TRUCK INVOLVED CRASH STUDY

REPORT ON:
FATAL AND INJURY CRASHES OF CARS
INTO THE REAR OF TRUCKS

by
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Abstract:
The study was aimed at clearly establishing the most influential factors contributing to the high level of fatalities and serious injuries arising from crashes involving trucks and other road users and identifying the most effective and practical countermeasures that can be incorporated into the truck design, to reduce the severity of injuries in crashes involving cars, motorcyclists, and pedestrians.

The study involved three components: literature review of past studies on truck involved crashes and comparison of international and Australian Design Standards; detailed investigation of actual crashes involving trucks and other road users; countermeasure development involving identification of design changes to trucks to help reduce their injury potential in collisions.

Detailed investigations were carried out on 45 crashes, including both fatal and hospital admission cases, with 19 of these crashes involving 25 fatalities. Detailed injury information was obtained for each case from coronial autopsy reports or from hospital records. This data was used together with the detailed vehicle inspections to ascertain injury sources and the characteristics of truck involved crashes.

This report is in two parts: the first provides initial findings in regard to the design of trucks which results in their greater harm potential compared with other crash types; the second details the findings in regard to the rear design of trucks and the issue of rear under-run protection.

Recommendations are given for countermeasure development for rear under-run crashes, with specific design recommendations for rear under-run barriers regarding height and load capacity.

Further work is being carried out on the design and testing of prototype under-run barriers for rigid trucks and articulated vehicles. The reports on the frontal and side design of trucks are being prepared.

Key Words:
Safety, accident, injury, heavy vehicle, design, vehicle occupants, motorcyclist, pedestrian, cyclist, under-run protection

Disclaimer
This report is disseminated in the interest of information exchange. The views expressed here are those of the authors, and not necessarily those of Monash University
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Contents

INTRODUCTION ............................................................................................................................................. 1

PART A: PROJECT OVERVIEW .......................................................................................................................... 2
  PROJECT OBJECTIVES ................................................................................................................................... 2
  STUDY METHOD ............................................................................................................................................ 2
  CRASH INVESTIGATIONS TO DATE ..................................................................................................................... 3
  COMPARISON OF FREQUENCY DISTRIBUTION OF CRASH TYPE WITH MASS DATA ANALYSIS ................. 3
  PRELIMINARY FINDINGS ON TRUCK DESIGN AND INJURY SEVERITY ................................................................ 4

PART B: CRASHES INVOLVING CARS INTO THE REAR OF TRUCKS ................................................................. 6
  PROBLEM DEFINITION ................................................................................................................................... 6
  PREVIOUS WORK ON REAR-UNDER-RUN CRASHES ....................................................................................... 6
  CASES INVESTIGATED IN THIS STUDY .............................................................................................................. 8

MAJOR CONCLUSIONS DRAWN FROM THE CASE STUDIES ..................................................................................... 10

COUNTERMEASURES ....................................................................................................................................... 12
  General Requirements .................................................................................................................................... 12
  Barrier Height (roadway clearance) ..................................................................................................................... 12
  Regulations on Under-run Barrier Height .......................................................................................................... 13
  Barrier Load Capacity ..................................................................................................................................... 13
  Comparison of Barrier Test Load Requirements ............................................................................................... 14
  Comments on the Regulations .......................................................................................................................... 15
  Summary of Recommendations for Countermeasures .......................................................................................... 15

CONCLUSIONS ................................................................................................................................................ 17
  PART A: GENERAL .......................................................................................................................................... 17
  PART B: CRASHES INVOLVING CARS INTO THE REAR OF TRUCKS ............................................................. 18

RECOMMENDATIONS ..................................................................................................................................... 20

REFERENCES .................................................................................................................................................. 21

APPENDIX 1 CASE STUDIES ................................................................................................................................ 23

APPENDIX 2 ADR 42.6 REAR BUMPER FOR SEMI-TRAILERS ............................................................................... 59

APPENDIX 3 SWEDISH UNDER-RUN PROTECTION REGULATIONS (1981) .................................................. 61
TRUCK INVOLVED CRASH STUDY: FATAL AND INJURY CRASHES OF CARS INTO THE REAR OF TRUCKS

INTRODUCTION

The role of heavy goods vehicles in injury and fatal crashes has been well documented in many industrialised countries. Studies in Australia, USA and Europe have clearly identified crashes involving trucks and other road users as contributing significantly to road injuries and death. In Australia trucks are involved in some 13% of multi-vehicle fatal crashes (Ogden & Tan, 1987). Ogden noted that in these multi-vehicle crashes, most at risk were the other road user, not the truck occupants. For rigid trucks 87% of the fatalities were not truck occupants, while for articulated trucks the equivalent figure is 78%.

Many researchers have found that accidents with heavy goods vehicles result in a disproportionate number of car occupant fatalities (Gloyns, 1989; Vulcan, 1987; Tan & Ogden, 1988). For example, in Britain Gloyns (1989) has calculated that the rate of car occupant fatalities is about four times as great for car-to-truck impacts as for to car-to-car impacts. In Victoria, some 30% of car occupants who are killed or seriously injured are involved in collisions with trucks.

Though much gain has been made in improving the crashworthiness of cars, and with even higher levels of occupant protection anticipated, in Australia little progress has been evident in truck design to reduce the potential for harm in crashes with other road users.

This project was commissioned by VICROADS to investigate the issue of truck design and its effect on the outcome of crashes involving other road users.

The findings from the study to date strongly support the view (OECD report on the Role of Heavy Freight Vehicles in Traffic Accidents, Montreal, 1987) that the design of current heavy freight vehicles makes few concessions with regard to the reduction of crash forces on the occupants of light vehicles.

The situation in Australia leaves considerable scope for improvement and hence a reduction in the risk of serious injury in crashes involving trucks. Australia currently has no effective regulations (despite the significant efforts of numerous road safety authorities and researchers) dealing with the three major areas of concern on truck design: frontal aggressivity, side under-run, and rear under-run. This contrasts with various European countries which have had regulations in place for side and rear barriers for some time.

For example Sweden has required rear under-run barriers (refer App. 3) on goods vehicles over 3.5t GVM, since 1974. Hogstrom and Svensson (1986), of Volvo in Sweden, report that prior to 1974, rear under-run crashes were responsible for between 13-14% of fatal accidents between heavy trucks and cars. This figure has reduced subsequently to about 3%, with Hogstrom attributing the reduction to the 1974 under-run regulations together with the compulsory use of seat belts and better lighting on the rear end of trucks. The equivalent percentage for Victoria is 9% (Cameron, 1990).

This report is the first in a series of interim reports from the study, and details the findings and recommendations regarding collisions of cars with the rear of trucks and the issue of rear-under-run. Subsequent reports will address the issues of the frontal design of trucks, and the side design of trucks and side under-run, respectively.
PART A: PROJECT OVERVIEW

PROJECT OBJECTIVES

The major objectives of this project were to:

- clearly establish the most influential factors contributing to the high level of fatalities and serious injuries arising from crashes involving trucks and other road users
- to identify possible modifications to the structure and design of the trucks (and cars) which would reduce the major injury causing aspects of these crashes
- to identify and compare those safety related regulations regarding truck design in force overseas but not currently adopted in Australia.

This study was not intended to address the issue of injury to the drivers and occupants of trucks. Numerous studies have established that in some 80% of cases (Ogden, 1988; Vulcan, 1987) the truck driver is uninjured in truck involved crashes. This is not to suggest that the safety of truck occupants be ignored, but rather that this issue should be the focus of a separate study.

STUDY METHOD

This study has required two major phases of work. The first was a detailed literature review of Australian and international research on crashes involving trucks and other road users. This review included a study of the pertinent heavy vehicle crash statistics for Australia and internationally.

The second involves the detailed investigation of some 80 truck related crashes that occurred in Victoria. The aim of these investigations was to enable the clear identification of the actual factors causing the high incidence of serious injury in truck/car related crashes. These investigations were intended to cover the majority of fatal crashes in Victoria over a 12 month period. In addition an equal number of hospitalisation only crashes were to be included. The crashes included: truck/car, truck/motorcycle and truck/bicycle.

The type of truck was specified as any goods vehicle over 3.5t GVM. Some fatal crashes involved trams and buses with cars were also investigated.

Notification of fatal crashes involving trucks was through the State Coroner's office. The injury details were obtained from autopsy reports through the Victorian Institute of Forensic Pathology. Injury only cases were notified through the hospital system developed by MUARC (Fildes, Lane, Lenard, Vulcan, 1991).

Inspection of trucks and cars involved in the crash were conducted at the crash repairers or towing depot yards. Each investigation included documentation of vehicle damage, measurements of deformation, intrusions, and correlation of occupant injuries with the vehicle and truck structure contact points. A photographic record was made for each vehicle.
CRASH INVESTIGATIONS TO DATE

Detailed investigations have been made of 45 crashes to the end of March. Of the 45 crashes, 19 crashes involved trucks and cars resulting in 25 fatalities and at least 8 seriously injured car occupants, and 20 non-fatal crashes involved serious injury to over 22 of the car occupants.

