have become obvious. Recent changes in safety legislation now require many large passenger-carrying road vehicles such as minibuses, buses and coaches to be fitted with seatbelts. Changes have also been made to the UK Construction and Use Regulations to require that a sample of each new type or model of low-volume vehicle be subjected to the regulatory destructive test to gain anchorage approval. However, because there is currently no evidence that untested anchorages have a high failure rate, as an interim measure, simple low-cost approval methods have been introduced for some types of vehicle produced in low volumes. These measures are pragmatic simplified rules often resulting in a high factor of safety; however, they have a number of limitations. Because of this the UK Department for Transport has contracted TRL Limited to develop effective low-cost approval methods for seatbelt anchorages in vehicles produced in low volumes. This report describes the investigation into alternative approval methods for the different types of vehicles.

1 Introduction

Until the late 1990’s it was unusual for seatbelts to be fitted in large passenger-carrying road vehicles such as minibuses, buses and coaches. However, more recently there has been increasing public awareness of the benefits of seatbelts as the savings from compulsory wearing in cars have become obvious; however, it is still a challenge to get some age groups to wear appropriate restraints. Because of this, the public’s attitude towards seatbelts and other vehicle safety systems has become more positive. As a result of this and Government targets to reduce road casualties, there is an ongoing process improving vehicle safety and introducing more demanding safety legislation.

Manufacturers of minibuses, coaches and other vehicles produced in small numbers have been required to comply with the regulatory strength requirements for seatbelt anchorages for many years. However, the regulatory tests are very expensive for vehicles produced in small numbers because they involve the destruction of at least one full vehicle shell. For mass production these costs can be spread over a large number of vehicles and are not onerous. Because minibuses and coaches are normally produced in small numbers the costs of any testing would have to be carried over very few vehicles. Indeed, in some cases, vehicles like minibuses and coaches have tailor-made seating arrangements, so for every vehicle on the road one vehicle shell would have had been destroyed in testing if the regulations were strictly applied. Because of these problems, manufacturers of low-volume vehicles in the UK have not necessarily been required to prove by testing that their anchorages meet the strength requirements.

The methods used to show that untested anchorages would probably meet the strength standard have become increasingly demanding. Recently, changes have been made to the UK Construction and Use Regulations which require any seatbelt anchorage used in buses, coaches or minibuses first registered since October 2001 to meet the technical requirements of the EU anchorage Directive 2003/20/EC. This has lead to changes in the UK procedure for obtaining a certificate of initial fitness for Public Service Vehicles (PSVs). Manufacturers of PSVs are now required to satisfy the Certifying Officer as far as possible that all of the anchorages on new vehicles meet the strength requirements. The seatbelt anchorages in vehicles manufactured for private use will be examined in their annual tests and documentation to prove their strength could be required. These changes to the procedure for obtaining a certificate of initial fitness imply that in future all vehicles produced in small numbers will have to be subjected to destructive testing as it is difficult, if not impossible, to predict accurately anchorage strength through calculation unless the structure is very simple. However, because of the low number of severe accidents that occur with these types of vehicle and a lack of evidence from accidents that untested anchorages have a high failure rate, there is a reluctance to force low-volume manufacturers to carry out these expensive tests. In response to this, the UK Vehicle and Operator Services Agency (Vehicle Inspectorate, undated). These design

1 Vehicle Inspectorate (VI) is now part of VOSA
rules are such that an inspector can confirm that a vehicle complies by using a combination of visual inspection (during construction) and manufacturer’s design and materials information. The VOSA design rules are pragmatic, simplified rules often resulting in a high factor of safety; however, they have a number of limitations. Because of this the UK Department for Transport has contracted TRL Limited to develop effective low-cost approval methods for seatbelt anchorages in vehicles produced in low volumes. This report describes the TRL study.

2 Method

Before work could be started on developing an approval method it was necessary to obtain an understanding of the current position. Information was required for low-volume vehicles regarding accidents, manufacturing methods (materials and designs) and methods used to assess seatbelt anchorage strength. UN ECE Regulation 14 (Economic Commission for Europe, 1994) and the equivalent EU directive (76/115/EEC as amended) specify different minimum anchorage strengths for different classifications of vehicle amongst other things, so information on these different vehicle groups was required. The vehicle classifications used in European legislation are as follows:

- M for carriage of passengers, 4+ wheels or (3 wheels and > 1 tonne)
- M1 <= 8 seats + driver (typically cars)
- M2 >8 seats + driver, <= 5 tonnes (typically minibuses)
- M3 >8 seats + driver, > 5 tonnes (typically buses or coaches)

National GB accident data are available from accident statistics gathered by the Police when they are called to or advised of an injury accident. This data is stored in a computerised database called STATS 19 making it easy to obtain statistics for specific vehicles and types of accident. The database contains fairly comprehensive information about each accident although vehicle impact speed is not included and occupant injuries are only described as slight, serious or fatal. However, this database has the advantage of being far larger than any other more detailed source. Therefore it was decided to analyse STATS 19 accident data for minibuses, buses and coaches. However, it should be noted that to make it easier for the Police to classify vehicles a different method is used in STATS 19 to that used in Regulation 14. The STATS 19 vehicle classifications are based on the following:

- Construction (what does it look like?)
- ≥8 passenger seats is a minibus
- ≥17 passenger seats is a bus or coach

These different classifications mean that accident statistics for vehicle types derived from STATS 19 data will not be precisely aligned with the European definitions, but overall the differences are thought to be small.

Manufacturers of low-volume vehicles have been required to meet specified seatbelt anchorage strengths for many years but have not necessarily been required to test the anchorages. Therefore, it was thought that both they and the approval authorities would have evolved informal systems to assess their anchorage designs. Obviously manufacturers would also be able to provide data on the manufacturing methods and materials used to make the vehicles. Therefore the STATS 19 data were used in conjunction with trade magazines to select appropriate bus, coach and minibus manufacturers, and the manufacturers of the most popular vans used for conversion into minibuses. Exploratory visits were then made to those manufacturers willing to co-operate, and letters requesting constructional information were sent to manufacturers of delivery vans popular for conversion.

Having gathered the necessary information, TRL then reviewed it and drew a series of conclusions. It is clear from this that the methods of construction and the engineering systems used to achieve suitable anchorage strength are very different depending on the type and size of vehicle concerned. Also, within each vehicle there are often some small areas which require different engineering
solutions to the main body of the vehicle. Therefore it would be advantageous to have more than one low-cost method, so that vehicle manufacturers and converters can choose the most appropriate solutions for each vehicle and seating area.

The data gathered in this first stage were then used to develop a number of suitable methods that could be used for low-cost approval of seatbelt anchorages. TRL then devised a way that the new and existing methods could be brought together into an overall multiple-route low-cost approval method. Promising existing methods were examined for weaknesses and where possible methods of overcoming these weaknesses are proposed. As already noted, some vehicles have different design solutions within them, where for instance the main seating area could have a standardised design, a raised floor area over the transmission another design and a rear bench seat over the engine a third design. Because of this it is proposed that a multiple approval route should be considered where large areas are subjected to more stringent testing (which could approve lightweight designs for example) and less stringent, but more conservative methods could be used for smaller areas.

Two representative sample vehicle sections were made, with seats and seatbelt anchorages that complied with the proposed low-cost approval methods. The seatbelt anchorages in these samples were then subjected to the regulatory pull test to determine whether they indeed meet the strength requirements. They were also subjected to an overload test to determine their factor of safety.

3 Analysis and discussion of STATS 19 results

STATS 19 is a comprehensive source of accident information including all injury accidents reported to the Police. From the database it was possible to determine the number of slight, serious and fatal casualties for each category of road user. The results of this analysis are shown in Table 3-1. A three year sample of the latest data was selected as it was thought that it would provide sufficient accidents to produce statistically significant results. Also, it was not possible to distinguish between certain vehicle types prior to 1999.

It can be seen from Table 3-1 that car users (drivers and passengers) are the single largest casualty group followed by pedestrians and then motorcyclists. It can be seen that casualties for users of minibuses, buses or coaches are a relatively small proportion of all road user casualties. They form only about 1 percent of all fatalities, 2 percent of all seriously injured casualties and 4 percent of all casualties with slight injuries. Vehicles that are produced in low volumes are predominantly minibuses, buses or coaches. The low number of casualties found within this group of vehicles and the high cost of carrying out regulatory anchorage strength tests both support the need for a low-cost anchorage approval method for vehicles produced in low volumes. Despite the small proportion of minibuses, buses and coaches in the sample there are still sufficient accidents to obtain a meaningful analysis of this subgroup.
Table 3-1: Casualties by road user type in accident years 1999 to 2001 (STATS 19)

<table>
<thead>
<tr>
<th>Road user type</th>
<th>Number of casualties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal</td>
</tr>
<tr>
<td>Pedestrians</td>
<td>2,553</td>
</tr>
<tr>
<td>Pedal Cyclists</td>
<td>437</td>
</tr>
<tr>
<td>Moped riders and passengers</td>
<td>47</td>
</tr>
<tr>
<td>Motor Cycles</td>
<td></td>
</tr>
<tr>
<td>Riders</td>
<td>1,607</td>
</tr>
<tr>
<td>Passengers</td>
<td>82</td>
</tr>
<tr>
<td>Taxi</td>
<td></td>
</tr>
<tr>
<td>Drivers</td>
<td>15</td>
</tr>
<tr>
<td>Passengers</td>
<td>11</td>
</tr>
<tr>
<td>Cars</td>
<td></td>
</tr>
<tr>
<td>Drivers</td>
<td>3,035</td>
</tr>
<tr>
<td>Passengers</td>
<td>1,987</td>
</tr>
<tr>
<td>Minibus</td>
<td></td>
</tr>
<tr>
<td>Drivers</td>
<td>13</td>
</tr>
<tr>
<td>Passengers</td>
<td>40</td>
</tr>
<tr>
<td>Bus or Coach</td>
<td></td>
</tr>
<tr>
<td>Drivers</td>
<td>5</td>
</tr>
<tr>
<td>Passengers</td>
<td>35</td>
</tr>
<tr>
<td>Light Goods Vehicle</td>
<td></td>
</tr>
<tr>
<td>Drivers</td>
<td>143</td>
</tr>
<tr>
<td>Passengers</td>
<td>52</td>
</tr>
<tr>
<td>Heavy Goods Vehicle</td>
<td></td>
</tr>
<tr>
<td>Rigid</td>
<td></td>
</tr>
<tr>
<td>Drivers</td>
<td>69</td>
</tr>
<tr>
<td>Passengers</td>
<td>17</td>
</tr>
<tr>
<td>Articulated</td>
<td></td>
</tr>
<tr>
<td>Drivers</td>
<td>65</td>
</tr>
<tr>
<td>Passengers</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Drivers</td>
<td>134</td>
</tr>
<tr>
<td>Passengers</td>
<td>27</td>
</tr>
<tr>
<td>Other Motor Vehicle</td>
<td></td>
</tr>
<tr>
<td>Drivers</td>
<td>31</td>
</tr>
<tr>
<td>Passengers</td>
<td>14</td>
</tr>
<tr>
<td>Other non motor vehicle</td>
<td></td>
</tr>
<tr>
<td>Drivers</td>
<td>14</td>
</tr>
<tr>
<td>Passengers</td>
<td>1</td>
</tr>
<tr>
<td>ALL CASUALTIES</td>
<td>10,283</td>
</tr>
</tbody>
</table>

Not only does the analysis of GB accident data show that there are few casualties found within the low-volume vehicle group, but when it is considered in the context of rate per 100 million kilometres travelled, as shown in Table 3-2 below, then it can be seen that it is a very low rate. It should be noted that the number of accidents found in the above analysis are for minibus, bus and coach, but the casualty rate for distance travelled given in Table 3-2 is only for bus and coach occupants. This low rate supports the use of low-cost approval methods for these vehicles.
A more detailed analysis of low-volume vehicles was required for this project. As already noted the STATS 19 database does not include detailed information on occupant injuries, the precise location of the passenger within the minibus or coach, nor the vehicle(s) speed at impact. The database used to include data on seatbelt usage but this was removed from STATS 19 due to unreliable self reporting. For bus and coach occupants, data on whether they were sitting, standing, etc. were available, and the results of the analysis are shown in Figure 3.1.

Figure 3.1. Casualties injured on a bus or coach by driver or passenger activity, accident years 1999 to 2001 (STATS 19)
The driver or passenger activity for buses and coaches shown in Figure 3.1 were selected in the STATS 19 database and by comparing the data with the injury class data it was possible to determine that most of the ‘not a passenger’ category were the drivers. Figure 3.1 shows that over 50 percent of the passenagers injured were seated, although it is not possible to say if the seat was forward, rear or side facing, or if they were fitted with seatbelts.

The database contained basic data on vehicle makes and models, allowing more specific searches to be made. From the lists of vehicle manufacturers’ make and model in the STATS 19 database, minibuses in accidents between 1999 to 2001 were sorted by make and where possible model, and a similar sort was carried out for coaches and buses in accidents over a 5-year period between 1997 to 2001. This information was then used to identify the vehicle makes for each class, and the top 15, in terms of accident involvement, are listed in Table 3-3. It has been assumed that the number of vehicles of each type, make and model involved in accidents will be roughly in the same proportion as found in the UK vehicle fleet. It is feasible that some vehicle models, by their use or design, are more likely to be involved in occupant injury accidents but the following analysis does not imply this.

Table 3-3: The top 15 minibus and bus or coach manufacturers involved in accidents (STATS 19)

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>No of vehicles in accidents</th>
<th>Manufacturer</th>
<th>No of vehicles in accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>FORD</td>
<td>1,230</td>
<td>DENNIS</td>
<td>10,402</td>
</tr>
<tr>
<td>MERCEDES</td>
<td>462</td>
<td>MERCEDES</td>
<td>3,917</td>
</tr>
<tr>
<td>LDV</td>
<td>431</td>
<td>SCANIA</td>
<td>1,868</td>
</tr>
<tr>
<td>RENAULT</td>
<td>214</td>
<td>DAF</td>
<td>1,395</td>
</tr>
<tr>
<td>LEYLAND DAF</td>
<td>170</td>
<td>LEYLAND AEC</td>
<td>1,363</td>
</tr>
<tr>
<td>VOLKSWAGEN</td>
<td>161</td>
<td>BRISTOL (BLMC)</td>
<td>863</td>
</tr>
<tr>
<td>TOYOTA</td>
<td>79</td>
<td>OPTARE</td>
<td>670</td>
</tr>
<tr>
<td>PEUGEOT</td>
<td>56</td>
<td>MAN</td>
<td>551</td>
</tr>
<tr>
<td>FREIGHT ROVER</td>
<td>48</td>
<td>RENAULT</td>
<td>406</td>
</tr>
<tr>
<td>TALBOT</td>
<td>37</td>
<td>BEDFORD</td>
<td>307</td>
</tr>
<tr>
<td>NISSAN</td>
<td>36</td>
<td>FORD</td>
<td>603</td>
</tr>
<tr>
<td>FIAT</td>
<td>32</td>
<td>DAIMLER</td>
<td>171</td>
</tr>
<tr>
<td>CITROEN</td>
<td>26</td>
<td>PEUGEOT</td>
<td>88</td>
</tr>
<tr>
<td>MAZDA</td>
<td>25</td>
<td>LEYLAND DAF</td>
<td>79</td>
</tr>
<tr>
<td>DENNIS</td>
<td>21</td>
<td>LDV</td>
<td>73</td>
</tr>
</tbody>
</table>

Total No, of minibuses in accidents 4,273 Total No, of buses in accidents 58,145
Table 3-3 shows that the main manufacturers within the minibus sector are Ford, Mercedes, LDV and Renault. These 4 manufacturers account for nearly 75 percent of the vehicles involved in accidents over the years 1999 to 2001. The bus and coach sector was dominated by four of the main bus and chassis manufacturers, with Dennis accounting for over 45 percent of the buses and coaches involved in accidents in the UK. It should be noted that most buses and coaches were classified by the manufacturer of the chassis, who was not necessarily the builder of the bodywork. Likewise for minibuses made by converting delivery vans or by coach-building a body on a chassis cab, these were identified by the vehicle manufacturer not the converter or coach-builder. It should be noted that the breakdown of data in Table 3-3 is not perfect. Some of the vehicle identifiers were left blank in the data set. One noticeable absentee in the coaches/buses list is Volvo, but according to the data most of the Volvos were either HGVs or cars. However, the data does give the best understanding of the vehicles involved in accidents and an idea of the manufactures on which to focus our investigation.

Figure 3.2 is a chart showing the proportion of vehicles by make involved in minibus and coach / bus accidents within the UK and includes the vehicles without make and model information.

