Development of test procedures, limit values, costs and benefits for proposals to improve the performance of rear underrun protection for trucks

by T L Smith, C Grover, T Gibson, W Donaldson and I Knight

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DEVELOPMENT OF TEST PROCEDURES, LIMIT VALUES, COSTS AND BENEFITS FOR PROPOSALS TO IMPROVE THE PERFORMANCE OF REAR UNDERRUN PROTECTION FOR TRUCKS

Version: Final

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Executive summary

Rear underrun (or underride) protection (RUP) aims to reduce the injury severity for the occupants of passenger cars that collide with a heavy goods vehicle (HGV). When such collisions occur, the crash structure of the smaller vehicle tends to pass underneath the stiff structures of the larger vehicle, thus bypassing the safety systems of the car and often resulting in extensive passenger compartment intrusion and serious or fatal injury. RUP systems are intended to provide stiff structure in a suitable position to prevent this underrun and provide a stable surface for the front of the car to interact with such that the frontal crush zone and restraint systems work as they were designed to do, thus greatly increasing the protection offered to occupants.

Directive 70/221/EC, as amended, made the fitment of RUP to HGVs mandatory. In 2006, the Directive was amended (2006/20/EC) to increase two of the test loads from 25kN to 50kN and to allow for interruptions in the RUP for tail lifts. At the same time the EC 5th Framework project, VC-Compat, was undertaking research intended to investigate whether RUP could be improved. The results of this research were published shortly after the 2006 amendment and recommended even higher test loads of 110kN, 180kN and 150kN as well as a reduced ground clearance of 400mm and an increase in the height of the RUP cross-member to 200mm. Tests conducted in Germany (ADAC, 2006) also showed that a RUP that passed the higher test loads required by the latest amendment of 70/221/EC was still not sufficient to withstand the impact of a small family car at 56km/h.

In response to the new information available, the European Commission contracted TRL to carry out further research to develop the recommendations from the VC-Compat project into a proposal for a further amendment to Directive 70/221/EC. The VC-Compat project qualified its' recommendations by highlighting some limitations of its work, as described below:

- The results of quasi-static point load tests carried out as per the regulatory method did not adequately predict the deformation experienced in a full scale impact test;
- The practical implications of reducing the RUP ground clearance was identified as a concern in some sectors of industry but was not assessed by the research; and
- Neither the principle of permitting RUP with lesser stiffness on smaller vehicles (<20 tonnes GVW), nor the appropriate magnitude of any reduction were assessed.

This research, therefore, focussed on investigating and resolving the above issues as well as providing an updated cost benefit analysis. The work involved literature reviews, a full scale impact test, finite element modelling, accident data analysis and consultation with industry.

The main findings of the work were as follows:

- The existing regulatory test method and limit values are not representative of a 75% overlap, 56 km/h collision between a small family car and a truck equipped with a minimally compliant RUP device. The standard of current rear underrun protection is, therefore, failing to fully exploit the potential of modern cars to protect their occupants.
- A quasi-static test where the total simultaneous force applied is 300kN, distributed along the cross-member by three simultaneous point loads replicates the behaviour observed during a 75% overlap, 56km/h collision much more accurately.
- An additional point load would be required for parts of RUP cross-members that are supported only at one end if it was considered necessary to also represent low overlap collisions where the outer edge of the RUP tends to deform around the mounting point. The research suggests that a point load equivalent to 274N/mm of unsupported structure, applied at the horizontal and vertical mid-points of the unsupported section, would be likely to be appropriate but this may require further assessment and validation.
- A reduction in the test loads applied to the RUP is appropriate for devices fitted to vehicles where the structural members (e.g. chassis) are likely to interact with the crash structure of the bullet vehicle. Ideally, a universal test method would be developed that would apply

forces accurately representing the front of the car to the appropriate parts of the rear of the vehicle such that the reduction in load applied to the RUP is specific to the structure of the particular vehicle it is fitted to. However, in the meantime, the research has suggested that for vehicles where the ground clearance of the main chassis members is in the region of 700mm or less, it would be appropriate to reduce the test loads applied to approximately 70% of those required for larger vehicles.

- The research has strongly demonstrated that a reduction in ground clearance is required to improve the level of protection offered to car occupants. Most of the research has suggested that the optimum ground clearance would be 400mm, although some has suggested that 450mm would be acceptable. Defining this ground clearance when the vehicle is laden would be expected to minimise the number of vehicles that may encounter operational difficulties or require adjustable devices as a result of the reduced ground clearance. However, this would decrease the level of protection offered by vehicles equipped with suspension types where the ground clearance depended on the load carried (pre-dominantly those with steel sprung suspension).
- The proposed changes to the RUP Directive are likely to result in a positive return on the costs incurred but the benefit to cost ratios are sensitive to estimates of the increase in the proportion of vehicles likely to require complex and/or adjustable designs of RUP.

A preliminary proposal to amend Directive 70/221/EEC has been produced based on the optimum requirements described above. However, there may be some scope for modifying some of the proposed requirements without substantially adverse effects on the level of safety offered where the research described above has suggested that other approaches or limit values may also be acceptable.

1 Introduction

Rear underrun (or underride) protection (RUP) aims to reduce the injury severity for the occupants of passenger cars that collide with a heavy goods vehicle (HGV). When such collisions occur, the crash structure of the smaller vehicle tends to pass underneath the stiff structures of the larger vehicle, thus bypassing the safety systems of the car and often resulting in extensive passenger compartment intrusion and serious or fatal injury. RUP systems, are intended to provide stiff structure in a suitable position to prevent this underrun and provide a stable surface for the front of the car to interact with such that the frontal crush zone and restraint systems work as they were designed to do, thus greatly increasing the protection offered to occupants.

Directive 70/221/EC, as amended, made the fitment of RUP to HGVs mandatory. In 2006, the Directive was amended (2006/20/EC) to increase two of the test loads from 25kN to 50kN and to allow for interruptions in the RUP for tail lifts. At the same time the EC 5th Framework project, VC-Compat, was undertaking research intended to investigate whether RUP could be improved. The results of this research were published shortly after the 2006 amendment and recommended even higher test loads of 110kN, 180kN and 150kN as well as a reduced ground clearance of 400mm and an increase in the height of the RUP cross-member to 200mm. Tests conducted in Germany (ADAC, 2006) also showed that a RUP that passed the higher test loads required by the latest amendment of 70/221/EC was still not sufficient to withstand the impact of a small family car at 56km/h. The results are shown in Figure 1-1, below.

Figure 1-1. Results of ADAC crash test with underrun protection conforming to 2006/20/EC

In response to the new information available, the European Commission contracted TRL to carry out further research to develop the recommendations from the VC-Compat project into a proposal for a further amendment to Directive 70/221/EC. The VC-Compat project qualified its' recommendations by highlighting some limitations of its work, as described below:

- The results of quasi-static point load tests carried out as per the regulatory method did not adequately predict the deformation experienced in a full scale impact test;
- The practical implications of reducing the RUP ground clearance was identified as a concern in some sectors of industry but was not assessed by the research; and
- Neither the principle of permitting RUP with lesser stiffness on smaller vehicles (<20 tonnes GVW), nor the appropriate magnitude of any reduction were assessed.

This research, therefore, focussed on investigating and resolving the above issues as well as providing an updated cost benefit analysis. The work involved literature reviews, a full scale impact test, finite element modelling, accident data analysis and consultation with industry. This report describes all of the findings of the project in full. A preliminary proposal for an amendment to Directive 70/221/EEC is included as Appendix B.

2 Task 1: Target population for RUP

The following section describes the relative importance of casualties from accidents where the front of a car collides with the rear of a truck, based on a review of existing literature, research and accident data. This information was used to identify the number of casualties that form the "target population" for improved RUP systems and provides baseline information for the cost benefit analysis.

2.1 Consideration of European accident statistics

Data from European accident databases or studies are summarised in the following sections.

2.1.1 EU-15 and EU-25 Data

Figure 2-1 shows the trend in the overall number of fatalities and injury accidents in the EU-15 and EU-25 (DG TREN, 2006). Both the number of injury accidents and the number of fatalities have been decreasing since 1999.

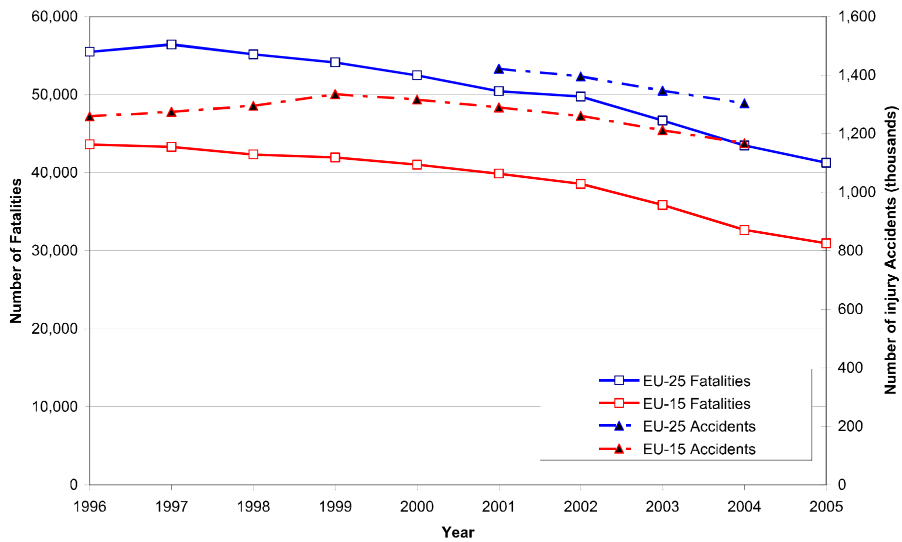


Figure 2-1. Trend in number of fatalities in EU 1996-2005 (DG TREN, 2006).

This data is not divided by the type of vehicle involved, so no further detail relating specifically to HGVs is available. It is, therefore, necessary to examine different data sources in order to estimate relevant information across Europe, based on a smaller sample of accidents.

2.1.2 CARE

CARE is the disaggregate database of road accident data that is maintained by the European Commission, bringing together the national databases of the Member States. At present, data are available for the 15 pre-Accession states, although access to German data is restricted and TRL was unable to incorporate this in the analysis. Data from Switzerland, Norway and the 10 Accession states are currently being incorporated into CARE, but are not available for analysis at present.

Smith *et al* (2008) reported an analysis of the CARE database. Figure 2-2 and Figure 2-3 show the proportion of national fatalities and the fatality rate per million population for 14 EU member states for accidents involving HGVs, light commercial vehicles (LCVs, goods vehicles of less than 3.5 tonnes, N1) and large passenger vehicles (LPVs, more than 16 seats).

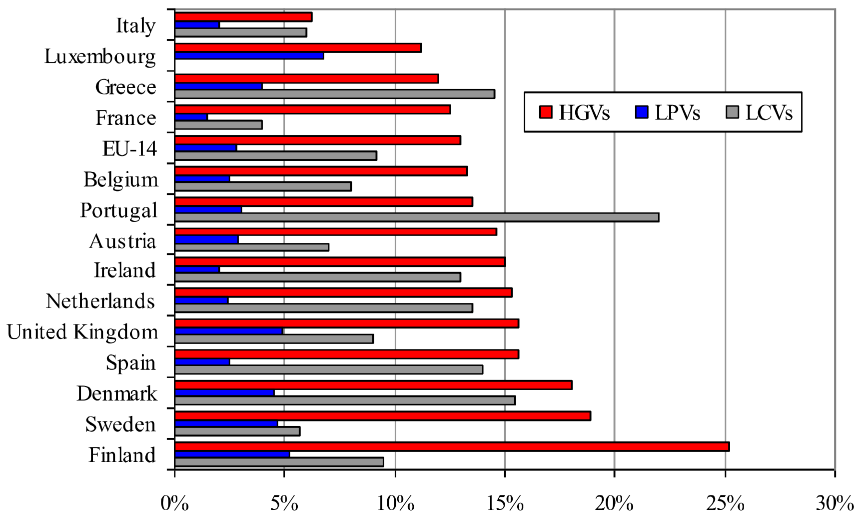


Figure 2-2. Proportion of national fatality total in LCV, HGV and LPV accidents, 2000 – 2004 (Smith *et al*, 2008).

The proportion of all fatalities that occur in accidents in France, Greece, Luxembourg and Italy that involve HGVs is lower than the average for the 14 member states. The highest proportion of all fatalities from accidents that involve HGVs is in Finland.

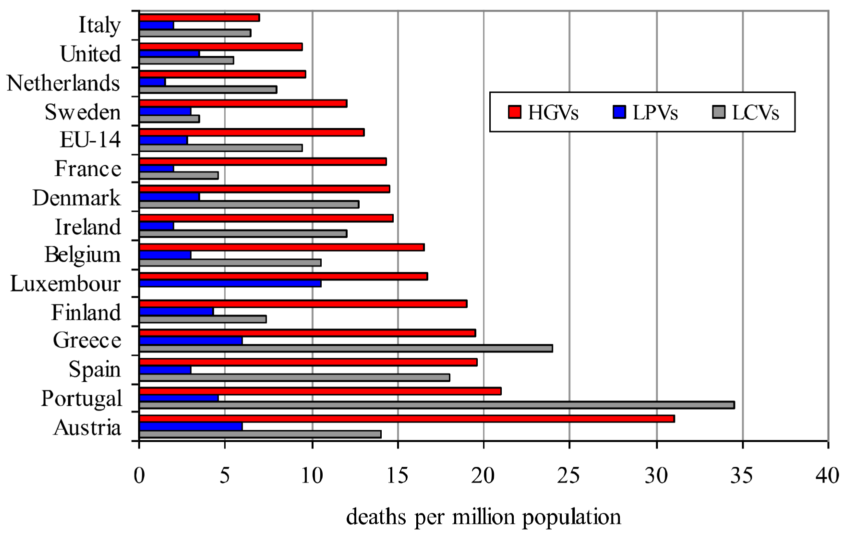


Figure 2-3. National fatality rates per million population in LCV, HGV and LPV accidents, 2000 – 2004 (Smith *et al*, 2008)

When considering the fatality rate per million population, Italy, UK, Netherlands and Sweden have a rate that is lower then the average. For accidents involving HGVs, Austria has the highest fatality rate.

It was noted that the low values for Italy were not as expected and may be the result of the transformation rules used to import the Italian data into the CARE database.

Figure 2-4 shows the trends in the proportion of the national fatality totals that are from accidents involving HGVs. National populations change only slowly, so it is more relevant to consider the changing proportion of the national fatality totals in these accidents. The five countries with the greatest totals are shown separately. Data for the UK is also presented because this figure is taken from research funded by the UK Department for Transport. The proportion for Italy is shown because the data is consistently low. Data from the remaining eight countries are grouped as 'Other'.

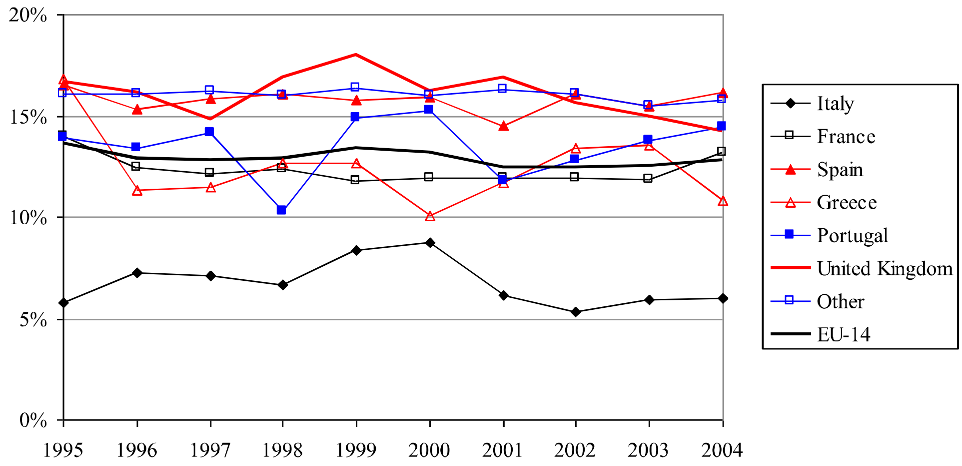


Figure 2-4. Proportion of fatalities in accidents involving HGVs (Smith *et al*, 2008)

The proportion of fatalities from accidents involving HGVs has fluctuated around a similar level for most of the Member States shown. However, the proportion of fatalities in Greece appears to have fallen. The proportion for the EU-14 has remained relatively constant at approximately 13%.

Accidents involving HGVs can result in fatalities both inside the HGV and outside the HGV. Figure 2-5 shows the distribution of fatalities in HGV accidents in 2004 by road user type across the 14 EU Member States with data accessible in CARE.

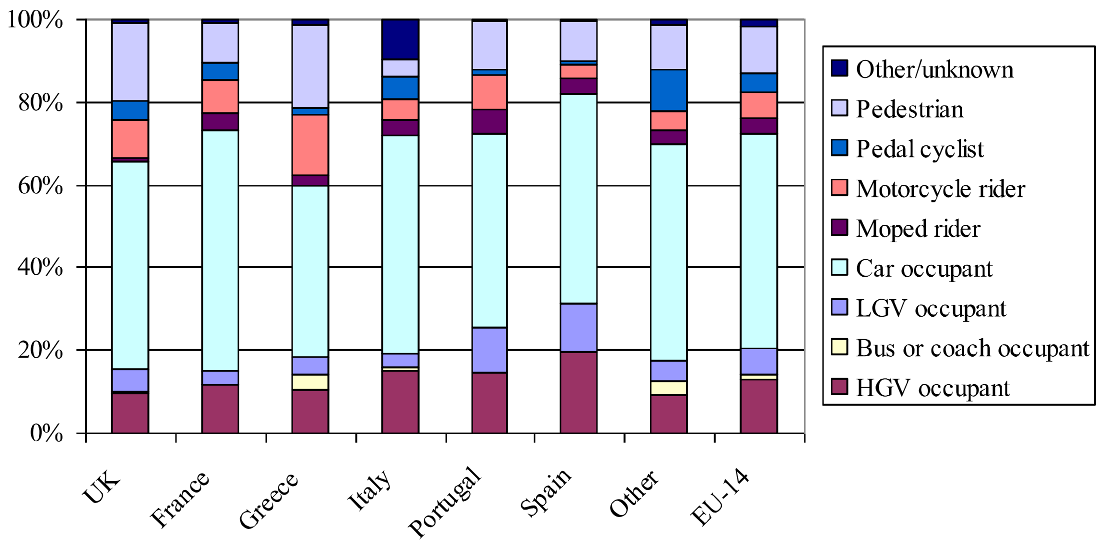


Figure 2-5. Distribution of fatalities in accidents involving HGVs in 2004, by road user type (Smith *et al*, 2008).

The average proportion of fatalities that were car occupants for the EU-14 was 52%. Greece had the lowest proportion of car occupants and France had the highest.

It is not possible to analyse this data any further with respect to impact configurations and the relevance to improved RUP design because the data cannot be broken down any further using fields that are relevant to RUP.

2.1.3 Other European data sources

The Organisation for Economic Cooperation and Development (OECD) compile the International Road Traffic and Accident Database (IRTAD) which gathers data on traffic and road accidents from 28 out of the 30 OECD member countries. The member countries are shown in Table 2.1.

Table 2.1. IRTAD member countries.

	Australia		Austria		Belgium		Canada
	Czech Republic		Denmark		Finland		France
	Germany		Hungary		Iceland		Ireland
	Israel		Japan		Korea		Netherlands
	New Zealand		Norway		Poland		Serbia & Montenegro
	Slovenia		Spain		Sweden		Switzerland
	United Kingdom		United States				

The European Members of OECD also contribute data to CARE, therefore no additional information is available from this source for the EU Member States.

2.2 Review of recent literature

2.2.1 GB National statistics – STATS19

A recent study completed for the UK Department for Transport included an extensive analysis of accident data relating accidents involving HGVs and other large vehicles. This source of data does include the detail necessary to separately identify casualties from accidents where the front of a car collided with the rear of an HGV. Smith *et al* (2008) report the findings of the study.

STATS19 contains data relating to personal injury accidents and the resulting casualties on the roads in Great Britain. Data from accidents that occurred during the period 2003 to 2005 was analysed to identify the main types of accident involving HGVs. The following sections reproduce those elements of the analysis carried out by Smith *et al* (2008) that are relevant to improved RUP. An overview of accidents and casualties where at least one HGV was involved is shown in Table 2.2, below.

Table 2.2. Accidents and casualties involving HGVs

Casualty Severity	GB Annual Average (2003-2005)	
	Accidents involving HGVs	Casualties from accidents involving HGVs
Fatal	446	568
Serious	1,667	2,160
Slight	10,247	15,307

There was an average of 1.3 killed or seriously injured casualties and 1.5 slightly injured casualties per accident.

To consider the relative importance of car occupants in relation to other road user casualties in impacts with HGVs it is necessary to identify where the HGV had a collision with the road user or the vehicle in which the road user was travelling. In STATS19, this is achieved by using the "1st point of impact" field. Figure 2-6 shows the distribution of casualties by road user type and severity where it was known the first point of impact was with an HGV. Note that in some accidents, the first impact may not be the most severe impact, for example a car has a minor collision with an HGV and then collides with a tree, where the impact with the tree resulted in fatal injuries.

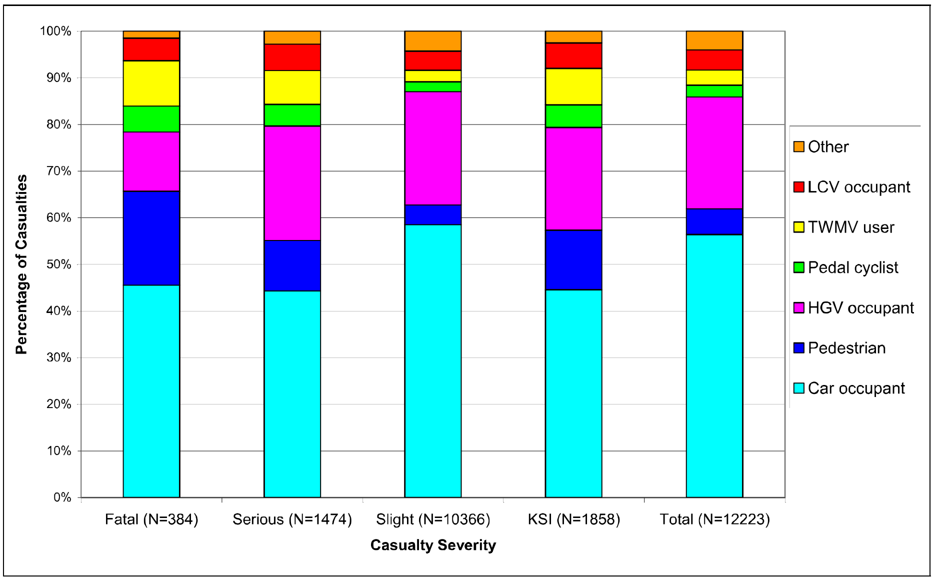


Figure 2-6. Casualties injured in impacts with HGVs by road user type (GB annual average 2003-2005).