COMPARISON OF FREQUENCY DISTRIBUTION OF CRASH TYPE WITH MASS DATA ANALYSIS

Table 1 sets out the distribution, found in this study, of car impact position and truck type for both the fatal and serious injury crashes.

Table 1  Car occupants killed or seriously injured in collisions with trucks.
Summary from 19 crashes involving fatalities and 19 injury only crashes investigated. (Percentages shown are relative to the total of fatalities and total of injuries respectively.)

<table>
<thead>
<tr>
<th>IMPACT TYPE</th>
<th>FATALITIES</th>
<th></th>
<th>SERIOUS INJURIES</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RIGID TRUCK</td>
<td>ARTICULATED</td>
<td>RIGID TRUCK</td>
<td>ARTICULATED</td>
</tr>
<tr>
<td></td>
<td>NO.</td>
<td>%</td>
<td>NO.</td>
<td>%</td>
</tr>
<tr>
<td>FULL FRONTAL</td>
<td>0</td>
<td>0%</td>
<td>5</td>
<td>20%</td>
</tr>
<tr>
<td>OFFSET FRONTAL</td>
<td>3</td>
<td>12%</td>
<td>5</td>
<td>20%</td>
</tr>
<tr>
<td>TRUCK INTO SIDE OF CAR</td>
<td>4</td>
<td>16%</td>
<td>5</td>
<td>20%</td>
</tr>
<tr>
<td>SIDE UNDER-RUN</td>
<td>1</td>
<td>4%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAR INTO REAR OF TRUCK-UNERUN</td>
<td>1</td>
<td>4%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAR INTO REAR OF TRUCK-NO UNERUN</td>
<td>1</td>
<td>4%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRUCK INTO REAR OF CAR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTALS</td>
<td>9</td>
<td>36%</td>
<td>16</td>
<td>64%</td>
</tr>
</tbody>
</table>

Table 2 below is a comparison between the distribution found in the mass data analysis and the crashes investigated to date in this study. From this comparison it is clear that the study has good representation in each of the categories highlighted from the mass data analysis.
Table 2  Comparison of distribution of crash type for mass data analysis and crashes investigated in this study. (The percentage distributions for the mass data analysis is based on Tables 2 and 3 from the Interim Reports by Max Cameron dated 11-9-90, "Accident Data Analysis Project, High Severity Group: Cars Struck by Heavy Vehicles".)

<table>
<thead>
<tr>
<th>IMPACT TYPE</th>
<th>FATALITY</th>
<th></th>
<th>SERIOUS INJURY</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>study</td>
<td>mass data</td>
<td>study</td>
<td>mass data</td>
</tr>
<tr>
<td>Frontal</td>
<td>52%</td>
<td>52%</td>
<td>32%</td>
<td>46%</td>
</tr>
<tr>
<td>Truck into side of car</td>
<td>36%</td>
<td>24%</td>
<td>31%</td>
<td>14%</td>
</tr>
<tr>
<td>Side under-run</td>
<td>4%</td>
<td>6%</td>
<td>13%</td>
<td>10%</td>
</tr>
<tr>
<td>Car into rear of truck</td>
<td>8%</td>
<td>9%</td>
<td>21%</td>
<td>17%</td>
</tr>
<tr>
<td>Truck into rear of car</td>
<td></td>
<td>5%</td>
<td>3%</td>
<td>8%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100%</td>
<td>96%</td>
<td>100%</td>
<td>95%</td>
</tr>
</tbody>
</table>

Overall the mass data analysis shows that for fatal cases the front of the truck is involved in 81% and the rear of the truck in 9% of the cases. For the serious injury cases, the front of the truck is involved in some 60% and the rear of the truck in some 17% of the cases.

**PRELIMINARY FINDINGS ON TRUCK DESIGN AND INJURY SEVERITY**

The major factors which distinguish crashes involving trucks from other multi-vehicle crashes may be broadly summarised as follows:

1. Size incompatibility of truck structures with those of other road users. This allows under-run by cars and other light vehicles and consequent significant car occupant compartment intrusion, whether impact is to the front, side or rear of the truck.

2. High stiffness of the truck, ratio of mass of truck to car, and little energy absorption by truck structure. This leads to a high energy absorption requirement of the car structure, which is further disadvantaged by the mismatch in chassis levels. Consequently the vehicle occupants will commonly experience significantly higher velocity changes compared to "equivalent" car-to-car impacts.

3. Direct occupant contact with unyielding parts (eg. bullbar, or steel framing) of the truck and intruded parts of the car, leading to severe head or chest injuries. This problem would apply even more so to pedestrians, cyclists and motorcyclists involved in crashes with trucks.

4. Unguarded wheel areas of the truck which allow pedestrians and cyclists to fall under wheels and suffer crushing injuries.

5. Trim on trucks (particularly vans) which can be dislodged in crashes and spear car occupants.
The issues relating to truck design can be categorised into four separate areas:

A. Rear design of trucks  
B. Side design of trucks  
C. Frontal design of trucks  
D. Car design

The occupant protection performance of cars must also be reviewed as it is the interaction between the two vehicles that leads to the resultant injury severity.

Modifications made to the structure of the truck alone can be limited in their effectiveness. For example modification of truck structures to prevent car under-run, eliminates a major causal factor for serious injury, but replaces it with another (although less significant): the problem of vehicle crashworthiness in offset impacts.

The remainder of this report will focus on category A: Rear Design. Subsequent reports in this series will address the other categories in turn.
PART B: CRASHES INVOLVING CARS INTO THE REAR OF TRUCKS

PROBLEM DEFINITION

In a major American review of *Features proposed for improving truck safety* (Adiv & Ervin, 1989, p18), the under-run problem was described as follows:

"Rear underride involves the front of a car or other small vehicle sliding under and colliding with the rear end of a truck or trailer. Underride occurs because the rear end of a truck or trailer is relatively high off the ground and there is too little structure under the rear end to resist the striking vehicle, or the structure present is not strong enough to accomplish that purpose. This type of crash typically results in substantial damage to the smaller vehicle and injury to the car occupants. Sometimes when a passenger car underrides a truck, the rear end of the truck crashes through the windscreen and penetrates the passenger compartment of the car. In those cases underride is considered "excessive". Death in accidents involving excessive underride usually results from severe head and upper body injuries. It has been estimated that excessive underride occurs in 30-40% of all fatal accidents in which a passenger car crashes into the rear of a truck."

This study also noted that 350 people were killed in under-run crashes in the USA for the year 1978. At least up to 1989, the USA has not had regulations requiring effective under-run protection on trucks.

In Victoria, eleven people were killed and some 108 seriously injured in under-run crashes over the 3 year period 1987 -1989 (Cameron, 1990). Extrapolating this to an Australia wide basis (assuming that Victoria accounts for 25% of the total Australian road toll), then under-run crashes represent a toll of some 15 fatalities and 138 serious injuries per annum.

The significance of a problem is not necessarily best gauged by the arbitrary measure of the annual contribution to the road toll. Rather it is sobering to realise that a problem which is not treated is cumulative in its impact on the community. For Australia, the cumulative toll from under-run crashes over the last 20 years would be at least 300 fatalities and some 2700 serious injuries. Any further inaction on the implementation of effective countermeasures would ensure continuance of this cumulation.

PREVIOUS WORK ON REAR-UNDER-RUN CRASHES

In Australia the problem of rear-under-run crashes has been highlighted continually since at least the 1960's. McLean (1966) in an impressive work on traffic accidents in Adelaide devotes a chapter to truck related crashes and gives examples of crashes involving excessive under-run.

In a major report to the Victorian Road Safety and Traffic Authority (*Truck and Bus Accidents in Victoria*, Pak Poy & Assoc., 1971), item 7 of its findings recommends:

“7. Reviewing measures to reduce the severity of collisions with the rear end of trucks.”
In the 1977 report *Heavy Vehicle Safety*, (House of Representatives Standing Committee on Road Safety, 1977, p79), after considering the conflicting arguments for and against rear under-run barriers concluded that:

"168. The Committee recommends that the Advisory Committee on Vehicle performance extend the Draft regulation on under run barriers to cover all trucks where the load carrying tray overhangs the rear suspension..."

In 1977 the NSW Traffic Accident Research Unit (Simons & Gillies, 1977) carried out a significant study examining the problem of cars crashing into the rear of tray trucks. This study included an experimental program of cars being crashed into the end of the unprotected tray. The impact in these cases was with the A-pillar of the car and roof structure. The test program also included the development and testing of lightweight, yet effective under-run barriers. This study particularly highlighted the low impact speed required to cause high levels of passenger compartment intrusion. It was found that at speeds of 15 km/h under-run resulted in significant reduction in occupant head space, and that a 25km/h collision produced a reduction in occupant head space that might have fatal consequences in real crashes. They also conclude that simple rigid under-run guards would reduce the severity of all crashes.

In submissions to the Victorian Social Development Committee Inquiry into Vehicle Occupant Protection (1990), Dr John Lane stated that the under-run barrier height required by ADR 42 for semi-trailers was too high, allowing under-run. He also recommended extension of the regulations to rigid trucks. Professor Noel Murray and the RACV also noted the "inadequacy of front, side and rear under-run barriers on trucks".