**Figure 3.2. Proportion of vehicles by make in bus, coach and minibus accidents (STATS 19)**

The recorded number of vehicles in accidents was 4,273 for minibuses and was 58,145 for buses and coaches in the periods 1999 to 2001 and 1997 to 2001 respectively. However, due to missing data (empty fields) in the STATS 19 database, the make of the vehicle could only be found for 3128 minibuses and 22,965 coaches and buses. For minibuses it was possible to break down the vehicles of known make into vehicle models in many cases where the data were provided. Table 3-4 shows the main minibus makes broken down into individual models and gives the number of vehicles involved in accidents over the 1999 to 2001 period. The model of bus or coach involved could not be identified in most cases due to missing data in the database, which imply empty boxes on the original STATS 19 accident forms filled out by the police, therefore no model breakdown could be produced.
Table 3-4: The top minibus makes broken down into models involved in accidents, years 1999 to 2001 (STATS 19)

<table>
<thead>
<tr>
<th>Make and model</th>
<th>No. of vehicles</th>
<th>Make and model</th>
<th>No. of vehicles</th>
<th>Make and model</th>
<th>No. of vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>FORD</td>
<td>Model not specified</td>
<td>24</td>
<td>LDV</td>
<td>200 SERIES</td>
<td>46</td>
</tr>
<tr>
<td>TRANSIT</td>
<td>1206</td>
<td></td>
<td>CONVOY</td>
<td>285</td>
<td></td>
</tr>
<tr>
<td>CITROEN</td>
<td></td>
<td></td>
<td>400 SERIES</td>
<td>93</td>
<td>MEsolid</td>
</tr>
<tr>
<td>BERLINGO</td>
<td>1</td>
<td>RENAULT</td>
<td>Model not specified</td>
<td>46</td>
<td>PEUGEOT</td>
</tr>
<tr>
<td>C SERIES</td>
<td>5</td>
<td>MASTER</td>
<td>97</td>
<td></td>
<td>BOXER</td>
</tr>
<tr>
<td>DISPATCH</td>
<td>1</td>
<td>TRAFFIC</td>
<td>71</td>
<td></td>
<td>EXPERT</td>
</tr>
<tr>
<td>RELAY</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td>PARTNER</td>
</tr>
<tr>
<td>VOLKSWAGEN</td>
<td>Model not specified</td>
<td>24</td>
<td>TOYOTA</td>
<td>Model not specified</td>
<td>14</td>
</tr>
<tr>
<td>CARAVELLE</td>
<td>32</td>
<td>HI LUX</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DELIVERY VAN</td>
<td>2</td>
<td>HI-ACE</td>
<td>62</td>
<td>2 SERIES</td>
<td>12</td>
</tr>
<tr>
<td>LT</td>
<td>30</td>
<td>LITE-ACE</td>
<td>2</td>
<td>3 SERIES</td>
<td>25</td>
</tr>
<tr>
<td>TRANS CARAVELLE</td>
<td>13</td>
<td>FIAT</td>
<td>4 SERIES</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>TRANSPORTER</td>
<td>51</td>
<td>DUCATO</td>
<td>10</td>
<td>5 SERIES</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DUCATO MAXI</td>
<td>20</td>
<td>SPRINTER</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SCUDO</td>
<td>2</td>
<td>VITO</td>
<td>22</td>
</tr>
</tbody>
</table>

Figure 3.3 shows the breakdown of minibus models where available. The figure shows that vehicles models such as the Ford Transit and LDV Convoy make up a majority of the identified vehicle fleet. Both the Transit and the LDV are produced by their manufacturers in minibus and delivery van versions. The minibus versions are production line-built and would have seatbelt anchorages that had been subjected to the normal high-volume destructive test requirements. However, an unknown but significant proportion of those produced as delivery vans would have been subsequently converted into minibuses. These converted delivery vans would be regarded as low volume for their seatbelt anchorage approval. Therefore a good indication of the typical methods and materials used in floor construction of vehicles most frequently converted can be obtained by examining the design of the delivery versions of these two vans along with the other top minibus models identified here from the STATS 19 data.
4 Construction methods

The main types of vehicles produced in low volumes are minibuses, buses and coaches (classified as M2 and M3 vehicles) and it was decided to concentrate on these. To obtain an understanding of the methods used to produce minibuses, buses and coaches it was decided to try to obtain information from the following:

1. Delivery van manufacturers
2. Minibus converters and coach builders
3. Coach and bus builders
4. Coach operators

The leading companies in each of the first three categories were contacted for information on their floor design and seatbelt anchorages. The manufacturers of delivery vans popular for conversion were identified by using the STATS 19 data, as reported in Section 3. Manufacturers, converters and coach and bus builders were identified using a combination of STATS 19 data, specialist minibus and coach publications and by consulting with people within the industry. Over 35 letters were sent out and, as may be expected, the response was slow in many cases. However, a large amount of information was collected and many useful contacts made. From this, four visits were arranged, one to a bus body builder, one to a converter and coach builder, one to a local coach operator and one to a leading manufacturer of seats and seat fixing systems. These visits proved extremely useful in identifying current manufacturing techniques and the methods used to assess anchorage strength. The data collected identified a variety of structures for the different vehicle types. The main vans and coach-built chassis could be categorised under two descriptions:

- Coach-built – bodywork consisting of floor, walls and roof frames covered with shaped or flat panels which are fixed to a separate chassis. The chassis consists of a structural framework with the wheels, suspension, steering, transmission and engine attached; some chassis are also
provided with a front cab. The chassis provides all of the strength needed for the vehicle to function (they can sometimes be seen being driven to the coach builders without bodywork).

- Large minibuses and small and large buses and coaches are made in this way, and also a few large delivery vans such as the Mercedes Vario Van.
- A variation on the coach-built chassis method seen with some coaches and buses is where the chassis is split into three parts: front, back and middle sections. The front and back sections include the steering, suspension, engine and transmission, etc. These front and back modules were designed for a coach-builder to insert their own middle section (a temporary middle section is used for delivery).

- Delivery van conversions – where seats are fixed to the floor of a delivery van using various load spreading systems. Windows are cut in the side and sometimes the roof is raised.

All the low-volume minibuses, buses and coaches seen could be categorised within these two methods of construction. However, there are a variety of different dimensions and materials used depending on the coach-builder or converter and the manufacturer of the base vehicle or chassis. In all the vehicles examined the seatbelt anchorages were incorporated in the seat and therefore their strength was dependent on both the seat frame and the seat’s attachment to the vehicle. Also, it was observed that in some vehicles the seat fixings in some areas were different from the solution used for the main area, because the main solution would have clashed with various vehicle features, such as under-floor reinforcements, wheel boxes and raised areas over engines and transmissions. All of these variations will pose problems, which will need to be overcome when developing low-cost approval methods.

Several different methods of construction were seen during the visits to manufacturers and it was clear that most of these were linked to the type and size of vehicle being made. However, it is likely that different combinations of the methods seen and reported here together with alternative or new methods are being used or will be used in future. Therefore, a low cost approval method or methods needs to be sufficiently flexible to take these different construction methods into account and be appropriate for all. This is one of the strengths of the current high cost destructive pull test method.

4.1 Coach-built

It was seen in the visits that coach-built vehicles could be subdivided into two main categories. For large minibuses and small buses and coaches it was seen that the coach-built body was fixed on top of two main longitudinal chassis rails. This method is referred to here as ‘coach-built on top of the chassis’. For large buses and coaches, the walls and in some cases the floor were more integrated with the chassis; this method is referred to as ‘coach-built within the chassis’ here.

4.1.1 Coach-built on top of the chassis

4.1.1.1 Large minibuses and small buses and coaches

Both large coach-built minibuses and small buses and coaches were observed being constructed with the floor being built on top of the main chassis rails of a chassis cab. A photograph of a typical chassis cab is shown in Figure 4.1.
The way that the floor is constructed is specific to the bodybuilder’s design and production method. Figure 4.2 shows an example of a coach-built floor of a large minibus. Welding to the chassis rails is either strictly specified by the chassis manufacturer or prohibited. In this case the chassis manufacturer provides brackets on the outer sides of the main longitudinal chassis rails. In the floor shown in Figure 4.2 the ‘C’ section cross-members are attached to a box member which is in turn bolted to the mounting brackets on the chassis rails. The use of structural tracking directly on top of the cross-members, as shown in Figure 4.2, meant that the use of separate longitudinal floor members was not necessary. A structural tracking system was also seen installed in a van conversion; the use of structural tracking systems is described further in Section 5.2. By building up the floor above the chassis using the box and ‘C’ section cross-members, the need for a wheel arch box is removed, providing a flat floor area of consistent design.
TRL were concerned that some of the floor designs for coach-built vehicles, obtained in this project, might have poor floor stability in frontal crashes. As the side-walls and roof are attached to the floor, the floor to chassis connection will have to carry both the occupant and the bodywork loads in a frontal crash. One design had the floor raised on 185 mm pedestals, to avoid the need for wheel arch boxes but no information was provided to show whether it had diagonal braces or stiff side rails to reinforce the structure. Without these there would be a high risk that the whole floor would hinge forward in a frontal crash, which might result in failures where it is attached to the chassis. Although this is not directly related to the strength of the seatbelt anchorages, visual inspection should include an assessment of the structural integrity of any raised floors, and this will require good engineering judgement or clear rules. In the raised floor example shown in Figure 4.2 there are deep ‘C’ section side rails, which will act as a diagonal brace.

The Mercedes Vario van, which is the largest van that Mercedes produce, is interesting because although it is a factory produced vehicle it does not have the normal welded monocoque van body. Instead, the Vario has a separate chassis with two main rails, and the bodywork and its attachment by rubber mounts to brackets on the chassis was similar to that of the coach-built vehicle in Figure 4.2. Figure 4.3 and Figure 4.4 show the floor fixings and how the cross-members are mounted to the chassis rails. The vehicle is therefore similar in principle to the smaller coach-built vehicles examined.
4.1.1.2 Full-size coaches

Full-size coaches normally have a high passenger floor above a luggage compartment (note that these are referred to as ‘high floors’ in this report). One of two methods seen for this consisted of a lower frame which was fixed on top of the two main chassis rails (in the central area this formed the luggage compartment floor). Side-walls and roof were attached to the lower frame and where the chassis had outriggers these were linked to the lower frame or side body structure. An intermediate frame, to supporting the ‘high floor’, was attached between the side-walls. One of the vehicles inspected at the coach operator had an intermediate frame for the ‘high floor’ made from approximately 40 mm wide by 25 mm deep by 3mm thick steel channel, see Figure 4.6. The frame had longitudinal channel positioned immediately below the floor mounted aisle side seat tracking. The seat tracking was fixed on top of the wooden floor by the use of self-threading screws (approximately 6mm diameter) into the steel channel below, see Figure 4.6. The maintenance department of the coach operator reported that it was common for the track to come loose under normal service loads due to stripping of the self cut threads in the under-floor channel members, allowing the track fixing screws to pull out. TRL therefore recommend, for attachments with implications for safety, such as the attachment of seat tracking, that appropriate bolt size and washers be used, with the normal engineering practice of requiring thread engagement equal to about one bolt diameter.
Figure 4.5. Underside of coach intermediate frame for the ‘high passenger floor’

Figure 4.6. Fixing aisle-side seat tracking of coach’s main passenger compartment floor
4.1.2 Coach-built within the chassis

Several different types of coach-built within the chassis vehicle were seen during the visits to the bus manufacturer and the coach operator and those with typical features or ones pertinent to anchorage approval methods are described below.

4.1.2.1 Large bus

One type of coach-built within the chassis vehicle seen was a bus with the floor fitted directly on top of the chassis. Examples of this bus at various stages of construction were seen during the TRL visit. The chassis used for this vehicle had heavy longitudinal rails and outriggers, see Figure 4.7.

![Figure 4.7. Dennis Dart chassis used for large buses](image)

![Figure 4.8. Large bus under construction (before the additional floor supports have been added)](image)
The floor was placed directly on top of the chassis with additional supports added when required by welding steel box and channel sections between the outriggers. This method of attaching the floor directly onto the chassis is referred to here as ‘Direct to chassis floor’. The main vertical side members were attached directly to the ends of the outriggers as shown in Figure 4.8. For the main passenger area, supports were added between the outriggers each side of the aisle, along the length of the vehicle, for attachment of the seat legs. The outer ends of the seats were fixed to a series of beams fitted between the main side uprights, just below the windows. With the floor directly on top of the chassis, the rear wheel arch and transmission area had to be raised and different solutions were seen for fixing seats in these areas, Figure 4.9 shows the floor construction in the wheel arch area.

![Figure 4.9. Example of how the floor is built up over the rear wheel arch.](image)

It can be seen in Figure 4.9 and Figure 4.10 that the rear raised floor area has a different method of construction to the main passenger section. The rear floor has a separate framework on which the floorboard rests. The anchorage strength in this section of the vehicle is dependent on both the seat to frame and frame to chassis fixings.

![Figure 4.10. Photograph of the raised rear floor.](image)

The seats at the rear of the low bus consisted of five individual seats on short legs that were fixed to a raised area over the engine. It was obviously more difficult to achieve suitable anchorage strength for three point seatbelts in this area because parts of the raised frame had to be removable for engine maintenance. The solution found for this area was to fit two diagonal braces from the raised area, one each side, onto the chassis rails in the engine bay; the right hand brace can be see in Figure 4.11.
4.1.2.2 Full-size coaches

The second type of large coach seen was one where the chassis was split into three parts: front, back and middle sections. The front and back sections included the steering, suspension, engine and transmission etc. The middle section had been made by the coach-builder and consisted of a space frame which acted as the chassis, the luggage storage area and the floor to the main passenger seating area. Side walls had been constructed attached to all three sections. Figure 4.12 shows an underside view of the coach and Figure 4.13 shows the interior of the middle chassis section and the rear engine/transmission unit.

Figure 4.11. Diagonal brace for rear seats
4.2 Delivery van floors

Letters were sent to the leading manufacturers of the top 21 delivery van models, identified by the STATS 19 search, requesting details of the floor construction of the models identified. Information on a total of six van models was obtained but some of these models were the same base van sold by collaborating manufacturers, leaving a total of four different van designs. It was found that most manufacturers supplied each model in a number of different variants, consisting of short, medium or long wheel-base versions. Figure 4.14 shows a manufacturer’s schematic diagrams of their delivery van, showing the two different length variants available. The main construction methods were found to be very similar for each manufacturer and model. Variants with longer wheelbases had more cross-members and supports and, obviously, longer floors. Typical delivery van floors consisted of a corrugated steel floor, made from modules, reinforced by two main longitudinal members, with a series of cross-members and outriggers welded to the underside of the floor; a typical example is shown in Figure 4.15.
Figure 4.14. Schematic diagram of long and medium wheel-base variants

Figure 4.15. Underside of a typical delivery van
As Figure 4.15 shows, the distinction between monocoque and chassis construction is less clear with vans than with cars. Effectively a chassis exists under the floor but it is attached to the body shell at many more locations than found with normal chassis construction so that the body shell contributes to the overall strength of the vehicle. The main rails and cross-members support the majority of the floor and there are some ‘outriggers’ to support the bodywork. From the information collected it was possible to obtain an understanding of the construction methods used by vehicle manufacturers and how these features interact with the installation of seats with integral anchorages. The three main common features of the van floors were:

- Longitudinal chassis rails
- Cross-members
- Corrugated floor

There are also other sections and supports that vary between manufacturers; however these were very difficult to define due to the different designs. The dimensions of the main components were found from scaled drawings and other information supplied by the manufacturers.

4.2.1 Summary of van design information obtained

One of the options for a low-cost approval method described later in this report requires a generic van floor module which approximately represents any delivery van. The aim of this summary is to provide a general specification for the common components, which could be used to design a generic van floor. However, it should be noted that many of the more popular vans models from different manufacturers use the same body shell under re-badging arrangements and the Fiat, Peugeot and Citroën in the following tables of dimensions are all for the same body shell. The dimensions given in the tables were found by measurements from the manufacturers’ scaled drawings. The drawings provided by the manufacturers of the three van body shells were to different scales and had different levels of detail.

4.2.1.1 Longitudinal chassis rails

The main longitudinals are the major load bearing part of the van floor. The longitudinals were constructed from a deep ‘U’ section, however the cross-section was found to vary between manufacturers. Figure 4.16 shows the typical longitudinal form and gives the key to the summary of dimensions given in Table 4-1, for three vehicles where detailed information was provided.
Figure 4.16. Cross-section of longitudinal chassis rail

Table 4-1: Geometry of the chassis longitudinals

<table>
<thead>
<tr>
<th>DIMENSIONS (mm)</th>
<th>Section A –A</th>
<th>Section B - B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>x  y  z  d  t</td>
<td>X  Y  Z  D  T</td>
</tr>
<tr>
<td>Van 1 (Renault)</td>
<td>40 90 90 120 2.25</td>
<td>40 90 90 68 2</td>
</tr>
<tr>
<td>Van 2 (Fiat)*</td>
<td>24 66 60 105 2</td>
<td>24 66 60 70 2</td>
</tr>
<tr>
<td>Van 3 (Peugeot)*</td>
<td>24 66 60 105 2</td>
<td>24 66 60 70 2</td>
</tr>
<tr>
<td>Van 4 (Citroen)*</td>
<td>24 66 60 105 2</td>
<td>24 66 60 70 2</td>
</tr>
<tr>
<td>Van 5 (Ford)</td>
<td>Geometry not defined, however the material was specified as 165 MPa 1.56 ±0.06 mm</td>
<td></td>
</tr>
</tbody>
</table>

* Difficult to measure accurately for these vehicles due to large corner radius.

Other vans have similar profiles to those stated in the table; however, due to lack of information, the exact measurements could not be recorded. The distance between centrelines for the vehicle longitudinals varied slightly, however it was found to be approximately 1200 mm.