Approximately 45% of killed or seriously injured (KSI) road users in impacts with HGVs were car occupants. This is by far the largest group of casualties.

The impact configuration, based on first point of impact, was known for 517 (98.7%) of the fatalities and 2,457 (98.9%) of the KSI casualties and is shown in detail in Table 2.3, below. The collision types relevant to RUP are highlighted in **bold.**

Table 2.3. Impact configurations as a percentage of fatal or KSI car occupants where first point of impact is with an HGV (fatal N= 517, KSI N=2457, GB accidents from 2003 to 2005 inclusive).

		Impact location on HGV							
		Front		**Rear**		**Offside**		**Nearside**	
		Fatal	KSI	Fatal	KSI	Fatal	KSI	Fatal	KSI
Impact location on car	**Front**	39.8%	30.0%	**13.2%**	**13.1%**	4.4%	8.9%	2.3%	3.2%
	Rear	8.7%	11.3%	0.1%	0.9%	0.0%	0.2%	0.4%	0.4%
	Offside	12.0%	8.9%	1.9%	0.9%	1.9%	2.7%	1.7%	3.4%
	Nearside	11.6%	7.4%	0.0%	0.4%	1.0%	5.2%	0.2%	0.4%
	Total	72.1%	57.6%	15.2%	15.3%	7.3%	17.0%	4.6%	7.4%

Impacts to the front of an HGV are most frequent and account for a higher proportion of fatal casualties than KSI casualties. Impacts with the rear of the HGV are more frequent for fatally injured car occupants than impacts to the side of the HGV (offside and nearside combined is 11.9%). However, if considering KSI casualties, the side of the HGV is the second most frequent impact location on the HGV.

Head-on collisions are the largest group when considering both fatal and KSI casualties. Casualties in impacts between the front of the car and the rear of the HGV are second most frequent if impacts to the offside and nearside of the car are dealt with separately. There was an average of 23 fatalities and 107 KSI casualties per year where the front of the car collided with the rear of an HGV.

Although the car collided with the HGV, the most severe injuries may have been sustained in a second impact. Analysis of the most severe impacts was, therefore, carried out using the Heavy Vehicle Crash Injury Study (HVCIS) Fatals Database, as described below.

2.2.2 GB Fatal accidents – HVCIS fatals database

Smith *et al* (2008) performed an analysis of the HVCIS Fatals Database. The HVCIS Fatals Database is based on data extracted from police reports of fatal accidents. Collection of data and population of the database is funded by the UK Department for Transport (DfT) and is managed by TRL on behalf of the DfT. The analysis was based on the final release of the HVCIS Fatals phase 1 database (April 2006), which contained data from 1997 to 2002 inclusive. This release of the HVCIS fatals database was compared with data from STATS19 and accidents involving HGVs were shown to be broadly representative in relation to the distribution of fatalities by road user group (Knight *et al*, 2006).

The HVCIS Fatals Database contains 541 car occupant fatalities where the most severe impact was with an HGV. The impact locations for both the car and the HGV are summarised in Table 2.4 and the configuration relevant to RUP is highlighted in **bold**.

Table 2.4. Impact configurations (1st point of impact) for car to HGV impacts resulting in car occupant fatalities (N=531).

		Impact location on HGV			
		Front	Rear	Offside	Nearside
Impact location on car	Front	36.3%	10.7%	5.6%	1.7%
	Rear	7.7%	0.0%	0.0%	0.2%
	Offside	17.1%	1.5%	2.4%	1.7%
	Nearside	13.7%	0.0%	1.1%	0.0%

Table 2.4 allows a comparison with the data that is available from STATS19 to gain an understanding of how the remainder of the analysis is representative of the overall accidents in Great Britain. When compared to the data for fatalities in Table 2.3, impacts between the front of cars and the rear of HGVs are slightly under-represented in the HVCIS data (13.2% for STATS19 and 10.7% for HVCIS) and impacts between the front of the HGV and the side of the car are slightly over-represented.

As mentioned earlier, the first point of impact is not always the most severe impact. The HVCIS Fatals Database records multiple impacts for each vehicle and ranks the impacts by order of occurrence and severity. Table 2.5 summarises the impact configurations where the impacts were the most severe for both the car and the HGV.

Table 2.5. Impact configurations (most severe impact) for car to HGV impacts resulting in car occupant fatalities (N=540).

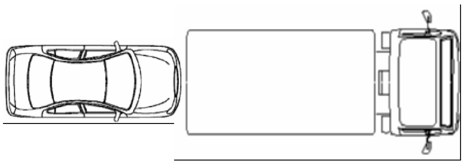
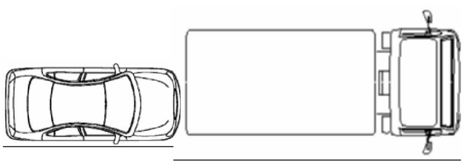
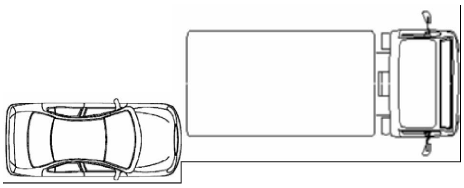
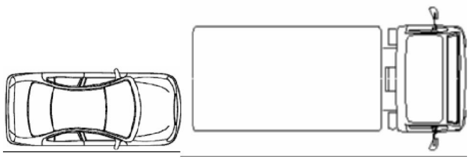
		Impact location on HGV			
		Front	Rear	Offside	Nearside
Impact location on car	Front	37.2%	10.7%	5.2%	2.0%
	Rear	6.3%	0.0%	0.0%	0.2%
	Offside	17.6%	2.0%	2.0%	0.7%
	Nearside	15.7%	0.2%	0.4%	0.0%
	Top	0.2%	0.0%	0.4%	1.1%

Table 2.5 shows that the difference between the 1st point of impact and most severe impact has no substantial influence on the proportion of fatalities that occur in collisions between the front of the car and the rear of the HGV. This means that when the first point of impact for a car is the rear of an HGV then, in almost all cases, that is also the most severe impact in the accident. The number of collisions recorded by STATS 19 as front of car to rear of truck is, therefore, a reliable indicator of the number of accidents that may be relevant to consideration of the performance of rear underrun protection.

Analysis of the Direction of Force (DoF) data showed that all impacts had a DoF between 11 o’clock and one o’clock for the car and from five o’clock to seven o’clock for the HGV. Eighty-eight percent of the impacts were 12 o'clock for the car and six o'clock for the HGV. It can, therefore, be concluded that angled impacts with the rear are relatively rare.

The HVCIS data also include the overlap of the impact and the distribution of accidents involving different categories of overlap is shown in Table 2.6.

Table 2.6. Impact overlap – Front of car to rear of HGV (N=58)

Ref No.	Impact Overlap	Description	Number of fatalities
1		Full overlap, impact fully distributed across front of car and rear of HGV	18 (31.3%)
2		Full overlap with offset, damage to full width of car and between one and two thirds of the width of the HGV. Offset to either left or right of the HGV	14 (24.1%)
3		Low overlap, damage to up to on third of the width of each vehicle. Offset to either left or right	11 (19.0%)
4		Partial overlap. Damage to between one and two thirds of the width of both vehicles. Offset to either the left or right	8 (13.8%)
5	Other		7 (12.1%)

Approximately 69% of the impacts occur with two thirds of the car or more overlapping with the rear of the HGV (ref nos. 1, 2 and 4, Table 2.6). Only 19% of the impacts occurred with a low overlap that involved only one third of the rear of the vehicles.

Information about the speed of the vehicles at the time of impact is recorded from a number of different sources. These sources include tachograph analysis, police accident reconstruction, skid marks and known travel speed and witness statements. The accuracy of these data sources can be varied and therefore information about impact speeds should be considered appropriately. Figure 2-7 shows the cumulative distribution of closing speed (relative speed between the car and the HGV) at impact where the impact speed for both vehicles was known.

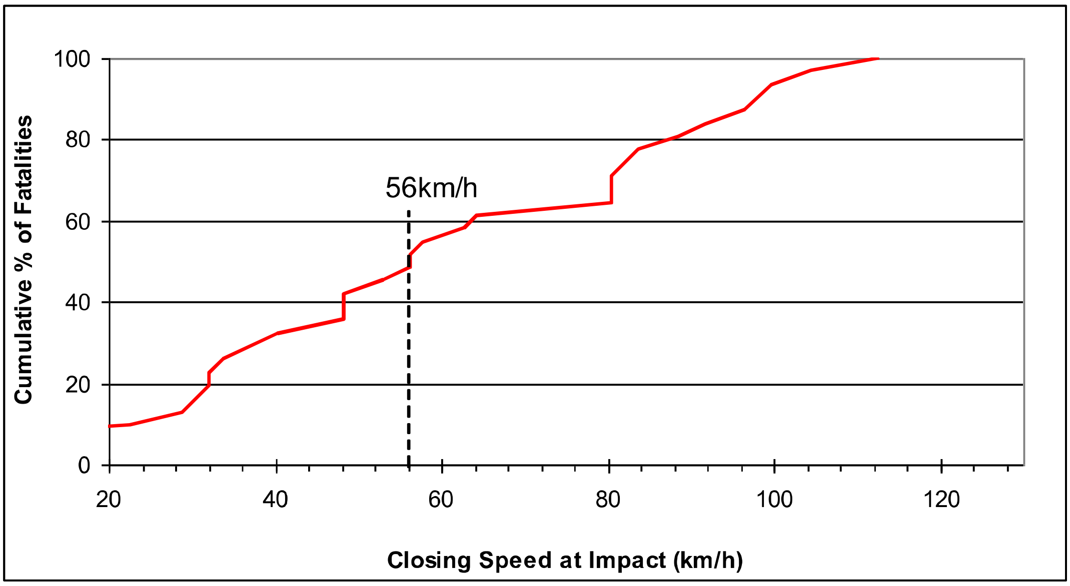


Figure 2-7. Closing speed at impact where front of car collided with rear of HGV (N=31)

Figure 2-7 indicates that if the rear of an HGV can be designed to ensure that the crash structure at the front of the car is engaged and that the car provides protection to the occupants at speeds up to 56km/h, then approximately 50% of the fatalities could be prevented. However, improvements in car safety now allows protection at higher speeds such as 64km/h, which is used in EuroNCAP but is not a legislative standard, so further savings could be possible if the RUP was designed to function effectively at higher speeds.

In reality, the effectiveness of underrun protection is also dependant on the occupant of the passenger car wearing a seatbelt. There are also other factors such as the age of the occupant and whether the car actually under-ran the structure of the HGV which can reduce the potential benefits of rear underrun protection.

For 55 of the cases, it was known whether or not the car under-ran the structure of the HGV. Underrun occurred for 85% of the fatalities. Where underrun occurred (N=47), the fitment of RUP was known for 41 HGVs. Of those where RUP fitment was known, 83% of the HGVs had a RUP fitted. There were eight fatalities where there was no underrun, with half of those HGVs being fitted with RUP. Where the RUP was fitted and there was no underrun, the closing speed at impact was between 32km/h and 56km/h for the three cases where speed was known. One of these fatalities was not wearing a seatbelt and another was aged 90. Both of these factors would be likely to have contributed strongly to the high injury severity at low speed. The third fatality was noted to have been sitting very close to the steering wheel in order to gain a better view, which may have contributed to the severity of the injuries sustained.

Where the use of the seatbelt was known for the car occupant, 83.7% were wearing the seatbelt (N=49). The age of the fatality was known for 57 fatalities, 5% were under 16 years of age and 14% were over 70 years of age.

2.2.3 VC-Compat

Analysis of national statistics and in-depth data sources were carried out as part of the VC-Compat research. Table 2.7 summarises the data sources that were used in the analysis.

Table 2.7. Data sources – VC-Compat.

Country	National statistics	In-depth data
France	Accident, vehicle fleet and traffic data from the Observatoire National Interministériel de Sécurité Routiére (ONISR)	-
Germany	”Verkehrsunfälle 1995-2001“: Statistisches Bundesamt (Hrsg.), Metzler-Poeschel Verlag, Fachserie 8, Reihe 7, Stuttgart 2001	GDV in depth analysis of 1997 police accident files from Bavaria Statistisches Bundesamt: Statistisches Jahrbuch 1999 für das Ausland, Metzler-Poeschel Verlag, Stuttgart, 1999
Netherlands	Wetenshappelijk instituut voor Verkeersveiligheidsonderzoek Statistical Analysis, the Netherlands, 2003	TNO collected data of accidents which happened in the Netherlands where at least one heavy vehicle above 7.5 tonnes was involved. A total of 30 cases were collected in the regions of Rotterdam, The Hague and Leiden during 2002 to 2004.
UK (except Ireland)	UK Department for Transport STATS19 Database, (see also http://www.dft.gov.uk/stellent/groups/dft_control/documents/contentservertemplate/dft_index.hcst?n=7537&l=3)	Knight, I. “Accidents Involving Heavy Goods Vehicles 1994 to 1996, The Transport Research Laboratory (TRL)- Vehicle Safety Systems, United Kingdom 2000
Spain	Spanish Traffic Department Annual statistics, Ministry of Interior 1995-2001	-
Sweden	Swedish Institute for Transport and Communications Analysis	-

Analysis of in-depth data for 2001 from France, Germany, the Netherlands and the UK was carried out and accidents were categorised by impact configuration. Figure 2-8 shows that between 7.2% and 14.3% of car to HGV accidents were relevant to RUP.

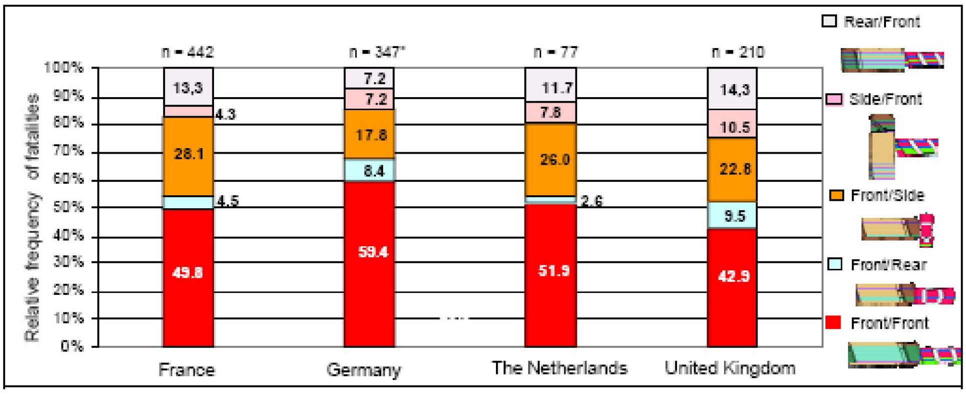


Figure 2-8. Car to HGV accidents by collision type – 2001. [German data from GIDAS (2) cases and the total evaluation in Bavaria (345) cases extrapolated to all car to truck accidents in Germany in 2001 (347 cases)].

Table 2.8 and Table 2.9 summarise the data identified from the participating Member States and how the data was extrapolated to make estimates of the relevance of rear underrun relevant accidents for the EU-15. This is the only source of data that allows the number of serious casualties in the EU-15 to be estimated.

Table 2.8. Estimating relevance of HGV accidents in EU-15.

		Accidents		Fatalities		Seriously injured	
Accidents with all road users and injuries to persons	VC COMPAT countries (Task 2.6)	893,347	69 %	27,364	65 %	231,957	69 %
	EU (15) IRTAD (2000)	1,229,668	100 %	42,098	100 %	336,171	100 %
Extrapolation factor		1,4		1,5		1,4	
Accidents with trucks over 3.5 t that resulted in personal injuries	VC COMPAT countries (Task 2.6)	49,602	69 %	3,881	65 %	15,010	69 %
	EU (15) extrapolated	71,887	100 %	5,970	100 %	21,755	100 %

Table 2.9. Estimating relevance of collisions between front of car and rear of HGV in EU-15.

	Accidents		Fatalities		Seriously injured	
All accidents involving trucks over 3.5 t *	71,887	100%	5,970	100%	21,755	100%
Thereby car to truck accidents *	43,132	60%	3,641	61%	16,098	74%
Car to truck accidents *	43,132	100%	3,641	100%	16,098	100%
Thereby car to truck front/front collisions *	12,076	28%	1,856	51%	4,990	31%
Thereby car to truck front/rear collisions *	7,332	17%	400	11%	3,380	21%

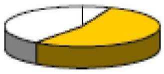
Analysis of the UK in-depth data showed that approximately 18% of fatalities were in impacts with a closing speed of 56km/h or less. In Germany, approximately 85% of the KSI casualties were in impacts with a closing speed of 56km/h or less.

The German in-depth data showed that only 11% of the RUP systems did not have any form of failure in the accidents. Twenty-five percent were torn off on one side and 14% were completely torn off.

2.2.4 E-Safety – heavy duty vehicles

The Heavy Duty Vehicles e-Safety Working Group (2004) collated information from accident cases provided by Volvo (Sweden), DEKRA (Germany), Cidaut (Spain) and Iveco (Italy). The research classifies heavy duty vehicles as those with a maximum mass exceeding 12 tonnes. The report noted that it was not possible to separate the Italian data by vehicle weight other than at a weight of 3.5 tonnes.

B.
Car Occupants



		S Volvo	E Cidaut	D DEKRA	I IVECO
6	Truck- car collision, oncoming traffic Truck front vs. car front,	30%	19%	19%	21%
7	Truck- car collision, oncoming traffic Truck front vs. car side	5%	27%	19%	11%
8	Truck- car collision, traffic ahead in same direction Truck front vs. car rear	15%	15%	16%	11%
10	Truck- car collision, traffic ahead in same direction Car front vs. truck rear	12%		6%	10%
9	Truck- car collision, intersection Truck front vs. car side	15%	1%	6%	18%
11	Truck- car collision, intersection Car front vs. truck side	12%		13%	9%
12	Truck- car collision, lane change accident Truck side vs. car side	10%	7%	6%	9%
B1	Other		32%	15%	11%

Figure 2-9. Classification of accidents resulting in KSI car occupant casualties from impacts with HGVs.

Impacts between the front of a car and the rear of an HGV is the fourth most frequent accident type in the Volvo sample. The DEKRA data shows this as the fifth most frequent, however it is equal with two other scenarios. The Iveco data also ranks the front to rear impact as fifth most frequent. This accident type is not specifically identified in the Cidaut data. Notes on this accident scenario reported that the accidents generally occur at high initial speeds on motorways when the HGV is stationary in traffic and that some occur in rest/parking areas.

2.3 Summary of information relating to target population

The accident data has shown that:

- Overall, the number of accidents and fatalities in the EU is decreasing;
- For the EU-14;
    - Approximately 13% of the national fatality total are in accidents involving HGVs;
    - The proportion of fatalities from accidents involving HGVs has fluctuated about the same level;
    - Car occupants account for just over half of all fatalities from accidents involving HGVs;
- From the literature, between 6% and 14% of car occupant fatalities arising from collisions with HGVs are in impacts that are relevant to RUP.

The data identified during this task has been used to make an estimate of the benefits of improved RUP. This benefit analysis can be found in Section 4.1.

3 Task 2: Identifying the requirements for RUP

3.1 Review of current and proposed rear underrun protection requirements

RUP is designed to withstand forces that are specified in regulations, which differ by country. The intended purpose of such regulations is to set a minimum standard which is representative of real-world conditions. This section considers the current status of these regulations, beginning with those regulations that were current, or proposed, in 2003 when a review was carried out as part of the VC-Compat project. This has then been updated with any research, proposals or amendments to regulations that have taken place since 2003.

The objectives of the review are to identify the requirements for RUP in relation to:

- Test loads
    - magnitude, direction and application area
    - Rate of application
- Ground clearance
- Energy absorption capability

3.1.1 Summary of VC-Compat literature review

This section provides the main details of the regulations in Europe, USA, Brazil and Australia that were current at the time of the original VC-COMPAT report. Regulatory exemptions are discussed in Section 3.4.1

3.1.1.1 Regulations

RUP in Europe is required to meet the standard described by EC Directive 70/221/EEC, as amended, or UNECE Regulation 58. Directive 70/221/EEC specifies requirements to be met during testing, whereas UNECE Regulation 58 also allows approval of RUP by calculation. UNECE Regulation 58 has also been adopted by authorities in Brazil and Japan.

In the US Regulations FMVSS 223 and FMVSS 224 cover rear impact protection for trailers and semi trailers, but not rigid vehicles. Since 26th January 1998 Canadian owned and operated trailers that travel to the US are required to meet the standards of FMVSS 223 and 224 regardless of where the trailer was manufactured. At the time of the review for VC-Compat, there was a proposal for a new standard in Canada (CMVSS 223). Information regarding CMVSS223 can be found in Section 3.1.1.2.

All of the above Regulations define the strength requirements based on a series of points at which certain static loads must be applied without exceeding specified deflections. The test points specified in these Regulations are illustrated in Figure 3-1. The positions of the test points for the Regulations from each country are given in Table 3.1.

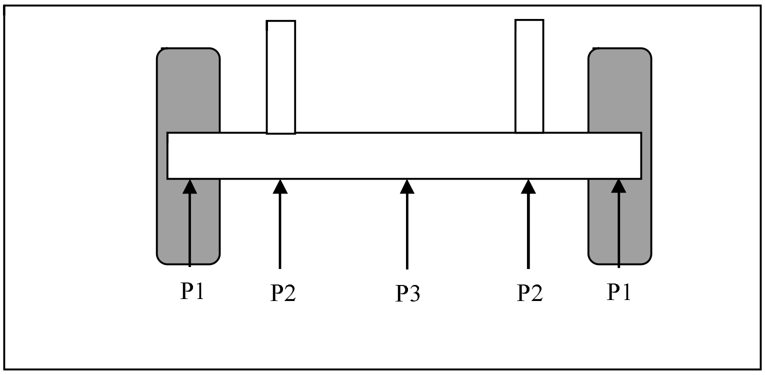


Figure 3-1. Static loading positions on underrun guards

Table 3.1 Existing static loading positions

Standard	Static loading positions		
	P1	P2	P3
UNECE Reg 58 / 70/221/EEC CONTRAN 805/95 (Brazil)	300mm inboard of outer face of tyre	700 to 1000mm apart, equidistant about vehicle longitudinal centreline	Vehicle longitudinal centreline
FMVSS 223 / 224 (USA)	3/4 of RUP length equidistant about centreline of RUP	710mm to 1270mm apart, equidistant about centreline of RUP	Vehicle longitudinal centreline

In Europe, the maximum allowable deflection is 400mm if the guard is fitted at the rearmost point. In the USA and Canada, the maximum allowable deflection is 125mm. The forces under which this deflection requirement must be met are defined in Table 3.2 for each Regulation.