In England Transport and Road Research Laboratory has been at the forefront of research relating to under-run protection for the rear and front of trucks. In a 1981 report analysing fatalities in heavy goods vehicle crashes (Riley et al 1981), it was estimated that some 20 of the 55 lives lost in rear under-run crashes could have been saved by the fitting of a suitable guard. This was based on the assumption that for restrained occupants crashes at 60km/h are survivable. The effectiveness of barriers would be expected to be higher with improved occupant restraint systems which are being made available in the 1990's.

**Injuries to Occupants in Under-run Collisions**

In series of case studies of actual crashes involving under-run, the Trauma Research group of the University of California (Appleby et al, 1970) concluded that:

"The head... is the human body region that most frequently sustains severe injury in underride collisions. The thorax and cervical regions are also primary areas for under-ride injuries."

In Britain, Gloyns and Rattenbury (1989), in a study of Coroner's records of fatal crashes concluded that high level major intrusion is seen in the majority of cases. For over 70% of fatal casualties in the study of crashes involving the front or rear of the truck, the passenger compartment intrusion extended into the space originally occupied by the casualty. *This intrusion gives rise to a high incidence of life threatening head and chest injuries.*
They also conclude that rear guards as a countermeasure in fatal accidents should be viewed very much as *working in conjunction* with an occupant restraint system, be it an air bag or a seat-belt.

In Germany, Danner and Langwieder (1981) analysed the characteristics of 1559 real car-to-truck crashes in which the car occupants sustained at least minor injuries (AIS 1). Their study showed that:

- car collisions into the truck rear have a frequency of 12% but they represent about 20% of the fatal and serious injuries of car occupants.
- 70% of rear end crashes are below 40km/h, but even at this speed level the consequences are very often serious because of the inadequate design of the underrun barrier. A review of countermeasures and European regulations is covered separately in the Chapter *Countermeasures*.

**CASES INVESTIGATED IN THIS STUDY**

Detailed investigations have been carried out on seven crashes of cars into the rear of trucks. The author has found that these cases are quite representative of features involved in rear under-run crashes in general. The detailed information obtained from these cases when analysed in the context of the various studies cited, enables a clear determination of the significant injury causation mechanism and recommendations for appropriate countermeasures.

The seven cases are set out in the following table:

<table>
<thead>
<tr>
<th>CASE NO.</th>
<th>CAR MODEL</th>
<th>YEAR</th>
<th>TRUCK TYPE</th>
<th>TRUCK MODEL</th>
<th>IMPACT TYPE</th>
<th>FATAL</th>
<th>INJURY</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-10-10-90</td>
<td>Toyota Camry</td>
<td>1990</td>
<td>Rigid</td>
<td>Mitsubishi van</td>
<td>rear under-run</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>F17-1-91</td>
<td>Mitsubishi Magna</td>
<td>1989</td>
<td>Articulated</td>
<td>Leyland with trailer</td>
<td>car into rear of trailer</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>FC/1202/90</td>
<td>Nissan Bluebird</td>
<td>1985</td>
<td>Rigid</td>
<td>Mazda van</td>
<td>car into rear of van</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>I-4-10-90</td>
<td>Ford Falcon</td>
<td>1981</td>
<td>Articulated</td>
<td>International</td>
<td>car into rear of truck</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>I-7-10-90</td>
<td>Holden Camira</td>
<td>1989</td>
<td>Rigid</td>
<td>Rigid truck</td>
<td>rear under-run</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>I-11-12-90</td>
<td>Mitsubishi Magna</td>
<td>1989</td>
<td>Rigid</td>
<td>Isuzu tray</td>
<td>rear under-run</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>I-17-2-91</td>
<td>Holden Nova</td>
<td>1989</td>
<td>Articulated</td>
<td>Volvo F10 &amp; trailer</td>
<td>rear under-run</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>

Of the seven cases three crashes involved 4 fatalities and four of the crashes resulted in injuries requiring hospitalisation. The estimated impact speeds varied from well below 40km/h to 75km/h.
For each of these cases a full summary is provided (Appendix 1) with the analysis set out under the following headings:

- CRASH CIRCUMSTANCES
- VEHICLE DETAILS
- CRASH DETAILS
- TRUCK AND VEHICLE DAMAGE
- SIGNIFICANT INJURIES AND CAUSE OF INJURY
- DESIGN COMMENT ON THE TRUCK AND CAR INVOLVED, AND RELEVANT ADRs
- POTENTIAL TRUCK AND CAR DESIGN COUNTERMEASURES

Each case also has detailed sketches setting out the impact interaction between the two vehicles, and a photographic summary highlighting the key features of the damage and performance of the car and truck.

The reader is encouraged to gain familiarity with the case summaries, set out in Appendix 1, before proceeding to the next section.
MAJOR CONCLUSIONS DRAWN FROM THE CASE STUDIES

- **Crash Types:** The injury and fatal crashes could be divided into two distinct crash types, depending on the design of the rear of the truck.

**Type 1:** Where the rear wheels of the truck are set close to the rear (say within 500-mm) the trucks structure acts as an impact barrier, with no excessive under-run. In these cases (Cases F17 & I4) the current truck structures provide virtually no energy absorption, and the resultant occupant injuries become a function of the car's crashworthiness. For example in case F4, the driver's fatal injuries (ruptured aorta, with fractured ribs and no head injuries) were a reflection of the significant chest impact with the steering wheel hub combined with the excess movement permitted by the seat-belt. In this case an improved occupant restraint system (e.g. belt pretensioner combined with supplementary airbag), may well have prevented the driver's fatal injuries.

**Type 2:** This is the classic under-run case where the vehicle under-runs the rigid tray (or floor of a van) of the truck with consequent high levels of intrusion into the passenger compartment exposing the occupants to fatal or serious head injuries. The impact is generally concentrated on the roof structure and A-pillars, which provide little resistance to this type of direct loading. In these cases the vehicle impact speed can be relatively low (30-40 km/h) and still result in serious injury. In excessive under-run crashes, by their very nature, occupant restraint systems can provide little or no protection to the car occupants.

- **Height of truck tray or van floor height:** The stiff floor structure of most trucks is sufficiently high to cause serious or fatal injury to the occupants of cars in an under-run situation. This applies even to smaller rigid trucks of around 2.5t (tare) and greater-

- **Under-run can be a low speed hazard:** In contrast to other crash types, rear under-run is a significant hazard even at relatively low speeds. As impact occurs generally above bonnet height, the windscreen pillars are incapable of resisting this type of loading and high occupant compartment intrusion can result.

- **Occupant protection systems may become ineffectual in under-runs:** Underrun negates the effectiveness of vehicle occupant protective measures such as seatbelts and airbags, and is more likely to result in direct occupant impact with the truck structure, with consequent severe or fatal head and chest injuries.

- **Current ineffective rear barrier designs could be readily upgraded.** Observations from the case studies and of vehicles on the roadway, show that many trucks and semi-trailers already have fitted some sort of rear barrier type structure. The configuration of these "guards" varies greatly and it is apparent by observation that few would act as effective under-run barriers. Common deficiencies are inadequate bracing and connection design and execution, and incorrect height. It is also apparent that even in many barriers which are made from substantial structural sections (as seen on semi-trailers, for example), the potential load resistance is wasted by inadequate design and detailing.

The low capacity of the under-run barrier analysed in Case I17, also highlights the well known inadequacy of the current ADR regulations (Murray, 1988), and which only applies to a very limited range of vehicles (semi-trailers). \(Refer\ to\ App.\ 2\ for\ ADR\ 42.6\ Rear\ Bumper\ For\ Semi-Trailers\).
It is evident that many of these barriers could be redesigned and substantially upgraded in capacity, with little penalty in the way of cost or weight increase, above what is already being incurred.

- **Rear Marking Plates** (ADR 13.6.101) These were prominent on the rear of two of the three fatal cases. The third case involved a van which was not required to display these plates as it was below the specified 12t GVM. Also three of the four injury cases investigated had the required plates. The regulations requiring rear marker plates to enhance visibility so as to help prevent rear crashes, only applies to vehicles over 12t GVM. However many vehicles below this mass pose an equal potential under-run hazard.

Although the case studies presented in this report identified that of the 7 trucks involved, 5 did have these plates in place, one conclusion to be drawn is simply that increasing the visibility of trucks is only one of the necessary measures required.

Nevertheless, improvements in truck visibility are self-evidently worthwhile interventions to help prevent the occurrence of rear end crashes. Consequently a review of the effectiveness of these plates (ie. their visibility) and also the extension to vehicles between 3.5t and 12t GVM should be seriously considered.

Also evident from the case studies is the apparent inability of some drivers to notice that a truck is stationary or slow moving, until an impact becomes unavoidable. The activation of the truck's brake light or some other supplementary light to alert car drivers that the truck is stationary or slow moving, may well be worthy of further consideration.

To date the major initiative in Australia to help prevent the occurrence of crashes into the rear of trucks has been to require conspicuity marker plates on the rear of trucks and trailers over 12t GVM.

The implied proposition that improving the visibility of the rear of trucks is *sufficient intervention* is contradicted by European experience, (as they have regulated for rear-under-run barriers on trucks), and from the sample of crashes investigated in this study. Effective intervention requires *not only* crash prevention measures but also measures for injury prevention in crashes.