4.2.1.2 Cross-Members

The layout of the van floors investigated showed that there were a series of cross-members to support the floor, as shown in Figure 4.15. However, as can be seen in the figure, the size and cross-section of these cross-members was found to vary considerably along the length of each vehicle. They were found to switch between heavy and light sections along the length of the vehicle. The arrangement and section of cross-members was found to be different between vehicles so it was concluded that although TRL had gathered sufficient information to specify a representative arrangement of cross-members it would not be practical to try to summarise these data here.
4.2.1.3 **Corrugated Floor**

All of the vans seen, or for which diagrams were obtained, had floors with longitudinal corrugations. The main under-floor stiffening structure was attached to the floor and the side-walls were joined to it. For most vans the floor came in up to 3 sections which were overlapped and spot-welded at the joins. This modular floor design allowed floors of different lengths to be assembled using more or fewer sections to make the floors for the short, medium and long wheel-base variants. Both the floors seen in vans being converted and the floors of vans for which diagrams were obtained had profiles as shown in Figure 4.17 below, although there were some differences in the ridges around the edges of the van floors.

![Figure 4.17. Diagram of the longitudinally corrugated van floor](image)

It was possible to identify the dimensions for some of the vans investigated and this gives a range of results for actual floors. Table 4-2 shows the measurements for the key dimensions indicated in Figure 4.17.

<table>
<thead>
<tr>
<th>Van</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>h</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Van 1 (Renault)</td>
<td>33</td>
<td>52</td>
<td>50</td>
<td>9.5</td>
<td>1</td>
</tr>
<tr>
<td>Van 2(Fiat)*</td>
<td>30</td>
<td>47</td>
<td>53</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Van 3 (Peugeot)*</td>
<td>30</td>
<td>47</td>
<td>53</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Van 4 (Citroen)*</td>
<td>30</td>
<td>47</td>
<td>53</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Van 5 (Ford) No dimensions specified although the material is stated as 250 MPa 0.9 ± 0.04 mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.2.1.4 **Problem areas when converting vans**

During the investigation, information was collected that identified a number of areas where problems were found when converting delivery vans into minibuses. The three main areas for the floor top were:

1) Where the front of the cargo floor joins the main cab.

2) At the rear end of the vehicle where the under-floor reinforcement is often lighter.

3) At the wheel arch where the presence of the heel box necessitates different methods of seat attachment.

Problems were also found in locating seat fixings on the underside of the floor where floor reinforcements and mechanical components clashed with seat fixings or the fixing of seat load-spreading channel or box sections, plates or washers.
At the back of the cab there is typically a step in the floor approximately 120 mm in height. The cargo floor of the van often joins the cab floor behind this step and in some vans this is an area where seat attachments might fail. The joint between the cargo floor and the step is normally spot welded together and although there are many small structures in this area, none seemed to be specifically aimed at strengthening the joint. The position of the cross-member adjacent to this joint will affect the strength of the joint. Figure 4.18 shows a typical simplified cross-section through the joint between the cab and the cargo floor of a van. Generally the larger the distance D (in Figure 4.18) the greater the stress that could be induced in the floor joint by the seatbelt anchorage forces and the more likely it is to fail without additional reinforcement. Because of this some seat/tracking manufacturers recommend that a length of steel angle should be welded along this interface to reinforce it.

![Diagram of the joint area between the cab and cargo floor section of a van](image)

**Figure 4.18. Diagram of the joint area between the cab and cargo floor section of a van**

The rear of the vehicle can also give problems when converted to take seats because the main longitudinals and cross-members taper off to the rear to reflect the lower demands on a van’s structure in this area.

The wheel arch areas also give problems as they often interrupt seat mounting reinforcements or tracking laid on top of the floor for seat leg fixings. This often results in the outer end of wheel arch seats being attached to the side of the vehicle instead of the floor. This then requires there to be adequate strength to accommodate such mountings. Normally the side of the vans is not strong enough for side mounting of seats without some reinforcement.

### 4.3 Seat manufacture

The seat manufacturer visited appeared to have designed their seats using a combination of experience, mathematical calculations and testing using an in-house anchorage pull-test facility. The older designs appeared to have been developed to suit low-investment manufacturing techniques e.g. bent tubes, simple flat brackets and hand welding. These welds are often at key points in the seat, where poor quality welds would compromise the seatbelt anchorage strength. However, as discussed below in Section 4.3.1, one manufacturer was in the process of switching to higher investment manufacturing methods, using more complex press tools, which amongst other things would give more consistent seatbelt anchorage strength.

#### 4.3.1 Conformity of production

For seats with integral seatbelt anchorages it is important to control the manufacturing quality or consistency of key areas critical to achieving the anchorage strength. The seats for low-volume vehicles are also produced in relatively small numbers so the designs often use hand welded joints in key areas; this is likely to result in variability in strength. The seat manufacturer visited, as part of their ISO 9001 accreditation requirements, had introduced three measures to provide evidence of conformity. Weld quality at key locations was monitored by testing sample assemblies from the main
production runs. These were selected at random from each welder every 6 months and by applying an appropriate load, the quality of the weld was tested. In addition, every 1000th seat is pull tested using the regulatory anchorage pull test. Finally new designs are being produced where welding is not required in some critical areas. This has been achieved in the new design for the Defender 3 seat where the need to weld in the critical seat squab to back areas has been removed by making the sides from pressed steel, see Figure 4.19.

![Image of new pressed-steel frame](image)

**Figure 4.19. New pressed-steel frame**

5 Current approval methods for vehicles using seats with integral anchorages

Information on current approval methods for seatbelt anchorages in low-volume vehicles was obtained from several sources, including VOSA, and from the visits to coach builders, converters and specialist tracking system manufacturers.

5.1 Visual inspection design rules

As already discussed, the methods used for low-volume vehicles, to assess whether seatbelt anchorages meet the regulatory strength requirements, have been changed for Passenger Service Vehicles (PSVs). As an alternative to the destructive testing of anchorages, VOSA will also accept anchorages in seats where the seat attachments in the vehicle comply with a standardised set of design rules. The VOSA inspector decides whether a vehicle complies with these design rules by a combination of visual inspection and information obtained from the converter / coach-builder during construction. These design rules were developed by VOSA in conjunction with STATUS at Manchester Metropolitan University (Vehicle Inspectorate, undated). PSV vehicles (especially buses) are manufactured within the Construction and Use Regulations (46, 47, 48 and 48a) and these incorporate sections from various European regulations.

All seatbelt anchorages in new buses, coaches and minibuses must meet the technical requirements for strength, position, etc. However, only PSV vehicles (i.e. those vehicles for hire or reward) have a mandatory VOSA inspection of their anchorages. For vehicles not intended for PSV use there is a voluntary option for the manufacturer to have the anchorages assessed by VOSA. Approval of the
seatbelt anchorages in PSV vehicles can be obtained from VOSA using the regulatory pull test method on a sample vehicle; however, the VOSA design rules (Vehicle Inspectorate, undated) provide an alternative low-cost approval option for some types of vehicle.

The VOSA design rules have been developed in such a way that compliance with them can be determined by Enhanced Visual Inspection. Although these rules do not specifically exclude large coaches that have a high passenger floor, positioned above a luggage compartment, it is thought that in practice they are more likely to use a more light-weight design and these will normally be approved by the regulatory pull test. Therefore it can be assumed that in practice the design rules normally are only applied to coach-built vehicles and converted panel vans where the seats are attached to a floor structure built directly on top of or within the chassis. The rules specify the minimum size, sections and material for the floor cross-bearers fitted to the chassis and their maximum spacing.

The current guidelines require longitudinal members to be fitted beneath the feet of any floor-mounted seats incorporating anchorages, except in some cases where heavy duty tracking suffices. The feet of the seat are then fixed through the floor to these longitudinal members. The size of longitudinal required varies depending on: the type of seat and seat fixing, class of vehicle (M2 or M3), the distance between supports (cross-bearers) and whether tracking (low-profile or heavy-duty) is used. The guidelines specify mild steel channel section, but box section may be used with similar dimensions. There is no allowance made for the use of high-strength steels or stronger cross-sections; the material used has to have the minimum dimensions set out in the guidelines. Figure 5.1 shows a typical coach-built vehicle made to the design rules.

![Figure 5.1. Coach-built chassis](image)

This is classed as Chassis, therefore not defined

Cross-bearer

Longitudinal member

The VOSA guidelines also cover side mounted and rear bench seats. Side-mounted seats require documentary evidence that the mounting method will meet the required strength, along with the requirement that any tracking extrusion used to attach the seat is itself being secured to structural members at least every 500mm. The guidelines state the cross-bearer requirements for rear bench seats, for two and three point seatbelts and for M2 and M3 vehicles, and give guidance on the strengths of the end frame to which the seat is attached. Figure 5.2 is a picture of a bench seat in a small bus manufactured to the VOSA guidelines; it can be seen that it is a substantial structure and is possibly stronger than the underlying structure to which it is attached.
Figure 5.2: Photograph of a bench seat manufactured to the VOSA design rules

For converted panel vans several permissible design solutions are described in the design rules. These include both types of ‘over-floor’ reinforcements described in the following Sections 5.2 and 5.3. For single seats fitted directly to the floor, minimum load spreading washer sizes are specified and these are required to be fitted beneath the floor at each rear seat leg and between the leg and the top of floor for each front seat leg. For double and triple seats fitted directly to the floor, substantial channel or box sections are required running longitudinally under the floor beneath the seat legs, along with load-spreading plates on top of the floor. Other acceptable options are also specified along with appropriate load-spreading requirements. For converted delivery vans the rules accept proven reinforcement systems, such as structural tracking.

5.1.1 Advantages and disadvantages of the VOSA design rules

The present VOSA design rules, when implemented sensibly, are likely to result in seat fixings that exceed the minimum seatbelt anchorage strength requirement. They appeared to be particularly suitable for the specified vehicles such as buses with ‘Direct to chassis floors’ where the chassis cross-members provide suitable fixings and any necessary additional mass will be low. However, the guidelines are conservative and do not allow the weight of the structure to be minimised by the use of lighter-weight, high-strength solutions. Therefore vehicle weight and fuel consumption could be higher than necessary and the vehicle stability could be compromised should any unnecessary extra mass increase the height of the vehicle’s centre of gravity. The guidelines are obviously low cost in terms of testing, as no test of the vehicle is required, but they do assume that proven seats are available. There is no official test for seats with integral anchorages as separate units.

Most of the forward-facing seats in coaches and buses have one wide leg to support the aisle end of the seat and the outer end of the seat base is attached to the vehicle side structure. It is more difficult to produce design rules for side fixings because the loading situation is more complex and the mass of the vehicle side structure must be minimised for vehicle rollover stability. This problem is not well addressed in the VOSA design rules and in practice it is thought likely that VOSA inspectors are relying on their engineering judgement or insisting on testing.

Most coaches have a high floor above a luggage compartment. Although the design rules do not specifically exclude ‘high floor’ coaches; it is thought that in practice they are more likely to use a more light-weight design. This is because in these vehicles the consequences of using conservative heavy solutions of the design rule type could result in two undesirable effects:
a) Vehicle rollover stability would be significantly reduced by the introduction of a far heavier passenger floor frame than currently used, because the additional mass will be about 1.5 m above the road level.

b) In an accident where the coach chassis takes the main contact, the mass of the heavier passenger floor frame (with the passengers’ mass attached to it indirectly by the seatbelts) would cause increased forces on its supporting structure, which could induce failure.

Therefore, in practice most coach seatbelt anchorage approvals in the UK will be made using the full regulatory destructive test.

For converted delivery vans the rules accept proven reinforcement systems, such as structural tracking. The comments above for coach-built vehicles with the floor on the chassis also apply to some extent to vans where longitudinal reinforcements above and beneath the floor are used. A further design option specified for individual seats attached directly to the vehicle floor provides pragmatic design rules for load-spreading washers, etc., which again may result in unnecessarily heavy vehicles. However, for van conversions the safety factors within the rules are thought to be smaller than those used for coach-built. For van conversions this reduces the problems of excessive weight but gives less certainty that the anchorages would meet the regulatory strength requirements. In this last case the use of the TRL solution for seat-fitting rules, for seats with integral anchorages that have been tested on a generic floor and side-wall module, described later in Section 6.2, might give more confidence of compliance.

In an accident situation all the seatbelt anchorages of the occupied seats will be simultaneously loaded. The design rules specify appropriate cross-members and longitudinal sections or beams to which the seats are attached. However, they do not specify how these members are attached to the vehicle chassis. Therefore, if the rules are used without understanding, this would permit a design where the joints between the seat supporting structure and the chassis might fail when all the seats are simultaneously loaded, particularly for coach-built vehicles if they are also carrying crash loading from the floor and body. The intentions of the current anchorage regulation (UN ECE Regulation 14) are discussed in Section 8.1.

5.1.2 Options for improvement

The current VOSA design rules for coach-built vehicles make use of tables of acceptable mild steel channel sections for the longitudinal members used beneath the seat legs. The tables have columns or rows for seat types (number of seating positions and legs per seat), vehicle class and the distance between bearers so that the minimum longitudinal section can be found. Stronger materials may be allowed in practice, though strictly ‘mild steel’ is specified. Larger sections can be used; however, as no section moduli are specified sections with higher section moduli are not permitted if they are smaller than the minimum section in any of the three dimensions. Box sections can be used but still have to be the same minimum size that is specified for channel. No allowance is made for stronger materials or higher section moduli in the method so it is not possible to take advantage of these stronger solutions to produce lighter weight designs. The methods could be amended so that they take account of the actual material strength and sections used. The amendments would involve providing suitable formulae so that the current strength requirements could be converted to take account of higher material strengths or higher strength sections. The formulae could be used to produce additional tabulations for existing high-strength materials and sections such as “Cromweld” steel sections, or the formulae could be incorporated within the design rules so that purpose made solutions or new materials and sections could be approved when required. Two options are available to derive the following:

1. Take typical or specific seat geometry and the regulatory anchorage pull forces and use them to derive simplified static seat-attachment forces and bending moments. These forces can then be used with beam formulae to calculate whether the proposed section and material strength is acceptable.
2. Use beam formulae to convert the current VOSA strength requirements for mild steel channel into requirements for stronger sections or materials.

The first method would essentially be a repeat of the work of STATUS and would help to confirm their assumptions before the method was expanded. The second method would simply convert the assumptions made by STATUS for new materials and sections.

Stronger materials with sections of equivalent strength would be lighter in weight as a result of using sections with one or more dimensions reduced. If the wall thickness were reduced the thinner material could give rise to local failures at seat locations and different sections are likely to cause different loading at the joint with the cross-bearsers. These two effects will need to be taken into account, if the tables are updated, and might be a reason not to attempt this improvement.

5.2 Structural over-floor reinforcement (tracking)

Two similar structural tracking systems were seen during the TRL visits. Both systems made use of a high strength extruded aluminium beam, which incorporated a ‘T’ slot to which the seat could be fixed. The seats could either be fixed directly to the ‘T’ slot by bolting directly or by using a drop-in-and-lock quick release system. These tracking systems are widely used in the production of both small minibuses made by converting delivery vans and larger minibuses made by coach-building a body on a chassis cab, see Figure 4.2. As well as providing a strong seat fixing the structural tracking can be used in constructing the vehicle floor by fixing the tracking directly on top of the cross-members, see Figure 4.2. This is because the section has a high section modulus. (In this report the use of structural tracking as shown in this figure is referred to as an over-floor system because the cross-members are the structural floor members, although it could be given a different name because the wooden floor is supported by the tracking.) For delivery vans the structural tracking can be used to spread seat loads into the floor of the van by fitting it to the top of the floor with fixings through the floor to load spreading beams or washers under the floor. Several ways of spreading the seat loads into the van floor structure were seen ranging from a length of 16 gauge (1.6 mm) 50 mm by 25 mm mild steel channel beneath the floor to a specially designed aluminium extrusion. With the tracking itself spreading the load on top of the floor, this load spreading beneath the van floor is thought to be critical to ensuring that the anchorage strength is sufficient. Figure 5.3 shows examples of these two load-spreading systems. The wide side flanges of the tracking provide a large fixing area which can help in avoiding clashes with under-floor features and the high strength of the section helps the floor resist the local bending moments from the seat leg reacting to the seatbelt anchorage loads. An added benefit of the system is that it also supports the wooden floor and tidies the cut edges.
Both manufacturers of the tracking systems use a similar method to try to ensure compliance with the regulatory minimum strengths. For coach-built vehicles, a representative floor structure is built on top of the proposed chassis. The floor, and if necessary the side wall, is fitted with a combination of tracking, seats, and seat quick release systems, which reflect the family of seats, seat layouts and seat mountings that the coach-builder intends to produce on that chassis and floor. The test piece is then subjected to a series of anchorage approval tests. The approval authorities select a series of worst-case seat configurations for these approval tests and by this means, if the sample passes, the family of different build options can be approved. Approving a family of different seating arrangements means that there is scope for tailoring the vehicle to the needs of each customer.

A similar system is used to try to ensure compliance when using the tracking system to convert delivery vans into minibuses, however in this case the approval is extended to include a group of delivery vans of similar size and construction. Depending on the approval authority, one or two of the vehicles in the group are fitted with the family of seat and tracking options chosen for approval and tested, again using a worst case selection method. The vehicle or vehicles are selected from within the proposed group, again based on worst case selection by the approval authority.