Table 3.2. Current underrun guard requirements.

Standard	Mass (tonnes)	Maximum ground clearance (mm)	Maximum distance from rear (mm)	Applied Force in static test (kN)		
				P1	P2	P3
UNECE Reg 58 / 70/221/EEC / CONTRAN 805/95 (Brazil)	< 20	550	400	12.5% of mass	50% of mass	12.5% of mass
	> 20			25	100	25
FMVSS 223 / 224 (US)	all	560	305	50	100	50
ADR 42/03 (Australia)	all	600	600	No force requirements at present		

Not all Regulations specify test forces in relation to the GVW of the vehicle to which the RUP is to be fitted. At present, only the EC Directive, UNECE Regulation and Brazilian standard specify such mass dependant requirements.

3.1.1.2 Proposed regulations

Brazil and Australia proposed new regulations, which were being reviewed at the time the VC-COMPAT report was produced. These proposals are summarised in Table 3.3. A new Canadian Standard was passing through the legislative process at that time and this has since passed into statute. The requirements of CMVSS223 are also described below.

Table 3.3. Proposed underrun guard requirements.

Standard	Mass (tonnes)	Maximum ground clearance (mm)	Maximum distance from rear (mm)	Applied Force in static test (kN)		
				P1	P2	P3
Brazil (UNICAMP)	4.6 – 6.5	400	0	50	75	50
	6.5 – 10			60	90	60
	10 – 23.5			80	120	80
	> 23.5			100	150	100
Australia	all	350-400	300	200	150	100
Canada (CMVSS223)	>4.536	560	305	-	50*	50*

*P2 is positioned 3/8th of the RUP width from the longitudinal centreline of the RUP and P3 is on the centreline of the RUP.

In addition to the above requirement, CMVSS223 requires that the RUP shall deflect by no more than 125 mm under a 350 kN uniformly distributed load applied over the full width of the guard while absorbing 20kJ of energy by plastic deformation. An alternative to this energy absorption requirement is for the RUP to withstand a 700kN load without separating from the chassis.

3.1.1.3 Regulatory action since VC-Compat review

In 2006, in Europe, Directive 70/221/EEC was amended to increase the test loads applied to P1 and P3 from 12.5% of the maximum permissible mass of the vehicle to 25%. The maximum test load to be applied to P1 and P3 increased from 25kN to 50kN. Specific requirements were also introduced for RUP fitted to vehicles with platform lifts and these are listed below:

- The lateral distance between the elements of the RUP and the lift element must not be more than 2.5cm;
- Each section of the RUP must have an effective area of at least $350 cm^2$;
- Alternative positioning of point P1 if it falls within the interruption; and
- The fitment position relative to the rear of the vehicle and the ground clearance requirement need not apply for the area of interruption or for the purpose of the platform lift.

The Canadian Standard was passed into statute in October 2004 (midway through the VC-Compat project), although it is was not necessary to meet the requirements until 1st September 2007.

No additional information was identified with respect to Brazilian or Australian proposals since the previous review.

3.1.1.4 RUP assessments

A number of authors reported on the assessment of different RUP designs, using both numerical simulation and real-world testing. The main areas considered during the studies included the effect of ground clearance and impact speed.

Ground clearance has been identified as one of the most critical factors in producing an effective underrun device. The literature reviewed considered ground clearance for the RUP from 300mm to 600mm. Welbourne (1998) showed that occupant compartment displacement reduced when the ground clearance reduced from 560mm to 400mm and that there was still 30mm reduction in displacement when ground clearance was changed from 480mm to 400mm. Atahan *et al* (2003) showed through numerical simulation that the optimum ground clearance was 400mm

Welbourne (1998) showed that in tests with a RUP of 480mm ground clearance that the injury response occurs earlier and the magnitude of the maxima is higher as the test speed increased from 48km/h to 56km/h and then to 64km/h. The trend in injury response was not completely consistent throughout the testing. The maximum displacement increased from 900mm at 48km/h to 1060mm at 64km/h.

The assessment of a number of alternative RUP designs was also reported. These included:

- Energy absorbing designs Persicke and Baker (1980), Bloch *et al (1998*), Mariolani *et al* (2001), Recnitzer *et al* (2001), Zou *et al* (2001), Rakheja *et al* (2001), Berg *et al (*2003);
- Articulated designs that provide additional ground clearance by pivoting up and rearwards when the RUP strikes the ground as the vehicle is moving forwards Persicke and Baker (1980), Mariolani *et al* (2001); and
- The pliers guard consists of a steel frame with a pivot at the forward end and suspended by a net of steel cables at the rear end. When a vehicle strikes the cables the steel frame is pulled upwards gripping the front of the car between the frame and the load bed, Bloch *et al (1998*), Mariolani *et al* (2001).

The literature indicates that the current ground clearance of 550mm is too high to engage the crash structure of the car. The performance requirements should be based on an impact at 56km/h and should consider offset impacts. Many of the authors propose a defined requirement for energy absorption capability.

3.1.2 Assessment of VC-Compat proposal

The following section describes the work carried out in VC-Compat to evaluate the effectiveness of a RUP that was designed to meet the proposed performance and geometric requirements.

3.1.2.1 VC-COMPAT Objectives

The objectives of the rear underrun section of VC-Compat research (Smith and Knight, 2006) were:

- To provide guidelines for improvement of existing legislation on rear underrun protection.
- To provide an indication of the benefits and costs for improved RUP systems for trucks.

3.1.2.2 VC-COMPAT Recommendations/proposal

The research indicated that a RUP device built to be minimally compliant with the current EC Directive (70/221/EEC) was inadequate to protect the occupants of modern passenger cars. Accordingly, it was recommended that the Directive should be amended to incorporate the following improvements:

- Decrease the maximum permitted ground clearance from 550mm to 400mm.
- Increase the minimum permitted height of the cross-member from 100mm to 200mm
- Increase the point loads that the RUP must withstand as follows
  - P1 increased from 25 kN to 110 kN
  - P2 increased from 100 kN to 180 kN
  - P3 increased from 25 kN to 150 kN

Although the above requirements were considered to be ideal, it was noted that simply replicating the main requirements in the existing FUP Directive in a revised RUP Directive would be likely to represent a substantial improvement over the current situation.

However, during the research and testing a number of issues were identified that would need further consideration before the above improvements could be implemented. These are discussed in Section 3.1.2.3 below.

3.1.2.3 Assessment of RUP device designed to meet VC-Compat proposal

During the development of the VC-Compat proposal a RUP was designed and tested. This section describes the testing of the RUP and summarises the main findings.

The geometry of the RUP was constrained by the geometry of the trailer that was obtained for use in a full scale crash test. The length of the upright members was determined by the ground clearance requirement of 400mm and the geometry of the mounting points was designed to match existing mounting points on the chassis. The height of the cross-member was specified to be 200mm in accordance with the previous recommendations. The material specification was determined using an iterative process based on the proposed force requirements for the quasi-static test. Engineering data tables were used to select a material characteristic and a three-dimensional CAD model was created. The CAD model was then used in a simple elastic finite element model which showed the RUP to be too strong. The material thickness was reduced and the elastic model was re-run. A plastic finite element model of this design was created and the test loads applied in the model using LS-Dyna. This analysis showed that the RUP would withstand the test loads within the permitted deflection of 400mm. The maximum deflection predicted was 6.4mm at P1. Figure 3-2 shows the final design of the RUP.

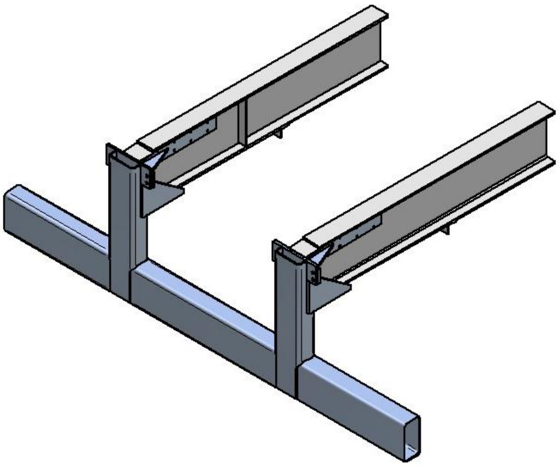


Figure 3-2. RUP Final Design.

Quasi-static tests were conducted in accordance with the method described in Directive 70/221/EEC and its subsequent amendments. However the test loads were substituted with the proposed test loads. Figure 3-3 shows the test set-up and Table 3.4 shows the results.

Figure 3-3.Test set-up point P3.

Because of symmetry, test loads were only applied at points P1 and P2 on one side of the guard.

Table 3.4. Results of quasi-static point load tests.

Test number	Load application point	Test load required (kN)	Peak load recorded (kN)	Peak displacement (mm)	Permanent set deformation* (mm)
1	P1 LHS	110	111.75	**44.3**	18
2	P3 CENTRE	150	151.77	**24.3**	4
3	P2 LHS	180	181.72	**20.0**	2.5

* deformation measured after loads had been removed

The RUP presented for testing successfully achieved the mechanical strength requirements as described. However, the actual deformation was greater than predicted using the simple finite element (FE) model.

A full scale impact test was carried out where a small family car was impacted into the rear of a semi-trailer fitted with the RUP made to the same specification as tested in Figure 3-3. The actual impact speed was 56km/h and the overlap was 76%. These are both within the permitted tolerances set out before the test. There was good initial interaction between the lower rail on the struck side of the car and the RUP. Figure 3-4 and Figure 3-5 show the two vehicles in their post impact positions.

Figure 3-4. Left side view

Figure 3-5. Right side view

With respect to the crash behaviour and deformation of the passenger car, it was concluded that:

- The drivers airbag fired at 16.2ms after t=0 (current clamp) and appeared on the film at 19ms. The passenger airbag appeared on the film 5ms later than the driver's.
- The passenger compartment remained intact; no compartment collapse
- There was no substantial deformation of the A-pillars
- Although the initial interaction between the right hand lower rail and the RUP cross-member was good, the front section (crush can) of the right hand lower rail bent downwards during the impact The front section of the lower rail diverted under the RUP, but the RUP interacted with the section of the lower rail directly behind the crush can.
- The right hand side lower rail, behind the crush can, failed in bending and therefore absorbed some of the impact energy. This downward bending failure is not what would have been expected from previous experience from car to barrier tests, where bending in a lateral direction was the failure mode seen. It is therefore not known if the amount of energy absorbed was more or less than that absorbed by the same component in a barrier test.
- During the impact, the engine displaced rearwards due to a combination of loading via the bumper beam and direct interaction with the RUP upright.
- The connection between the sub-frame and lower rails remained intact.

The dummy injury response showed that the risk of injury was within performance limits specified in frontal impact standards for Europe. The thorax was the area that was at highest risk of serious injury, however the chest deflection of 24mm and viscous criterion of 0.1m/s were well within the recognised limits of 50mm and 1.0m/s. From the kinematics of the driver dummy and the injury response, it was concluded that:

- The pressure and firing time of the airbag appeared to be appropriate

- There was a stable impact of the dummy head into the airbag (no contact with steering wheel)

With respect to the crash behaviour and deformation of the semi-trailer, it was concluded that:

- Both the RUP and the chassis deformed under loading, with some of the retaining bolts shearing off in the impact (Figure 3-6 and Figure 3-7).
- The maximum displacement of the RUP was 499mm. This displacement was measured at the extreme left hand side of the RUP. This measurement included the displacement due to the deformation of the chassis rails.
- There was deformation of the RUP cross-member, particularly in areas around the uprights.

Figure 3-6. Deformation of left hand chassis beam (blue)

Figure 3-7. Rear view of RUP

The force applied to the RUP during the impact was estimated as 318kN using the acceleration data collected during the test.

The force applied to the RUP was also calculated using the displacement of the RUP during the impact. The displacement of the RUP relative to the trailer chassis can be determined in two ways; from the post test static measurements and from the accelerometers. The post test measurements may be an underestimate of the displacement because of the elastic properties of the material. The accelerometer data may over-estimate the displacement because of noise generated during the impact. Therefore, these two methods were used to derive a range of work done by each structure. The results are shown in Table 3.5.

Table 3.5. Estimation of force on RUP.

Displacement	Work Done RUP	Force RUP
Static data 325mm	82.9kJ	255.1kN
Accelerometer data 613mm	82.9kJ	135.2kN

The following conclusions were drawn from the testing:

1. The RUP that was tested was capable of preventing the car from under-running the rear of the trailer. However for a vehicle with a shorter bonnet, contact could have occurred between the trailer load-bed and the car A-pillars.
2. The impact was managed to minimise the risk of injury to the car occupants. The occupant compartment integrity was maintained and the firing time of the airbag was not adversely affected.

3. The design of the lower rails (with crush cans) resulted in good interaction with the RUP and hence energy absorption. It is not clear whether this interaction would occur if the car had no crush cans.
4. Further investigation should be carried out to determine the reasons for chassis deformation and the differences between test methods.
5. The performance of the RUP during the vehicle impact test was not as expected based on the performance in the point loading test.

3.1.3 Assessment of 2006 amendment to Directive 70/221/EEC on RUP

ADAC reported on two rear underrun tests showing the difference in performance of a standard RUP (according to the 2006 amendment 2006/20/EC) and a highly reinforced RUP, to demonstrate the need to improve the current EC Directive,(ADAC, 2006).

The ADAC report noted that serious or fatal injuries are a frequent outcome of rear end collisions of cars or other vehicles with trucks. In Germany, there were concerns over whether the revised Directive would provide adequate protection for drivers and front seat passengers.

In order to find out whether a RUP designed to the requirements of the 2006/20/EC amendment provides car occupants with sufficient protection against injuries, ADAC carried out an appropriate crash test programme. The first test involved a collision with a RUP that was shown to just pass the new requirements. A second crash test involved a prototype RUP device intended to be more robust.

For both crash tests the ADAC engineers used the same make and model of small family car, similar to the Ford Focus. The dimensions and weight of this vehicle were representative of an average passenger car. The use of identical engines, safety equipment, weight and attitude of the seats ensured identical test conditions in the two tests.

The test vehicles impacted the stationary truck at 56 km/h with 75% overlap. The test speed of 56km/h was selected because each passenger car must pass a 56 km/h frontal crash test during type approval.

3.1.3.1 ADAC crash test 1

The first test involved an impact on a RUP designed to meet the loading requirement specified in the 2006/20/EC amendment.

The test vehicle was occupied by two shop window mannequin occupants and collided with a stationary semi-trailer. The semi-trailer had a chassis height of 990 mm and was equipped with a new RUP complying with the 2006 /20/EC amendment. The ground clearance of the RUP was 550 mm. Shop window mannequins were used because it was anticipated that the RUP would not prevent underrun and would, therefore, result in damage to the occupants of the car. If proper instrumented crash test dummies are damaged, they are very expensive to repair.

The first ADAC crash test showed that even a RUP that complies with the revised requirement does not protect passenger car occupants against life-threatening injuries at a collision speed of 56 km/h. This can be seen visually in Figure 3-8, below.

Figure 3-8. Result of ADAC crash test with RUP compliant to 2006/20/EC

Immediately after the initial impact, the RUP failed because the connection to the truck chassis was too weak. As a result of this failure, the passenger car under-ran the rear of the semi-trailer by a considerable distance. The tailgate of the truck pressed the airbags down so that they could not protect the occupants. The passenger compartment was completely destroyed up to the rear doors. ADAC described the implications as 'clear', and considered that in such an incident, there would be an extreme risk of serious or fatal injuries to the car occupants.

3.1.3.2 ADAC crash test 2

The second test assessed a RUP device developed by ADAC to provide effective protection to the car occupants.

The passenger car used in the test was occupied by two 50th percentile Hybrid III anthropometric test devices (ATD). The car impacted the rear of a truck similar to that used in test 1 (990 mm chassis height) which was fitted with an improved RUP device. Diagonal bracings from the RUP to the chassis provided greater stability. The ground clearance was less than the EU-compliant device, at 450 mm. Sensors were installed on the RUP device to measure the force loading during the impact and ADAC kindly supplied TRL with the data. Combining the results from these sensors suggested that the total load applied by the car to the RUP during the test was as shown in Figure 3-9, below.

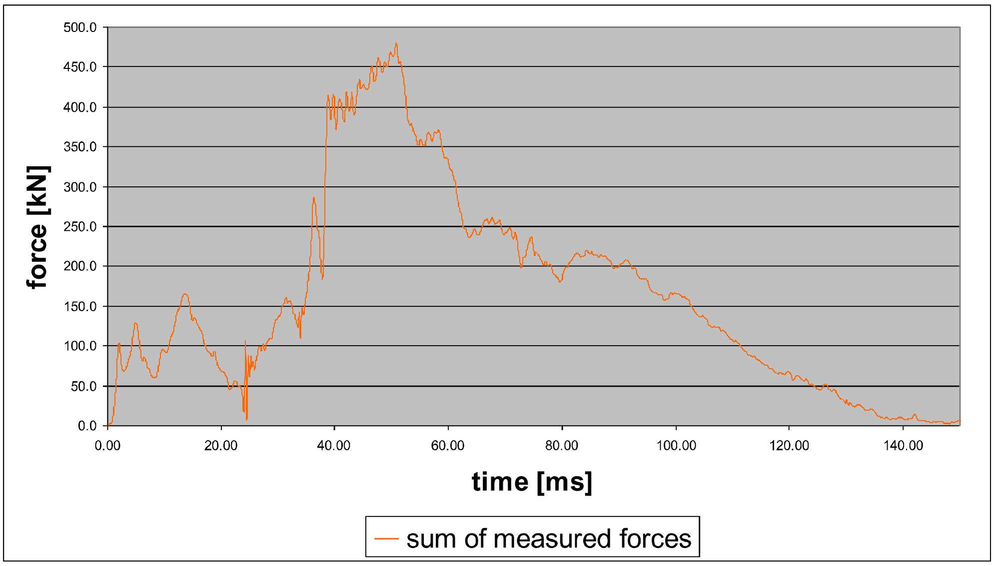


Figure 3-9. Sum of measured forces on RUP cross member during 2nd ADAC test

It can be seen that the peak force applied during the test was measured at more than 450kN. However, the outcome of this test was completely different to the first. The RUP device with lower ground clearance, stabilized by angled struts, withstood the force of the impact and allowed the crumple zones of the passenger car to perform their function. The car did not underrun the truck and the airbags remained in place and would have protected the occupants. The tailgate of the truck did not intrude into the passenger space. ADAC considered that the danger of life-threatening injury was much reduced. The result can be seen visually in Figure 3-10, below.

Figure 3-10. Result of 2nd ADAC test with strengthened and lowered RUP

3.1.3.3 ADAC conclusions

ADAC concluded that these tests were a clear demonstration that the requirements of the latest amendment to the EC Directive on RUP are insufficient to protect car occupants against life-threatening injuries. ADAC considers that their RUP design from the second test showed where potential for improvement exists, achievable at little cost.

ADAC suggested the following modifications to the performance requirements for underrun guards:

- The static test loads for approval of RUP devices should be raised and applied simultaneously. However, no indication of recommended load figures was provided.
- The RUP should be placed as near to the rear of the vehicle as possible, because;
  - The current Directive states that "This requirement will be satisfied if it shown that both during and after the application the horizontal distance between the rear of the device and the rear extremity of the vehicle does not exceed 40cm at any of the points P1, P2 and P3". Therefore, if the RUP is rigid and does not deform, then it can be positioned up to 40cm from the rear of the vehicle. This potentially allows the impact partner to under-run up to 40cm prior to interaction and deformation of the crash structure of the car. For vehicles with short frontal structures, there is an increased likelihood of interaction with the A-pillar of the car.
- The ground clearance should be reduced to ensure proper interaction with the cars energy absorbing structures. Again, no figure is suggested, although the test was carried out at 450mm and it was considered that this worked well.

3.1.4 Assessment of RUPs meeting other international standards/proposals

Akiyama (2005) examined the effectiveness of the RUP that was introduced to Japan in 1991 according to ECE-R58. According to ITARDA, fatalities and serious injuries in car to truck rear-end collisions decreased from 11.6% to 7.6% as a result. Akiyama pointed to a need for further improvement of RUP in order to achieve greater fatality reduction because, in general, the safety performance of passenger cars was improving such that higher collision speeds were becoming survivable. A prototype of an enhanced RUP was developed, able to cope with up to 55km/h in rear-end collision between large trucks and cars. Akiyama proposed that further discussions should take place on setting the crash test condition that RUP should meet, in order to achieve worldwide consensus on RUP testing. To date, this is still pending and no additional information was available.

3.2 Test method – evaluation of the VC-Compat proposals

During the VC-Compat quasi-static test, the RUP was fitted to a pair of steel "I" section beams designed to replicate the trailer chassis, and the deformation in these beams was negligible. In the full scale dynamic test, the chassis members were deformed and the maximum displacement exceeded 400mm. Possible reasons for the difference in chassis deformation between the two types of test were cited and are reproduced below:

- Differences between the static and dynamic nature of the tests and the forces involved
- Differences in material properties
- A possible fault in the chassis members of the trailer.

VC-Compat recommended that appropriateness of the quasi-static test using sequential point loads be investigated further before implementing a new standard. This section of the report describes such an investigation.

3.2.1 Full scale test with replica chassis

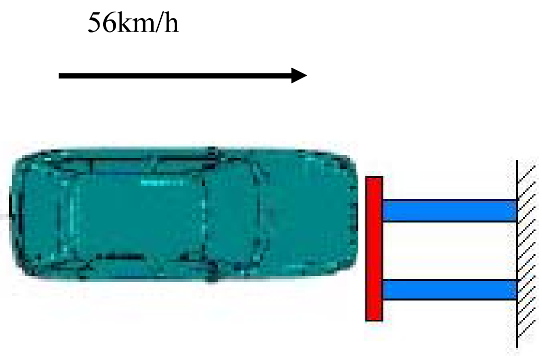
This section of the report describes the method used and results from a full scale crash test between the front of a passenger car and a RUP test rig. The test rig used for this test was fitted with the prototype RUP device and replicates the chassis rails of a semi-trailer unit. The objective of this test was to investigate the differences between the VC-Compat full-scale test and quasi-static test. This would help to identify if the difference was related to variation in the test equipment (i.e. replica chassis different to actual semi-trailer chassis) or whether the quasi-static regulatory test method/forces were fundamentally poor at predicting full scale dynamic performance.

3.2.1.1 Test configuration

The test was set-up to closely match the configuration of the RUP used in the quasi-static testing that was part of the VC-Compat research. The set-up of the car was the same as that used in the VC-Compat full scale test. Table 3.6 summarises the test configuration. Figure 3-11 and Figure 3-12 show the actual pre-impact test set-up.

Table 3.6. Test configuration.