The next section reviews the work done on injury prevention by the application of rear under-run barriers on trucks.
COUNTERMEASURES

General Requirements

To reduce the injury potential to the occupants of cars colliding with the rear of trucks, the first prerequisite is to prevent excessive under-run. The second consideration is the management of the impact energy so as to reduce occupant compartment intrusions and passenger deceleration to tolerable levels.

The first objective is achieved by including on the rear of the truck a structure (barrier) of sufficient strength and appropriate height, to be able to sustain the impact load from the car. This type of barrier could be regarded as effectively rigid with little deformation and energy absorption properties. Occupant survivability then becomes a function of the impact speed and the vehicle's crashworthiness.

To further reduce the risk of injury (or to increase the tolerable impact speed), the provision of deformable barriers with significant energy absorption characteristics is required.

As many rear impacts are not central, barriers must also be able to act in offset impacts. In these cases the load from the vehicle is not distributed over the full width, but is resisted by only part of the barrier structure.

In addition, barriers must also be designed so as not to unduly compromise the truck's functional performance. The main considerations are: ground clearance for access on grades; to minimize barrier weight to avoid any significant loss of load capacity; and to minimize any additional cost.

Barrier Height (roadway clearance)

The height of the barrier above road level is a critical factor in determining the effectiveness of the under-run guard. Numerous researchers have pointed out the importance of matching the height of the rear barrier to the "chassis" (front side rails) level of the car to prevent under-run and to ensure maximum utilisation of the energy absorption capabilities of the front structure of the car. Murray (1988) in a major study (examining car-to-truck impacts and the fitting of energy absorbing guards to heavy trucks) includes a survey of 49 cars which found bumper heights to vary from 350mm to under 600mm for unladen cars. Beerman (1984) in Germany found that the height of the upper edge of the front chassis beams varied from 350mm to 500mm, for cars loaded with one occupant.

Langwieder and Danner in their review of some 1200 crashes concluded that underrun protection should have a ground clearance of no more than 300mm and be mounted as near as possible to the rear end.
Regulations on Under-run Barrier Height

<table>
<thead>
<tr>
<th>BARRIER HEIGHT</th>
<th>AUSTRALIA (current ADR 42.6)</th>
<th>SWEDEN</th>
<th>ECE REG. 58</th>
<th>USA (proposed Adv. 1989)</th>
<th>Langwieder &amp; Danner</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>600mm unladen</td>
<td>550mm unladen</td>
<td>550mm unladen</td>
<td>550mm</td>
<td>300mm</td>
</tr>
<tr>
<td>TRUCK TYPE</td>
<td>semi-trailer</td>
<td>all &gt; 3.5t GVM</td>
<td>semi-trailer</td>
<td>general</td>
<td></td>
</tr>
</tbody>
</table>

It is apparent that the barrier height should be kept as low as possible, with the desirable level falling between 300mm to 500mm, *but not more than 500mm*. For Australian regulations, the specification for minimum clearance height could be made a function of the length of overhang of the rear of the truck from the rear wheels, the position of the rear barrier, and the performance requirements of the truck.

The exact specification of the barrier height is beyond the scope of this study. Nevertheless the selection of barrier height parameters should be based on a *compromise* between meeting the needs of the operational requirements of the truck, and with due consideration of the protection and safety of the other road users sharing the roadway environment. This compromise may well result in changes to permissible truck configurations as well as to changes to the various regulations governing truck dimensions and weights.

**Barrier Load Capacity**

The performance and actual loading on rear under-run barriers in crashes has been subject to investigation by special crash test programmes and of course by investigation of actual crashes.

The energy to be dissipated by a car impacting the rear of a truck is given by (Murray, 1988):

\[
E = \frac{m_1 m_2 V^2}{2(m_1+m_2)},
\]

and

\[
F = \frac{m_1 m_2 V^2}{2(m_1+m_2)s}
\]

where:
- \(E\) = energy
- \(F\) = force acting between the two vehicles
- \(m_1\) = car mass
- \(m_2\) = truck mass
- \(V\) = car closing speed
- \(s\) = crush distance

The force \(F\) is also the force acting on the under run barrier by the car. As an example, the following table shows the variation of force \((F)\) with truck mass, for a car mass=1200kg, and impact velocity \(V=50\) and 60km/h, for \(s=600mm\).  

<table>
<thead>
<tr>
<th>TRUCK MASS</th>
<th>3.5t</th>
<th>5.5t</th>
<th>10.5t</th>
<th>10t</th>
<th>40t</th>
</tr>
</thead>
<tbody>
<tr>
<td>V=50km/h</td>
<td>F (kN)</td>
<td>144</td>
<td>156</td>
<td>171</td>
<td>183</td>
</tr>
<tr>
<td>V=60km/h</td>
<td>F (kN)</td>
<td>207</td>
<td>223</td>
<td>246</td>
<td>262</td>
</tr>
</tbody>
</table>

These calculations show that the theoretical barrier strength for a 50km/h collision varies from 144kN for a 3.5t truck to 188kN for a 40t truck. Also shown is the increased loading for the higher speed of 60km/h.
This Table illustrates that for a typical car mass the required theoretical barrier strength is only some 30% greater for a 40t truck than a 3.5t truck. Beerman also made this point in his paper, and further confirmed it with actual crash tests which showed negligible difference in impact loading for a 3t and 8t truck. Beerman went on to recommend that the rear under-run barrier should be designed for a quasistatic load of:

- 150kN per drop arm
- 100kN in the middle
- 100kN 300mm from the end

In Germany, Langwieder and Danner concluded after investigation of truck crashes that though the ECE regulation R58 undoubtedly represents an improvement, there are still problems in the case of offset impacts to the outer end of the under-run guard, with the risk of this part being bent off. They recommend an improvement in the bracing members and an increase in the ECE -R 58 test loads from 100kN to 150kN.

In the USA (Tebay, 1977; for the Insurance Institute for Highway Safety) five crash tests were carried out into the rear of semi-trailers, at impact speeds ranging from 48km/h to 60km/h. The vehicle's weight varied from 1200kg to 1700kg. The original manufacturer's guard (23kg weight, ground clearance 711mm) was found to be ineffective in preventing excessive under-run in these crashes. The redesigned guard only weighed 8kg extra (31kg, ground clearance 530mm) and was considered to perform acceptably as passenger compartment penetration was prevented. These tests clearly demonstrated that effective lightweight guards are achievable.

**Comparison of Barrier Test Load Requirements**

The following table is a summary and comparison of the various under-run barrier load test requirements, with the recommendations from the various researchers previously cited. (Refer to Figure 1. for definitions of the load application points.)

<table>
<thead>
<tr>
<th>Test load (kN)</th>
<th>Sweden-original</th>
<th>Sweden-modified</th>
<th>U.K (EEC)</th>
<th>E.C.E</th>
<th>USA proposed</th>
<th>Langwieder &amp; Danner</th>
<th>Beerman</th>
</tr>
</thead>
<tbody>
<tr>
<td>truck size</td>
<td>3.5t GVM</td>
<td>3.5t GVM</td>
<td>-</td>
<td>3.5t GVM</td>
<td>4.6t GVM</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>outer edge</td>
<td>50</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>50</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>centre</td>
<td>50</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>50</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>off centre</td>
<td>200</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>150</td>
<td>150</td>
</tr>
</tbody>
</table>

(In Figure 1, P₁ = off centre; P₂ = outer edge; P₃ = centre)
Comments on the Regulations

The test load requirements in the original Swedish regulations were halved due to some truck models apparently being unable to comply without chassis strengthening.

The UK, EEC and ECE regulations are based on the Swedish model.

The test loads given are the maximum values required and would apply to trucks of 20t GVM and greater. For smaller trucks, the regulations also allow forces to be calculated depending on the truck mass. The outer force is required to be only 12.5% of the GVM and the off centre force is 0.5GVM.

For example for a 3.5t truck:

outer edge test load: \(0.125 \times 3500\text{kg} = 4.4\text{kN}\)
off centre \(0.5 \times 3500\text{kg} = 17.5\text{kN}\)

These values are extremely low, and are self evidently quite inadequate. The author is not aware of whether European manufacturers use these lower bound values.

Summary of Recommendations for Countermeasures

A. Crash prevention:

A1. Review the effectiveness of current measures taken to improve the conspicuity of the rear of trucks. This study should include a review of:

- the current design and reflectivity standards for the rear marking plates (ADR 45).
- modification of truck rear lights to indicate trucks are stopped or going slow.

A2. Extend the regulation (ADR 13.6.101 Rear Marking Plates) for rear conspicuity to include heavy vehicles and trailers having a GVM greater than 3.5t.

B1. Revise ADR 42.6 for rear under-run barrier design for semi-trailers to be in line with the European ECE standards except as noted:

1. Test Load for the under-run device.

The following table summarises the recommended minimum test loads for different vehicle and trailer categories.