Following such testing the approval authority can add an additional factor of safety by, for example, requiring track fixings at a maximum of 1.1 metres, despite the system having passed in the tests with fixings at 2 metre spacing.

Once approved, the manufacturer of the tracking system is then free to make vehicles to the approved design or to supply others with the tracking system in kit form for use with the approved combination of vehicles, seats and seat plans. The kits are supplied with detailed fitting instructions so that other users fit the system in the approved manner. The fitting instructions give the approved seating arrangements for specific vehicles and the seats that can be used. The guidelines highlight where the fixings should be placed and how to tackle problem areas such as fuel tanks and wheel arches.

This method of approving specific designs was only found being used in the minibus industry, however, this concept might be adapted to large coaches and buses.

5.2.1 Advantages and disadvantages of the structural over-floor reinforcement approval method

For both van conversions and coach-built vehicles this approval method has the advantage of providing strong evidence that the seatbelt anchorages in both the floor and side walls of vehicles made to the approved design will meet the regulatory minimum strength requirements. Coach builders can make vehicles using any combination of tracking, seats types, seat layouts and seat release systems on the chassis and floor approved. A variation of this method is the approval of various seat types, seat attachment methods (including those bolted in directly) and seat layouts for a specific vehicle or a specific coach-built floor and chassis combination by testing one or more specimens with a worst case set of combinations. For vans the kit of parts and conversion method for a family of similar delivery vans are approved by testing the weakest one or two vans in the family (the weakest is identified by visual inspections and engineering judgement based on prior experience). Then, any of the approved family of vans can be converted both by the tracking manufacturer and any other converter who purchasers a kit of seat and tracking and follows the installation rules. For van conversions it also has the advantage that small companies, by buying approved kits, only have to meet a small proportion of the approval costs.

The only minor disadvantages with the method itself are:

a) Engineering judgement is required in selecting the worst-case seat positions, mounting methods, etc. in coach-built vehicles and, for families of delivery vans, worst-case vans to test. Testing every seat combination and every delivery van model in the family would reduce the need for engineering judgement, but at increased cost. For van conversions it would result in a design tailor-made for that model and more specific fitting instructions.

b) Converters and their customers might want seats in slightly different positions to those approved.
c) Different seats to those used in the approval test cannot be fitted.

d) For van conversions, the majority of the development cost is with the tracking manufacturer and they will only sell their kits if they are commercially viable.

e) For van conversions, the design is based around the weakest vehicle in the family; it is not tailored to each vehicle.

Currently there appear to be a number of potential problems in the way in which the method is administered, as follows:

a) The tracking manufacturer and the vehicle producer are self-examining and self-administer certification of each vehicle produced.

b) There is no formalised method for agreeing whether a proposed variation from the approved design is acceptable, this is often undertaken by the tracking manufacturer.

c) Some national approval authorities require different worst-case methods and do not necessarily accept each other’s approval.

The method of approving families of designs is also used for vehicles made with fixed seat positions. In the two examples seen this was achieved by using lengths of the structural tracking, but to save unnecessary expense the matrix of holes machined to take the adjustable seat fixings was omitted. The fixed seats were then simply bolted through the structural tracking. However, a family of fixed seat plans could also be approved using other shapes / sections of over-floor reinforcing not intended for tracking.

5.2.2 Options for improvement

Formalising the approval method and agreeing national approval with other European countries would encourage further investment because then the vehicle model can be sold to many more vehicle converters and coach builders. The requirement for engineering judgement on the worst vehicle in a family of vans and of the design not being tailored to suit each vehicle in the family could be resolved by testing each model, but at increased cost. Costs would be reduced and testing of each model would be encouraged if approval throughout Europe were standardised.

Different types of seat could be approved by testing the seats on rigid mountings through force transducers. Then alternative seats of equivalent or lower attachment force than the seats originally approved in a vehicle model could be used in that model, without having to re-test or re-inspect the combination of seat and model. Alternatively the seats could be tested when fitted to a generic van or coach-built floor using the approved tracking and track fitting rules for the vehicle concerned.

5.3 Floor inserts (an over-floor system)

During TRL’s visits to minibus manufacturers, a structural floor insert system was seen which consisted of a series of interlocking aluminium extruded rectangular sections, some of which included seat mountings. The rectangular aluminium ‘planks’ had been tailored so that when assembled they matched the floor plan of the delivery van being converted. The plank assembly had been glued as one unit to the floor of the van, see Figure 5.4.
Figure 5.4 Glued-in structural floor

A structural deck complete with seat anchorages has also been devised by STATUS; the deck consists of a steel framework which is fitted on top of a van floor and attached by bolts through the original van floor to under-floor load-spreading members.

As with structural tracking systems, these solutions can be tested using the regulatory pull tests for the vehicle model or models and seat concerned. Approved kits can then be used by the floor insert manufacturer or sold as kits to others.

5.3.1 Advantages and disadvantages of floor inserts

As for the bolted-in solution, this approval method has the advantage of providing strong evidence that the seatbelt anchorages in vehicles made to the approved design have the required strength. However, for the glued system it is more difficult to be confident in the conformity of the glued joint, which is critical to the system’s performance. TRL understands that the glues used are capable of penetrating the paint on the van floor and provide extremely strong bonds that in some applications can replace welds, however, it is impossible to see if good adhesion has been achieved or if the glue has fully filled the cavity between the van floor and the insert. Both these systems are only intended for delivery vans but the principles might be transferable to other types of vehicles, however the approval method is in principle the same as that used for approving structural tracking.

5.3.2 Options for improvement

As already noted, this method is very similar in principle to that of structural tracking and suffers from some of the same problems. Because the floor unit is tailor-made to fit each vehicle model, it would seem reasonable to test each version and not approve a family of vehicles. For alternative seats the solutions for structural tracking could be used.

5.4 Independent testing of seats with integral anchorages

The VOSA design rules specify suitable fixings for seats that have integral seatbelt anchorages. Also, manufacturers of non-PSV minibuses, which have less formal approval requirements, may require seats with anchorages that have been shown to comply. However, when seats with integral anchorages are used, the regulatory pull test is of the complete vehicle, including all the seat
supporting structures, and not just the seat on its own. To overcome this problem seat manufacturers carry out informal tests of their seats with them fixed to a rigid mounting. However, a rigid mounting does not match the interactions between the seat and the vehicle when the seat fixings in the vehicles suffer significant deformation. For these vehicles, tests on a rigid base can give a false indication of the seat’s strength when attached to deformable structures. One option to overcome this is to also test seats independently on a generic flexible-floor and / or side-wall module.

5.4.1 Advantages, disadvantages and suggestions to improve independent testing of seats

For seats with legs for attachment to the floor, testing with the seat fitted to rigid mountings will provide reasonable confidence that when fitted to a vehicle with a strong floor the anchorages will meet the strength requirements. However, it is less suitable for vehicle designs where significant deformation of the seat fixing is anticipated. It is also less suitable for seats with a combination of floor and side-mountings where deformation of the seat structure may be reduced by testing it attached to a rigid structure. One option used to overcome this is to also test the seat mounted to a generic flexible-floor and side-wall module. However, without fitting rules as provided in the VOSA design rules or as proposed in Section 6.2 of this report the approved seats could be poorly fitted in the vehicle and then the anchorages would not meet the strength requirements.

As discussed in Section 4.3.1, conformity of seat production is very important in areas critical to meeting anchorage strength requirements. For example, in a previous project for the DfT a critical foot weld failed at a very low force in a full-scale minibus sled test, when similar seats had performed without failure in earlier tests. The cause of the failure was reported as being due to very poor penetration of the weld (Lawrence, 2001). Obviously, approval tests are of less use if some of the seats actually fitted to vehicles on the road have sub-standard welds or other defects at critical locations. The seat manufacturer visited in the current project had conformity of production procedures which appeared to reduce the risk of sub-standard seats to an acceptably low level. Currently no regulations require this of all seat manufacturers, therefore TRL recommend that this requirement be added for all seats with integral anchorages intended for use in vehicles produced in low volumes, for both regulatory and low-cost anchorage approval (it has been assumed in this study that large volume car manufacturers already insist on this).

The seatbelt is another important component in the chain of protecting the vehicle occupant in an accident. It was also noted in the previous project for DfT that seatbelt reel failure had been induced in severe impacts by plastic distortion of the anchorage face. The seatbelts are supplied to the seat manufacturer ready to mount into the seat, and will have been subjected to the normal regulatory approval test. In addition, the seatbelts will have been tested fitted to rigid anchorages adjusted to match the positions of the integral anchorages in the seat intended for fitting in a minibus, bus or coach. Therefore the effects of any anchorage distortion on the seatbelt will not have been tested.

5.5 Testing all low-volume vehicles to Regulation 14

Obviously the option of testing to Regulation 14 (Economic Commission for Europe, 1999) would provide the normal level of confidence that the anchorages meet the regulatory requirements. However, because of the low numbers of minibuses, buses and coaches made it would be so expensive that many of the small converters and coach builders would be forced to stop making vehicles. This method would also inhibit the current helpful practice of tailoring individual vehicles to meet the customer’s requirements.

6 TRL’s proposals for new low-cost approval methods

Two methods have been devised by TRL for vehicles with seats with integral seatbelt anchorages, and a further method has been devised for anchorages in the vehicle structure. In addition TRL have proposed an adaptation of the current visual inspection design rules that were described in Section 5.1.
6.1 Static seat attachments strength test method (for seats with integral anchorages)

With this proposal the seat attachment points in the vehicle would be tested using a simple loading frame. The loading frame would be adjusted to represent the seat feet or the seat side mountings of the seats intended for that vehicle. A simple jack would be used to apply a force to the loading frame to reproduce in the vehicle a simplified representation of the forces seen in a separate test of the seat, as shown in Figure 6.1 below.

![Figure 6.1. Seat test to find attachment forces and vehicle test of seat attachments](image)

Seat test on rigid base with force measurement

Seat attachment test in vehicle set to match seat test forces and seat fixings

Seat manufacturers making seats for use in low-volume vehicles would be required to carry out the current anchorage regulation tests but with their seat mounted on a rigid base and / or side wall, with suitable load transducers measuring the main forces at the seat attachments. They would have to test the seat in its standard configuration and follow a programme of worst-case testing of any fitting adjustments provided in the seat. (Adjustment of the position of the seat legs is often provided to help with fitting around wheel-arch boxes. This is achieved by a clamp-type design so that they can be fixed at any position along the width of the seat.) These tests could be used to both approve the anchorages in the seat and to provide force data which could be used in a separate test to assess the strength of the seat attachment points in the vehicle. Based on these tests the seat manufacturer would then provide data on the forces at the seat attachment points, resulting from the anchorage test. The worst-case variation in these forces due to any acceptable seat-fitting adjustments such as adjustable positions of the seat legs would also be given.

For each vehicle model that the manufacturer, converter or coach-builder produces, a simplified static test would be required of each seat attachment on at least one vehicle or on a representative vehicle sub-assembly. The factor of safety that can be built into a vehicle will depend on the effects of any additional mass on vehicle stability and integrity. For vehicles with a high factor of safety the test could be in the form of a proof test where no damage is expected, in this case it would be reasonable to test a full vehicle. For vehicles such as coaches with a high passenger floor where it is more difficult to achieve a high factor of safety then destructive tests of a vehicle sub-assembly would be appropriate. The simplified test would make use of loading frames or brackets to reproduce the specific seat’s attachment points. The brackets would be bolted into the vehicle floor or side fixing points and then a static load would be applied, for a set minimum time of say 30 seconds, to the brackets at such a point and direction that it reproduces the main pattern of forces seen in the seat test. Suitable simulated seat attachments would be used to connect the bracket to the vehicle so that the
seat’s footprint is simulated. To take account of the higher demands of a static test the force could be slightly lower than seen in the regulatory ‘quasi static’ test of the seat, by say about 15 percent. This test loading on the floor of a sample vehicle or on a representation of the vehicle floor would, if satisfactory, approve all future vehicles made to that design with that seat. The test programme would take into account the worst case seat mounting situations chosen for the vehicle and the forces applied would have to match or be 85 percent of the appropriate seat manufacturer’s test. If the floor or side fixing strengths were below the prescribed limits then the design of the vehicle or sample would have to be revised until it passed. If a sample were used then these changes would have to be incorporated in the vehicles produced and a government appointed inspector would have to judge whether the real vehicle construction matched that of the specimen. For subsequent vehicles the inspector could ensure that it had been built to the approved design.

### 6.1.1 Advantages and disadvantages of static seat attachments strength test method

The main advantage of this test method would appear to be for vehicles with seat fixings intended to be strong enough to withstand the test load without deformation. By testing a random sample of seats, seat manufacturers with poor conformity of production could be eliminated. For these vehicles it would provide strong evidence that the seatbelt anchorages in vehicles would meet the strength requirements. Floor and side wall seat mountings of different design within the vehicle could all be assessed and an existing design could be approved for different seats, without further testing if they had similar fixing geometry and loads or with new tests if the seats were not similar. However, without a costing exercise the potential financial savings over a full regulatory pull test are not clear. Obviously there would be a saving of the cost of a number of seats that would be destroyed in a regulatory test, and the equipment cost for simple loading brackets and hydraulic jacks should be far lower for a static test. If the equipment were installed at the vehicle manufacturers then transport costs for the body shell would also be saved. A further advantage of this test method for vehicles with strong seat fixings is that seats would perform in the vehicle in a similar way to that in the seat manufacturer’s tests.

For vehicles where some deformation is anticipated particularly where one end of a seat is more rigidly attached than the other, (a combination of legs and side mounting) then the attachment forces in real life might be higher than those measured in a test of the seat on rigid mountings.

Where symmetrical deformation is anticipated then testing on a representative sample would give good results and save damaging the real vehicle. However, in this case the savings of the simplified test would probably not be justified, as the sample could just as easily be subjected the regulatory test. In this case a regulatory test would have the advantage of also providing more realistic seat to vehicle interactions.

A further advantage is that alternative seats could be approved for use with the vehicle, at the time or at a later date, provided their seat test forces were all less than the vehicle test forces, and their seat fixings were all comparable with those used in the vehicle test.

This test method would have to be developed further before it could be used. The possible loading modes on floor and any side wall fixings as the seat deforms would have to be considered in order to specify the axes of force that would need to be measured. The loading brackets would have to be designed with suitable adjustable fixings to cover the range of fixings used in seats. Consideration would also need to be given to the number and positions of loading points in order to reproduce the main fixing forces seen in the seat tests.

A possible alternative to measuring the seat attachment forces is to calculate them from the seat geometry and the regulatory pull test forces. Where the anchorages, the seat construction and the seat attachments at each end are all symmetrical, then calculated equivalent static attachment forces can be estimated reasonably accurately. However, asymmetry such as one leg and one side fixing or a twin seat with both the upper anchorages on the left or both on the right, is often seen in seats with integral anchorages. Asymmetry in any of these features would cause some twisting of the seat resulting in
complex loading at the seat fixings, which could not be calculated accurately. Therefore calculation of seat attachment forces is only recommended for the symmetrical situation.

6.2 Seat fitting rules derived from tests on a generic floor and side-wall module (for seats with integral anchorages)

Seat manufacturers making seats for use in low-volume vehicles would be required to carry out the current anchorage regulation tests but with their seat mounted on one or two types of standardised generic floor and side-wall module (one to represent a van floor and one to represent a coach-built floor). They would have to follow a specified programme of worst-case testing (of seat location with regard to floor reinforcing members and any fitting adjustments provided in the seat) agreed with a government appointed inspector. Based on these results the seat manufacturer would then be required to provide fitting rules to limit the seat fitting options to those that achieved the required anchorage strength in their tests.

Each vehicle produced would then be examined by an appointed inspector to ensure that the floor structure was at least as strong as the generic floor and side-wall and that the seats had been fitted in compliance with the seat manufacturer’s instructions.

6.2.1 Specifying generic floor and side-walls for anchorages on seats

If the generic floor and side-walls option is chosen then modules to represent a typical van floor and a typical coach-built floor will have to be designed and manufactured. The floor module would need to include a side-wall and simulated wheel arch box for seats with side fixings. For testing seats for M1 vehicles with seat-mounted belts, the van floor could probably be used to represent a car. Data have already been obtained on floor construction for delivery vans and it would be possible to use this to design a representative module. Limited data have also been obtained for coach-built vehicles, however the diversity of designs seen during the TRL visits appear to make this option less practical than originally thought. As part of an approval test method it would be important to make the performance of a generic floor and side-wall module repeatable in a seat test. This might be achieved by specifying the sheet steel material by both grade and yield strength. Then sheets of material that will be repeatable can be purchased using the steel supplier’s tensile test data to select sheets with yield strengths within a suitable range.

6.2.2 Advantages and disadvantages of testing on generic floor and side-walls

For the generic floor and side-wall to be representative, manufacturers must use similar designs for their vehicles. If the floor were representative then the test would have the advantage of reproducing the floor-to-seat interactions that would occur in the real vehicle and they would also be of comparatively low cost. Therefore depending on the degree of standardisation between vehicle models, it would provide strong or reasonable evidence that the anchorages would meet the strength requirements if fitted in accordance with the fitting rules. For delivery vans and possibly small coach-built vehicles there appears to be a reasonable degree of standardisation so it would be suitable for these types of vehicles. Generic floor and side-wall modules could also be of use if an approval method for the seat fixings is used, as in the VOSA design rules; in this case a generic floor and side-wall module might be needed for separately approving seats with integral anchorages.