Test Date	June 27th, 2007
Location	Millbrook, UK
Topic	RUP Test
Test Number	B3504
Test Protocol	



Vehicle 1:	Passenger car	Test Rig:	Chassis rails and RUP
Brand/type:	Vauxhall Astra	Brand/type:	N/A
Impact side:	Front	Impact side:	
Speed:	56km/h	Speed:	N/A
Overlap:	75% (of the car)	Details:	
Test mass:	1448kg	Test Mass:	
Dummy:	RHS – Hybrid III	Dummy:	N/A

Figure 3-11. Overhead view, lateral alignment.

Figure 3-12. Left side view, vertical alignment.

3.2.1.2 Results

The actual impact speed was 56.1 km/h and the overlap was 75%. These were both within the permitted tolerances set out before the test. There was good initial interaction between the lower rail on the struck side of the car and the RUP. Figure 3-13 and Figure 3-14 show the car and the RUP in their post impact positions.

Figure 3-13. Overhead view.

Figure 3-14. Left side view.

With respect to the crash behaviour and deformation of the passenger car, it was concluded that:

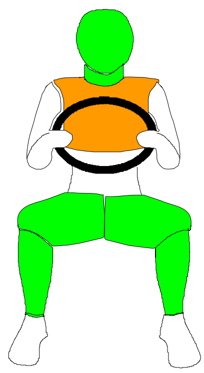
- The drivers airbag fired at 13.6ms after t=0 (current clamp) and appeared on film at 18ms. The passenger airbag appeared on the film 6ms later than the drivers.
- There was no substantial deformation of the A-pillars.
- During the impact the engine displaced rearwards due to a combination of loading via the bumper beam and direct contact with the RUP upright.
- The RUP upright directly impacted the front bulkhead causing an additional acceleration spike at 125ms. This was not seen in the VC-Compat test.

Table 3.7 summarises the peak values from the dummy data.

Table 3.7. Dummy measurements.

Parameter	Peak Value
Head	
HIC_{36}	104
3ms exceedence	25.0 g
Neck	
Shear (Fx)	-0.3 kN
Tension (Fz)	0.7 kN
Extension (Myoc)	-8.2 Nm
Chest	
Deflection	-34 mm
Viscous Criterion	0.16 m/s
Pelvis	
Acceleration	25.9 g
Femur axial compression	
Left	-0.13 kN
Right	-0.18 kN
Knee displacement	
Left	-0.6mm
Right	-0.3mm
Tibia compression	
Upper left	0.77kN
Upper right	1.27kN
Lower left	1.15kN
Lower right	1.73kN
Tibia index	
Upper left	0.16
Upper right	0.23
Lower left	0.22
Lower right	0.24

Injury level to each body region based on EuroNCAP ratings



From the kinematics of the driver dummy and the dummy data, it was concluded that:

- The pressure and firing time of the airbag appears to be appropriate.
- There was a stable impact between the dummy head and the airbag (no contact with the steering wheel).
- The measurements for all body regions were within the threshold values used in EuroNCAP assessments (EuroNCAP, 2002) indicating that the vehicle performed adequately (although the impact speed was lower than used in EuroNCAP frontal impact tests).
- The injury response in this test was similar to the full scale VC-Compat test. The main difference is that the risk of thoracic injury is higher than in the previous test.

With respect to the crash behaviour and deformation of the test rig, it was concluded that:

- Both the RUP and chassis rails deformed under loading. (Figure 3-15 and Figure 3-16)
- The maximum displacement of the RUP was 716mm. The displacement was measured at the extreme left hand side of the RUP. This measurement included the displacement due to the deformed chassis rails (Figure 3-17)
- There was deformation to the RUP cross-member, particularly in areas around the uprights.

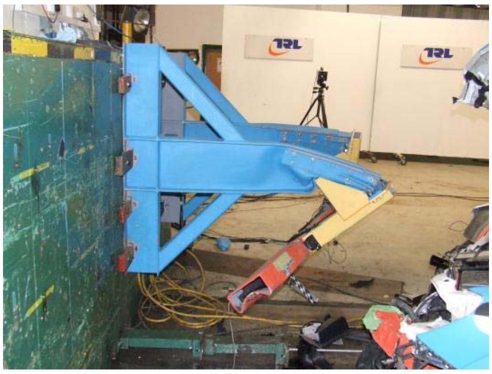


Figure 3-15. Deformation of the left hand chassis beam (blue).

Figure 3-16. Rear view of RUP.

Figure 3-17 shows how the RUP deformed during the test (B3504, blue). The maximum deflection was measured at the left hand side of the RUP and was 716mm. There was an increase in the RUP deflection compared to that measured in the previous test, carried out as part of the VC-Compat research, where the RUP was fitted to a semi-trailer (B3108, red). The difference in the maximum measured deflection between the two tests was 317mm.

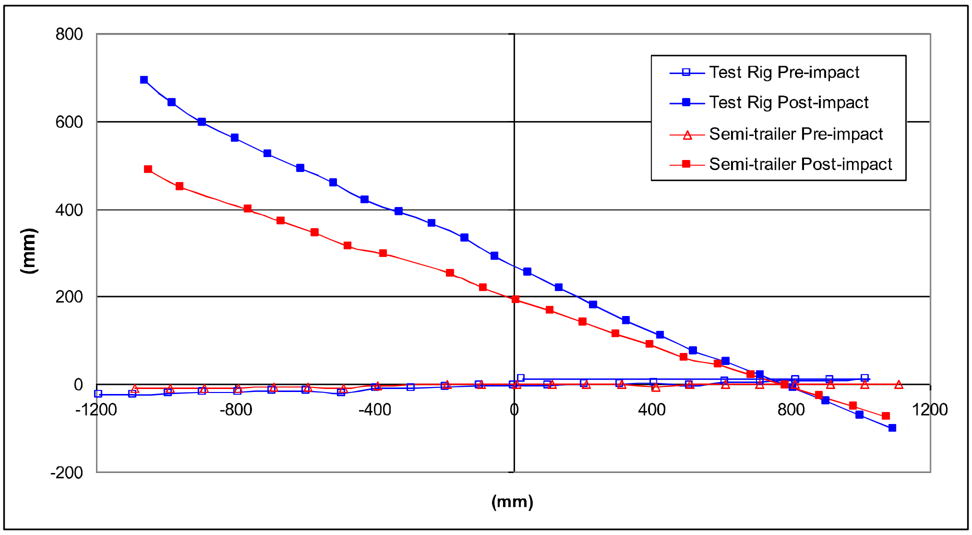


Figure 3-17. RUP Deflection compared to previous test.

3.2.1.2.1 Comparison with VC-Compat full scale test

Figure 3-18 shows the acceleration of the car at various positions on the vehicle. Figure 3-19 to Figure 3-21 show a comparison between the accelerations measured in the test where the RUP was fitted to replica chassis rails (B3504, blue) and where the RUP was fitted to a semi-trailer (B3108, pink)

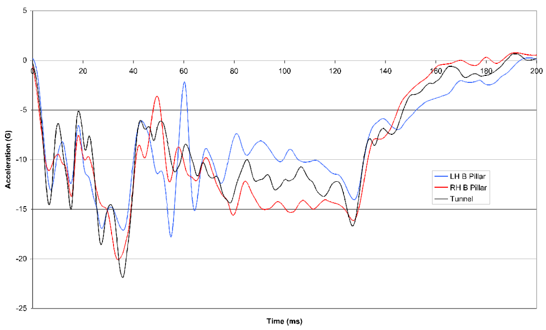


Figure 3-18. Car acceleration vs time.

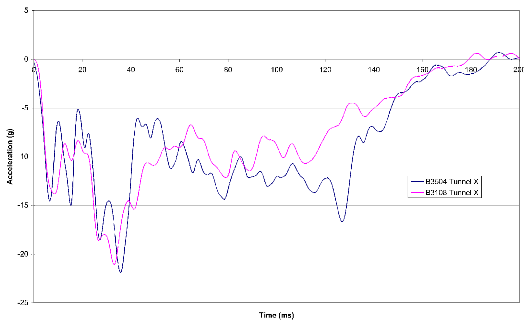


Figure 3-19. Tunnel acceleration comparison.

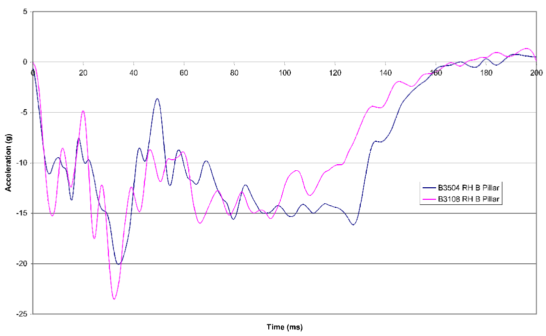


Figure 3-20. RH B pillar acceleration comparison.

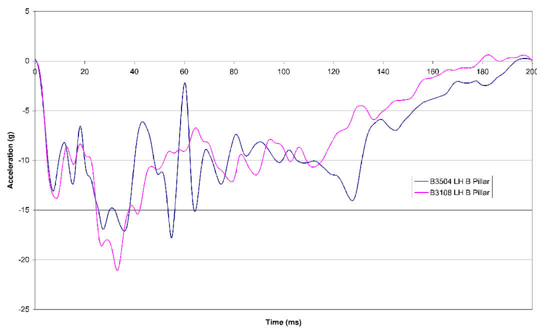


Figure 3-21. LH B pillar acceleration comparison.

From the analysis of the acceleration traces, it can be seen that for the accelerometer placed on the tunnel the initial peak is comparable to that from the VC-Compat test. However, there is a secondary peak later on in the impact that was not present in the VC-Compat test where the upright of the RUP directly impacted the front bulkhead of the car.

For the data from the B-pillar accelerometers, the traces show that the initial peak accelerations occur at a similar time to the previous test, however there is an increase in the magnitude of these values for both sides of the car.

The results of this test, particularly in relation to the deformation of the RUP and chassis, showed great similarity to the full scale test from VC-Compat and very little similarity to the quasi-static test results from the exact same test rig set-up. Therefore, it can be concluded that the deformation behaviour observed in the VC-Compat test was not the result of differences between the test rig and the semi-trailer properties and is, therefore, highly likely to be a fundamental difference showing that the quasi static test method using the sequential point loads recommended by the VC-Compat project does not accurately predict the actual behaviour in real crash conditions.

With this test result in mind, the emphasis of the research was changed from validating the point load requirements recommended by VC-Compat to a fundamental review of the regulatory test methods. This was commenced by examining the forces applied by the car to the RUP in the test to compare the results with the static loads previously predicted.

3.2.1.2.2 Force and energy calculations

Estimation of the force applied to the RUP can be made using a number of different methods and data sources from the test, these are:

- Acceleration of the car
- Displacement of the RUP
- Strain gauge data

The force applied to the RUP was estimated using the acceleration data collected during the test. The following method was used to derive Figure 3-22:

$Force_{RUP} = Force_{car}$

$= (Mass_{car} \times Acceleration_{car})$

$Peak\ Force_{RUP} = 276.96kN$

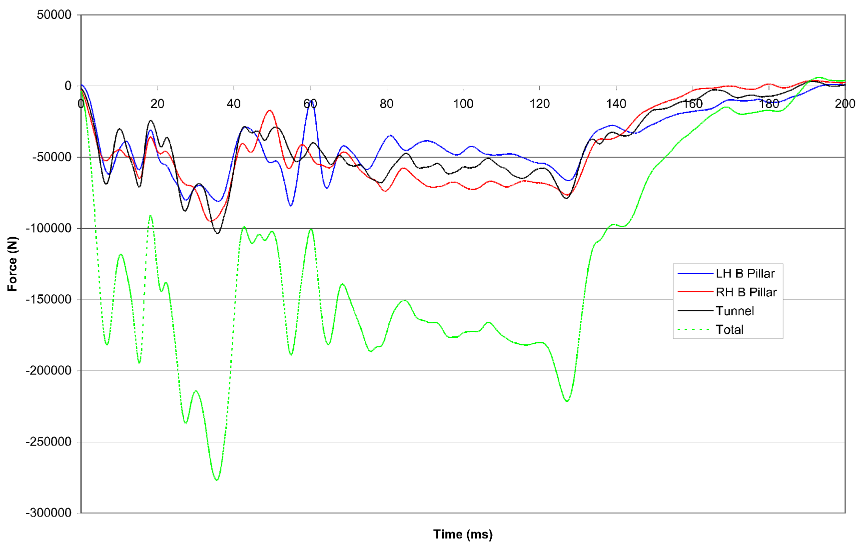


Figure 3-22: Force vs Time

Alternatively, the force acting on the RUP can also be estimated using the principles of conservation of energy.

Work Done = Change in Energy

= Initial Kinetic Energy – Final Kinetic Energy

Work Done = Force x displacement; so

Force x displacement = Initial Kinetic Energy – Final Kinetic Energy

Assuming that the initial conditions are at the point of impact (t=0) and final conditions are at the point of maximum displacement (t=140ms), the final velocity of the car is zero and hence the final kinetic energy is zero, therefore:

Work Done = Initial Kinetic Energy = Force x Distance

Work Done = $\frac{1}{2} mv^2$ = F x d

$$F = \frac{(\frac{1}{2} mv^2)}{d}$$

Where:

m = mass of car = 1448kg

v = velocity of car = $15.58ms^{-2}$

d = distance moved by RUP = 0.716m

So:

F = 245.6kN

Strain gauge analysis

To estimate the load applied to the RUP during the impact test it was instrumented with eight strain gauge rosettes. Each rosette, comprising three separate grids aligned at 45° increments (A, B and C), facilitated the calculation of the magnitude and direction of the principal strains at the locations where the rosettes were mounted. Figure 3-23 shows the location of the rosettes (numbered one to eight).

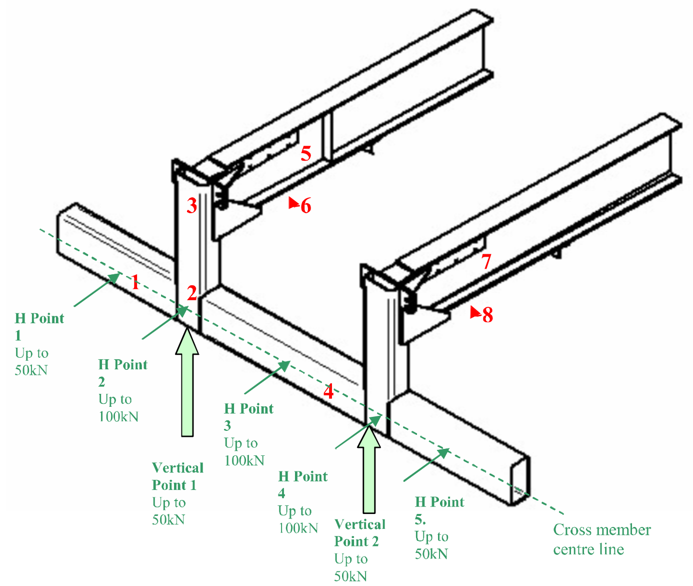


Figure 3-23. RUP strain gauge locations and calibration loading points.

Before the impact test, a calibration test was performed to determine the load-strain relationship for the rosettes on the RUP. The gauge outputs were sampled and recorded whilst the RUP was loaded quasi-statically. Figure 3-23 indicates the position and direction of the loads applied during the calibration. Loads H1 and H5, H2 and H4, and H3 correspond to the positions of the point loads P1, P2 and P3 applied during the component test specified in Directive 70/221/EEC. The loads were applied individually up to a pre-set maximum load such that the elastic limit of the entire structure was approached but not exceeded. Post test measurements confirmed there was no residual plastic deformation of the RUP after the loads had been removed.

The substantial deformation of the RUP that occurred in the impact test resulted in the strain measured at gauge locations 4, 5 and 6 rapidly exceeding the ±8,200με range of the recording equipment. The strains measured at location 3 remained within the elastic range for the material whilst those at location 1 just exceeded the elastic limit. Substantial plastic deformation occurred at all other gauge locations but remained within the range of the recording equipment.

Estimates of the load applied to the RUP by the car in the impact test were calculated by initially determining the relationship between the applied load and principal strains from the calibration test. Assuming the RUP structure behaved linearly in the elastic region, the relationship was extrapolated to determine the equivalent point load required to generate the principal strains occurring in the impact test. Analysis is focussed on the load that would be required at point H2 because this was the calibration loading point that was nearest to the centre of force that the car would apply to the RUP. It is also limited to rosette three because the direction of the principal strain at this location in both the impact test and the calibration tests were similar, and the magnitude of the strains indicated the material deformed in a wholly elastic manner in this region.

Rosette three was mounted with gauge B aligned with the vertical axis of the upright. Gauges A and C were at 45° either side of gauge B. During the calibration test there was a fault with gauge A which meant that strain measurements were not recorded. However, assuming the load applied at point H2, directly below the centreline of the upright, would generate pure bending (no torsion) at the location of rosette three, gauges A and C should both experience the same strain therefore the output of gauge A would be equal to that of gauge C. Using this assumption the magnitude of the maximum principal strain occurring at gauge three during loading in the calibration test was calculated and is shown in Figure 3-24. The curve shows both the loading and unloading of the RUP.

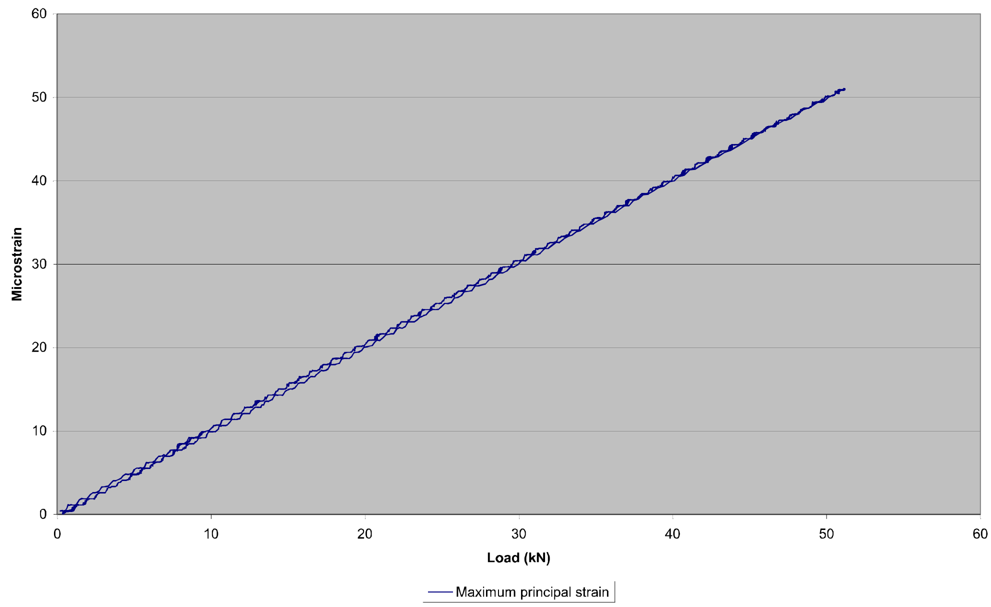


Figure 3-24: Rosette 3 maximum principal strain from H2 loading during calibration test.

Elastic deformation at the location of rosette three produced a linear load-strain relationship with a ratio of 1.01με/kN. The strain returned to zero when the load was removed indicating no permanent deformation.

Figure 3-25 shows the maximum principal strain calculated from the data recorded for rosette three during the impact test.

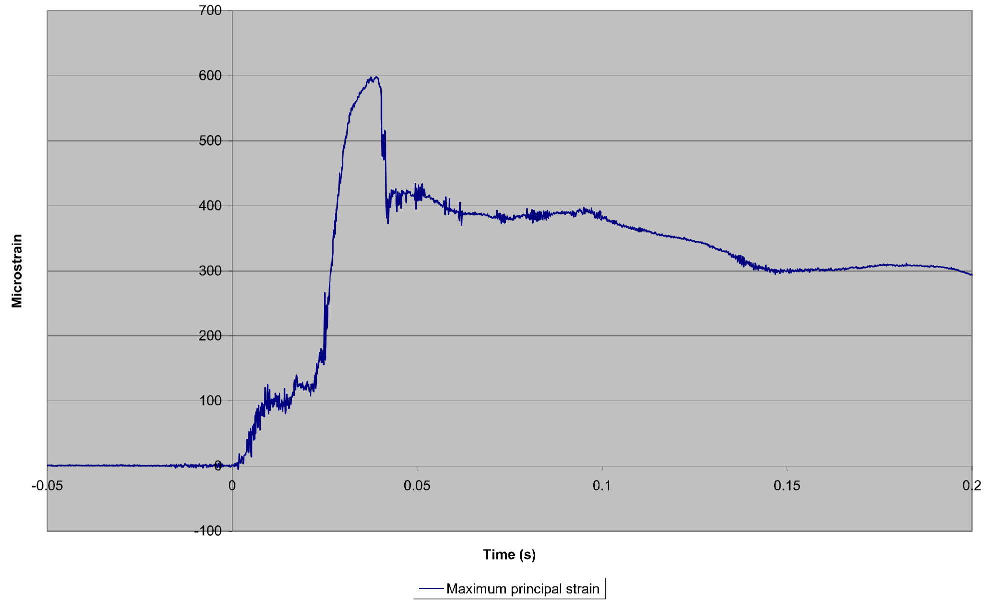


Figure 3-25: Rosette 3 maximum principal strain during impact test.

The peak strain at rosette three was 598με at t = 0.039s, indicating the structure deformed elastically at this location. The direction of the maximum principal strain as the peak value occurred was 33° to the vertical axis of the upright. By extrapolating the load-strain relationship identified in the calibration test, and taking the difference in the direction of the maximum principal strains into account, the equivalent point load that would be required at point H2 to produce a strain of magnitude similar to that occurring in the impact test was estimated to be 507kN.

3.2.2 Performance difference between dynamic and quasi-static tests

The maximum deflection of the RUP (and chassis rails) during full scale dynamic impact tests has been shown to greatly exceed that seen in the quasi-static sequential point load tests. Analysis of forces during the full scale impact tests have shown that the estimated force consistently exceeds the highest proposed individual test load applied during the quasi-static loading condition. To investigate the appropriateness of the sequential loading test procedure some numerical simulation was carried out.

3.2.2.1 Model development

To investigate the appropriateness of the test method, the multi-body truck model that was developed as part of the VC-Compat project was used. The chassis geometry was based on a larger vehicle (>20 tonnes) but the vehicle model was ballasted to 12 tonnes. A finite element RUP was constructed to replace the multi-body RUP that had previously been used. The car was a multi-body model with contact facet surfaces to provide an enhanced geometric representation of the vehicle. Figure 3-26 shows the models used in the simulation exercise.