<table>
<thead>
<tr>
<th>VEHICLE TYPE</th>
<th>GOODS VEHICLE</th>
<th>TRAILER</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADR CATEGORY</td>
<td>MEDIUM (NB)</td>
<td>HEAVY (NC)</td>
</tr>
<tr>
<td>GVM</td>
<td>3.5t to 12t</td>
<td>&gt; 12t</td>
</tr>
<tr>
<td>TEST LOAD LOCATION</td>
<td>TEST LOAD</td>
<td></td>
</tr>
<tr>
<td>OFF CENTRE</td>
<td>P₁</td>
<td>100kN</td>
</tr>
<tr>
<td>CENTRE</td>
<td>P₂</td>
<td>100kN</td>
</tr>
<tr>
<td>300MM FROM EDGE</td>
<td>P₃</td>
<td>100kN</td>
</tr>
</tbody>
</table>

2. Barrier height:

To be the minimum practical to suit specific vehicle type performance requirements, and to be in the range 300mm to 500mm maximum.
CONCLUSIONS

PART A: GENERAL

Crashes involving trucks and other road users are recognised internationally to be a significant contributor to the total number of people killed or seriously injured in road crashes. In Australia trucks are involved in some 13 % of multi vehicle fatal crashes.

Many researchers have noted that in these multi-vehicle crashes, most at risk were the other road user, not the truck occupants. For car occupants the rate of fatalities is about four times as great for car-to-truck impacts as for to car-to-car impacts. In Victoria, some 30% of car occupants who are killed or seriously injured are involved in collisions with trucks.

The objectives of this project were to clearly establish the causal factors contributing to the high level of fatalities and serious injuries arising from crashes involving trucks and other road users and to identify possible countermeasures.

This study has included a detailed literature review of Australian and international research on crashes involving trucks and other road users, and the detailed investigation of truck-involved multi-vehicle crashes. Some 45 crashes have been investigated to date: of these 19 crashes involved trucks with cars, resulting in 25 fatalities and over 8 seriously injured car occupants, and 20 non-fatal crashes involved serious injury to over 22 of the car occupants. The type of truck was specified as any goods vehicle over 3.5t GVM.

The following table summarises the distribution of crash type (for car-to-truck crashes) for the mass data and for the crashes in this study. A comparison shows that the study has good representation in each of the categories.

<table>
<thead>
<tr>
<th>IMPACT TYPE (Part of Truck Contacted)</th>
<th>FATALITY</th>
<th>SERIOUS INJURY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>study</td>
<td>mass data</td>
</tr>
<tr>
<td>Front of truck</td>
<td>88%</td>
<td>81%</td>
</tr>
<tr>
<td>Side of truck</td>
<td>4%</td>
<td>6%</td>
</tr>
<tr>
<td>Rear of truck</td>
<td>8%</td>
<td>9%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100%</td>
<td>96%</td>
</tr>
</tbody>
</table>

The general conclusions regarding the actual causal factors contributing to the high injury risk to car occupants may be summarised as follows:

1. Size incompatibility of truck structures with those of other road users, allowing under-run by cars and other light vehicles and consequent significant car occupant compartment intrusion.

2. High stiffness of the truck, ratio of mass of truck to car, and little energy absorption by truck structure. This leads to the car occupant being subjected to significantly higher velocity changes compared to "equivalent" car-to-car impacts.
3. Direct occupant contact with unyielding parts of the truck (e.g., bullbar, or steel framing of the truck) and car, leading to severe head or chest injuries.

4. Unguarded wheel areas of the truck which allows pedestrians and cyclists to fall under wheels and suffer crushing injuries.

5. Trim on trucks (particularly vans) which can be dislodged in crashes and spear car occupants.

The findings from the study to date strongly support the view (OECD report on the Role of Heavy Freight Vehicles in traffic Accidents, Montreal, 1987) that the design of current heavy freight vehicles makes few concessions with regard to the reduction of crash forces on the occupants of light vehicles.

Australia currently has no effective regulations dealing with the three major areas of concern on truck design: frontal aggressivity, side under-run, and rear under-run. This contrasts with various European countries which have had regulations in place for side and rear barriers for some time. This situation in Australia leaves considerable scope for improvement and hence a reduction in the risk of serious injury in crashes involving trucks.

The development of countermeasures can be progressed by systematically reviewing the three major areas of a truck offering a hazardous interface with other road users:

A. Frontal design of trucks
B. Rear design of trucks
C. Side design of trucks

This first report presents the specific conclusions and recommendations for the rear design of trucks. Subsequent reports will examine the front and side design of trucks.

**PART B: CRASHES INVOLVING CARS INTO THE REAR OF TRUCKS**

In Australia crashes of cars into the rear of trucks accounts for some 9% of fatal injuries and some 17% of serious injury, for truck involved crashes. Nationally, the cumulative toll over the last 20 years, arising from under-run crashes would exceed some 300 fatalities and some 2700 serious injuries.

Though the problem of under-run crashes has been highlighted in Australia, at least for the last 25 years, no effective countermeasure have as yet been introduced. In Sweden the introduction of rear under-run protection devices (acting together with improvements in occupant restraint, and improved rear visibility of trucks) has resulted in a reduction in fatalities due to under-run crashes from 13% to about 3%, according to Swedish reports.

From the detailed investigation of the seven under-run crashes, together with the findings from the previous work of Australian and overseas researchers, the main characteristics of under-run crashes can be summarised as follows:

- Where the rear wheels of the truck are set close to the rear (say within 500-mm) the trucks structure acts as a impact barrier, with no excessive under-run. In these cases the resultant occupant injuries become a function of the vehicle crashworthiness.
Where the vehicle under-runs the rigid tray (or floor of a van) of the truck high levels of intrusion into the passenger compartment result, exposing the occupants to fatal or serious head injuries.

The stiff floor structure of most trucks is sufficiently high to cause serious or fatal injury to the occupants of cars in an under-run situation.

In contrast to other crash types, rear under-run is a significant hazard even at relatively low speeds (less than 40 km/h). As impact occurs generally above bonnet height, the windscreen pillars are incapable of resisting this type of loading and high occupant compartment intrusion can result.

Under-run negates the effectiveness of vehicle occupant protective measures such as seat-belts and airbags, and is more likely to result in direct occupant impact with the truck structure, with consequent severe or fatal head and chest injuries.

The current ADR regulations (ADR 42.6 Rear Bumper For Semi-Trailers, refer App. 2.), only applies to a very limited range of vehicles, and is known to be inadequate. Common deficiencies found on rear guard designs are inadequate bracing and connection design and execution, and incorrect height, with the potential load resistance being wasted by inadequate design and detailing.

It is evident that many of these barriers could be redesigned and substantially upgraded in capacity, with little penalty in the way of cost or weight increase, above what is already being incurred.

Increasing the visibility of trucks is only one of the necessary countermeasures to reduce the incidence of under-run fatalities and serious injuries (five of the seven trucks involved in the rear under-run crashes investigated, had rear marking plates)

The experience of Sweden and other European Countries clearly demonstrates that low cost and effective countermeasures can be introduced to significantly reduce fatalities and serious injuries arising from crashes of cars into the rear of cars.

The situation as regards rear under-run barriers on trucks is well summarised by the 1987 OECD report as follows:

"... NO SUBSTANTIVE TECHNICAL PROBLEMS REMAINED TO BE SOLVED WITH RESPECT TO THE PROVISION OF EFFECTIVE REAR UNDER-RIDE PROTECTION. IT WAS PRINCIPALLY A MATTER FOR REGULATORY INITIATIVES BY RESPONSIBLE AUTHORITIES TO BRING ABOUT THE GENERAL USE OF CHEAP, EFFECTIVE SYSTEMS ..."
RECOMMENDATIONS

REAR UNDER-RUN: RECOMMENDED COUNTER MEASURES

A. CRASH PREVENTION:

A1. Review the effectiveness of current measures taken to improve the conspicuity of the rear of trucks. This study should include a review of:

- the current design and reflectivity standards for the rear marking plates (ADR 45).
- modification of truck rear lights to indicate trucks are stopped or going slow.

A2. Extend the regulation (ADR 13.6.101 Rear Marking Plates) for rear conspicuity to include heavy vehicles and trailers having a GVM greater than 3.5t.

B. INJURY PREVENTION:
SPECIFICATION FOR REAR UNDER-RUN BARRIER ON GOODS VEHICLES

Revise ADR 42.6 for rear under-run barrier design for semi-trailers to be in line with the European ECE standards except as noted below:

1. Test Load for the under-run device.

The following table summarises the recommended minimum test loads for different vehicle and trailer categories.