For larger coach-built vehicles a wide range of design solutions were found being used, making the generic floor and side-wall method less suitable or possibly unsuitable for these vehicles. Although this solution is comparatively low cost it extends the current seat manufacturers’ test programme and therefore their costs.
6.3 Approval of anchorages in the vehicle by calculation

Most M1 vehicles have at least two seatbelt anchorages per seat in the vehicle structure. Most M1 vehicles are mass-produced and the anchorages in these will have been tested to the full regulatory requirement. A small number of specialist vehicles such as kit cars will be produced in low volumes and for these TRL propose the following. Using typical anchorage geometry combined with the current anchorage regulation pull-test loading conditions and pass requirements the regulatory pull test forces could be used to calculate the typical forces on the floor and B pillar mountings or, for seat mounted anchorages, on the seat attachment points. The calculations of anchorage forces would use the assumptions that the regulatory pull test forces were applied statically, with no friction between the belts and the body blocks used to apply the load. Low-volume vehicle producers would then be required to satisfy a government appointed inspector that their design would carry these forces by providing suitable static-loading stress-analysis calculations. In some M1 vehicles some of the anchorages are attached to the seat. For some anchorages in the seat, the methods already described for seats with integral anchorages could be used, with adjustment to take account of the number of anchorages in the seat. It has been assumed that seatbelt anchorages directly attached to the vehicle structure in low-volume vehicles will normally only be found in M1 vehicles, however, similar methods would be used to calculate typical static strength requirements for floor and wall anchorages in M2 and M3 vehicles.

The demands on a structure are lower if a force is applied for a short duration. This is the case for seatbelt anchorages in most real-life crashes. Because of this, the regulatory pull test is a quasi-static test where the required force only has to be held for no less than 0.2 seconds. Normally, structural stress calculations are conservative and use the material yield stress value instead of its ultimate strength and an additional safety factor is also applied. To allow to some extent for the short real-life load duration, consideration should be given to using the minimum ultimate tensile strength for the material and a lower factor of safety, in the anchorage strength calculation.

Sophisticated calculation methods such as finite element analysis (FE) are required to calculate accurately stresses in complex structures such as cars. However, by making reasonable assumptions, simpler methods can be used to calculate stresses. These methods are acceptable when the simplifications result in an underestimate of the real strength of the structure.

6.3.1 Advantages and disadvantages of approval by calculation

Calculations of static anchorage forces from the regulatory pull-test requirements will not necessarily reflect the loads that would be seen in an actual test. The use of conservative simplified calculations will result in anchorages that are stronger than the minimum requirements; however, this should provide the necessary factor of safety. It should not be difficult to achieve higher strengths in a vehicle structure. Nevertheless, the simplifications in the calculations and differences between static and dynamic loading mean that this method is not very precise, but it is likely to be conservative. Alternatively, FE analysis can be used to produce more realistic estimates. The cost of using FE analysis is now comparatively low due to the advances in computer hardware and software.

6.4 TRL enhanced design rules for coach-built vehicles

The existing visual inspection rules (Vehicle Inspectorate, undated), described in Section 5.1, are based on the work of the Specialist Transport Advisory & Testing Utility Society (STATUS). These are described as Enhanced Visual Inspection and sometimes as enhanced design rules. Therefore, to avoid confusion, where necessary the further enhancements proposed here are referred to as the ‘TRL enhanced design rules’.

It is thought that there are a number of areas where improvements can potentially be made. This TRL proposal concentrates on increasing the flexibility for manufacturers of coach-built vehicles.

The STATUS rules for coach-built vehicles are for a base vehicle with a chassis that is assumed to have adequate strength. Typically, cross-bearers are placed sideways at intervals above the chassis
and longitudinal sections between the cross-bearers. Seats are normally attached to the longitudinal sections, either directly or via tracking. Minimum section sizes are given for the longitudinal sections, for both M2 and M3 vehicles, for different seat and seat leg configurations, for three ranges of cross-bearer interval and for different tracking options (none, low-profile and heavy-duty). The cross-bearers are required to be slightly stronger than the longitudinal sections. The seats have to have integral seatbelt anchorages and have to have been independently tested. Any tracking used should also have been tested.

No attempt has been made to directly increase flexibility in the choice of cross-bearer. However, increasing choice for the longitudinal sections would automatically increase the choice for the cross-bearer by the rule that links the cross-bearer’s size to that of the longitudinal. The loads on the cross-bearers would be difficult to analyse by simple calculation methods, as the forces from the longitudinal sections will cause torsion, and bending in both vertical and fore-aft directions. Some recommendations are, however, made:

- Normal practice is to link the outboard ends of the cross-bearers, but this is not required by the STATUS rules. This should be made a requirement.
- Currently, moment of inertia (I) values can be used to compare the cross-bearer strength with the next thicker longitudinal section. It is suggested that the section modulus (I/y) be used instead, as this is a better link to the strength of the beam.
- Currently, the strength of the cross-bearers should be the same or greater than the next available thickness of the longitudinal section. If these are standard sections there may not be a suitable available thickness. This could instead be a requirement to increase the section modulus by a minimum percentage, perhaps by 20 percent. Also, the wall thickness of the cross-bearer should be at least that of the longitudinal section.

Attempts were made to calculate the stresses on the longitudinal sections that would be generated in the regulatory pull test for anchorages that are integrated in the seat. For the purpose of the calculations it was assumed that the longitudinal sections were fitted between the cross-bearers with the joints ‘built in’ i.e. totally rigid whereas in reality some movement would occur. The seat was assumed to apply two loads, vertically downward from the front foot and vertically upward from the rear foot. These arise because the seat has to resist the torque about its feet that the test loads applied to the seatbelt anchorages generate. This was calculated by superimposing the bending moments produced by the two forces. However, this calculation produced estimates of bending moments that were well in excess of those that the sections specified by STATUS could safely take. The discrepancy is believed to arise in a large part because the stress in the longitudinal section is reduced by the support from the seat foot, assuming that the foot runs between the front and back legs. TRL has some concerns that the difference in calculated stress was so much higher than the STATUS sections could withstand, however the time available was not sufficient to derive a more accurate method. However, it was thought reasonable for this study to work on the basis that the STATUS requirements were substantially correct, because they have used their testing experience and some validation.

Therefore it was decided to transform the minimum section dimensions of the STATUS design rules for coach-built vehicles into a form where they could be used to specify equivalent strength sections of different form and / or a higher-strength steel. The minimum acceptable strength for the floor members supporting the seats is implied in the STATUS design rules by the material and section specified. The permitted sections in the STATUS design tables can be compared with alternative sections by comparing the section moduli. Therefore the first stage was to substitute section moduli in the design tables. These were calculated from the dimensions specified. This would enable alternative (lighter) sections to be used provided that they had the same or a higher section modulus value to the original steel channel specified.

The next step is to allow for materials of different strength to the mild steel used in the STATUS requirement. This can be taken into account by considering the ratio of strength of the new material to the original STATUS material. These two factors could then be combined to allow any
combination of alternative section and material strength. For example the strength of a 76 by 38 mm standard mild steel channel specified by STATUS (for a double seat with three legs for 600 to 800 mm span) can be matched theoretically by a 100 x 60 x 2 mm channel made from high-strength steel, with a weight reduction of 50 percent.

However, other failure modes will need to be considered and additional rules will be needed to protect against them. Structures with walls that are too thin could fail by local buckling rather than the standard bending failure mode. In particular channel sections can fail by folding in or out of the flanges. The example quoted previously (100 x 60 x 2 mm channel) may be vulnerable to this failure mode.

The section moduli of the sections specified by STATUS were calculated, see Tables 6-1 and 6-2. These correspond to the two Table 1’s in the M2 and M3 coach-built sections of the STATUS document. These are only for seats directly fitted to the vehicle as in the ‘with tracking’ cases the tracking and longitudinal sections form a combined beam. As the combined neutral axis will not be coincident with the neutral axis of the longitudinal section, the section moduli of the longitudinal is less directly relevant in this more complex case. For consistency these are all calculated values, though more accurate values are available for the two standard channels.

Table 6-1. M2 vehicles - Section moduli for the minimum channel sections required by STATUS for vehicles with seats fitted directly to the vehicle

<table>
<thead>
<tr>
<th>Seat type</th>
<th>Distance between successive bearers</th>
<th>Minimum section moduli (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;400 mm</td>
<td>400 mm - 600 mm</td>
</tr>
<tr>
<td>Single</td>
<td>0.93</td>
<td>1.72</td>
</tr>
<tr>
<td>Double with 2 legs</td>
<td>1.72</td>
<td>3.00</td>
</tr>
<tr>
<td>Double with 3 legs</td>
<td>1.33</td>
<td>3.00</td>
</tr>
<tr>
<td>Double with 4 legs</td>
<td>0.93</td>
<td>1.72</td>
</tr>
<tr>
<td>Triple with 3 legs</td>
<td>1.72</td>
<td>3.00</td>
</tr>
<tr>
<td>Triple with 4 legs</td>
<td>1.33</td>
<td>3.00</td>
</tr>
<tr>
<td>Triple with 6 legs</td>
<td>0.93</td>
<td>1.72</td>
</tr>
</tbody>
</table>
Table 6-2. M3 vehicles - Section moduli for the minimum channel sections required by STATUS for vehicles with seats fitted directly to the vehicle

<table>
<thead>
<tr>
<th>Seat type</th>
<th>Distance between successive bearers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;400 mm</td>
</tr>
<tr>
<td>Single</td>
<td>0.64</td>
</tr>
<tr>
<td>Double with 2 legs</td>
<td>1.33</td>
</tr>
<tr>
<td>Double with 3 legs</td>
<td>0.93</td>
</tr>
<tr>
<td>Double with 4 legs</td>
<td>0.64</td>
</tr>
<tr>
<td>Triple with 3 legs</td>
<td>1.33</td>
</tr>
<tr>
<td>Triple with 4 legs</td>
<td>0.93</td>
</tr>
<tr>
<td>Triple with 6 legs</td>
<td>0.64</td>
</tr>
</tbody>
</table>

It was ascertained from discussions with STATUS that they had used safety factors that varied in the range of 1.5 to 3, as they were using a limited set of channel sections. The stress calculation by TRL mentioned above was used to estimate 'safety factors'. Since these are all less than unity the TRL calculation was assumed to be flawed. However, it does provide a guide as to which cases have more or less strength in reserve. These values are shown in Tables 6-3 and 6-4 below.

Table 6-3. M2 vehicles - ‘Relative’ safety factors for the minimum channel sections required by STATUS for vehicles with seats fitted directly to the vehicle

<table>
<thead>
<tr>
<th>Seat type</th>
<th>Distance between successive bearers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;400 mm</td>
</tr>
<tr>
<td>Single</td>
<td>0.16</td>
</tr>
<tr>
<td>Double with 2 legs</td>
<td>0.15</td>
</tr>
<tr>
<td>Double with 3 legs</td>
<td>0.18</td>
</tr>
<tr>
<td>Double with 4 legs</td>
<td>0.16</td>
</tr>
<tr>
<td>Triple with 3 legs</td>
<td>0.15</td>
</tr>
<tr>
<td>Triple with 4 legs</td>
<td>0.16</td>
</tr>
<tr>
<td>Triple with 6 legs</td>
<td>0.16</td>
</tr>
</tbody>
</table>
Table 6-4. M3 vehicles - ‘Relative’ safety factors for the minimum channel sections required by STATUS for vehicles with seats fitted directly to the vehicle

<table>
<thead>
<tr>
<th>Seat type</th>
<th>Distance between successive bearers</th>
<th>400 mm - 800 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;400 mm</td>
<td>400 mm - 600 mm</td>
</tr>
<tr>
<td>Single</td>
<td>0.17</td>
<td>0.18</td>
</tr>
<tr>
<td>Double with 2 legs</td>
<td>0.18</td>
<td>0.29</td>
</tr>
<tr>
<td>Double with 3 legs</td>
<td>0.19</td>
<td>0.25</td>
</tr>
<tr>
<td>Double with 4 legs</td>
<td>0.17</td>
<td>0.18</td>
</tr>
<tr>
<td>Triple with 3 legs</td>
<td>0.18</td>
<td>0.29</td>
</tr>
<tr>
<td>Triple with 4 legs</td>
<td>0.16</td>
<td>0.22</td>
</tr>
<tr>
<td>Triple with 6 legs</td>
<td>0.17</td>
<td>0.18</td>
</tr>
</tbody>
</table>

As discussed above, the aim of calculating the section moduli was so that they could then be used to allow almost any size or form of cross-section, provided the section modulus met the minimum requirements. However, as suggested by the ‘relative’ safety factors in Tables 6-3 and 6-4 the cross-sections proposed by STATUS were based on available sizes so some cross-sections specified were unnecessarily strong when the next standard size down was only just too weak. As steel sections can be tailor made to almost any size it was thought beneficial to reduce the few cases with a large ‘relative’ safety factor. In addition the TRL calculations in Tables 6-1 and 6-2 made no allowance for corner radii which would have slightly overestimated their moduli. Based on this TRL’s suggested moduli are shown in Tables 6-5 and 6-6. The section moduli have been reduced to a convenient round number, so that the current STATUS sections would always be acceptable. The reductions in section moduli have been kept small, except where there appeared to be a greater reserve of strength.

Table 6-5. M2 vehicles - TRL suggestions for minimum section moduli, for vehicles with seats fitted directly to the vehicle

<table>
<thead>
<tr>
<th>Seat type</th>
<th>Distance between successive bearers</th>
<th>400 mm - 800 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;400 mm</td>
<td>400 mm - 600 mm</td>
</tr>
<tr>
<td>Single</td>
<td>0.90</td>
<td>1.65</td>
</tr>
<tr>
<td>Double with 2 legs</td>
<td>1.65</td>
<td>2.90</td>
</tr>
<tr>
<td>Double with 3 legs</td>
<td>1.30</td>
<td>2.80</td>
</tr>
<tr>
<td>Double with 4 legs</td>
<td>0.90</td>
<td>1.65</td>
</tr>
<tr>
<td>Triple with 3 legs</td>
<td>1.65</td>
<td>2.90</td>
</tr>
<tr>
<td>Triple with 4 legs</td>
<td>1.30</td>
<td>2.80</td>
</tr>
<tr>
<td>Triple with 6 legs</td>
<td>0.90</td>
<td>1.65</td>
</tr>
</tbody>
</table>
Table 6-6. M3 vehicles - TRL suggestions for minimum section moduli, for vehicles with seats fitted directly to the vehicle

<table>
<thead>
<tr>
<th>Seat type</th>
<th>Distance between successive bearers</th>
<th>Minimum section moduli (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;400 mm</td>
<td>400 mm - 600 mm</td>
</tr>
<tr>
<td>Single</td>
<td>0.62</td>
<td>0.90</td>
</tr>
<tr>
<td>Double with 2 legs</td>
<td>1.30</td>
<td>2.80</td>
</tr>
<tr>
<td>Double with 3 legs</td>
<td>0.90</td>
<td>1.65</td>
</tr>
<tr>
<td>Double with 4 legs</td>
<td>0.62</td>
<td>0.90</td>
</tr>
<tr>
<td>Triple with 3 legs</td>
<td>1.30</td>
<td>2.80</td>
</tr>
<tr>
<td>Triple with 4 legs</td>
<td>0.90</td>
<td>1.65</td>
</tr>
<tr>
<td>Triple with 6 legs</td>
<td>0.62</td>
<td>0.90</td>
</tr>
</tbody>
</table>

The percentage reductions in moduli of the TRL proposal compared with those calculated for the STATUS sections are shown in Tables 6-7 and 6-8.

Table 6-7. M2 vehicles - Reduction in section moduli in TRL suggestions, for vehicles with seats fitted directly to the vehicle

<table>
<thead>
<tr>
<th>Seat type</th>
<th>Distance between successive bearers</th>
<th>Reduction in section moduli (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;400 mm</td>
<td>400 mm - 600 mm</td>
</tr>
<tr>
<td>Single</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Double with 2 legs</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Double with 3 legs</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Double with 4 legs</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Triple with 3 legs</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Triple with 4 legs</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Triple with 6 legs</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
Table 6-8. M3 vehicles - Reduction in section moduli in TRL suggestions, for vehicles with seats fitted directly to the vehicle

<table>
<thead>
<tr>
<th>Seat type</th>
<th>Distance between successive bearers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;400 mm</td>
</tr>
<tr>
<td>Single</td>
<td>4</td>
</tr>
<tr>
<td>Double with 2 legs</td>
<td>2</td>
</tr>
<tr>
<td>Double with 3 legs</td>
<td>3</td>
</tr>
<tr>
<td>Double with 4 legs</td>
<td>4</td>
</tr>
<tr>
<td>Triple with 3 legs</td>
<td>2</td>
</tr>
<tr>
<td>Triple with 4 legs</td>
<td>3</td>
</tr>
<tr>
<td>Triple with 6 legs</td>
<td>4</td>
</tr>
</tbody>
</table>

Limits would also need to be placed on the sections that can be used. As previously mentioned, local buckling could cause failure if the wall thickness was too thin. The wall thickness also has to be adequate to prevent the fixings pulling through, unless additional washers are used. Channel sections can fail by the flanges folding in or out.