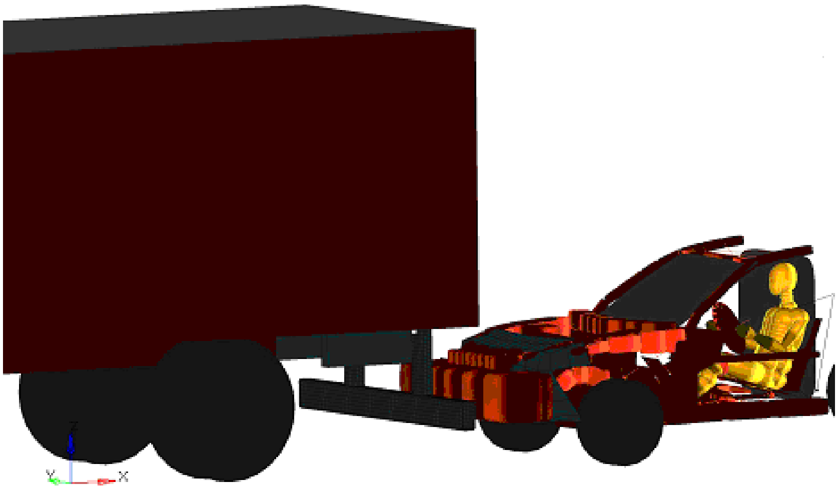


Figure 3-26. Visualisation of the vehicle models used to assess the appropriateness of the test method.

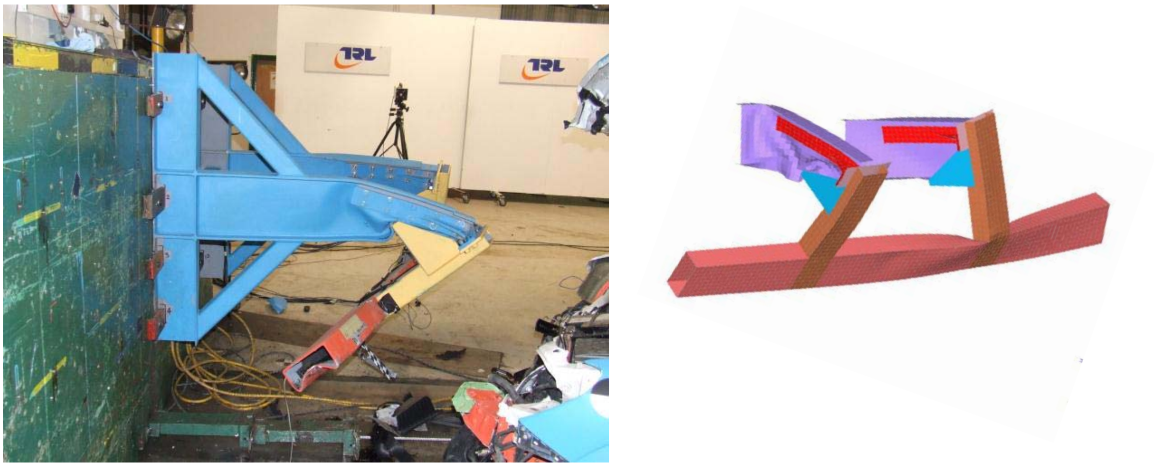
To evaluate the performance of the model, simulations of the quasi-static sequential point load test and the car impact into the test rig-mounted RUP were compared to the physical tests. Table 3.8 shows the comparison of the quasi-static sequential loading.

Table 3.8. Comparison of simulated predictions of displacement with physical test measurements.

Loading position	Point load (kN)	Physical test measured deformation		Simulated predicted deformation	
		Peak (mm)	Permanent (mm)	Peak (mm)	Permanent (mm)
P1	110	44	18	27	11
P2	180	24	4	23	13
P3	150	20	3	13	4

A comparison of the peak deformation when the RUP was loaded at P2 and the permanent deformation when loaded at P3 show good correlation between the physical test and the simulation. There is a greater difference in both the peak and permanent deformation when the RUP was loaded at P3, however the deformation was of the same order of magnitude and considered appropriate for the purpose of this study.

A comparison of the deformation from the car impact into the test rig-mounted RUP is shown in Figure 3-27.



Physical Test (a) Simulated car impact (b)

Figure 3-27. Comparison of deformation of test rig-mounted RUP after impact by car.

This comparison shows that the amount of deformation in the simulated impact is similar to the physical test and the failure occurs in the chassis rail in both instances. This RUP model was then fitted to the rear of the multi-body truck model and a further car impact simulation was carried out. Figure 3-28 shows the total force that was measured in the RUP during the simulated impact. Forces at location equivalent to the P1, P2 and P3 positions from the point loading test are also shown.

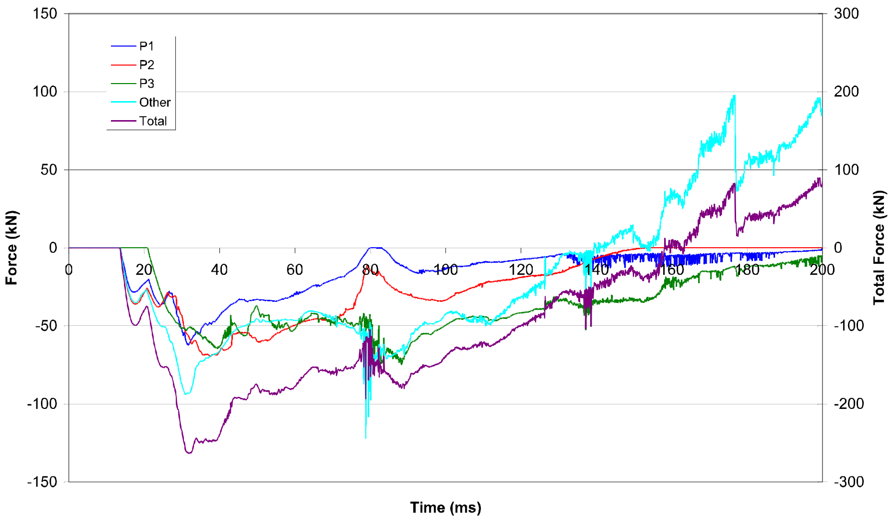


Figure 3-28. Longitudinal forces in RUP during simulated car impact.

Figure 3-28 shows that at any moment in time, the total force includes a component that is not acting at any of the points P1, P2 or P3 and this “other” force is of greater magnitude than the individual forces at each of the identified points. The predicted total force in the RUP is 260kN. The maximum forces applied at P1, P2 and P3 were 62kN, 70kN and 75kN respectively. Although these are of similar magnitude to those specified in the latest amendment to Directive 70/221/EC, in a vehicle impact the forces are applied simultaneously and as shown there is a force of greater magnitude applied in other areas of the RUP during the impact.

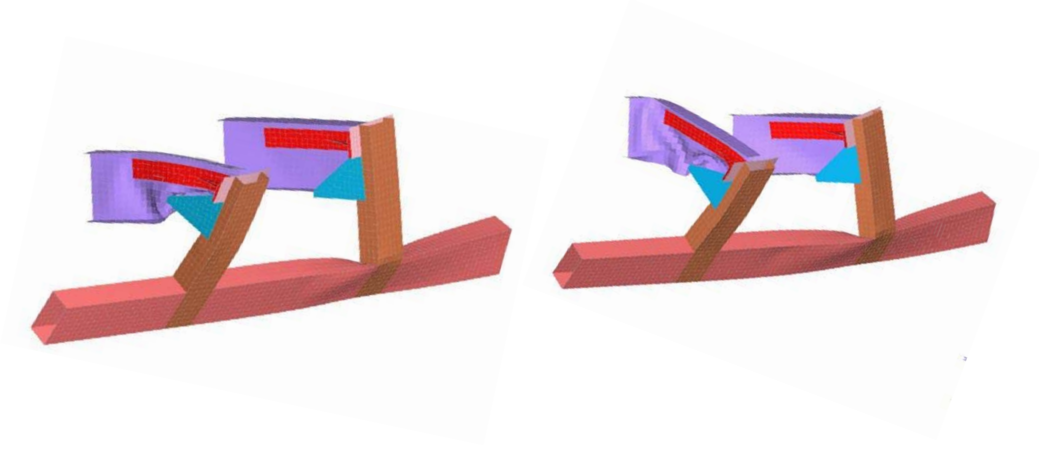
This evidence and the estimated forces applied to the RUP from the full-scale vehicle test indicate that the current sequential point loading method does not adequately represent a real-life vehicle impact. There is therefore a possibility that RUP devices that pass such a test could fail in-service.

3.2.2.2 Sequential vs simultaneous loading

As shown by the testing and simulation the total force applied to the RUP in a vehicle substantially exceeds any one of the current regulatory point loads and also the point loads proposed during the VC-Compat research, the maximum proposed load being 180kN. To achieve a test method that represents a vehicle impact, either simultaneous point loads or a distributed load should be considered.

The recently adopted Canadian Standard CMVSS223 requires the RUP to withstand two individual point loads of 50kN without deflecting more than 125mm. In addition, a 350kN uniformly distributed load is applied over the entire width of the RUP which must absorb 20kJ of energy by plastic deformation within the first 125mm deformation. An alternative to the energy absorption requirement is for the RUP to resist a 700kN load to show that separation of the RUP from the chassis is prevented.

To investigate the appropriateness of a simultaneous point load test to represent a vehicle impact a simulation was run using the model described earlier. Test data and simulation predictions so far have indicated that a total force of approximately 270kN is applied when a medium sized car impacts a RUP. Therefore, three 90kN loads were applied simultaneously at points P1, P2 and P3 in the model. Figure 3-29 shows the comparison of the simultaneous point loads (a) with the RUP after the car impact (b).



Simulated simultaneous point loads (a) **Simulated car impact (b)**

Figure 3-29. Comparison of simultaneous point simulation with car impact simulation.

This comparison shows that there are similar levels and types of deformation when the RUP is loaded to 270kN quasi-statically compared with the vehicle impact, indicating that the simultaneous loading at three points to a total of 270kN is representative of the vehicle impact for this vehicle set-up.

However, the loading requirement of 270kN was derived from tests and simulation of a RUP that exceeded 400mm deformation (RUP_{STI}). Therefore, further investigation of the force that should be applied was required because the force generated in an impact with a stiffer RUP is likely to be higher. The RUP was re-designed to deform less than 400mm during the simultaneous loading. This was achieved by changing the thickness of the materials used in each component of the RUP and the chassis members. The maximum deflection predicted under a load of 270kN was 270mm (RUP_{STF}). The modified version of the RUP (RUP_{STF}) was then assessed by simulating the car impact and the predicted loads were identified. The total force generated in the modified RUP (RUP_{STF}) was 271kN, with a maximum deflection of 411mm. This indicates that the proposed loading of 270kN is suitable for the assessment of RUP fitted to larger vehicles based on the RUP design and bullet vehicle used in this study.

The RUP that has been developed during this study shows good performance when impacted by a car with a relatively high overlap (75%). However, some impacts occur with a much smaller overlap between the two vehicles. A simulation was run to investigate how the RUP performs in a low overlap dynamic impact. The set-up of the simulation and resulting deformation is shown in Figure 3-30.

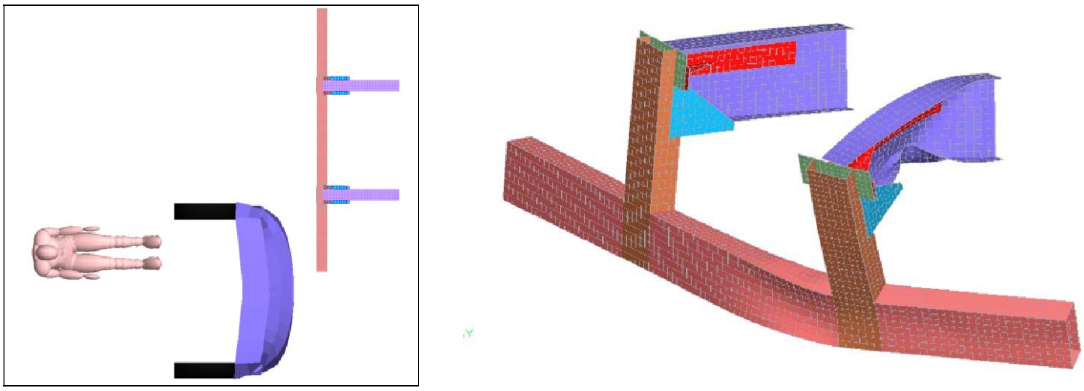


Figure 3-30. Set-up (left) and resulting deformation (right) from simulation of low overlap dynamic car impact.

The maximum deflection predicted from this simulation run was 800mm. This is double the 400mm that is specified as the maximum deflection in the current Directive. The peak total load applied to the RUP during this impact was 172kN.

This suggests that the simultaneous point loads are sufficient for representing a high overlap impact, but that an additional test is required to ensure the structural performance of the unsupported part of the RUP during low overlap impacts. This has not been the main focus of this research and the following test is proposed as a theoretical solution. However, this theoretical solution is likely to require further evaluation and validation.

Based on the analyses in this project, then it seems likely that, if RUP is to be effective for low overlap collisions, any part of the RUP cross-member that is supported at only one end should be subjected to a point load test. The load should be applied to the geometric centre of the un-supported part of the cross-member as defined in Figure 3-31. This test should also be applied to RUP that is split to allow the fitment of tail lifts. The length of the cantilever member may vary between RUP designs. Therefore the force to be applied should be proportional to the length of the cross-member section to which the load will be applied. The results of the simulation described above suggest that a value of 274N/mm is suitable based on the size of car used in the study.

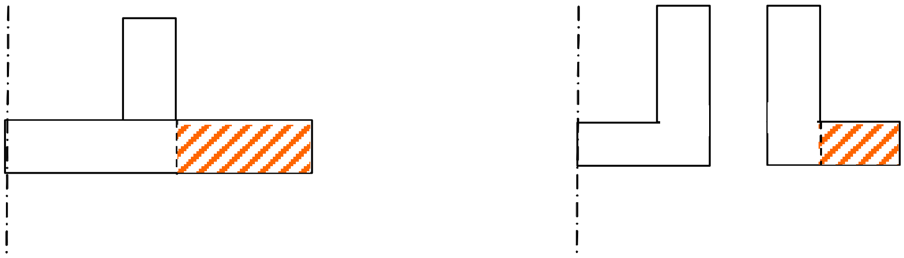


Figure 3-31. Definition of the midpoint of the un-supported cross-member.

3.3 Smaller vehicles – analysis of requirements for smaller trucks

Numerical simulation carried out in VC-Compat indicated that interaction between the structural members of the front of the car and the chassis of the HGV could influence the outcome of an impact to the rear of an HGV. Such interaction is much more likely with smaller, particularly rigid, HGVs. In Europe, current requirements allow smaller HGVs (up to 20t) to have RUP devices approved using test loads that are proportional to the maximum permissible mass of the vehicle. These loads are lower than the 50kN and 100kN loads applied to RUP for vehicles with a GVW of 20t or more. This section of the report investigates the structural interaction with the chassis for smaller vehicles to determine if lower force requirements are still appropriate for the smaller vehicles.

When considering HGVs smaller than those used in the test conducted during the VC-Compat project, the chassis may be lower and the overall weight of the vehicle may also be lower. This may lead to greater direct interaction between the car and the chassis and a lower change in velocity for the same impact conditions. These factors would be expected to lead to reduced forces being applied to the cross-member of the RUP.

The current Directive bases the maximum test loads for the RUP on a percentage of the Gross Vehicle Weight up to a maximum value, which is equivalent to a 20 tonne vehicle. This means that currently smaller HGVs can have weaker RUP. To consider the performance of RUP on smaller HGVs, the vehicle model described in section 3.2.2.1 was scaled to the geometry of a 12 tonne vehicle. The previously modified RUP model was also scaled to fit the smaller vehicle and was fitted to the rear of the 12 tonne vehicle model. An initial simulation of a dynamic impact with a car showed a maximum deflection of 156mm (RUP12TI) therefore the RUP was modified further to be “minimally compliant” and the predicted deflection increased to 377mm (RUP12TF). The predicted forces generated in the final version of the RUP are shown in Figure 3-32.

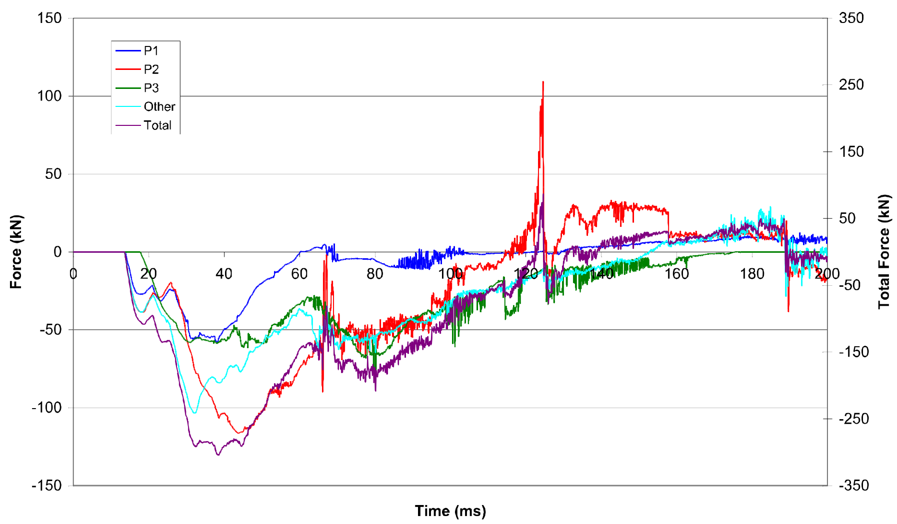


Figure 3-32. Predicted longitudinal forces in RUP for simulated car impact into RUP fitted to 12 tonne HGV.

The peak total force predicted during the impact was approximately 300kN. The peak loads at P1, P2 and P3 were 57kN, 113kN and 102 kN respectively. This total force is 30kN higher than that generated in the modified RUP fitted to a vehicle with the geometry of a large semi-trailer (RUP_{STF}), however the bullet vehicle was initially decelerated over a shorter distance. There is also a change in the distribution of the forces amongst the points P1, P2 and P3, with maximum forces for the semi-trailer model (RUP_{STF}) of 65kN, 78kN and 88kN respectively. This simulation shows that the performance of the smaller 12T vehicle in a dynamic impact with a passenger car is similar to that shown for the semi-trailer.

A quasi-static loading of 300kN was applied evenly distributed at points P1, P2 and P3 to the RUP fitted to the 12T vehicle (RUP_{12TF}). The simulation resulted in the failure of the RUP before a total force of 300kN could be generated. This is illustrated in Figure 3-33, below.

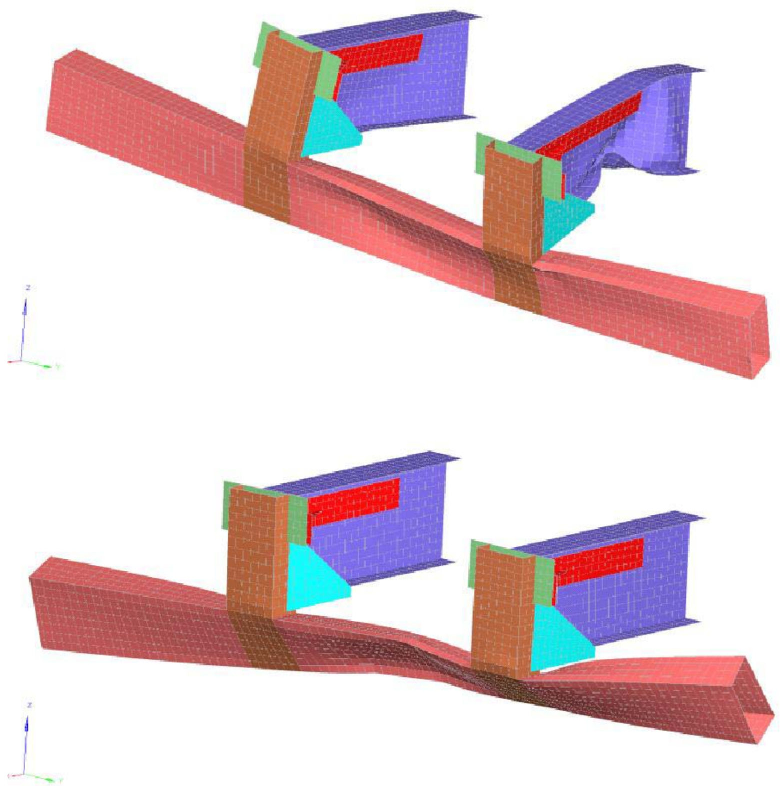


Figure 3-33. Deformation of RUP fitted to 12t vehicle after car impact loading (top) and 300kN loading simultaneously at three points (bottom).

This result is different to the behaviour seen during the dynamic impact and is most likely attributed to all the force being applied to the cross-member rather than being distributed in the upright and the chassis as seen from the dynamic impact. Figure 3-34 shows the alignment of the car with the RUP and chassis of the 12t vehicle. It is therefore necessary to consider this loading behaviour for the proposed test method.

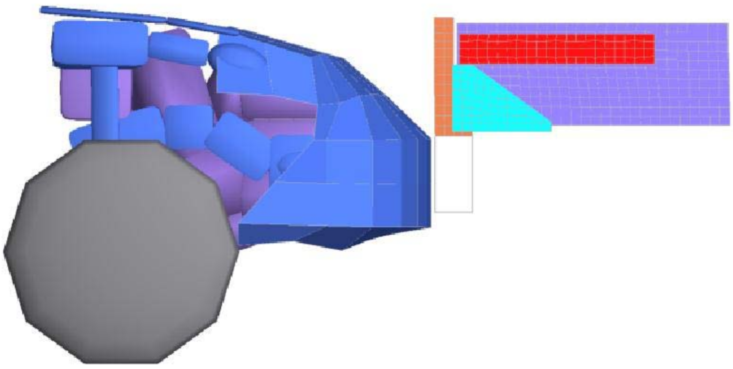


Figure 3-34. Alignment of car structure with chassis of 12t vehicle.

It can be seen that with the smaller vehicle the upper load paths in the car may interact directly with the chassis. To address this loading behaviour, the addition of a fourth test point was investigated. The set-up of the simulation was as shown in Figure 3-35**.**

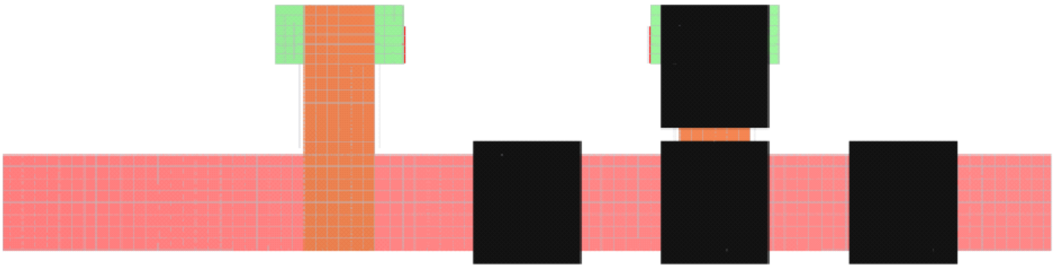


Figure 3-35. Proposed test method with point P4 on upright.