<table>
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<th>VEHICLE TYPE</th>
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<td>GVM</td>
<td>3.5T to 12T</td>
<td>&gt;12T</td>
</tr>
<tr>
<td>TEST LOAD LOCATION</td>
<td>TEST LOAD</td>
<td></td>
</tr>
<tr>
<td>OFF CENTRE</td>
<td>P₁ 100kN</td>
<td>150kN</td>
</tr>
<tr>
<td>CENTRE</td>
<td>P₂ 100kN</td>
<td>100kN</td>
</tr>
<tr>
<td>300mm FROM EDGE</td>
<td>P₃ 100kN</td>
<td>100kN</td>
</tr>
</tbody>
</table>

2. Barrier height:

To be the minimum practical to suit specific vehicle type performance requirements, and to be in the range 300mm to 500mm maximum.
REFERENCES


[This document has been created through Optical Character Recognition by Glenda Cairns. Every attempt has been made to correct any recognition errors, and we apologise if any have been missed.]
APPENDIX 1

CASE STUDIES

CASE STUDIES
CASE F10.10.90
CASE F17.01.91
CASE FC.1202.90
CASE I4.10.90
CASE I7.10.90
CASE I11.12.90
CASE I17.02.91
TRUCK RELATED CRASH STUDY
CASE SUMMARY (FATAL)

CASE IDENTIFIER : F10/10/90
DAY : Saturday
MONTH : October
TIME : 6:30 am
WEATHER : Fine
ROAD TYPE : Major Country Highway
INTERSECTION TYPE : Nil
SPEED ZONE : 100 km/hr

VEHICLE DETAILS
TRUCK MODEL : Mitsubishi van
TARE WEIGHT : 7420 kg
GROSS WEIGHT : 13650 kg
VEHICLE MODEL : Toyota Camry Station Wagon
YEAR : 7/1990
MASS : 1200 kg

CRASH DETAILS
The van was travelling along the highway up a hill, at about 40-50 km/hr. The van was in the left lane, adjacent to the uphill passing lane. The car was travelling (probably around the 100 km/hr speed limit) behind the van and apparently did not see it as it appears to have swerved at the last second to avoid running into rear of it. However, the passenger side penetrated under the truck’s rear resulting in severe underrun to this side.

TRUCK DAMAGE
- Minor damage.
- Rear bumper slightly bent and 3 supporting bolts sheared. Bumper reacted against other framing and remained effectively in place.

SIGNIFICANT INJURIES
Driver : Minor injuries.
Front Passenger : Fatal, severe head injuries.
Rear Passenger (Passenger Side) : Severe injuries, chest and head injuries.
Truck Driver : Uninjured.

CAUSE OF INJURY
The front passenger’s fatal injuries resulted from the under-run with direct head impact with the rear bumper being most probable. The under-run forced the front passenger back onto the rear passenger, contributing, it would appear, to the the injuries to this person. The rear passenger may also have made contact with the intruded parts of the vehicle.

VEHICLE DAMAGE
The front of the car was undamaged, with the impact forces being concentrated just above bonnet level into the passenger side structure and roof. The impact point was over a width less than 500 mm, and was with the stiff rear bumper of the van, which was just above the cars bonnet height.
The A and B-pillars were torn away with the doors still attached, resulting in the side structure being ripped away from the vehicle. The roof was sheared back towards the rear seat, particularly on the passenger side.
**DESIGN COMMENT**

**TRUCK DESIGN:**
The height of the rear bumper, which was quite strong, was 770 mm which was just above the car's bonnet level, and thus readily allowed under-run. The truck's wheels were well back from the rear of the truck (2.3 m) and were not impacted. The crash highlights the devastating consequence of under-run, even where the actual under-run is of a relatively small width.

**VEHICLE DESIGN:**
The connection of the roof sheeting, A & B-pillars to the car structure appears to suffer from inadequate welding. Similarly, the door structures lack integrity as the outer skin is poorly attached and the side intrusion bar is connected to only act effectively under transverse loads. However, in this type of under-run crash, the solution lies more with the truck design and prevention of under-run.

**ADR'S:**
There are no ADR requirements for rear bumper design of trucks other than semi-trailers.

**POTENTIAL TRUCK & VEHICLE DESIGN COUNTERMEASURES**

**TRUCK:**
Lowering the height of the rear bumper of the vehicle to that of the car bumper, and providing properly engineered attachments would prevent or reduce the under-run potential of most rear end collisions. That is the impact load would be largely taken by the front body of the car rather than the weak roof structure, consequently preventing the massive intrusion into the passenger compartment.

**VEHICLE:**
The crash highlights potential weakness in the car structure design which would be relevant in various other types of crashes, but it is unrealistic to try to design the car A-pillar to withstand the under-run forces.
CASE F10/1993

PHOTO 1. Rear view of the van. (Support bracket repaired)
PHOTO 2. Rear view of van's bumper at crash site. Bumper was slightly bent, and the 5 support bolts failed allowing the bumper to drop marginally.
PHOTO 3. Detail of rear bumper and support brackets. Impact side (looking from underneath).
PHOTO 4. Side view of station wagon. A-pillar and B-pillar were torn out by the impact.
PHOTO 5. Driver's side view of the car. Note largely intact side structure.
PHOTO 6. Overhead view of the station wagon.
FIGURE 1a : CASE F10/10/90
PLAN OF VIEW OF REAR SECTION OF VAN AND INFERRED TRAJECTORY
OF THE STATION WAGON AT POINT OF IMPACT.

Note: The front of the car was undamaged, except for near the windscreen pillar, where the
bonnet was marked with the black rubber from the truck bumper buffer. Similarly, the passenger
side front guard had black markings from contact with the truck's wheels, but was otherwise
undamaged.

FIGURE 1b
SIDE ELEVATION OF VAN AND STATION WAGON

Note: The 3 bolts holding the bumper support bracket failed in the impact. However, the
bumper then reacted against the van frame.
FIGURE 1c
SIDE ELEVATION OF VAN SHOWING EXTENT OF UNDER-RUN ON PASSENGER SIDE.
(Note that front of the car did not impact rear wheel of truck. Refer Figure 1a)
TRUCK RELATED CRASH STUDY
CASE SUMMARY (FATAL)

**CASE IDENTIFIER**: F17/1/91  
**DAY**: Wednesday  
**MONTH**: January  
**TIME**: 9.15am  
**WEATHER**: fine  
**ROAD TYPE**: highway, rural  
**INTERSECTION TYPE**: no  
**SPEED ZONE**: 100 km/hr

<table>
<thead>
<tr>
<th>VEHICLE DETAILS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TRUCK MODEL</strong></td>
</tr>
<tr>
<td><strong>TARE WEIGHT</strong></td>
</tr>
<tr>
<td><strong>GROSS WEIGHT</strong></td>
</tr>
<tr>
<td><strong>VEHICLE MODEL</strong></td>
</tr>
<tr>
<td><strong>YEAR</strong></td>
</tr>
<tr>
<td><strong>MASS</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CRASH DETAILS</th>
</tr>
</thead>
<tbody>
<tr>
<td>The fully loaded truck was going up a hill at around 30km/h. The car was travelling at an estimated 95-100km/h (witnesses) when it collided with the rear of the trailer. This gives a speed difference at impact of around 70km/h. Based on the vehicles frontal crush (800mm average), the estimated velocity change was 78km/h (Crash 3 program). The impact was full frontal with no roof structure contact. Driver killed, no other passengers.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TRUCK DAMAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>The main impact was with the rear axle, spring hangers and wheels of the trailer, with very little damage occurring to these structures. As the axle was positioned only 500mm in from the end, under-run was prevented.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VEHICLE DAMAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>The front of the car was crushed some 900mm on the drivers side and 700mm on the passenger side, with the E-W engine being pushed back into the fire wall. The A pillars showed rearward loading with some roof buckling as a result. The dashboard and steering wheel showed residual rearward displacement of around 150mm. Markings on the steering wheel hub and the drivers seatbelt safety criteria indicated high contact loading between these two surfaces. The back of the rear seat had been loaded by heavy boxes in the boot and had broken free. It does not appear that the drivers seat was loaded by these goods.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SIGNIFICANT INJURIES</th>
</tr>
</thead>
</table>
| Driver: 25y, male, 73kg  
*cause of death:* ruptured descending aorta.  
Other injuries include fractures of left 1st, 2nd, 4th ribs, facial lacerations but no significant head injury.  
*Truck Driver:* nil |

<table>
<thead>
<tr>
<th>CAUSE OF INJURY</th>
</tr>
</thead>
<tbody>
<tr>
<td>The ruptured aorta appears to be a result of deceleration loading and chest impact with the steering wheel. Though the driver was wearing an inertia reel belt, the belt stretch combined with the rearward steering wheel displacement resulted in heavy chest loading onto the steering wheel hub.</td>
</tr>
</tbody>
</table>
**DESIGN COMMENT**

**TRUCK DESIGN:**
The structure of the rear of the trailer formed a virtual rigid impact barrier for rear end collisions. This structure (rear axle/suspension mounting brackets/rear wheels) have a very high load capacity and were not deformed in the impact. This type of structure provides very little energy absorption for impacting vehicles, but it does prevent rear under-ride.

**VEHICLE DESIGN:**
The main problems from an occupant protection viewpoint were:
- Insufficiently energy absorbing steering hub and column
- Excess slack/stretch in seat belt
- Failure of rear seat back due to deceleration loading from boot contents

**ADR'S:**
ADR 10: Review effectiveness of current energy absorption requirements and actual performance of steering columns/hubs

---

**POTENTIAL TRUCK & VEHICLE DESIGN COUNTERMEASURES**

**TRUCK:**
This type of rear trailer structure does effectively prevent rear under-ride, but provides no energy absorption. This puts greater onus on the car design for occupant protection.