The STATUS rules include tables of sections for two classes of tracking. These could also be treated in a similar way. However, as previously stated, the longitudinal section and the tracking would work together so it would be less appropriate to use the section moduli as the neutral axis of them combined would not coincide with their individual positions. The tracking cases would therefore need further consideration, as if section moduli are used additional ‘rules’ may be needed to ensure that the worst case combination of section and tracking are catered for.

As already noted the other option to reduce weight would be to allow beams made from thinner, higher strength materials. A new reduced section moduli for the stronger material could then be calculated by multiplying it by the proportion of the yield (or 0.2% proof) stress of the original STATUS mild steel over that of the new high strength steel. Alternatively, the requirement could be stated in terms of the yield stress multiplied by the section modulus, which would be the bending moment in units of Nm. The STATUS rules are understood to use a yield stress of 200 MPa. This is low for mild steel, but has been used by them as most of the sections recommended by STATUS are non-standard, and would typically be made by folding sheet. This process will produce weaker sections (with potential for splitting), especially if carried out without considering the grain direction. There are a number of issues that would need to be considered before selecting what material strength to use to find the proportional strength of the new high strength and the original STATUS material:

- What safety factor would be appropriate? There is the risk that the STATUS stress calculations have over simplified the structure, but work because the low yield stress value assumed in their calculations has effectively provided additional safety factor. Reverting to a more accurate yield stress could possibly lose this additional margin. This could be avoided by using a higher yield stress in this reverse calculation, perhaps of 250 or 300 MPa.
- Should specified minimum values of yield stress for high-strength materials be used or should the test values for the specific batch be used? Variation within that batch may mean that the test result is not representative.
- There is a risk that welding could weaken the structure by reducing the local yield stress. The ends of the longitudinal sections experience high stresses, where they would be welded to the cross-bearers.
• Compatibility has to be maintained between longitudinal sections and cross-bearers. Similar materials should be acceptable, but a high-strength longitudinal section welded to a cross-bearer made of a weak material could cause the latter to fail locally.

6.4.1 Advantages and disadvantages of TRL proposal for enhanced design rules

The TRL proposal will allow manufacturers to make lighter vehicles with equivalent strength to the STATUS rules. The TRL proposal will retain the benefits of the STATUS rules which allow complying vehicles to be approved by low-cost inspection. Lighter vehicles will offer considerable benefits in terms of stability and fuel consumption.

However, the STATUS rules are not a guarantee that the vehicle is safe in an accident, but rather, that it would be capable of passing the legislative anchorage pull tests requirements if it were tested. These pull tests have a number of weaknesses. The main weakness in the current context is that only one row of seats is tested at the time. Structures, such as the cross-bearers, could pass the pull test yet fail in an accident when all seats will be loaded simultaneously. The TRL proposal does not address these issues, as the purpose remains to require compliance with legislative standards only.

The TRL proposal could be further improved by adding as necessary good engineering practice rules for connections, gussets, etc. The need for some rules was identified when designing the coach built specimen for the TRL ‘validation’ tests. It is thought that the inclusion of the rules used by TRL to design this specimen, or similar rules, would improve any low cost approval method; see Section 7.2 for TRL’s good engineering rules.

These provisional TRL enhanced design rules are thought to require further refinement before they could be used in a regulation.

There is a potential problem that was highlighted by a steel manufacturer and that is that some high strength stainless steels become brittle at low temperatures (this can be at around 0°C). This is potentially critical in the UK in terms of decreased safety and crash performance during the winter months. While this could apply to any method of testing or inspection, the use of high strength stainless steels would be more attractive to manufacturers if the TRL proposed rules were used instead of the STATUS rules.

7 Validation tests

As highlighted in Sections 5 and 6 of this report, this study has identified a number of methods that could be used in low-cost approval methods. As discussed in the following chapter, Section 8, a multi-approval route appears to be the most reasonable option for approving vehicles made in small numbers, to allow for the different scales of production and methods of construction. Before these ideas can be used to regulate the strength and suitability of seatbelt anchorages in these vehicles they need to be developed so that there is a high level of confidence that they will provide the necessary strength without being unreasonably demanding for manufacturers. They also need to be developed into a set of rules and guidelines that it is feasible for manufacturers to follow.

There was provision within this study to manufacture and test two specimens to give some indication of the potential of up to two of the approval methods proposed. Although these two tests may well be insufficient to give the necessary confidence to use them in a formal approval process they will give some indication of the validity of the idea(s). As already noted it can be seen from Sections 5 and 6 that there are a number of possible methods that could be used.

Some of the approval methods identified are considered not to need validation to show that they will provide suitable anchorages.

However, there is some debate about the appropriateness of using structural over-floor reinforcement kits (and seats) when they have not been tested on all the members of the family of similar delivery vans that they are intended for. For example a design with its track, seat and attachment rule might only have been tested on two out of a family of eight different, but similar delivery vans. An extra
margin of safety can be given by testing worst-case vehicles in the family, by showing that the design exceeds the strength requirements and by requiring more conservative use in the real vehicles than in the test sample (more fixings and smaller pitches). However despite this there is still some doubt as to whether this will give sufficient confidence that the full family of vans would meet the minimum strength requirements.

As discussed in Sections 5.1.1 and 5.3.2 the current VOSA design rules for coach-built vehicles are thought likely to result in seat fixings that exceed the minimum seatbelt anchorage strength requirement. It is thought that they might be improved if they were changed to allow the weight of the structure to be minimised by the use of lighter weight, high strength solutions as outlined in Section 6.4. However, TRL are concerned that the inappropriate yield stresses could be used to calculate revised section moduli and that such solutions might not reach their full theoretical strength due to local failures (buckling).

Taking these points discussed above into account it was decided to carry out validation tests on two different floor samples:

1) A delivery van fitted with an ‘approved’ structural tracking and seat kit.
2) A section of coach-built floor built following enhanced design rules.

In order to be able to test certain areas of the floor beyond the regulatory requirements, stronger M1 seats were fitted.

7.1 Delivery van

As noted above, the main concerns about the use of an approved structural tracking and seat kit with a delivery van is that it may not be appropriate for the untested vans in the family of similar vans. Therefore a delivery van shell was obtained that was one of the untested models within the approved family. Different and stronger seats to those used in the original approval were used to allow the track and vehicle to be loaded beyond the regulatory requirements and to see how alternative seats worked with the tracking and fixings. The manufacturer of the kit also arranged for the tests to be formally witnessed by VOSA so that if they met the regulatory requirements the new configuration could be approved. The van was fitted with a tracking system designed to the approved methods with four rows of seats fitted, as shown in Figure 7.1.
7.2 **Coach-built floor**

First a chassis was obtained of a type commonly used for coach built vehicles and then a floor specimen was designed to fit on the chassis.

7.2.1 **The TRL design**

The TRL proposed enhanced design rules, described in Section 6.4, were used to select suitable cross-sections for high-strength steel floor members. As the design of the floor specimen evolved, a number of problems were encountered which were resolved using good engineering practice. These solutions were converted into rules for specifying gussets, fixings, etc. These rules could be added to the TRL enhanced design rules proposed in Section 6.4. On one side of the specimen, box cross-sections were used for the longitudinal members and on the other side channel cross-sections were used. This arrangement was adopted so that two different solutions could be tested within one sample.

As discussed in Section 6.4, to allow for stronger materials TRL propose to use the proportions of the yield (or 0.2% proof) stress presumed by STATUS for mild steel over that of the new high-strength steel. The calculation used can be defined as:

\[
\text{MATERIAL SectionModulus} = \frac{\text{STATUS } \sigma_y}{\text{MATERIAL } \sigma_y} \times \text{STATUS SectionModulus}
\]

The value for the yield stress of steel used in the STATUS calculations was 200 MPa which is at the low end of the range found with mild steel. For STATUS, using a low value gave an added safety factor to their calculations, but the reverse will be true when it is used to find a conversion factor for high strength material. The TRL coach-built floor specimen was made from Cromweld stainless steel and the stated properties for the yield stress of the material were a minimum of 320 MPa with a
typical value of 376 MPa. In a situation where a range is given for the yield stress, TRL propose that
the lowest value should be taken as this will give an added safety factor. However, for the purpose of
validating this design method it was decided to reduce the safety factor for the specimen by taking the
typical value for the new material and the lowest value (200 MPa) for the STATUS mild steel.

The actual dimensions of the TRL floor are shown in CAD drawings in Appendix A.

7.2.1.1 Longitudinals

The spacing of seat longitudinals in the floor was arranged to fit M1 doubles with 3 legs at a seat pitch
of 750 mm as this represented one of the worst case loadings for the floor. The strength of the
longitudinal to which the seat was mounted was determined by looking up the minimum allowed
section modulus for an M2 vehicle and this was 4.0 cm$^3$ as shown in Table 6.5 of Section 6.4.

In this study Cromweld stainless steel was used to make the sample floor. As discussed in
Section 7.2.1 above, to allow for the use of stronger materials TRL propose to use the proportions of
the yield stress of the original STATUS mild steel over that of the new high strength steel. For this
specimen, to reduce the safety factor, a low value was used for the STATUS steel of 200 MPa and a
typical value of 376 MPa instead of the minimum was used for the Cromweld. This meant that a
section modulus of at least 2.12 cm$^3$ ((200/376) × 4 cm$^3$) was required for a longitudinal made from
Cromweld. The dimensions for the box and channel longitudinals for the specimen were then
selected to exceed this minimum section modulus value. However, the sections actually chosen
exceeded the minimum value by some margin, the channel section modulus was 2.67 cm$^3$ and the box
section 3.16 cm$^3$. With these sections selected, TRL then defined rules for the cross-member
dimensions and a number of good engineering rules that were applied to specify the dimensions,
design, etc. for the rest of the chassis.

7.2.1.2 Cross-members

The cross-members run across the vehicle width and provide support for the seat mounting
longitudinals. The longitudinal members are typically fitted between deeper cross-members. It is
important that these sections are at least as strong as the longitudinal members and secured in place as
they provide the structural stability of the floor. Cross-members are often made from tall sections to
get the floor clear of the wheels. In such situations there is a risk of lozenging in real accidents and
therefore good engineering practice is to prevent this by the use of appropriate packing and / or using
gussets (see Section 7.2.1.4 for packing sections).

TRL suggest that:

- ‘The cross-member section should be no thinner than the longitudinal and have a section
  modulus at least 20 percent greater than that required for the longitudinal’.
- For cross-member sections up to 1.5 times the height of the longitudinal no gussets are
  required between the cross-member and the longitudinal. For sections where the H/h value is
  greater than 1.5, gussets are required, see Figure 7.2.

![Figure 7.2 Rules for gussets between cross-member and longitudinal](image-url)
Gussets should be used between the chassis rail and the cross-members where the cross-members are tall and ‘tower’ like. Tall cross-members are sometime used to give a flat floor above the wheels. These structures are prone to lozenging in a frontal crash, particularly channel type cross-members used on edges. As a guideline if the base of a ‘tower’ is less than the height then a gusset should be used, see Figure 7.3. However, gussets or other forms of diagonal brace may be needed for shorter ‘towers’ if they are particularly prone to lozenging. It is also recommended that this guideline be used for any tower like structure that is likely to lozenge in a frontal crash.

![Diagram](image)

**Figure 7.3 Rule for gussets between tall cross-member and chassis**

### 7.2.1.3 Longitudinal adapter

Many coach-built vehicles have two longitudinal beams which are attached to each main chassis rail. The floor cross-members are then fixed to these longitudinal beams or adapters. The longitudinal adapters are attached directly to the chassis unless packing is required to raise the floor over the wheels. Some designs do not use these beams at all and in these circumstances the cross-members are attached directly to the chassis rails (tall cross-members are often used so that the floor clears the wheels).

TRL suggest that the adapter should be:

- At least as heavy gauge as the cross-members
- At least 1.5 times the height of the cross-members
- At least 1/2 as wide as the chassis rails

To produce a completely flat floor the height of the floor above the chassis rails should be sufficient to clear the wheels with the suspension fully compressed. The floor can be raised by packing sections between the chassis and the underside of the longitudinal adapter (this would be better than using tall cross-members that are prone to lozenging).

If packing sections between the chassis and the longitudinal adapter are required, TRL suggest they should be:

- At least as heavy a gauge as the adapters
• Long enough to prevent lozenging by having a length to height ratio of more than one (L/h>1)
• At least as wide as the adapters

7.2.1.4 Overhanging floors

Many chassis used for coach-built vehicles are comparatively narrow, resulting in the floor having to overhang it at each side. TRL suggest that gussets should be used where floor cross-members overhang the chassis a significant distance. The proposed rule for this is that gussets should be added when the overhang is one third or more of the total floor width, see Figure 7.4

![Figure 7.4. Rule for gussets for overhanging floor structures](image)

7.2.1.5 Gussets

Ideally gussets should be as large as possible (wide and deep). For gussets attached by welding they should be approximately the same gauge as the members they are to be attached to.

Where gussets can be loaded in compression then they should either be made of thin metal and stiffened by bending a right angle flange on the diagonal or made of thick metal.

7.2.1.6 Load-spreading washers

Load-spreading washers should be used as necessary for the seat leg fixings. For the rear seat feet they should be used on the underside of the longitudinal to prevent the fixing bolts pulling through the longitudinal and for the front feet they should be used on top of the longitudinal (or the overlying floor board) to prevent the feet from punching through.

7.2.2 TRL coach-built floor

The coach-built floor designed for this study complied with the design rules listed in Section 7.2.1. The floor had to be raised approximately 290 mm to be above the travel of the suspension and to give
enough clearance for vehicle yawing whilst cornering. Therefore packing pieces were used to raise the floor 290 mm; these were made long to prevent lozenging. The floor structure was made from Cromweld stainless steel which was supplied in the required sections, cut to length and then welded together. TIG welding was used on the chassis due to the thin walls of some of the materials used. The floor was fastened to the chassis by a series of fixing plates bolted to the packing pieces and chassis. As this was only a section of a coach-built floor and no bodywork was to be attached, a side brace was welded to the ends of the cross-members. Figure 7.5 shows the TRL coach-built floor (without the plywood floor and seats) attached to the chassis. Although the TRL floor section was designed to fit a size of chassis normally used to make M3 vehicles it was designed to meet M2 loads as this was thought to be a more demanding validation test, as the higher forces would be more likely to provoke buckling or tearing failures.

The seats were attached to the floor by M12 bolts, and load-spreading washers were placed under the front seat foot and under the floor for the rear foot. In a previous study into retro-fit seat belts Lawrence and Hardy (1997) estimated that the minimum plate (washer) circumference for spreading the seat loads on the floor was 250 mm (65 x 65 mm or 40 x 90) for a seat with an integral 2-point belt for a 1.6 mm thick steel floor, however, they were unable to provide similar guidance for 3 point belts. The dimensions of washers chosen by TRL were 75 x 35 x 4 mm thick and they were again made from Cromweld. Figure 7.6 shows the load spreading washers in place before testing. Two plates were used under the rear feet (the load washers used by TRL were deliberately rather small in order to produce a low factor of safety).
Whilst assembling the seats it was found that some of the welds on two of the seat legs looked rather poor quality, as the welds had some holes in them and were not very tidy. The strength of these welds is critical in determining the performance of the seats. The quality of the welds is an important issue and quality control is vital, as is discussed in Section 4.3. These legs were marked and used on the coach-built specimen for the left hand window seats, row 1, which was tested to M2.

7.3 Test results

Some of the seat belt anchorages in both the van conversion and the coach built floor section were subjected to a M2 pull test and some to a M1 pull test. The aim of the more demanding M1 pull test was principally to determine the safety factor of the M2 design. However, the company who designed the van conversion kit were also interested in obtaining M1 approval for some seat and mounting combinations.