The total force of 300kN was distributed in a ratio of 70:30 between points P1, P2 and P3 on the cross member and P4 on the upright. This distribution was taken from the results of the simulated dynamic impacts in which 72% of the force generated in the 12T RUP and 71% of that in the semi-trailer RUP was at points P1, P2 and P3. Therefore the proposed loading for the test was:

- P1=P2=P3=70kN
- P4=90kN

The test method requires that all four loads are applied simultaneously. The position of point P4 was determined from the car geometrical/structural database that was created as part of the VC-Compat project (Tiphane, 2005). The measurements for the top of the engine and the top of the upper rails for the 55 vehicles in the database were averaged and weighted for sales volume. This calculation showed that the weighted average height of a structural member (based on the engine and upper rail) was 775mm above the ground.

Although this set up allowed the correct force levels to be generated in the RUP, the deformation of the chassis member from the dynamic impact was not replicated. From the visualisation of the numerical simulation, it was evident that the position of P4 was above the centre of the chassis member and was therefore not likely to generate bending in the chassis. The model was re-run with the following changes:

- P4 was 650mm from the ground – based on the position of the interacting parts of the bullet vehicle from the model run. This is specific to the bullet vehicle model used, whereas the previous vertical position of P4 was based on the whole vehicle fleet.

- The plates at P2 and P4 were reduced in height to allow P4 to be positioned at 650mm from the ground.

The set-up of the model is shown in Figure 3-36, below.

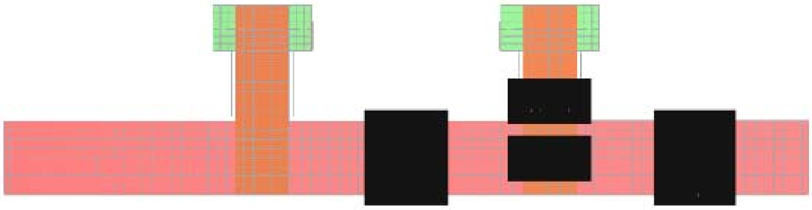


Figure 3-36. Set-up of the 4 point loading method (p4=650mm).

The deformation of the RUP cross-member was similar to that seen in the dynamic impact, however there was minimal deformation in the chassis member. The maximum displacement was 45mm.

To investigate the performance of the RUP further, the dynamic impact was re-run. This time, the front of the RUP structure was sectioned to identify the forces applied to individual parts (based on points P1 to P4) as shown in Figure 3-37**.**

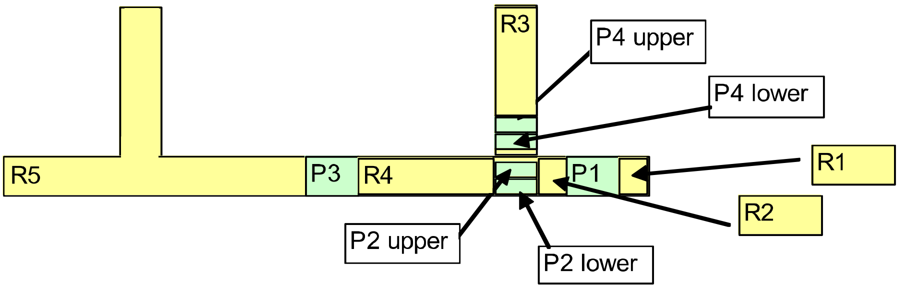


Figure 3-37. Sectioning of RUP structure for dynamic impact.

The results from the simulation showed that area P2 upper and R2 (between P1 and P2) had the two highest predicted forces applied. This suggests that the points P2 and P4 may need to be positioned outboard of the upright member.

A number of four point loading simulations were run to investigate this further. Moving both P2 and P4 outboard of the upright member resulted in the largest deformation in the chassis member, although the difference between this and the previous simulation was barely visible. The set-up for this simulation is shown in Figure 3-38.

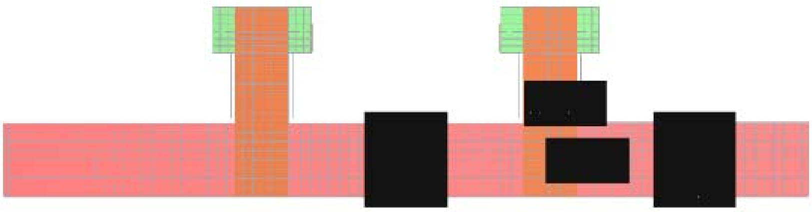


Figure 3-38. Set-up of 4 point loading method (P2 and P4 offset).

The maximum deflection in this simulation was 72mm. This is still much smaller than in the dynamic impact.

This investigation has not been able to identify the point loading set-up required to replicate the deformation from a dynamic car impact where the bullet vehicle interacts with the chassis of the HGV.

However, this investigation has highlighted some key areas to be considered when determining requirements for smaller vehicles:

1. Any special requirements for "smaller" vehicles should be based on geometric requirements rather than the GVW. The geometry of the structures will affect the interaction of the bullet vehicle more than the GVW;
2. The total test load should be applied over a two dimensional area rather than in a straight line. However, the use of point loads may result in problems for some designs of RUP where there is no structure to which to apply the load. Some form of barrier loading may be more appropriate;

3.4 Practical implementation – ferries; tail-lifts; off-road use

HGVs require a minimum level of manoeuvrability in order to fulfil their purpose of transporting goods and supporting the economy. This minimum standard will vary depending on the type of operation being undertaken, for example, the requirements of urban delivery vehicles are different to those of tipping vehicles delivering aggregates or long distance international operations regularly using roll-on roll-off (Ro-Ro) ferries. In addition to this, many vehicles are equipped with tail lifts to enable loading and unloading at sites with no facilities. The installation of RUP or the modification of RUP to introduce new requirements or to improve performance could potentially have implications for the practical ability of the vehicle to complete some of these tasks efficiently. Such difficulties are regularly cited as objections to new requirements but can often be overcome with innovative designs. These practical implications have been investigated and the results are reported in this section. The aim of the investigation was to:

- Review the exemptions for current / proposed regulations. This was based on a review of regulations and literature as well as consultation with stakeholders. The aim was to identify where it has been considered that fitment of current RUP designs may be inappropriate and, wherever possible, why it was considered inappropriate. This helps to inform the assessment of what the implications of future changes may be;
- Generate a list of potential concerns. Stakeholders from a broad cross section of Government, research establishments, and industry were asked for their input and concerns;
- Assessment of the proposed changes to RUP in terms of their effects on each of the implications listed by the stakeholders. The assessment approach was hypothetical using geometrical analysis and other analysis techniques as appropriate;
- Ensure that the provision of tail lifts is maintained. Some vehicles are fitted with a RUP that has interruptions to allow a tail lift to be fitted. These are referred to as "split RUP". The proposed requirements should not preclude the fitment of tail lifts.

3.4.1 Review of exemptions

A review of worldwide regulations has been carried out to investigate the types of vehicle that are currently awarded exemptions The investigation has looked at the EU, USA, Canadian, Australian and Brazilian standards in detail and also considered exemptions in Japan, although there was limited information available.

3.4.1.1 EC - Directive 70/211/EEC

The exemptions contained in the EC Directive are expressed in reasonably general terms, which are listed below:

- Tractors for semi-trailers,
- 'slung' trailers and other similar trailers for the transport of logs or other very long items
- Vehicles for which rear underrun protection is incompatible with their use.

Information gathered during the consultation suggests that while the exemptions for "tractors for semi-trailers" and "slung trailers" are reasonably clearly and consistently applied across Europe, the interpretation of "incompatible with use" varies considerably in different Member States.

In Germany, very few exemptions from fitting a RUP are made provided the vehicle design allows RUP mounting. RUP is considered incompatible with use for vehicles with low superstructures or bodywork or those with no suitable mounting point available. Examples of such vehicles are waste disposal (refuse) trucks, heavy load trailers with low beds, special trailers for glass transport (low beds) and fire trucks etc. There are also vehicles where the fitment of RUP is not possible because of attached loading platforms that include hydraulic loading platforms that can be folded underneath the cargo box and where small fork lift trucks are carried at the rear of the vehicle. Off-road use is not considered incompatible unless it is "extreme". Examples of extreme off-road vehicles include trucks with drilling devices, special military trucks or fire trucks. Most of these vehicles feature an off-road chassis with all-wheel drive, high ground clearance and (also due to omitting FUP and RUP) large approach and departure angles to allow rough ground to be traversed.

Stakeholders from Germany also considered that other European countries allowed more exemptions than they did. For example, they claimed that in France, many construction site trucks and trailers do not carry RUP at all. The reason may be that these vehicles have to be able to back-up very closely against road pavers that feed them with asphalt, which is prevented by RUP. However, in Germany, the RUP are designed to fold away on construction site trucks.

Sweden appears to have similar exemptions to Germany, interpreting the requirements in a similar manner. Examples of vehicles that are exempt in Sweden include: converter dollies for semi-trailers, recovery trucks, truck chassis during transport from manufacturer to body builder, trucks designed for large ground clearance intended for off-road operations and some designs of tipper vehicles. Vehicles where any underrun protection, with respect to the design and purpose of the truck, would mean considerable difficulties are also excluded, however, this has to be proven and decided in every single case. No specific details of the evidence required to exempt a vehicle was provided.

In the UK, The Road Vehicles (Construction and Use) Regulations 1986 (HMSO, 1986) Regulation 49 covers RUP for national approval. This regulation mentions specific types of vehicle that are exempt from the requirements, however these are not necessarily how the certification or enforcement agency would interpret the exemptions if a UK manufacturer was applying for EC approval. These vehicle types are:

- A motor vehicle with a maximum speed not exceeding 15mph
- A motor car or heavy motor car constructed or adapted to form part of an articulated vehicle
- An agricultural trailer
- Engineering plant
- A fire engine
- An agricultural motor vehicle
- A vehicle fitted at the rear with apparatus specially designed for spreading material on the road
- A vehicle so constructed that it can be unloaded by part of the vehicle being tipped rearwards

- A vehicle owned by the Secretary of State for Defence and used for naval, military or air force purposes
- A vehicle to which no bodywork has been fitted and which is being driven or towed-
  - For the purpose of a quality or safety check by its manufacturer or a dealer in, or distributor of, such vehicles; or
  - To a place where, by previous arrangement, bodywork is to be fitted or work preparatory to the fitting of bodywork is to be carried out; or
  - By previous arrangement to premises of a dealer in, or distributor of, such vehicles;
- A vehicle which is being driven or towed to a place where by previous arrangement a device is to be fitted so that it complies with this regulation
- A vehicle designed and constructed, and not merely adapted, to carry other vehicles loaded onto it from the rear
- A trailer specially designed and constructed, and not merely adapted, to carry round timber, beams or girders, being items of exceptional length
- A vehicle fitted with a tail lift so constructed that the lift platform forms part of the floor of the vehicle and this part has a length of at least 1m measured parallel to the longitudinal axis of the vehicle
- A trailer having a base or centre in a country outside Great Britain from which it normally starts its journeys, provided that a period of not more than 12 months has elapsed since the vehicle was last brought into Great Britain
- A vehicle specially designed, and not merely adapted, for the carriage and mixing of liquid concrete
- A vehicle designed and used solely for the delivery of coal by means of a special conveyor which is carried on the vehicle and when in use is fitted to the rear of the vehicle so as to render its being equipped with a rear under-run protective device impracticable
- An agricultural trailed appliance

One stakeholder from Germany raised a concern over the compliance with the requirements for RUP. RUP can be approved to UNECE Regulation 58 (as a substitute to 70/221/EEC) which allows approval by calculation only, without any physical test. In Germany, the large truck and trailer manufacturers are often required to provide proof in the form of actual test results for their RUP designs, however the practice may be different for small companies specialising in custom-made superstructures and bodywork. It is believed that some RUP designs are required to show only a calculation (probably based on simple static assumptions), especially if they are intended only for a small number of vehicles.

The consultation with European industry has also provided information on the number of vehicles excluded. In Germany, it has been suggested that as a rough estimation the percentage of vehicles exempt would be less than 5% of the respective fleet (not considering semi-trailer tractor units). However, information from Sweden suggests a different picture with an estimated 15 – 20 percent of the vehicle fleet being exempt. In Great Britain, approximately 16% of rigid goods vehicles over 3.5t are classified as body type “tipper” which have been exempt from fitting RUP. Rigid vehicles account for 71% of all goods vehicles over 3.5t. Therefore an approximation of the vehicle fleet that is exempt from fitting RUP is 11% (DfT, 2007). This is an under-estimate since it assumes that no articulated vehicle combinations will be exempt and that all other types of rigid vehicle are not exempt. In reality, other types of rigid vehicle such as skip loaders and mobile plant will not be required to fit RUP.

3.4.1.2 USA – FMVSS224

The standards in the USA are similar to the EC, but do state specific vehicle types where the underrun device may be incompatible with their use. The directive states that the following vehicles are excluded:

- Single Unit (Straight Body) Trucks
- Special Purpose Vehicles (i.e. dumpers, farm equipment, vehicle with rear mounted lift gates)
- Wheel Back Vehicle (vehicle with a permanently fixed rear axle, with tyres whose rearmost surface is located no more than 305 mm from the rear of the vehicle)

No additional information regarding vehicle exemptions in the USA was obtained. However, these exemptions are quite different to those for the EC, and appear to offer the potential for a greater number of vehicles to gain exemptions.

3.4.1.3 Canada - CMVSS 223

The requirements of CMVSS 223 apply to newly manufactured trailers with a GVWR of 4,536 kg or more, with the following exceptions

- a pole trailer, a pulpwood trailer, a wheels back trailer or a trailer designed to be used as temporary living quarters
- a low-chassis trailer
- a trailer designed to interact with, or having, work-performing equipment located in or moving through the area that would be occupied by a horizontal member that meets the configuration requirements

Consultation with Transport Canada has identified that these vehicles are excluded because their design does not permit the installation of a rear guard, their wheels or structure prevent or limit rear under ride, or they rarely travel on public roadways. Also, trailers that are designed exclusively for the transportation of dangerous goods and that meet the rear impact protection requirements of National Standard of Canada CAN/CSA — B620-98, Highway Tanks and Portable Tanks for the Transportation of Dangerous Goods, dated August 1998, are exempt from the energy absorption requirement of the new CMVSS223. Single-unit trucks are also excluded from the requirements because data taken from the Canadian and U.S. collisions statistics indicate that single-unit trucks are rarely involved in fatal rear-end collisions.

The CMVSS 223 does not specify requirements for split RUP as in the EC directive.

3.4.1.4 Brazil - CONTRAN 805/95

The following specific exemptions were identified for Brazil:

- Incomplete or unfinished vehicles
- Vehicles to be exported
- Tractor trucks
- Vehicles constructed especially for self-carrying or very long cargoes
- Vehicles in which the attachment of the specified rear guard is incompatible with their use
- Vehicles with the rear guard incorporated in their body according to the manufacturer's original design
- Military vehicles
- Collector's vehicles

No additional information was identified.

3.4.1.5 Australia - ADR 42/04

The Australian Standards state that "every 'Semi-trailer' must be provided with a continuous rear bumper which must be constructed such that:

- The lower edge is no more 600 mm from the ground;
- The bumper contact surface is located not more than 600 mm forward of the rear of the vehicle and is painted white
- The ends of the bumper extend to within 300 mm of each side of the vehicle, unless the rearmost point of the tyres is within 600 mm of the 'Rear End' of the vehicle, in which case the tyres must be considered as meeting the requirements over their width
- The member which is, or directly supports, the bumper contact surface is of material having no less strength than steel tubing of 100 mm outside diameter and 8 mm wall thickness
- The structure supporting the member can transmit no less force than that member can sustain, and provides a continuous force path to vehicle members of strength consistent with the forces to be sustained."

These requirements are for every semi trailer on the Australian roads; however they have made a few exceptions. Vehicles fitted with cargo access doors, tailgates or other such structures that when closed afford comparable protection are exempt as are vehicles that have the rear end of their vehicle no more than 155mm from their rear tyres.

3.4.2 Potential operational issues

Part of the consultation with stakeholders requested information about operational issues that could be affected by changes to the RUP Directive. The three main areas of concern raised by the stakeholders were ferry access, off- road use and construction site vehicles.

Boarding and alighting from ferries often requires vehicles to negotiate steep ramps, as shown in Figure 3-39. It was suggested that the RUP of some vehicles can contact the ground during this manoeuvre, causing damage to the RUP and/or difficulties in moving vehicles about.

Figure 3-39. Ramp to embark and disembark from a ferry.

To avoid damage to the either the RUP or ramp, the position of the RUP relative to the rear wheel is of critical importance. Stakeholders suggested that the minimum angle used by most transport related companies is 8 degrees as shown in Figure 3-40. If vehicles cannot meet this requirement they are often fitted with an adjustable RUP such that it can be moved out of harms way either before or during the manoeuvre.

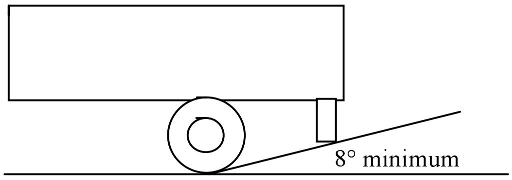


Figure 3-40. Typical minimum departure angle required by transport companies for ferry operation.

It is claimed that, despite some of the measures put in place for ferries, the ground clearance is not always sufficient and can, therefore, result in damage and even detachment of the RUP from the trailer.

Stakeholders cited similar ground clearance concerns for off-road use and construction site. Although they acknowledge the possibility of a folding or adjustable RUP, it is claimed that these can be very expensive and that the possibility of regular damage resulting in large repair costs remains an issue. They also expressed concern that such damage may not be repaired immediately or that the adjustable guard may be left in the stowed position while travelling on the road. In these circumstances the vehicle would not offer protection to passenger vehicles.

The construction industry were concerned that reducing the ground clearance for an empty tipper to 400mm, would result in just 250mm ground clearance for a two-axle tipper in loaded conditions because of the deflection of the, typically steel, suspension. They believe that this clearance would reduce the departure angle to such an extent that it would not be possible to negotiate construction sites. It was also considered that the lower ground clearance and increased loads would have implications for wider design issues such as carrying capacity because much higher forces and torques would be applied to the mounting points. Some stakeholders considered that the lower levels of traffic and reduced speed on construction sites was sufficient to justify an exemption from the proposed new requirements for vehicles that were *solely* used on such sites.

Stakeholders from Canada believed that a post-test ground-clearance limit of 560 mm was sufficiently low that small vehicles would be protected and sufficiently high that it would not impede normal trailer operations.

The German Insurance Association (GIA) suggested that a reduction in ground clearance would cause operational issues with trailers that are used on ferries or trains and also for construction vehicles on rough terrain. They considered that this would be more of an issue for vehicles with large rear overhangs. The GIA does not rule out the fact that lower ground clearance is possible and highlighted that ground clearances less than 550 mm are found frequently when the truck or trailer concept allows so (sometimes even requires so), i.e., for vehicles solely used on the roads.

There is support for lower ground clearance from the automotive manufacturing industry and they believe that changes should be made to vehicles where there will be a qualified effect on road safety (i.e. category O4 vehicle). It is their suggestion that: *"….the height of the average RUPS should be designed to interact with the crash-boxes of passenger cars. Therefore, the height of RUPS of a laden vehicle should not exceed 400mm above street level. In order to do so, the height of RUPS of an unladen vehicle should not exceed 450mm for air suspension i.e. 500mm for steel suspension. However, to maintain full functionality of the vehicles, a minimum departure angle of 8° has to be accommodated in all cases."*

Other stakeholders also identified concern over whether the RUP specification should be based on a laden or unladen condition. The ground clearance is currently measured unladen, which means that it can be considerably reduced when load is carried and the suspension is compressed, depending on suspension type. Stakeholders considered that if the ground clearance was reduced to 400 mm measured unladen, then for some fully laden vehicles there would be a risk of the RUP hitting either speed bumps or slip road ramps. These stakeholders recommended defining the RUP ground clearance in laden conditions.

3.4.3 Assessment of potential implications of changes to RUP requirements

The following sections critically review the concerns raised by the stakeholders. The review is based on observations and geometric analysis.

3.4.3.1 Test procedure

The stakeholders raised concerns about the use of a dynamic test (pendulum) being too expensive. Also, concern was raised about potential difficulties in applying a distributed load because of the profile of the RUP.

These concerns were considered when generating the proposed amendment, which is based on the quasi-static application of simultaneous point loads, thus eliminating the concerns of these stakeholders. While a distributed load may be more appropriate in an ideal world, it would require a deformable element to load the RUP in a representative manner which adds to both the complexity and cost of the test and may introduce further concerns with respect to repeatability and reproducibility.

3.4.3.2 Ground clearance

Most of the concerns raised by the stakeholders related to the proposed change in ground clearance requirement from 550mm to 400mm.

The rear ground clearance is of particular concern for ferry operation. Currently a departure angle of at least 8° is recommended. Semi-trailers are most affected by this both because they are the most likely HGV to travel on ferries and also because they tend to have long rear overhangs. The VC-Compat project collected geometric data that included the rear overhang of semi-trailers.

Table 3.9 shows calculated departure angles for semi-trailers with worst case and average rear overhangs based on the measurement of 24 semi-trailers.

Table 3.9. Calculated departure angles for semi-trailers,

Rear overhang (mm)	Departure angle (°)	
	550mm RUP	**400mm RUP**
Maximum = 3340	9.4	6.8
Average = 2493	12.4	9.1

This analysis shows that for some semi-trailers a reduction in ground clearance will result in a departure angle lower than the recommended 8°. These calculations are also based on unladen conditions, so in reality there is likely to be more of a reduction in the departure angle. To reduce the number of vehicles that are likely to have a departure angle less than 8° when laden, the ground clearance requirement could be specified for the laden condition rather than the unladen condition that is currently used. Where a vehicle is fitted with air suspension (self-levelling) the effect of this change should be minimal on the in-service ground clearance compared to specifying the ground clearance in the unladen condition. Where vehicles are fitted with steel suspension, the in-service ground clearance will increase when the vehicle is unladen. However, the types of vehicle that are most likely to be affected by this are those fitted with air-suspension

If there is still an issue with the departure angle, one solution is to use an adjustable RUP, in the same way as currently used for some vehicles. However, increasing the number of vehicles that require an innovative or adjustable RUP would increase the cost of introducing the requirement because such designs tend to be more expensive.

Figure 3-41 shows a four axle tipper on an unmade road. The rear overhang of this vehicle is small in comparison to semi-trailers and therefore it could be argued that the extent of underrun could be small. However the structure at the rear of such a vehicle is not conducive to engaging the crash structure of a passenger car.

Figure 3-41. Tipping vehicle on un-made road.