**VEHICLE:**
In this type of crash improved occupant restraint systems may have prevented fatal injuries. The provision of belt pretensioners and supplementary airbag may well have prevented the fatal chest injuries, noting that there were no significant head injuries.
CASE F17/191

PHOTO 1. Rear view of trailer. (note white panel is new)
PHOTO 2. Rear view of trailer, showing rear axle and spring bucket support.
PHOTO 3. Side view of car showing front crash.
PHOTO 4. View of car showing crush. (measuring bars are at original length)
PHOTO 5. Interior view, note steering wheel deformed.
PHOTO 6. Seat belt showing abrasion marks from high pressure contact with steering wheel hub.
FIGURE 1a: CASE F17/91
REAR IMPACT: Car into Truck. Side elevation showing car relative to truck.

FIGURE 1b
Side view showing impact with rear structure.
**TRUCK RELATED CRASH STUDY**

**CASE SUMMARY (FATAL)**

<table>
<thead>
<tr>
<th>CASE IDENTIFIER</th>
<th>FC/1202/90</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAY</td>
<td>Friday</td>
</tr>
<tr>
<td>MONTH</td>
<td>March</td>
</tr>
<tr>
<td>TIME</td>
<td>3:30am</td>
</tr>
<tr>
<td>WEATHER</td>
<td>fine</td>
</tr>
<tr>
<td>ROAD TYPE</td>
<td>main highway, suburban</td>
</tr>
<tr>
<td>INTERSECTION TYPE</td>
<td>na</td>
</tr>
<tr>
<td>SPEED ZONE</td>
<td>75 km/hr</td>
</tr>
</tbody>
</table>

**VEHICLE DETAILS**

<table>
<thead>
<tr>
<th>TRUCK MODEL</th>
<th>Mazda E3000 van</th>
</tr>
</thead>
<tbody>
<tr>
<td>TARE WEIGHT</td>
<td>2650kg</td>
</tr>
<tr>
<td>GROSS WEIGHT</td>
<td>5200kg</td>
</tr>
<tr>
<td>VEHICLE MODEL</td>
<td>Nissan Bluebird 4d sedan</td>
</tr>
<tr>
<td>YEAR</td>
<td>1985</td>
</tr>
<tr>
<td>MASS</td>
<td>1100kg</td>
</tr>
</tbody>
</table>

**CRASH DETAILS**

The Nissan went into the left lane to pass a truck, and collided with the rear of the parked Mazda van. The collision was an offset rear under-run. The two female passengers were killed. Estimated (witness) impact speed was in excess of 75km/h.

**TRUCK DAMAGE**

The rear under-run guard was totally torn away. The rear suspension mounting bracket was fractured as a result of the car's impact with the rear wheels, displacing the rear wheels by some 550mm. Details of the truck structure and under-run barrier are given in FIGURES 1, 2, 3 & 4.

**VEHICLE DAMAGE**

The passenger side under-run the floor of the van over a width of 700mm, with penetration extending back to the C pillar. The roof was torn back to the C pillar, the A and B pillars were sheared off or heavily deformed above door level. The frontal deformation on the passenger side was around 700mm, and included significant dashboard intrusion.

**CAUSE OF INJURY**

As the cars cabin was sheared off to a height of some 950mm, both of the passenger's heads would have been exposed to direct impact with the stiff frame of the rear of the truck and for the deformed and intruded parts of the car body. The injury mechanism of under-run crashes is clearly demonstrated by the presence of the facial head injuries and absence of any other serious injuries.

**SIGNIFICANT INJURIES**

*Driver* : Male, 20 (7) yr, minor injuries
*Front Passenger* : Female, 20 yr, severe head injuries; widespread skull fractures, widespread subarachnoid haemorrhage, and multiple lacerations to the brain, no other significant injuries except for a fractured left humerus.
*Rear Passenger (Driver Side)* : Female, 21 yr, severe facial and head injuries; cranial vault was widely fractured, with gross pulping of the cerebral tissue. No other significant injury.
*Truck Driver* : mil, truck was parked overnight.

*(This case is fully detailed in the report "Car Crash Investigation: Engineering Report for the State Coroner, Report by George Rechnitzer, 4-7-90)"
DESIGN COMMENT

TRUCK DESIGN:
The rear under-run barrier of the truck, though at a suitable height, was poorly designed and constructed, offering only a low speed resistance to under-run. Calculations of the impact load capacity of the rear bumper system for offset impacts indicate a resistance of 25kN. This indicates a maximum impact speed of 20km/h for a 1100kg car. The height of the van's floor level is dictated by the chassis design and height of the cab, and this results typically in the stiff floor structure being above that of car bonnets (particularly if the car is braking or is loaded up). Though vans typically have aluminium (or steel) sheeting skirts down to match the rear bumper level, these are of low strength and provide no significant under-run protection for cars.

VEHICLE DESIGN:
It is unrealistic to design vehicle structures (the A pillars and roof) to withstand direct loading as arise in under-run crashes. Nevertheless the crash did highlight the light construction of the roof and A and B pillars of the car. In addition the cars chassis beams were unsymmetric, being shorter on the passenger side. The vehicle's performance in this crash suggests that it may not fare well in offset crashes, particularly on the passenger side.

ADR's:
There are no Australian Design Rules governing rear under-run barrier design for rigid trucks. (Nor are there any ADRs for offset frontal impact performance of cars)

POTENTIAL TRUCK & VEHICLE DESIGN COUNTERMEASURES

TRUCK:
Introduce ADR requirements specifying the performance requirements for rear under-run barriers on all goods vehicles of 3500kg GVM or greater, so as to prevent under-run penetration.

VEHICLE:
Introduce ADR specifying offset frontal impact performance standard.
PHOTO 3 (AIS) SIDE VIEW OF TRUCK, IMPACT SIDE. 
NOTE POSITION OF TRUCK PUSHED INTO TREE.

PHOTO 4 (AIS) REAR VIEW OF TRUCK SHOWING DAMAGE TO REAR CORNER 
WHERE THE CAR HIT THE TRUCK. NOTE DAMAGED REAR WHEELS

CASE FC/1202/90

(from "Car Crash Investigation: Engineering Report for the State Coroner, Report by George Rechnitzer, 4-7-90")
PHOTO 5 (AIS) FRONT VIEW OF CAR AT CRASH SCENE. NOTE EXTENT OF ROOF DAMAGE.

PHOTO 6 (AIS) PASSENGER SIDE VIEW OF CAR AT CRASH SCENE
PHOTO 34  DETAIL OF REAR TRUCK BARRIER SHOWING CHANNEL SECTION AND BRACING CONNECTIONS
(Refer to FIGURES 3&4 for layout of these members)

PHOTO 35  UNDERSIDE VIEW OF CHANNEL SECTION
FIGURE 1a
PRE-CRASH SHOWING
RELEATIVE DIMENSIONS FOR
TRUCK AND CAR

FIGURE 1b
INFERRED POSITION OF CAR
AT POINT OF MAXIMUM
DEFORMATION,
DURING THE CRASH
**Figure 2**

Plan on Truck and Car, showing relative position (inferred) prior to impact

*For Section S1 & S2 refer Figures 4a & 4b*
FIGURE 3a  PLAN VIEW OF REAR CHANNEL SECTION ON TRUCK SHOWING SUPPORT AND BRACING MEMBERS

* For Sections S1 & S2 refer to FIGURES 4a & 4b.

FIGURE 3b  REAR ELEVATION OF TRUCK SHOWING CHANNEL SECTION AND SUPPORT FRAMING
FIGURE 4a  SECTION S1  SHOWS MAIN CHASSIS BEAM AND DETAILS OF MAIN FRAMING MEMBERS

FIGURE 4b  SECTION S2  SHOWS BRACING AND HANGER DETAIL FOR CHANNEL SECTION
TRUCK RELATED CRASH STUDY
CASE SUMMARY (INJURY)

CASE IDENTIFIER : 14/10/90
DAY : Monday
MONTH : October
TIME : 1520hrs
WEATHER : dry
ROAD TYPE : Freeway
INTERSECTION TYPE : na
SPEED ZONE : 100 km/hr

VEHICLE DETAILS
TRUCK MODEL : International T2670 & trailer
TARE WEIGHT : 11 400kg
GROSS WEIGHT : 34 000kg
VEHICLE MODEL : XD Falcon
YEAR : 1981
MASS : 1380kg

CRASH DETAILS
Car was travelling along freeway, and the driver thought that the truck in front was moving as it did not show any stop lights or other lights. At the last moment driver realised truck was actually stationary, braked, but hit rear of truck at estimated impact speed = 38km/h (Crash 3 program).

TRUCK DAMAGE
The truck suffered very little damage, with the main impact force being on the rear of the chassis on the two spring hanger brackets. These are quite rigid sections and were undamaged.