7.3.1 Delivery van tests

The results of the anchorage pull test of the delivery van are shown below in Table 7-1, for convenience the floor plan is shown again, see Figure 7.7.
Figure 7.7 Van seating configuration for validation testing
Table 7-1. Results of testing a delivery van fitted with structural tracking to M1 and M2 requirements

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Belt</th>
<th>Seat type</th>
<th>Seat mass (kg)</th>
<th>Hold time (s)</th>
<th>Load required # (daN)</th>
<th>Peak load achieved (daN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4827</td>
<td>LH Lap</td>
<td>M2 Treble – 3 legs</td>
<td>64.8</td>
<td>0.591</td>
<td>886.7</td>
<td>898.2</td>
</tr>
<tr>
<td>Row 4</td>
<td>LH Diagonal</td>
<td></td>
<td></td>
<td></td>
<td>675.0</td>
<td>748.3</td>
</tr>
<tr>
<td>(back)</td>
<td>Ctr. Lap</td>
<td></td>
<td></td>
<td></td>
<td>886.7</td>
<td>926.9</td>
</tr>
<tr>
<td># tested to M2</td>
<td>Ctr. Diagonal</td>
<td>M2 Treble – 3 legs</td>
<td>64.8</td>
<td>0.591</td>
<td>886.7</td>
<td>926.9</td>
</tr>
<tr>
<td></td>
<td>RH Lap</td>
<td></td>
<td></td>
<td></td>
<td>675.0</td>
<td>711.5</td>
</tr>
<tr>
<td></td>
<td>RH Diagonal</td>
<td></td>
<td></td>
<td></td>
<td>886.7</td>
<td>912.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>675.0</td>
<td>676.7</td>
</tr>
<tr>
<td>C4828</td>
<td>LH Lap</td>
<td>M1 Single – Side mounted</td>
<td>27.8</td>
<td>0.73</td>
<td>1899.2</td>
<td>1899.7</td>
</tr>
<tr>
<td>Row 3</td>
<td>LH Diagonal</td>
<td></td>
<td></td>
<td></td>
<td>1350.0</td>
<td>1415.1</td>
</tr>
<tr>
<td># tested to M1</td>
<td>Ctr. Lap</td>
<td></td>
<td></td>
<td></td>
<td>1899.2</td>
<td>1909.2</td>
</tr>
<tr>
<td></td>
<td>Ctr. Diagonal</td>
<td></td>
<td></td>
<td></td>
<td>1350.0</td>
<td>1422.2</td>
</tr>
<tr>
<td></td>
<td>RH Lap</td>
<td>M1 Single – Side mounted</td>
<td>27.8</td>
<td>0.73</td>
<td>1899.2</td>
<td>1909.1</td>
</tr>
<tr>
<td></td>
<td>RH Diagonal</td>
<td></td>
<td></td>
<td></td>
<td>1350.0</td>
<td>1347.0</td>
</tr>
<tr>
<td>C4829</td>
<td>LH Lap</td>
<td>M2 Double – 2 Legs</td>
<td>44.4</td>
<td>5.87</td>
<td>892.7</td>
<td>917.0</td>
</tr>
<tr>
<td>Row 2</td>
<td>LH Diagonal</td>
<td></td>
<td></td>
<td></td>
<td>675.0</td>
<td>741.0</td>
</tr>
<tr>
<td># tested to M2</td>
<td>Ctr. Lap</td>
<td></td>
<td></td>
<td></td>
<td>982.7</td>
<td>919.5</td>
</tr>
<tr>
<td></td>
<td>Ctr. Diagonal</td>
<td></td>
<td></td>
<td></td>
<td>675.0</td>
<td>766.9</td>
</tr>
<tr>
<td></td>
<td>RH Lap</td>
<td>RIPS Seat</td>
<td>49.5</td>
<td></td>
<td>1160.0</td>
<td>1178.4</td>
</tr>
<tr>
<td></td>
<td>RH Diagonal</td>
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<td></td>
<td></td>
<td>675.0</td>
<td>679.1</td>
</tr>
<tr>
<td>C4830</td>
<td>LH Lap</td>
<td>M1 Single</td>
<td>27.8</td>
<td>0.72</td>
<td>1895.7</td>
<td>1900.9</td>
</tr>
<tr>
<td>Row 1</td>
<td>LH Diagonal</td>
<td></td>
<td></td>
<td></td>
<td>1350.0</td>
<td>1480.2</td>
</tr>
<tr>
<td># tested to M1</td>
<td>Ctr. Lap</td>
<td></td>
<td></td>
<td></td>
<td>1797.6</td>
<td>1826.8</td>
</tr>
<tr>
<td></td>
<td>Ctr. Diagonal</td>
<td></td>
<td></td>
<td></td>
<td>1350.0</td>
<td>1414.9</td>
</tr>
<tr>
<td></td>
<td>RH Lap</td>
<td>M1 Double – 3 Legs</td>
<td>45.6</td>
<td></td>
<td>1797.6</td>
<td>1835.7</td>
</tr>
<tr>
<td></td>
<td>RH Diagonal</td>
<td></td>
<td></td>
<td></td>
<td>1350.0</td>
<td>1377.6</td>
</tr>
</tbody>
</table>

The van converted by fitting an approved tracking kit would have been classed as an M2 vehicle. It can be seen from the results in Table 7-1 that it passed the M2 requirements on all seats tested to M2. Observation of the M2 seat test showed very little deformation of the seat, tracking and the floor. Some seats were tested to M1 and although there was some deflection in the seat back, as shown in Figure 7.8, they nevertheless passed all the M1 requirements. There was also minimal damage caused to the plastic reinforcement in the seat top where the seatbelt comes out of the seat. In passing the M1 requirements it can be assumed that they would have also passed the less demanding M2 requirements. All the seats fitted in the delivery van met the requirements of Regulation ECE R14.05 paragraph 5 and inspection of the vehicle showed that there was no obvious deformation or damage to the van floor or side structures caused by testing the van.
7.3.2 Coach-built floor tests

The results for testing the coach-built floor are shown in Table 7-2, see Figure 7.9 for seat configuration. Calculation of the mass of the TRL floor and of a similar one made to the STATUS design rules showed a weight saving of about 50 percent. The mass of the completed TRL floor section was compared with that of a conventional M3 floor and it was found that the mass of the TRL M2 floor was about half that of the ‘weaker’ M3 floor.
Table 7-2. Results of testing the TRL coach-built floor to M1 and M2 requirements

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Belt</th>
<th>Seat type</th>
<th>Seat mass (kg)</th>
<th>Hold time (s)</th>
<th>Load required # (daN)</th>
<th>Peak load (daN)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LH Window Lap</td>
<td>M1 Double fixed to channel</td>
<td>898.8</td>
<td></td>
<td>911.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LH Window</td>
<td>M1 Double fixed to channel</td>
<td>675.0</td>
<td></td>
<td>678.89</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LH Window</td>
<td>M1 Double fixed to channel</td>
<td>898.8</td>
<td></td>
<td>917.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LH Aisle Lap</td>
<td>M1 Double fixed to channel</td>
<td>675.0</td>
<td>0.754</td>
<td>678.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LH Aisle Lap</td>
<td>M1 Double fixed to channel</td>
<td>675.0</td>
<td></td>
<td>689.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LH Aisle Lap</td>
<td>M1 Double fixed to channel</td>
<td>898.8</td>
<td></td>
<td>916.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RH Aisle Lap</td>
<td>M1 Double fixed to channel</td>
<td>675.0</td>
<td></td>
<td>682.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RH Aisle Lap</td>
<td>M1 Double fixed to channel</td>
<td>675.0</td>
<td></td>
<td>682.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RH Window Lap</td>
<td>M1 Double fixed to channel</td>
<td>4500.0</td>
<td>1350.0</td>
<td>1082.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RH Window Lap</td>
<td>M1 Double fixed to box</td>
<td>4500.0</td>
<td></td>
<td>Not achieved</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RH Window Lap</td>
<td>M1 Double fixed to box</td>
<td>1350.0</td>
<td></td>
<td>970.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RH Window Lap</td>
<td>M1 Double fixed to box</td>
<td>1797.6</td>
<td></td>
<td>1349.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RH Window Lap</td>
<td>M1 Double fixed to box</td>
<td>1350.0</td>
<td></td>
<td>683.41</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RH Window Lap</td>
<td>M1 Double fixed to box</td>
<td>1797.6</td>
<td></td>
<td>1559.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RH Window Lap</td>
<td>M1 Double fixed to box</td>
<td>1350.0</td>
<td></td>
<td>867.31</td>
<td></td>
</tr>
</tbody>
</table>

The results from testing the floor showed that the TRL sample floor designed to meet the TRL enhanced design rules for M2, but with a lower factor of safety than TRL will recommend to others, passed the M2 requirements when fitted to a chassis normally used for M3 coach-built vehicles. The legs with the apparently poor quality welds used on the coach-built specimen for the left hand window seats, row 1, showed no distress in the test. Although flexing of the floor during the M2 pull test was acceptable the floor longitudinals were found to be somewhat distressed after the test, see Figure 7.10.
Testing the floor beyond M2 requirements (with the pull rig set for M1) caused a catastrophic failure in the floor. The overall force on each seat pair in the row tested to M1 was significantly in excess of the M2 requirements; however, the pulling forces were not well balanced, as can be seen in Table 7-2, probably due to some rams having to contend with large displacements. Figure 7.11 below shows the force time histories of the loads applied to the seat belt pull blocks for this test and the sudden drops in force shows both the first individual failures and the final catastrophic failure.

![Figure 7.10 The coach-built floor following an M2 test of row 1](image)

![Figure 7.11: Load transducer time histories for the M1 test to row 2 of the TRL coach-built floor](image)
It was not possible to be clear as to where the first failure occurred from observing the test but the impression gained was that failures occurred first in the right hand side of the row (the box longitudinals) which caused a jerk, which precipitated the final failure. The time histories tend to suggest that the first failure occurred in the floor of the right-hand aisle seat.

As previously mentioned, the right hand longitudinal floor members were made from box section and the left hand side from U-Channel. As discussed, it appears that the box section in this instance was not as strong as the channel. This may be due to the fact that it was thinner material with only a 1.5 mm wall thickness; it failed at the welds around the anti-crush tubes as shown in Figure 7.12. The slightly thicker U-channel failed around the seat mounting holes as shown in Figure 7.13. The use of larger load spreading washers might have improved the situation slightly; however, it is thought that the ultimate failure mode would have been the same. For the channel the failure by the bolt hole demonstrates that the bolt hole will have a larger weakening effect on a small beam made from high strength steel than it will have on a larger mild steel beam.

The target section modulus values for the TRL floor beams were deliberately selected to give a low factor of safety. However, selection of the nearest round size up meant that in fact that the safety margin was higher than intended. The failure loads for the anchorages as a percentage of M1 and M2 requirements are shown in Table 7-3. The table shows that the lap belt loads for all the seats were all at least 50 percent greater than the M2 requirements. The ‘low’ failure loads on the two right hand diagonal belts are thought to be due to the pulling rams having to contend with large displacements.

<table>
<thead>
<tr>
<th>Seat Belt</th>
<th>M1 Requirement (kN)</th>
<th>M2 Requirement (kN)</th>
<th>Peak Load (kN)</th>
<th>Percentage of M1 loads achieved</th>
<th>Percentage of M2 loads achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>LH Window Lap</td>
<td>1797.6</td>
<td>898.8</td>
<td>1684.1</td>
<td>93.7%</td>
<td>187.4%</td>
</tr>
<tr>
<td>LH Window Diagonal</td>
<td>1350.0</td>
<td>675.0</td>
<td>1082.5</td>
<td>80.2%</td>
<td>160.4%</td>
</tr>
<tr>
<td>LH Aisle Lap</td>
<td>1797.6</td>
<td>898.8</td>
<td>1715.9</td>
<td>95.5%</td>
<td>190.9%</td>
</tr>
<tr>
<td>LH Aisle Diagonal</td>
<td>1350.0</td>
<td>675.0</td>
<td>970.5</td>
<td>71.9%</td>
<td>143.8%</td>
</tr>
<tr>
<td>RH Aisle Lap</td>
<td>1797.6</td>
<td>898.8</td>
<td>1349.3</td>
<td>75.1%</td>
<td>150.1%</td>
</tr>
<tr>
<td>RH Aisle Diagonal</td>
<td>1350.0</td>
<td>675.0</td>
<td>683.4</td>
<td>50.6%</td>
<td>101.2%</td>
</tr>
<tr>
<td>RH Window Lap</td>
<td>1797.6</td>
<td>898.8</td>
<td>1559.7</td>
<td>86.8%</td>
<td>173.5%</td>
</tr>
<tr>
<td>RH Window Diagonal</td>
<td>1350.0</td>
<td>675.0</td>
<td>867.3</td>
<td>64.2%</td>
<td>128.5%</td>
</tr>
</tbody>
</table>
7.4 Discussion of the TRL validation tests

The validation test to the van, fitted with an approved kit of structural tracking and under-floor load spreaders, show that the system tested was well designed and met the requirements easily. For this system the result suggests that there would be high confidence that it would meet at least the M2 requirements when fitted to any of the approved family of vans that it was designed for, provided the kit was fitted in the approved manner. There would also be a reasonably high confidence that any van in the family converted with this system would meet the M1 requirements when the seats were fitted at the same positions (some customers request anchorages stronger than the regulatory requirements).

The validation test of the TRL coach-built floor specimen showed that the floor met the M2 requirements; however, it was clear that there was a relatively small safety margin. The failure modes showed that TRL’s concerns that the structure might fail by buckling or tearing appeared to be justified by the failures in the overload test. Designing and testing to the M2 requirements rather than for the less demanding M3 requirements, means that higher loads were applied to the floor. However, in hindsight the risk of buckling or tearing failures might have been worse in the M3 case, because the current TRL method might have allowed thinner sections. In most cases, users of the rules would round-up to the nearest convenient size giving an extra margin of safety, however this should not be relied on. Therefore, although the TRL specimen passed the regulatory requirements it would be prudent to require additional measures to improve confidence in the TRL enhanced design rules. These could be achieved by using more conservative yield stress values to convert the section moduli and by introducing additional rules for section shape and wall thickness. With further work to improve the TRL enhanced design rules they appear to be a good option. The principles applied to the TRL floor show that a lightweight strong structure can be designed at relatively low costs. The savings of such lightweight structures could be considerable, by reducing fuel consumption and reducing the risk of accidents by improving stability due to the low weight of the floor structure.

An alternative but less likely conclusion could be drawn from the TRL results, where the specimen was made to have ‘equivalent’ strength to that required by STATUS. This is that the original STATUS rules might not have a sufficient margin of safety to account for a worst case use of minimum strength steel. In most cases the strength of steel exceeds the minimum strength requirements by a large margin so by using their experience of what was known to pass, STATUS may not have made sufficient allowance for the use of minimum strength steel.

8 Discussion of multi-route approval methods

In developing more formal low-cost approval methods, for seatbelt anchorages in vehicles produced in small numbers, a number of factors should be taken into account. These should include:

- The cost and effectiveness of the method
- Suitability for the type of vehicle
- Consequences of over-design

Also, ideally, they should use existing approval methods to make best use of the intellectual investment already made by the industry.

However, first it would be logical to examine the intentions of the regulatory test in order to determine in which accident situations anchorages were intended to be effective. Ideally any low-cost approval method should result in vehicles and anchorages which would provide the best outcome in any survivable accident or potential accident situation. This would obviously be preferable to methods that proved the required anchorage strength but compromise other functional or primary safety aspects, for example by causing a higher rollover risk in coaches with ‘high floors’. This is discussed in the following section.
8.1 Intentions of the current anchorage regulation

Unfortunately no succinct summary of the intentions of the authors of the regulatory tests, UN ECE Regulations 14 and 16, for seatbelt anchorages and seatbelts could be found, however, some reasonable assumptions can be made. Firstly, from both the anchorage pull-test force and the dynamic test for the complete restraint system, it can be concluded that the tests, with some additional margin of safety, represent a simplification of the forces seen when the test vehicle impacts a car head on, both travelling at a speed of about 50 km/h. Secondly, it can be assumed that it was intended that when fully occupied, all the seatbelt anchorages should remain attached to the vehicle structure during the crash so that the anchorages’ deceleration, and through the seatbelt the occupant’s deceleration, is controlled by the vehicle deformation. As the regulations were originally only intended for cars they require all belt anchorages of the same row of seats to be tested simultaneously. Because of this and the integrated design of the bodywork of a car it can be safely assumed that all of the anchorages would remain attached to the vehicle structure in a severe 50 km/h impact.

However, large vehicles were later added to the scope of the regulation and for these larger vehicles the situation regarding integrity of all the anchorages when simultaneously loaded in an accident is less clear. Larger minibuses, buses and coaches normally have a separate chassis and it is the chassis which is likely to make contact and absorb energy in impacts with other vehicles and objects. However, the seats with their integrated anchorages are not necessarily attached directly to the chassis, but instead to the floor structure and in all the vehicles seen except the ‘Direct to chassis floor’ buses, the attachment of the floor structure to the chassis was indirect. Therefore, ideally, tests to represent a 50 km/h crash test for these vehicles an integrity test of the floor to chassis connection should be included. This should include the seatbelt loading and the load due to the mass of the floor and any vehicle bodywork attached to the floor. The occupant loads could be reproduced by simultaneously testing all the seatbelt anchorages using the current regulatory anchorage tests. Although this will not include any forces due to the floor and bodywork, because the quasi-static regulatory anchorage test is of a longer duration than a typical crash it would probably be a reasonable solution. However, this is thought to be impractical due to the larger number of seats in these vehicles, which would require many pulling jacks and also because one row of seats would obstruct access of the test equipment to other rows. Therefore, regulatory tests to the anchorages in large vehicles generally involve only simultaneous loading of up to one row of seats.

Obviously it would be unnecessary to include an integrity test if those designing the vehicles adequately took these forces into account. Of the vehicles examined by TRL, none gave reasons for strong concerns about vehicle integrity, nevertheless, in the authors’ opinion many designers had not taken sufficient effort to consider these loads, as demonstrated by a general absence of diagonal braces to transfer frontal impact loads between floor and chassis. In the authors’ opinion the side body panels were playing a critical role in providing the required integrity, which may not have been fully recognised by the vehicle designers. Also, the relatively recent introduction of seatbelts in these vehicles means that the total load transferred between the floor and the chassis has been significantly increased by requiring it indirectly to restrain the vehicle occupants, making the integrity issue a new one.