Other points from this photograph are also worthy of note:

- The road on which this vehicle is travelling is an unmade road on a quarry and is thus considered to be "off-road". However, although the surface is likely to be rough it is not sufficiently uneven and nor does it have sufficiently large changes in gradient to cause ground clearance problems
- The vehicle appears to be equipped with a tow hitch. This is mounted at a position that appears to be similar to that at which rear underrun protection would be mounted, thus restricting the departure angle and manoeuvrability by a similar amount.

Although just one photograph is shown here, Smith & Knight (2004) found that these characteristics were very common. Although they were unable to quantify the frequency of different situations numerically they did conclude that vehicles that were used in extreme off road situations, such as military vehicles, did require very large approach and departure angles, a large proportion of vehicles that simply used quarries and ordinary construction sites were much less likely to require the same and frequently other aspects of their vehicle design meant that the manoeuvrability was restricted to a similar extent to that imposed by the fitment of underrun protection.

Departure angles have been calculated from vehicle specification sheets for a range of tipping vehicles and are summarised in Table 3.10. It should be noted that this calculation does not consider the location of additional equipment such as tow hitches, only the main structural and body elements of the vehicle.

Table 3.10. Calculated departure angles for tipping vehicles (MAN, Mercedes-Benz, 2008).

Vehicle Type	Rear overhang (mm)	Chassis ground clearance (mm)	Departure angle (°)		
			No RUP	550mm RUP	400mm RUP
Mercedes-Benz 2 axle	1150	887 unladen	38	26	19
Mercedes-Benz 3 axle	1350	817 unladen	31	22	17
MAN 4 axle	850	735* unladen	40	33	25

* estimated based on distance from ground to top of frame less the frame height from the Mercedes (289mm)

This analysis showed that the four axle vehicle could still be classified as an off-road vehicle (class G) even when equipped with a 400mm RUP located at the very rear of the vehicle because it still has a departure angle of 25 degrees. The three axle vehicle no longer meets this requirement for G class, but the departure angle is more than double that typically required for ferry operations. Many of these vehicles are likely to be used on un-made roads rather than rugged off-road terrain. It is unclear how many vehicles would be likely to encounter an incline twice as steep as the ferry ramp shown in Figure 3-39. Moving the RUP further in-board from the rear of the vehicle (up to 400mm is permitted, depending on deflection characteristics) would increase the departure angle further.

3.4.4 Provision of tail-lifts

The 2006 amendment to Directive 70/221/EEC provides requirements for RUP in relation to geometry and positioning of the RUP and the application of the test loads where the fitment of the RUP interferes with the operation of a platform lift. Figure 3-42 shows examples of tail lifts fitted to HGVs, with and without the need for split RUP (Ratcliff Palfinger, 2008).

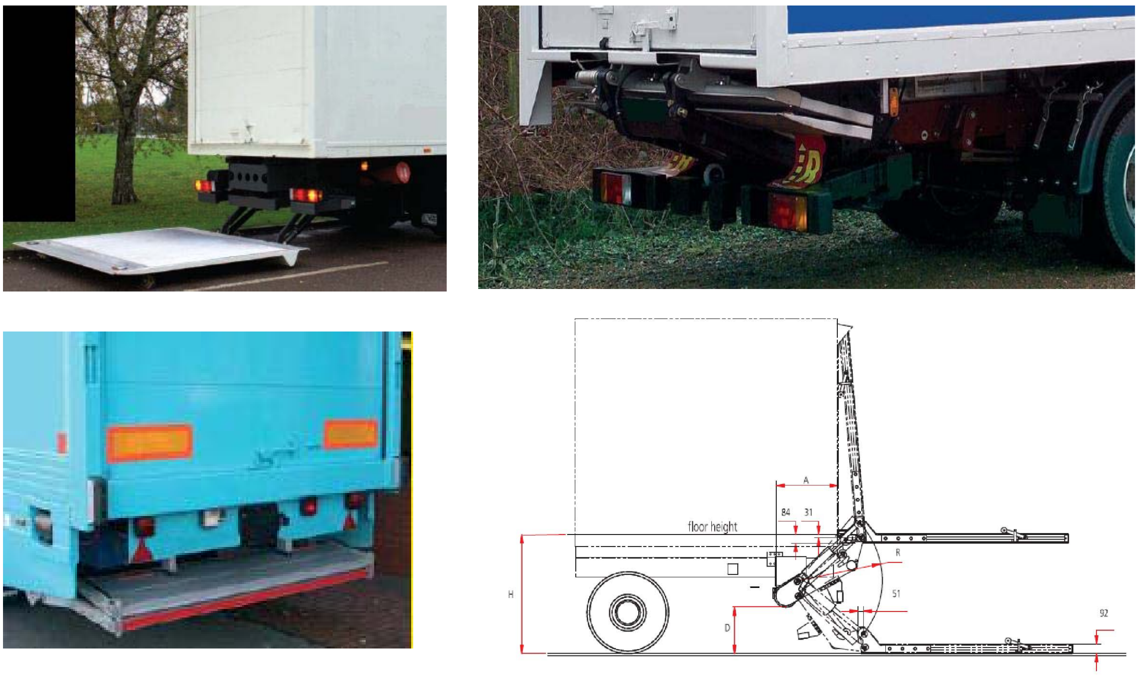


Figure 3-42. Examples of tail lift requiring split RUP (top) and no split RUP (bottom) (Ratcliff Palfinger, 2008).

These examples show that it is possible to fit tail-lifts without creating interruptions in the RUP. However, where there are interruptions in the RUP there are often structures associated with the lifting mechanism in the interrupted areas, which are likely to prevent underrun. Information received during the consultation suggested that in the German fleet there may be up to 80 different designs of RUP for the provision of tail lifts. The variation in the position of the RUP structure is an important consideration when proposing a revised test procedure.

The investigation of alternative loading patterns (Section 3.3) considered the addition of a fourth test point. However, for some RUP designs (including those where the RUP is in one piece) there is no structure in this area to which the load can be applied.

One concern related to RUP that are interrupted to allow for tail lift structures is their performance in an angled collision. This concern stems from the fact that such RUP can support relatively narrow sections of RUP cross members on long horizontal mountings. The length of these horizontal mountings can be sufficient that if load was applied to the cross-member at relatively small angles it could still produce quite large moments around the base of the mounting. It is, therefore, possible that angled loading could lead to premature collapse, which would not be identified by the regulatory test procedure because the test forces are all applied directly in line with the vehicle. To some extent the proposed requirements to carry out a point load test on any part of the cross-member supported at only one end will ensure some mounting stability but this may not be sufficient for an angled collision.

The accident analyses described in section 2.2 showed that angled collisions with the rear of a truck were relatively rare. It is also likely that only a small subset of vehicles will be equipped with RUP that is interrupted and horizontally mounted in order to make space for a tail lift. The casualty prevention benefits of ensuring the lateral stability of such a RUP in an angled collision may, therefore, be relatively small. If it was considered necessary to enhance the RUP standard to account for this potential weakness, then it is likely that the test procedure for all RUP would need amendment to include requirements for the application of an appropriately angled load.

4 Task 3: Estimates of the cost/benefit

4.1 Estimating benefits

Improved rear underrun protection is a measure aimed at mitigating injury to car occupants when collisions with the rear of a truck occur. Therefore, potential benefits are related to the reduction in the numbers of fatal and serious injuries to car occupants. The following analysis considers the benefits associated with fatalities and serious casualties separately.

Section 2.2.3 reviewed data from VC-Compat that had been used in a cost-benefit analysis. The data used in VC-Compat related to accidents in 2000 and 2001. The section that follows describes an updated cost-benefit analysis using the most recent data that was available. The use of different data sources and estimating techniques have resulted in values that are not directly comparable to the information presented previously.

4.1.1 Fatality reduction benefits

Figure 2-1 showed the number of fatalities in the EU-15 and EU-25 for the period 1996-2005 (EC, 2006). Table 4.1 shows the fatality data that formed the basis of the following analysis. Data from 2004 was selected because it was the most recent year where all required data was available. Note that data presented previously for the EU-15 from VC-Compat was for the year 2000.

Table 4.1. Fatality data used for benefit calculations.

Data Source	All accidents - number of fatalities, 2004**	Accidents involving HGVs - number of fatalities, 2004**
EU-25	43,472	***5,544***
EU-15	32,637	***4,162***
EU-14 (CARE*)	26,795	3,417

* CARE database covers EU-15 but excludes data from Germany.
** CARE data - Ireland 2003, Luxembourg 2002, Netherlands 2003.

The figures shown in ***bold italics*** in Table 4.1 are estimates. These were derived based on the assumption that the proportion of all fatalities that occurred in accidents where at least one HGV was involved was the same (13%) for the EU-15 and EU-25 as it was for EU-14, where it was known from analysis of the CARE database, see section 2.1.2. Looking at the estimate of the number of fatalities in accidents involving HGVs in the EU-15 and comparing with the data from VC-Compat, there appears to have been a 30% reduction in the number of fatalities. It is possible that the reduction may be related to a factor that has influenced all types of accident such as reduced speeding. However, it could also be related to a factor that is specific to one group of accidents, for example the fitment of FUP and its effect on head-on collisions. If it is the latter, then the benefits of improved RUP predicted by this research may be an under-estimate.

The next step in identifying the benefits associated with improved RUP was to estimate the number of fatalities that were involved in impacts where the front of a car collided with the rear of an HGV. This is the target population and if improved RUP was 100% effective then this would be the estimated number of fatalities that could be prevented. From the CARE database 52% of fatalities in HGV accidents were car occupants however, the remaining level of detail required to define the target population is not available in the CARE database or IRTAD to give a figure for Europe. It is therefore necessary to look at previous research that makes estimates for individual Member States. The data that was available is shown in Table 4.2. The e-safety working group on heavy duty vehicles categorised casualties by impact type, however the fatal and serious casualties were grouped together and so were not appropriate for this analysis.

Table 4.2. Proportion of car occupant fatalities in impacts where front of car collides with rear of HGV.

Member State	Source	Years	Car occupant fatalities in impacts where front of car collides with rear of HGV (percentage of all car occupant fatalities in accidents involving HGVs)
Germany	VC-Compat (Gwehenberger *et al, 2003)*	1998	7.2%
Holland	VC-Compat (Gwehenberger *et al, 2003)*		11.7%
France	VC-Compat (Gwehenberger *et al, 2003)*		13.3%
GB	VC-Compat (Gwehenberger *et al, 2003)*	1994-1996	14.3%
GB	HVCIS (Smith *et al, 2008)*	1997-2002	10.7%
GB	STATS19 (Smith *et al, 2008)*	2003-2005	13.2%

The lowest proportion is seen for Germany at 7.2% taken from the analysis carried out for VC-Compat (Gwehenberger *et al, 2003)*. The highest proportion is for the UK, also from the VC-Compat research. However there is more recent data for the UK which indicates that the proportion of rear-end impacts to the HGV may be reducing. However, it has not been possible to identify any more recent analyses for other Member States.

For the purposes of this analysis, it was assumed that the proportion of fatalities that occurred in rear-end collisions for the EU-15 and EU-25 were within the range of the values shown in Table 4.2. However, the figure that defines the lower boundary is from relatively old data. Assuming that the proportion of fatalities from RUP relevant accidents in Germany has fallen by the same proportion in GB, then the revised value for Germany would be 6.7%. Therefore, the target population for improved RUP was defined by multiplying the number of fatalities in accidents involving HGVs (Table 4.1) by the proportion of those fatalities that are car occupants (52%) and the proportion that are involved in rear-end impacts (6.7% to 14.3%). The estimated target population is shown in Table 4.3.

Table 4.3. Target population of fatalities for improved RUP.

	EU-15	EU-25
Minimum	144	192
Maximum	309	412

In reality the improved RUP will not be 100% effective, i.e. it will not reduce all fatalities (or injuries) to non-injuries because there is a large number of variables that can influence the outcome of an accident. The effectiveness of the improved RUP is defined by a range of criteria such as impact speed and overlap, seatbelt use, age of fatality etc. Information from the literature relating the effectiveness of RUP was minimal; however, many research programmes agreed that the RUP should be able to withstand impacts with a closing speed of 56km/h.

Smith *et al* (2008) defined an improved RUP with the following criteria based on analysis of the HVCIS Fatals Database of GB accidents.

- The RUP would reduce a fatality to a serious injury
- The RUP is effective where the closing speed between the vehicle is 80km/h or less
- If RUP was already fitted, they were not designed to absorb energy
- The HGV was underrun by the car
- The car occupant fatality wore a three point seatbelt
- Fatality 70 years old or under

The limit on closing speed of the vehicle was based on the FUP testing carried out during the VC-Compat project, where tests at 75km/h showed acceptable risk for occupant injury. Also, the impact speed contained in the HVCIS Fatals Database tends to be over-estimated because of the accident reconstruction techniques used. This method produced a range of effectiveness from 12.1% to 58.6%. The minimum effectiveness assumed that the improved RUP was not effective if any of the criteria were unknown. The maximum value estimated that the improved RUP was effective for all fatalities were the criteria were unknown. A best estimate of the effectiveness was calculated by applying the proportional effectiveness from where all criteria were known to the fatalities where there were unknown criteria. The best estimate was 22.6% effective.

The HVCIS Fatals Database allows an estimate of the effectiveness of a range of countermeasures to be assessed. For each accident record in the database, a subjective assessment is made as to which measures could have prevented the accident or reduced the severity of the fatality to non-fatal. To reduce the subjectivity of the assessment, there are three levels of effectiveness that can be assigned for each fatality; definitely, probably or maybe. The number of fatalities assigned to each effectiveness level are multiplied by 1, 0.75 and 0.25 respectively and summed to provide a best estimate of the effectiveness of the measure. “Stronger and Lower Rear Underrun Protection” is one of the measures included in the study and the effectiveness was estimated to be 34.1%. This is similar to the effectiveness of 36% applied to the data in the VC-Compat analysis (Gwehenberger *et al*, 2004)

Most individual member states have derived monetary valuations for the prevention of road accident casualties. However, these valuations are based on different methodologies and differ substantially between Member States. A variety of values that represent the EU as a whole have been used and reported by a number of research projects. The values selected for use in this project were those derived by Dodd *et al* (2007), which were based on earlier research by Elvik *et al* (2003). Elvik *et al* (2003) calculated values for 1999 based on an average of the individual values for the EU-15 Member States. To estimate the equivalent values for 2004, Dodd *et al* (2007) used the trends in GB casualty valuations from Road Casualties Great Britain (DfT, 1999-2005). A multiplication factor by which GB values had increased was applied to the value derived by Elvik *et al* (2003). The estimated valuations produced by this process were €1,227,049 for a fatality, €137,875 for a serious injury and €10,630 for a slight injury. For each fatality that is reduced to a serious injury the associated valuation is therefore €1,089,174. Table 4.4 summarises the estimated benefits from reducing fatalities to serious injuries.

Table 4.4. Estimated reduction in number of fatalities from improved RUP and the associated financial valuation.

Source	Effectiveness	Estimated reduction in number of fatalities		Estimated fatality prevention financial benefit (€M)	
		EU-15	EU-25	EU-15	EU-25
Minimum	12.1%	17	23	18.9	25.2
Maximum	58.6%	181	242	197.6	263.2
Best Estimate (minimum target population)	22.6%	32	43	35.4	47.1
Best Estimate (maximum target population)	34.1%	70	93	76.1	101.4

4.1.2 Serious injury reduction benefits

To estimate the benefits of improved RUP in terms of the reduction of serious injuries, a similar approach was taken as used in the analysis of fatality benefits. The only differences were in the sources and availability of data.

The DG-TREN pocketbook (DG TREN, 2006) contains the number of fatalities and total number of accidents for the EU-15 and EU-25. The total number of seriously injured casualties is not presented. The CARE database does allow analysis by casualty severity, however, the range of definitions for serious casualties is much greater than for fatalities, making comparisons between different Member States unreliable and most of the analysis is focused on fatalities. It is, therefore, necessary to estimate a realistic number of serious casualties for Europe. For the purposes of this analysis, the severity distribution of casualties has been defined based on previous research studies and applied to the total accident data for 2004 for EU-15 and EU-25. The first step involved estimating the total number of casualties. Table 4.5 shows the fatality distribution taken from the analysis of national statistics reported as part of VC-Compat based on data from 2001.

Table 4.5. Fatality distribution from individual Member States (Gwehenberger *et* al, 2003).

Member State	Fatalities	Total casualties	Fatalities as proportion of all casualties
Germany	6,977	501,752	1.39%
France	8,160	162,105	5.03%
Netherlands	993	25,908	0.79%
Great Britain	3,450	313,308	1.10%
Spain	5,510	155,116	3.56%
Sweden	583	22,913	2.54%
Total	**25,673**	**1,181,102**	**2.17%**

For comparison, similar analysis using data from 2004 for Great Britain only showed that 1.14% of casualties were fatal, which is similar to the value from 2001. Therefore, these proportions have been applied to the overall number of fatalities for EU-15 and EU-25 to estimate a range of casualty figures as summarised in Table 4.6. From the analysis of accident data carried out in VC-Compat, 19.6% of the casualties were seriously injured, this percentage is applied to the estimated total number of casualties as shown in Table 4.6. For comparison, the proportion of all casualties that were seriously injured in 2001 was 11.84% and 11.04% in 2004. This shows that there has been a slight reduction in the number of casualties seriously injured since the VC-Compat analysis, however the following analysis has been restricted to only the proportion taken from VC-Compat.

Table 4.6. Estimated numbers of casualties for EU-15 and EU-25 for 2004.

	Proportion of casualties that are fatal	Estimated total number of casualties		Proportion of casualties that are serious	Estimated total number of serious casualties	
		EU-15	EU-25		EU-15	EU-25
Minimum	1.10%	648,360	863,606	19.6%	127,332	169,604
Maximum	5.03%	2,963,894	3,947,862	19.6%	582,080	775,322
Best Estimate*	2.17%	1,501,485	1,999,956	19.6%	294,877	392,772

*Best estimate is based on the total number of fatalities and casualties for the Member States in the analysis.

To estimate the target population, the proportion of the serious casualties that were car occupants in front of car to rear of HGV impacts needs to be identified. The VC-Compat analysis showed that 1.01% of all serious casualties were in this type of accident. Analysis of the STATS19 database for 2003-05 showed that 0.34% of serious injuries were in accidents of this type. Therefore, the target population of serious casualties for improved RUP was estimated using 0.34% as a minimum and 1.01% as a maximum proportion of serious casualties. A range of best estimate values was calculated by applying the range of proportions to the best estimate of the total number of serious casualties. The estimated target populations are shown in Table 4.7.

Table 4.7. Target population of serious causalities for improved RUP.

	EU-15	EU-25
Minimum	433	577
Maximum	5,879	7,831
Best Estimate (minimum)	1,003	1,335
Best Estimate (maximum)	2,978	3,967

The effectiveness of the RUP for serious casualties could not be estimated in the same way as for the fatalities. Therefore, the effectiveness was taken from the VC-Compat research. An effectiveness of 52% was applied to the target population. The effectiveness was based on case-by-case analysis of accidents in Germany. The estimated benefits of improved RUP in terms of reduction in slight casualties and the associated financial values are shown in Table 4.8.

Table 4.8. Estimated benefits of improved RUP for serious casualties.

Source	Effectiveness	Estimated reduction of serious casualties		Estimated serious casualty prevention financial benefit (€M)	
		EU-15	EU-25	EU-15	EU-25
Minimum	52%	225	300	28.6	38.2
Maximum	52%	3057	4072	389.0	518.1
Best Estimate (minimum)	52%	521	694	66.3	88.4
Best Estimate (maximum)	52%	1549	2063	197.1	262.5

4.1.3 Cost-benefit assessment

The benefits from casualty reduction as describe above are compared to the cost of fitting improved RUP. The benefits associated with the reduction in fatal and serious casualties were combined. Firstly, the cost that can be spent per new vehicle registered for the benefit to cost ratio to be equal to one (i.e. a break-even cost) can be calculated. The number of new commercial vehicle registrations (>3.5t) was from the DG-TREN pocketbook (EC, 2006). In 2004 there were 381,585 new registrations in EU-15 and 418,925 in EU-25. The break even costs are shown in Table 4.9.

Table 4.9. Break even costs for improved RUP.

	Estimated break even costs	
	EU-15	EU-25
Minimum	€125	€151
Maximum	€1,537	€1,865
Best Estimate (minimum)	€267	€323
Best Estimate (maximum)	€716	€1,479

To calculate the benefit-cost ratio, information relating to the cost of RUP taken from the consultation were used. A range of costs were provided by the respondents from 100€ to 4600€ depending on the complexity of the design and whether or not the development of the RUP was included in the cost. For this analysis, the following assumptions were made in determining the ranges of costs used:

1. The minimum cost is the lowest cost over and above what is currently spent on the RUP. This therefore excludes development costs and is estimated at €100. This cost is used to calculate the maximum benefit to cost ratio.
2. If all vehicles were fitted with a fixed RUP and were already required to fit a RUP the upper cost would be expected to be approximately €200. This cost is used to calculate the upper minimum benefit-cost ratio.
3. In reality there will be a mixture of different designs of RUP of different complexity. Information provided during the consultation indicated costs for folding RUP of 850 to 1600€ and 1900 to 4600€ for sliding or extending RUP which includes the costs associated with development of the RUP. A third benefit to cost ratio is calculated assuming that 20% of the vehicle fleet are fitted with a folding RUP and 5% with a sliding/extending RUP. The cost assigned to these RUP designs is the mid-range cost for each type. The remaining 75% are

fitted with a fixed RUP costed at €200. This assumption results in the lower minimum benefit-cost ratio.

The outcome of this analysis is summarised in Table 4.10.

Table 4.10. Benefit-cost ratios for improved RUP.

Benefit-cost ratio	Lower minimum estimated benefit-cost ratio		Upper minimum estimated benefit-cost ratio		Maximum estimated benefit-cost ratio	
	EU-15	EU-25	EU-15	EU-25	EU-15	EU-25
Minimum	0.2	0.3	0.6	0.8	1.3	1.5
Maximum	1.1	3.4	3.0	9.3	15.4	18.7
Best Estimate (minimum)	**0.5**	**0.6**	**1.3**	**1.6**	**2.7**	**3.2**
Best Estimate (maximum)	**1.3**	**2.7**	**3.6**	**7.4**	**7.2**	**14.8**

The analysis process has resulted in a number of different benefit to cost ratios being calculated. Using figures for the EU-15 the benefit to cost ratio is between 0.2 and 15.4 based on the overall minimum and maximum values. However, it is more likely to lie within the range 0.5 to 7.2 based on the best estimates. For the analysis based on EU-25 the benefit to cost ratio is between 0.3 and 18.7. However, using the best estimate figures the range is reduced to 0.6 to 14.8.

This analysis shows that the proposed improvements to RUP are likely to have economic benefits based on reductions in fatal and serious casualties. However, the positive benefit to cost ratio is likely to depend quite strongly on the proportion of vehicles that may require specialist design to meet the new requirements and overcome operational difficulties such as the use of RO-RO ferries or use off-road. It should be noted that potential benefits associated with a reduction in accident severity reducing the delay time and congestion caused or the additional costs associated with reduced payload because of the increased mass of the RUP have not been considered.

5 Discussion

The requirements of current rear underrun protection legislation were amended in 2006, to increase two of the test loads from 25kN to 50kN and to allow for interruptions in the RUP for the provision of tail lifts. A wide variety of research, including the EC project VC-Compat and tests by ADAC in Germany, provides strong evidence to demonstrate that in order to protect the occupants of modern cars in collisions at 56 km/h, further increases to the regulatory minimum standards would be required.

Previous research has suggested that the stiffness of the RUP needs to be increased and its' maximum ground clearance decreased. Based on the results of this previous research it appeared that three main problems still needed to be resolved:

- The test method and limit values used to assess the stiffness of RUP needed to be further investigated because of concerns that the previous proposals still did not replicate real collisions in an adequate manner
- The application of the test method and limit values to smaller vehicles needed to be investigated to assess whether lesser requirements were appropriate for smaller vehicles
- The ability to implement the requirements in a practical, cost-effective manner needed to be investigated, particularly with respect to concerns that reduced ground clearance may cause problems in some particular types of vehicle operation.

Most existing rear underrun regulations and most of the previous research has been based on a test method involving quasi-statically applying point loads to the device sequentially, one at a time. However, in the VC-Compat project it was found that the results of such a test did not accurately predict the performance of the same device used in a full scale dynamic test. The recent development of the Canadian rear underrun regulation also found the sequential point load test to be inadequate and was implemented on the basis of a quasi-static test using a distributed load of much larger magnitude (350kN). The results of the tests and simulations described in detail in section 3.2.2 of this report also appear to confirm these results, demonstrating that the existing test method even with modified test loads does not represent real dynamic behaviour and suggesting that a larger distributed load does in fact accurately represent the observed dynamic performance. However, this research suggested that the magnitude of the distributed load should be between 270kN and 300kN, although this was based on assessment with only one type of medium sized passenger car and the necessary load may vary with the mass and stiffness characteristics of the car that collides with the RUP. On the basis of this research, and combined with the Canadian research, it is proposed that, any amendment to the present Directive should be based upon a quasi-static test using a distributed load of 300kN. However, it should be noted that any value in the range of 270kn to 350kN would be expected to represent a substantial improvement in safety.

Some stakeholders expressed concern that there could be practical problems applying a distributed load. If the load is applied with a rigid device then it is possible that the load could become focussed on particular parts of the RUP as it deformed. In an ideal world, the load would be applied using a deformable barrier of constant stiffness such that the load remained evenly distributed even when the RUP began to deform. However, this would be considerably more expensive, may introduce repeatability problems, depending on the nature of the barrier used, and has not been assessed or validated. The research carried out for this project has suggested that the use of 3 simultaneously applied point loads would adequately represent the distributed load and would successfully avoid these potential problems and this is the solution that TRL would propose for a draft amendment to the Directive.

In addition to the above, the research has suggested that a RUP that passes the requirement for a distributed load, as described above, could still fail in real life where the outer edge of the device is of cantilever design (i.e. supported at only one end) and a vehicle collides with the RUP with a low overlap such that it does not directly load the mounting point. In order to prevent this possibility the application of a further separate (and sequentially applied) point load has been proposed. However, this proposal has not been extensively assessed or validated and further work may be required. Based on the results of the single low overlap simulation carried out, it appears that a point load applied to the centre of the cantilever section would be appropriate. However, the magnitude of the load should be proportional to the length of the unsupported member. For the conditions that were simulated a point load equivalent to 274N/mm may be appropriate. For the prototype RUP evaluated in this project a requirement of 274N/mm of unsupported cross-member translates to a point load of 172kN applied in the geometric centre of the unsupported end (i.e. mid point between the outer edge of the vertical support and the outer edge of the cross-member). However, before such a method can be implemented, further investigation is required.

One factor could cast some doubt on the need for the more demanding tests described above. The current Directive requiring front underrun protection is based on the quasi-static application of a sequence of point loads, which are higher than those required by the rear underrun Directive but lower than those recommended by the VC-Compat project for rear underrun. Tests carried out as part of the VC-Compat project, showed that front underrun protection that was compliant with the relevant Directive was effective and did not collapse in collisions with a medium sized car at speeds of up to 75km/h. However, there are number of factors that may require consideration when comparing these results with those of rear underrun:

- FUP is designed and fitted by OEMs and is integrated with the vehicle in a relatively complex manner likely to require the use of CAD and finite element modelling techniques. It is possible, therefore, that they are primarily designed to meet real world crash requirements and, as such, are usually constructed to a standard considerably exceeding that required to just pass the regulatory test. It is possible that if the same test was applied for rear underrun that it would prove similarly effective but this would rely on industry continuing to over-engineer devices in relation to the standard. It should be noted that in most cases rear underrun protection will be constructed not by the OEM truck manufacturer but by an OEM trailer manufacturer or a third party body builder. These companies may or may not approach the design of rear underrun protection in the same way as the truck OEMs appear to have approached the design of front underrun protection
- The chassis at the front of a vehicle is often lower to the ground than for the rear, particularly semi-trailers. Therefore, the moment generated when the force is applied is smaller for FUP than RUP, thus making it easier to construct a very stiff FUP, in excess of minimum requirements.
- There are often more structures and components at the front of a vehicle, which the FUP and collision partner can interact with to dissipate the load, than there are at the rear. This greater interaction with other structures may reduce the level of force applied directly through the FUP, thus meaning that lower minimum force requirements for the FUP are technically justified.

The current Directive requires test loads to be proportional to the GVW of the HGV, up to a stated maximum that is equivalent to the proportional loads for a vehicle of 20 tonnes. Not all of the regulations allow smaller vehicles to be approved to lower test loads in this way and the origins of the requirement are unknown. It can be hypothesised that the lower test loads were specified because the lighter vehicles are more likely to have structures closer to the rear of the vehicle and lower to the ground than the heavier vehicles. This hypothesis was tested using numerical simulation and it was shown that the passenger car interacted to some extent with the chassis of a 12 tonne vehicle and that a weaker RUP was still able to prevent underrun. If the quasi-static loads shown to be appropriate for the largest vehicles were applied to this weaker RUP then the deformation was excessive. This means that a RUP that would work in service on a smaller vehicle could be failed by the approval test, thus meaning that, if the Directive required the same test forces for all HGVs then it would require unnecessarily stiff devices on smaller vehicles.

A number of alternative test set-ups were investigated to try to identify a test type combined with limit values that could adequately predict the performance for all vehicle sizes. However, the deformation in the quasi-static tests could not be matched to the deformation observed in the simulated dynamic car impact. To fully define test requirements specifically for RUP fitted to HGVs where there is likely to be interaction with the chassis requires further investigation. However, in the interim period, a requirement where the test load applied to the RUP cross-member is reduced for vehicles were the ground clearance of a structural member at the rear of the HGV is lower than a specified value, should provide a suitable level of protection.

All of the research identified, with the exception of that in the USA and Canada, has suggested that there are strong safety grounds for reducing the maximum permitted ground clearance of rear underrun. Most of this research has recommended a maximum of 400mm, although some research has suggested that performance can still be acceptable with 450mm. However, several stakeholders have expressed strong concerns about the implications of such a move on the manoeuvrability of vehicles in certain specific operations, most notably those involving travel on Ro-Ro ferries and for vehicles used off-road.

A preliminary analysis of these problems has suggested that for many of the vehicles used in these types of operation, the proposal will not have any substantial negative effect. However, any vehicle used in extreme off-road conditions, such as military vehicles, some fire appliances and a few very specialist construction vehicles, would be likely to require exemption from the requirements. In general, many of the vehicles used in more common construction industries (e.g. use on quarries or house building sites) would be unaffected but it is likely that there would be a small increase in the proportion of vehicles requiring specialist movable or adjustable RUPs. It was also suggested that the impact of any change could be minimised by changing the maximum ground clearance requirement to be measured in the laden condition rather than the unladen condition as it is now. The reason for this is that for vehicles equipped with steel sprung suspension, as often used in the construction industry, a requirement for a ground clearance of 400mm when the vehicle is unladen could translate to a ground clearance of less than 300mm when laden, thus having a greater effect on manoeuvrability. Although changing the requirements to be measured laden will mean that such vehicles could have an inappropriately high ground clearance when unladen, vehicles are typically used unladen for less than 30% of the distance that they travel. Vehicles equipped with air suspension will be much less affected by this change.

During the consultation, some concern was also raised about the ability to mount RUP up to 400mm forward of the rear of the vehicle so long as the RUP does not deflect beyond 400mm under the test loading. However, the Directive is worded such that the RUP should be mounted as near to the rear of the vehicle as possible and continuing with this allowance would also allow greater flexibility in terms of minimising the implications of lower ground clearance (e.g. moving the RUP forward of the rear of the vehicle increases the departure angle, and thus the manoeuvrability).

The cost-benefit analysis has shown that investment in improved RUP has the potential to provide a positive return, although the benefit to cost ratios are sensitive to the proportion of vehicles that may require innovative or adjustable designs in order to meet both the new safety requirements and the operational requirements of the industry that they will be used in. The estimated benefit-cost ratios of 0.5 to 7.2 for EU-15 and 0.6 to 14.8 for EU-25 suggest that the return is more likely to be positive than negative.

6 Conclusions

The following conclusions can be drawn from this research:

1. The existing regulatory test method and limit values are not representative of a 75% overlap, 56 km/h collision between a small family car and a truck equipped with a minimally compliant RUP device. The standard of current rear underrun protection is, therefore, failing to fully exploit the potential of modern cars to protect their occupants.
2. A quasi-static test where the total simultaneous force applied is 300kN, distributed along the cross-member by three simultaneous point loads replicates the behaviour observed during a 75% overlap, 56km/h collision much more accurately.
3. An additional point load would be required for parts of RUP cross-members that are supported only at one end if it was considered necessary to also represent low overlap collisions where the outer edge of the RUP tends to be bent around the mounting point. The research suggests that a point load equivalent to 274N/mm of unsupported structure, applied at the horizontal and vertical mid-points of the unsupported section, would be likely to be appropriate but this may require further assessment and validation.
4. A reduction in the test loads applied to the RUP may be appropriate for devices fitted to vehicles where the structural members (e.g. chassis) are likely to interact with the crash structure of the bullet vehicle. Ideally, a universal test method (potentially using a deformable barrier) would be developed that would apply forces accurately representing the front of the car to the appropriate parts of the rear of the vehicle such that the reduction in load applied to the RUP is specific to the structure of the particular vehicle it is fitted to. In the meantime, the research has suggested that for vehicles where the ground clearance of the main chassis members is in the region of 700mm or less, it would be appropriate to reduce the test loads applied to approximately 70% of those required for larger vehicles. However, further research is required to examine the issue of the ground clearance of structural members and their interaction with the bullet vehicle.
5. The research has strongly demonstrated that a reduction in ground clearance is required to improve the level of protection offered to car occupants. Most of the research has suggested that the optimum ground clearance would be 400mm, although some have suggested that 450mm would be acceptable. Defining this ground clearance when the vehicle is laden would be expected to minimise the number of vehicles that may encounter operational difficulties or require adjustable devices as a result of the reduced ground clearance. However, this would decrease the level of protection offered by vehicles equipped with suspension types where the ground clearance depended on the load carried (pre-dominantly those with steel sprung suspension).
6. The proposed changes to the RUP Directive are likely to result in a positive return on the costs incurred. However, the benefit to cost ratios are sensitive to estimates of the proportion of vehicles likely to require complex and/or adjustable designs of RUP to meet the more stringent requirements.
7. A preliminary draft proposal to amend Directive 70/221/EEC has been produced based on the optimum requirements described above. However, there may be some scope for modifying some of the proposed requirements without substantially adverse effects on the level of safety offered where the research described above has suggested that other approaches or limit values may also be acceptable.

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Appendix A. Consultation Questionnaire

Please provide feedback or comments relating to the following questions? Comments or feedback on the subject of rear underrun protection legislation that are not related to these topics are also welcome.

1. Test methods

a. Current legislation requires quasi-static tests with sequential loading at individual points. What are your thoughts relating to alternative methods such as:
   i. Simultaneous loading at all points
   ii. Distributed loading (eg 300kN over a specified distance)
   iii. Dynamic testing (eg pendulum test)

2. Exemptions

a. For what specific types of vehicles are exemptions from rear underrun protection requested? For what type of vehicles are the exemptions accepted or rejected? What information is provided when requesting an exemption?

b. What proportion of your vehicle fleet (trucks, trailers and semi-trailers) and/or the National/European fleet are exempt from fitting RUP?

c. What specific operations are currently hindered by the current RUP ground clearance of 550mm? Will there be any additional operations that will be more difficult if the ground clearance is reduced to 400mm? Can you provide any evidence of these difficulties such as photographs?

d. In your experience how often are RUP damaged and to what extent? What kind of operations cause the damage?
   i. Complete replacement
   ii. Bent cross member
   iii. Bent upright
   iv. Damaged mounting
   v. Other (please specify and include photograph if possible)

3. Costs

a. What is the cost (in Euros/GBP) of a current RUP device?
   i. Fixed RUP
   ii. Adjustable RUP
   iii. Split RUP for tail lifts

b. What is the mass of a current RUP device?
   i. Fixed RUP

ii. Adjustable RUP

iii. Split RUP for tail lifts

4. If you design RUP systems how often do the designs exceed the minimum requirements in relation to strength and ground clearance? What are the reasons for exceeding minimum requirements (eg customer specifications, availability of materials, simplicity of design etc)?

5. Split RUPs

   a. How often are split RUPs required? What proportion of the fleet require them? Do all vehicles with tail lifts require them?

   b. What are the main factors that require the RUP to be split?

   c. How many different designs of RUP are you aware of to allow the use of tail lifts?

   d. What is the typical geometry of a split RUP?

   e. Are you aware of any testing of split underrun devices (for tail lifts) that exceeds the current standards, for example dynamic tests, oblique quasi-static loading?

6. Other comments and feedback

Appendix B. Preliminary Draft Proposal

2. DEFINITIONS

2.1. Vehicle type for the purposes of rear underrun protection

The term ‘vehicle type for the purposes of rear underrun protection’ means vehicles which do not differ essentially with respect to the following main characteristics:

2.1.1. width of the rear axle, structure, dimensions, shape and materials of the rear part of the vehicle in so far as they have a bearing on the requirements of 5.1 to 5.4.5.5;

2.1.2. suspension characteristics in so far as they have a bearing on the requirements of 5.1 to 5.4.5.5;

2.1.3. type of rear underrun protection device, if fitted.

2.2. Type of rear underrun protection device

The term ‘type of rear underrun protection device’ means devices which do not differ essentially with respect to the following main characteristics:

2.2.1. shape;

2.2.2. dimensions;

2.2.3. attachment;

2.2.4. materials.

2.3. Cantilever section of cross-member

The term ‘cantilever section of cross-member’ means a section of the cross-member of the rear underrun protection device that is supported at one end (Appendix 6, Figure 1)

5. SPECIFICATIONS

5.1. All vehicles must be so constructed and/or equipped as to offer effective protection over their whole width against underrunning from the rear by a vehicle of categories M_1 and N_1 (1).

5.1a. The vehicle shall be tested under the following conditions:

— it must be at rest on a level, flat, rigid and smooth surface,

— the front wheels must be in the straight-ahead position,

— tyres must be inflated to the pressure recommended by the vehicle manufacturer,

— the vehicle may, if necessary to achieve the test forces required, be restrained by any method specified by the vehicle manufacturer,

— if the vehicle is equipped with hydropneumatic, hydraulic or pneumatic suspension or a device for automatic levelling according to load, it must be tested with the suspension or device in the normal running condition specified by the manufacturer.

5.2. Any vehicle in one of the categories M_1, M_2, M_3, N_1, O_1 or O_2 (1) will be deemed to satisfy the condition set out in 5.1:

— if it satisfies the conditions set out in 5.3, or

— if the ground clearance of the rear part of the laden vehicle does not exceed 40 cm over a width which is not shorter than that of the rear axle by more than 10 cm on either side (excluding any tyre bulging close to the ground). Where there is more than one rear axle, the width to be considered is that of the widest. This requirement must be satisfied at least on a line at a distance of not more than 45 cm from the rear extremity of the vehicle.

5.3. Any vehicle in one of the categories N_2, N_3, O_3 or O_4 ($_1$) will be deemed to satisfy the condition set out in 5.1 provided that:

— the vehicle is equipped with a special rear underrun protective device in accordance with the requirements of 5.4, or

— the vehicle is so designed and/or equipped at the rear that, by virtue of their shape and characteristics, its component parts can be regarded as replacing the rear underrun protective device. Components whose combined function satisfies the requirements set out in 5.4 are considered to form a rear underrun protective device.

5.4. A device for protection against underrunning from the rear, hereinafter referred to as 'device', generally consists of a cross-member and linking components connected to the chassis side-members or to whatever replaces them. It must have the following characteristics:

5.4.1. The device must be fitted as close to the rear of the vehicle as possible. When the vehicle is laden ($_1$) the lower edge of the device must at no point be more than 40 cm above the ground;

5.4.2. The width of the device must at no point exceed the width of the rear axle measured at the outermost points of the wheels, excluding the bulging of the tyres close to the ground, nor must it be more than 10 cm shorter on either side. Where there is more than one rear axle, the width to be considered is that of the widest;

5.4.3. The section height of the cross-member must be not less than 20 cm. The lateral extremities of the cross-member must not bend to the rear or have a sharp outer edge; this condition is fulfilled when the lateral extremities of the cross-member are rounded on the outside and have a radius of curvature of not less than 2,5 mm;

5.4.4. The device may be so designed that its position at the rear of the vehicle can be varied. In this event, there must be a guaranteed method of securing it in the service position so that any unintentional change of position is precluded. It must be possible for the operator to vary the position of the device by applying a force not exceeding 40 daN;

5.4.5. The device must offer adequate resistance to forces applied parallel to the longitudinal axis of the vehicle, and be connected, when in the service position, with the chassis side-members or whatever replaces them.

This requirement will be satisfied if it is shown that both during and after the application the horizontal distance between the rear of the device and the rear extremity of the vehicle does not exceed 40 cm at any of the points P1, P2, P3 or P4. In measuring this distance, any part of the vehicle which is more than 3 m above the ground when the vehicle is laden must be excluded;

5.4.5.1. Points P1 are located 30 cm from the longitudinal planes tangential to the outer edges of the wheels on the rear axle; Point P3 is on the median longitudinal plane of the vehicle. Points P2, which are located on the line joining points P1 and P3, are equidistant from points P1 and P3. The height above the ground of points P1 and P2 must be defined by the vehicle manufacturer within the lines that bound the device horizontally. The height of the points must not, however, exceed 50 cm when the vehicle is laden.. Point P4 is located at both the lateral and longitudinal centre point of cantilever section of the cross-member;

5.4.5.2. A horizontal force of 10×10^4 N must be applied simultaneously to each of the three points P1, P2 and P3 on one side of the device. A total force of 30×10^4 N must be applied.

5.4.5.3. If the device is not symmetrical, the test must be repeated using points P1 and P2 on the opposite side of the device combined with point P3.

5.4.5.3.1. Where the main structural members (chassis) of the vehicle to which the device will be fitted have a ground clearance of [70 cm] or less in the laden condition, the total force applied shall be [21×10^4 N], [7×10^4 N] at each point P1, P2 and P3.

5.4.5.4. Where any part of the cross-member has a cantilever section (supported at only one end) a horizontal force equivalent to 274N/mm and proportional to the length of the cantilever section shall be applied at point P4.

5.4.5.5. Whenever a practical test is performed to verify compliance with the abovementioned requirements, the following conditions must be fulfilled:

5.4.5.5.1. the device must be connected to the chassis side-members of the vehicle or to whatever replaces them;

5.4.5.5.2. the specified forces must be applied by rams which are suitably articulated (e.g. by means of universal joints) and must be parallel to the median longitudinal plane of the vehicle via a surface not more than 25 cm in height (the exact height must be indicated by the manufacturer) and 20 cm wide, with a radius of curvature of 5 ± 1 mm at the vertical edges. The forces shall be applied such that:

5.4.5.5.2.1. the centre of each surface is placed simultaneously at points P1, P2 and P3.

5.4.5.5.2.2. the force is applied at P4 independently of points P1, P2 and P3.

5.4.5.5.3. the two independent tests described in 5.4.5.5.2.1 and 5.4.5.5.2.2 shall be carried out using two different devices, such that each test is carried out on a new and undamaged device. However, if it can be shown that after the forces have been applied simultaneously to points P1, P2 and P3, the permanent forward deflection of the point P4 is less than [10]mm, the force can be applied at P4 on the previously tested device.

5.4a. For vehicles fitted with a platform lift the fitting of the underrun device may be interrupted for the purposes of the mechanism. In such cases, the following must apply:

5.4a.1. The lateral distance between the fitting elements of the underrun device and the elements of the platform lift, which make the interruption necessary, may amount to no more than 2,5 cm;

5.4a.2. The individual elements of the underrun protection device must, in each case, have an effective surface area of at least 700 cm^2;

5.4a.3. The individual elements of the underrun protection device must be of sufficient dimensions to comply with the requirements of paragraph 5.4.5.1, whereby the relative positions of the test points are determined. If the points P1, P2 or P3 are located within the interruption area mentioned in 5.4a, the points to be used will be located at the nearest available position. The points must remain between the median longitudinal plane of the vehicle and the outermost edge of the device. The points must be positioned to minimise the deviation from the even distribution of the forces on the device;

5.4a.4. For the area of interruption of the underrun device and for the purposes of the platform lift, point 5.4.1. need not apply.

5.5. By way of derogation from the abovementioned requirements, vehicles of the following categories need not comply with the requirements of this Annex as regards rear underrun protection:

— tractors for semi-trailers,

— 'slung' trailers and other similar trailers for the transport of logs or other very long items,

— vehicles for which rear underrun protection is proven to be incompatible with their use by geometric analysis or evidence from trials based on realistic usage.

Appendix 6

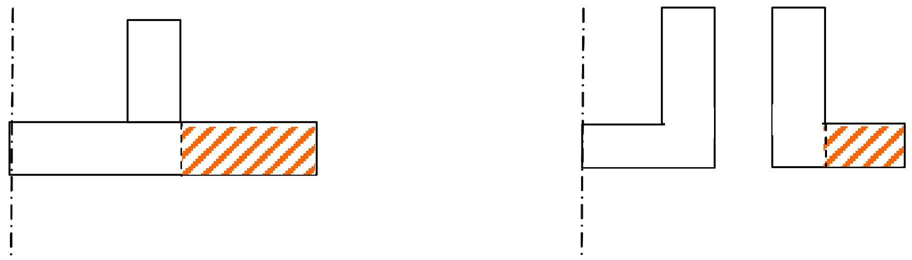

Figure 1