It can be concluded from the above discussion that for large vehicles both a low-cost and the full-cost regulatory test methods should ideally include an integrity test of the vehicle structure. However, as an integrity test is not practical in the current regulatory anchorage test it has been concluded that it is outside the scope of a low-cost method for this current study. Nevertheless, because structural integrity is such an important requirement, TRL recommends that the designers of vehicles with a separate passenger floor should, at the very least, be required to calculate the forces on the floor structure. This can be done using the floor mass and the mass of any structures attached to the floor, which will include the mass of the seats and a full complement of passengers. Using the correct units the total mass or sub-masses can be multiplied by the acceleration given in the following table to find the forces. The designers should then be required to identify the members carrying these forces to the chassis and show, using simplified calculations and stated assumptions (such as short impact duration, justifying the use of ultimate material strengths) why they consider them to be sufficient. Table 8-1 gives the accelerations that equate to the current regulatory requirements.
Table 8-1: Crash accelerations that equate to the Regulation 14 anchorage tests

<table>
<thead>
<tr>
<th>Vehicle class</th>
<th>Acceleration (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>20</td>
</tr>
<tr>
<td>M2</td>
<td>10</td>
</tr>
<tr>
<td>M3</td>
<td>6.6</td>
</tr>
</tbody>
</table>

8.2 Summary of the potential of approval options

8.2.1 Independent test of seats with integral anchorages

Currently Regulation 14 requires seatbelt anchorages fixed to the seat or the vehicle structure to be tested only when assembled as a complete seat and body-shell structure. There is no formal test for seats as independent units. However, an independent test of the seat is necessary for any low-cost method that effectively approves just the floor mountings as being suitable for use with a seat that has integrated anchorages. This could be resolved by introducing compulsory independent testing of all seats for use in any type of large passenger carrying road vehicles, including those for non-PSV use.

Independent testing would provide a supply of approved seats for use in vehicles of any vehicle type. It is proposed that the seat be tested on a rigid floor, with a rigid side wall if side-fixing seats are to be tested. Worst-case testing would be used for seats that allow adjustment for leg position and optional leg lengths to provide leg position adjustment rules and maximum allowed leg lengths. It could also be used to determine seat attachment-forces which could be used to judge their suitability for replacing approved seats for both approved designs of new vehicles and for retro-fitting to older vehicles for refurbishment or change of use.

8.2.2 Design rule methods

The STATUS / VOSA design rules can be applied to buses and coaches with low-floors and minibuses made by coach-building onto a chassis or by converting delivery vans. They were introduced as a temporary low cost approval method and specify how the vehicle should be made or converted. The main criticisms of the method are that they are conservative and do not allow the weight of the structure to be minimised by the use of lighter weight, high strength solutions. A further concern is that if not implemented sensibly they might in practices provide inadequate seat attachments. They are also thought to give insufficient guidance on attaching fixings for side mounted seats.

The TRL enhanced design rules described in Section 6.4, when combined with the good engineering rules, including those outlined in Section 7.2.1, would overcome the first two of these problems for coach-built vehicles. The validation test discussed in Section 7.4 appears to show that this method works, however, further development of the design rules would be needed before they could be used as a regulatory approval method. There are issues, concerning side mountings and the use of tracking, that have not been addressed in the TRL enhanced design rules and validation tests.

If TRL enhanced design rules for coach-built vehicles were integrated with the current VOSA design rules for other vehicle types then they could be used to approve all PSV type vehicles with the exception of most high-floor coaches. Ideally the combined package of TRL and VOSA design rules would be further enhanced and ‘tidied-up’ in this process.
8.2.3 Structural over-floor systems reinforcement (tracking)

This method makes use of the regulatory pull test to approve kits for van conversion or for use with coach-built floors. Alternatively, approval of various seat types, seat attachment methods (including bolted in directly) and seat layouts for a specific vehicle or a specific coach-built floor and chassis combination can be obtained by regulatory testing of one or more specimens on a worst case basis. The method can potentially be used for any PSV and for minibuses sold for non-PSV use.

The concern of using worst-case testing selected by engineering judgment in the approval method has been addressed to some extent in the validation tests of the van conversion. In this case the good performance of the kit in passing the M1 tests when it was approved for the less demanding M2 requirement shows that it exceeded the M2 requirements when used in a van not originally tested. This shows that the approval method combined with the standard of engineering judgment that was used in this case provided a good safety margin. However, it does not prove that it would have worked with a poorer standard of engineering judgment. Unfortunately it is difficult to prescribe a standard of engineering judgment in a regulation; however, in reality some judgment is always needed.

Nevertheless, the results of tests to the tracking system fitted in a delivery van and seats that were previously untested, supports the idea that such systems can be approved for a family of vans by looking at their construction and reading across good/bad design features. The use of different seats to those previously approved by pull tests show that well engineered tracking systems can be used with any approved seat.

8.2.4 Floor inserts

The approval of floor inserts makes use of the current (high cost) regulatory tests. However, by supplying kits to others the cost of approval can be shared, making it effectively a low-cost method.

The attachment of floor inserts by bolting can be policed by visual inspection, however, there is no practical visual method for glued in inserts. The problem of detecting poor glue adhesion is outside the scope of this study. However, requiring proof of training and use of a check list for each vehicle made or requiring test specimens to be produced for each vehicle made might give improved confidence. Test specimens might consist of ones covered with oil, to represent a used vehicle, or one with poorly adhering paint, because the glue is claimed to penetrate paint if used correctly.

8.2.5 Static seat attachment strength tests

With this idea the seat attachment points in the vehicle are tested using a simple loading frame and jack to reproduce a simplified representation of the forces seen in a separate test of the seat. Although this method has a number of advantages it would require investment in new test equipment.

8.2.6 Seat testing on generic floor and side-walls to define fitting rules

This method would be suitable for converting delivery vans and for making coach-built vehicles that had a similar structure to the generic module. This method has several advantages, the most significant of which is that it would simply reproduce the seat-to-vehicle structure interactions seen in real vehicles and that small manufacturers could obtain approval by simply using approved seats and following the rules. However, it would not accommodate very well the diversity of vehicle designs seen in this study and might in many cases not provide the necessary confidence.

8.2.7 Approval of anchorages in the vehicle by calculation

A small number of specialist vehicles such as kit cars will be produced in low volumes. A few might be one-off vehicles such as an electric car built by an enthusiast. Most of these low-volume vehicles
are thought to be made on space frames or chassis. For these vehicles, TRL has propose that static-loading stress-analysis calculations be carried out for the vehicle and compared with the stresses caused if the regulatory pull test force was applied statically. If suitable conservative simplifications are used in the calculation method then there should be a high safety factor. It should therefore be particularly suitable for low-volume cars where high-strength anchorages in the vehicle should be relatively easy to achieve.

8.2.8 Destructive testing all low-volume vehicles

The current regulatory anchorage test can be used to test all vehicles produced in small numbers and this would obviously provide a good level of confidence that all subsequent vehicles of the same type would comply. For vehicles produced in small numbers this method would not produce as high a level of confidence as a mass produced vehicle because the construction methods used are likely to result in greater variability. Obviously this option could not be classed as a low-cost solution, and would have serious cost implications for small manufacturers. Nevertheless, it would be a reasonable fall-back position for all cases of dispute and for vehicles where the design was such that low-cost methods are considered unsuitable. Coaches with a ‘high floor’ are an example where low-cost methods are thought to be unsuitable. As coaches are typically made in moderate numbers it may not be considered necessary to develop a low-cost method for them. If a low-cost method is required then it may be practical to develop a design rule method similar to that proposed by TRL; this would need to be combined with suitable good engineering rules. However, this method may give unacceptably low confidence levels as the factors of safety to allow for uncertainties in the method would have to be kept small in order to avoid unacceptably high centres of gravity which would have a seriously detrimental effect on vehicle stability and hence primary safety.

8.3 Options for low-cost approval methods

As previously mentioned there are a number of different types of vehicle construction, which reflect the use, vehicle type, size and body shell or chassis of vehicles being made. There are also a number of potential test methods already in use together with the additional ones devised or refined by TRL, each with its own advantages, disadvantages and limitations. It is also clear that for some vehicles, such as coaches with high passenger floors the results of using a low-cost approval method might be to require vehicles to have unnecessarily strong and heavy floors which could have detrimental effects on primary safety.

Taking these factors into account it is not considered feasible to use one set approval method to meet the targets of approval cost effectiveness, for all types of vehicle. Therefore it is proposed to use a combination of approval methods in a multi-route approach. Not only will this give the necessary confidence that the anchorage-strength requirements are met in low-volume vehicles, but it will be less likely to inhibit the current diversity of vehicles and scales of manufacturing.

A total of eight possible approval methods have been outlined above. The new TRL static seat attachment strength test method has several advantages, however it is not recommended due to the initial investments costs. Seat testing on generic floor and side-walls to define fitting rules has some advantages but the generic floor may be too dissimilar to those of real vehicles to give confidence. Approval of floor inserts already makes use of the regulation approval method so this cannot be regarded as a new method. If these methods are excluded then there are five methods considered suitable for use within a multi-path low-cost test approval method.

The test options that are recommended for a multi-path approval system are:

1. Independent test of seats with integral anchorages on a rigid floor and side-wall, to show that the anchorages in the seat met the strength requirements and to define seat leg adjustment limits. This would include an option to record seat attachment forces.

2. Enhanced design rule methods.
3. Structural over-floor systems reinforcement (tracking) and approval for a specific vehicle or a specific coach-built floor and chassis combination with various seat types, seat attachment methods (including bolted directly) and seat layouts

4. Approval of anchorages in the vehicle by calculation (stressing).

5. Test to full regulatory requirements.

All the methods above have benefits and limitations but together they appear to cover all types of vehicle and manufacturing methods. Some would require further refinement and development before they could be used in a regulation or standard. Ideally, to simplify the administration of a low-cost approval method the number of options should be minimised. However, the range of vehicles, and fixing structures (for seats with integral anchorages) found mean that more than one low-cost approval method may be required. Also a significant investment has been made in obtaining approval for current systems. These considerations suggest that a multi-path low-cost approval system should be used to provide suitable approval options for all.

The five tests described above can be used in different combinations to provide a multi-approval route for different types of vehicle and scales of manufacturing. Large passenger vehicles can be broken down into the following three categories:

- Small minibuses and taxis (both converted delivery vans)
- Large minibuses, buses and coaches with floors on or close to the chassis (coach-built onto a chassis)
- Coaches or buses with ‘high floors’ (coach-built onto a chassis or a space frame)

Special cars and kit cars are also produced in small numbers, making a total of four types of vehicle needing a low cost approval method.

It is proposed that for all vehicles that use seats with integral anchorages, the seats must be produced by a manufacturer with a quality control system. Figure 8.1 shows the possible options for the various types of vehicles. The figure shows that the different approval paths or routes that can be used for each type of vehicle. The options give a low cost approval method for all but ‘high floor’ coaches and buses. The low cost approval methods are not shown in detail in Figure 8.1, but the boxes for each vehicle type represent a series of approval routes that could be used on that type of vehicle. A separate flow chart for each vehicle type is shown in Figure 8.2 to Figure 8.5. Although the flow-charts imply that any one vehicle would only be approved by one route, in practice different areas within the vehicle could be approved by different routes or even different vehicle types (e.g. a coach with high and low floor sections).

This study intended to produce improved methods that could be considered for incorporation in some form of approval procedure. Although this study has gone some of the way to develop the ideas into a form suitable for use in an approval procedure, further work will be required to produce an approval procedure. TRL suggests that the options be discussed with all the stakeholders before the approval methods are finalised.
Figure 8.1: Overview of possible anchorage approval routes

Figure 8.2: Approval Methods for Van Conversions
Includes small vans converted into taxis, which need to meet M1 anchorage requirements
Figure 8.3: Approval methods for ‘low floor’ coach-built vehicles (buses and low-floor coaches)

- Low cost approval methods
  - Independent test of seats – strength and fitting rules
  - Follow the enhanced design rules

- Reg. 14 pull test
  - Fit approved tracking kits and seats to fitting rules
  - Use approved floor, seat layouts and seats

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Figure 8.4: Approval methods for ‘High floor’ coach-built vehicles

- HIGH FLOOR COACH-BUILT VEHICLES (Coaches and large minibuses)
  - Reg. 14 pull test

APPROVED
9 Conclusions

1) Analysis of GB accident data has shown that there are few casualties found within the low-volume vehicle group. This supports the use of low-cost approval methods for these vehicles.

2) Vehicles produced in low volumes are predominantly minibuses, buses or coaches and an analysis of GB national accident data (STATS 19) shows that these vehicles account for only about 1 percent of all road user fatalities, 2 percent of all seriously injured casualties and 4 percent of all casualties with slight injuries.

3) Analysis of the GB accident data provided the proportions of vehicles by make in minibus, coach and bus accidents. The GB data also showed that for injured bus or coach passengers more than half were seated and so might have benefited from wearing seatbelts.

4) Information has been obtained from various sources on the construction methods used to make large passenger-carrying vehicles in low volumes; the main methods are:
   - Minibuses made by converting delivery vans
   - Coach-built minibuses, buses and coaches made by building bodywork onto different types and sizes of chassis

5) Although there were only two main construction methods being used to make large passenger carrying vehicles in low volumes, significant differences were found between vehicles of different sizes, vehicles made for different purposes and vehicles made by different scales of production.

6) Information has been obtained on some of the current approval methods used for seatbelt anchorages in vehicles made in low volumes and TRL has also proposed further methods, including an improved design rule method.

7) The advantages and disadvantages of and options to improve existing and new test methods have been discussed.

8) It was concluded that a number of different low-cost approval options were needed to reflect the range of vehicles and design solutions found. However this conflicts with the need for a simple,
easy to administer, low-cost approval method. In order to achieve the best compromise between these two requirements TRL suggests that the options be discussed with all the stakeholders before the approval methods are finalised.

9) Proposals have been produced for a for a multi-path low-cost approval route method that could be used to obtain a high level of confidence that seatbelt anchorages meet regulatory strength requirements.

These have been used to produce proposed low-cost multi-path approval methods for each of the main types of vehicles produced in small numbers:

- Minibuses and taxis made by converting delivery vans
- Coach-built vehicles with low floors (buses and low-floor coaches)
- Coach-built vehicles with ‘high floors’
- Special cars, kit cars, etc.

10) The proposals for a multi-path low-cost approval method are intended to be suitable for incorporation in some form of approval procedure. Although this study has gone some of the way towards developing the proposals into a form suitable for use in an approval procedure, further work will be required to produce a complete solution.

11) Some of the approval methods identified as being suitable for a multi-path approval method are considered not to need validation to show that they will provide anchorages equivalent to the regulatory requirements.

12) It was decided to carry out a limited programme of validation of two of the proposed approval methods.

- The use of structural over-floor reinforcement kits (and seats) in a delivery van that had not been tested with the kit, but was similar to vehicles that it had been tested with.
- A TRL adaptation of the VOSA visual inspection rules (design rules) for coach-built vehicles. The adaptation was to allow savings in weight through the use of high strength materials and beams with their cross-sections (shape) selected to give a high strength to weight ratio.

13) The validation tests to a delivery van, fitted with tracking intended to meet the M2 seatbelt anchorage strength requirements, showed:

- The van met all pull test requirements for an M2 vehicle and the seats selected for the more demanding M1 test also passed, indicating that the tracking and floor assembly had a large safety margin. It was therefore concluded that in this case the tests showed that the method of approving a large family of similar vans, by testing just the two vans in the family that were thought to be the weakest, worked well.

14) The validation tests of the light-weight M2 coach-built floor, designed to a less conservative version of the TRL enhanced coach-built design rules than would ultimately be recommended, showed:

- The light-weight coach-built floor passed all of the M2 pull test requirements. However, when it was subjected to the more demanding M1 tests it failed before it met the required load. It can therefore be concluded that it has a small margin of safety. It also showed that:
  - The principles applied to the TRL floor showed that a lightweight strong structure can be designed at relatively low cost. The savings of such lightweight structures could be considerable in reduced fuel consumption and a reduced risk of accidents from improved stability, by reducing mass and the height of the centre of gravity.
  - Care is needed in proposing suitable section modulii and in developing rules to prevent buckling and tearing failures.
15) Data on the design of delivery van floors have been obtained from several manufacturers and have been summarised. These could be used to design a generic van floor and side-wall module which approximately represents any delivery van and which could be used in sub-systems seat tests.

16) A number of observations have been made that might help to improve large passenger vehicles produced in low volumes:

- It has been concluded that having anchorages that meet the strength requirements does not guarantee integrity of the complete vehicle in an accident. Although an integrity test is outside the scope of the current study, it is considered so important that TRL recommends that, at the very least, designers of vehicles with ‘high floors’ (coaches) should be required to calculate the forces on the floor structure and show that the suitability of members carrying these forces to the chassis have been considered.

- For mechanical attachments with implications for safety, such as the attachment of seat tracking to the underlying floor structure, TRL recommends that appropriate bolts (size and grade) and washers (size and thickness) be used along with the normal engineering practice of requiring a minimum thread engagement equal to about one bolt diameter.

- Obviously, approval tests are of less use if some of the seats actually fitted to vehicles on the road have sub-standard welds or other defects at critical locations. TRL recommends that conformity of production procedures be added for all seats with integral anchorages intended for use in vehicles produced in low-volumes, for both regulatory and low-cost anchorage approval (it has been assumed that large volume car manufacturers already insist on this).

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References


Appendix A. CAD drawings of TRL coachbuilt floor
Appendix B. 3D Views of the assembled Chassis

Figure 6: 3D drawing of chassis from above (without wooden floor)

Figure 7: 3D drawing of chassis from below (with wooden floor)