SIGNIFICANT INJURIES
Driver : 24y, 95kg, male.
Fractured femur with bruising, lacerations near knee,
Front Passenger : 23y, 55kg, female
minor injuries: facial lacerations, and deep lacerations over r. tibia
Truck Driver : nil

CAUSE OF INJURY
Driver: Fractured femur due to leverage against steering wheel rim. Knee injuries due to impact with hand brake handle.
Front passenger: possible head impact with windscreen, and leg impact with glove box

VEHICLE DAMAGE
The impact was over the full width of the front of the car, with loading being above bumper level. Impact was equivalent to a "barrier" type, with no roof intrusion. The steering wheel was displaced downwards some 100mm, with the rim bent at the bottom. Parking brake handle and the glove box door were fractured. Though patient and ambulance statements indicate that seat belts were worn, belts showed little signs of loading.

DESIGN COMMENT
This type of trailer has no under-run guard fitted, and impact occurs with the wheels and suspension brackets of the truck. The tray overhang is less than 500mm out from the stiff rear spring hangers (height of 640mm) and with the distance to the face of the rear wheels being similar, the risk of under-run for offset or direct impact is minimized, except for high speed impacts.
DESIGN COMMENTS cont.

VEHICLE DESIGN:
The placement of the handbrake handle to be reviewed to avoid potential knee contact. Revue of steering system design to minimize chance of downward movement of steering wheel in certain types of impacts. Glovebox/dashboard to be made of yielding and not brittle materials.

ADR'S: *Trucks to be fitted with lights to indicate that they are stopped.*
(rather than only when the brakes are applied.)

---

POTENTIAL TRUCK & VEHICLE DESIGN COUNTERMEASURES

TRUCK:
The potential for under-run with this type of trailer is low, however vehicle occupant decelerations could be lowered by the fitting of an energy absorbing rear guard.

Though the truck did have the required conspicuity plates, the further avoidance of rear end collisions may be possible by trucks having to have their hazard lights flash when they are stopped, not only when braking.

VEHICLE: no comments.
CASE 14/10/96

PHOTO 1. Side view of truck and trailer.

PHOTO 2. Rear view of trailer. Note spring support brackets.

PHOTO 3. Side view of vehicle.

PHOTO 4. Interior of vehicle. Note missing wheel.

PHOTO 5. View of trailer relative to a car.

PHOTO 6. Front view of the car. Note holes in bonnet showing impact with trailer spring support brackets.
FIGURE 1a : CASE 14/10/90
REAR IMPACT : Car into Truck. Side elevation view showing car relative to truck.

FIGURE 1b
Side view showing impact deformation.
TRUCK RELATED CRASH STUDY
CASE SUMMARY (INJURY)

CASE IDENTIFIER : 17/10/90
DAY : Monday
MONTH : October
TIME : 12.30pm
WEATHER : -
ROAD TYPE : main road, suburban
INTERSECTION TYPE : na
SPEED ZONE : 60km/h

VEHICLE DETAILS
TRUCK MODEL : Mazda tray truck (1984)
TARE WEIGHT : -
GROSS WEIGHT : -
VEHICLE MODEL : Holden Camira
YEAR : 1989
MASS : 1056kg

CRASH DETAILS
The car was travelling behind the tray truck at about 40km/h. The truck stopped suddenly resulting in the car under-running the rear of the tray of the truck. Though this crash did not result in serious injury, it very clearly illustrates the potential and real hazard of rear under-run.

VEHICLE DAMAGE
The car suffered moderate damage as the impact speed was relatively low. The windscreen header was also dented, but intrusion into the passenger compartment was minor.

TRUCK DAMAGE
Refer to photos. Minor damage. (truck not inspected)

SIGNIFICANT INJURIES
Driver : Minor injuries, cut above eyebrow, not hospitalised (there were no other passengers).
Truck Driver : nil

CAUSE OF INJURY
not applicable

DESIGN COMMENT
This case clearly highlights the under-run potential with rigid tray trucks. In this case the low impact speed prevented significant intrusion into the car's passenger compartment, but the potential is well indicated.

VEHICLE DESIGN :
No comment, as vehicle design factors were not relevant.

ADR'S :
Currently there are no ADRs in place for under-run protection on rigid trucks.

POTENTIAL TRUCK & VEHICLE DESIGN COUNTERMEASURES
TRUCK : The need and benefits of properly designed rear under-run barriers is clearly identified for rigid tray trucks, not just for semi-trailers as is the current ADR requirement.

VEHICLE : nil
CASE 1 7/10/90

PHOTO 1. Side view of car and truck (at crash scene).
PHOTO 2. Detail of Photo 1, at crash scene.
PHOTO 3. View of car.
PHOTO 4. Front view of car, showing impact point above windshield from rear of truck.
PHOTO 5. Interior of car, with the only damage being to the windshield header.

(NB: Impact speed was less than 40 km/hr as both vehicles were travelling at about this speed prior to impact.)

(Photos 1 & 2 courtesy of Narrabeen Gazette)
**TRUCK RELATED CRASH STUDY**

**CASE SUMMARY (INJURY)**

<table>
<thead>
<tr>
<th>CASE IDENTIFIER</th>
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</tr>
</thead>
<tbody>
<tr>
<td>DAY</td>
<td>Monday</td>
</tr>
<tr>
<td>MONTH</td>
<td>December</td>
</tr>
<tr>
<td>TIME</td>
<td>1625hrs</td>
</tr>
<tr>
<td>WEATHER</td>
<td>?</td>
</tr>
<tr>
<td>ROAD TYPE</td>
<td>main road</td>
</tr>
<tr>
<td>INTERSECTION TYPE</td>
<td>na</td>
</tr>
<tr>
<td>SPEED ZONE</td>
<td>60 km/hr</td>
</tr>
</tbody>
</table>

**VEHICLE DETAILS**

<table>
<thead>
<tr>
<th>TRUCK MODEL</th>
<th>1981 Isuzu tilt tray</th>
</tr>
</thead>
<tbody>
<tr>
<td>TARE WEIGHT</td>
<td>6650kg</td>
</tr>
<tr>
<td>GROSS WEIGHT</td>
<td>12800kg</td>
</tr>
<tr>
<td>VEHICLE MODEL</td>
<td>Mitsubishi Magna GLX</td>
</tr>
<tr>
<td>YEAR</td>
<td>1989</td>
</tr>
<tr>
<td>MASS</td>
<td>1200kg</td>
</tr>
</tbody>
</table>

**CRASH DETAILS**

The tilt truck was stationary (in gear, driver's foot on brake, apparently) on the side of the highway, on a bend. The car went off the road pavement and collided with the rear of the truck. The impact was offset on the passenger side. It is not known why the car driver left the roadway at this point. Impact speed is estimated to be 45km/h (Crash 3 program). The truck was also towing a cherry picker.

**TRUCK DAMAGE**

The truck suffered little damage. The front passenger side of the car struck the spare wheel carrier and the side of the truck's towing frame. The roof of the car struck the end of the tilt tray, which was made of heavy steel framing.

**VEHICLE DAMAGE**

The impact was offset about 50% on the passenger side with the impact being taken partly by the front of the car, and by the roof structure. The under-run resulted in significant deformation and intrusion (app. 300mm) of the roof structure and passenger side A pillar.

**SIGNIFICANT INJURIES**

Driver: Female, 60y (est.) seat belt not worn (no signs of loading). Serious injuries, details not available
Front Passenger: Male, 64y, seat belt worn. Multiple serious injuries: head injuries, including skull fractures and facial lacerations, blunt impact to upper chest wall.
Truck Driver: Nil

**CAUSE OF INJURY**

Driver: Likely impact with steering wheel and windscreen. Head contact with intruded roof structure was possible, but driver's side did not under-ride the truck's tray.
Front passenger: Head injuries due to direct contact with intruded roof structure and/or steel sections of rear of tray. Blunt chest injury suggests direct contact with rear of truck tray.

**DESIGN COMMENT**

TRUCK DESIGN: This type of tray design presents a particularly hazardous under-run potential. With no under-ride barrier and the wheels set back some 2.5m, and the stiff tray structure being over 900mm above roadway, any rear end collisions would result in under-ride. The provision of tilt trays with under-run guards is more difficult because of their functional requirements. However, the hinged steel plates at the end of the tray could be designed to turn down instead of up and thereby act as under-run barriers.

ADR'S: Include vehicles of this type in proposed new ADR's for rear under-run barriers.
POTENTIAL TRUCK & VEHICLE DESIGN COUNTERMEASURES

TRUCK: Modify design of the rear of tilt tray so as to provide protection against under-run.
CAR: NIL

FIGURE 1a: CASE 11/12/90
REAR IMPACT: Car into Truck. Side elevation view showing car relative to truck.

FIGURE 1b
Side view showing under-ride.
CASE 111/12/90

PHOTO 1. Rear of tilt-tray (scale bar is in 100 mm).
PHOTO 2. Side view of tilt-tray.
PHOTO 3. Side view of damaged car showing roof and A-pillar deformation.
PHOTO 4. Interior of car showing dashboard intrusion.
PHOTO 6. Front view – note impact point on roof surface.
TRUCK RELATED CRASH STUDY
CASE SUMMARY (INJURY)

<table>
<thead>
<tr>
<th>CASE IDENTIFIER</th>
<th>117/2/91</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAY</td>
<td>Wednesday</td>
</tr>
<tr>
<td>MONTH</td>
<td>February</td>
</tr>
<tr>
<td>TIME</td>
<td>9:52am</td>
</tr>
<tr>
<td>WEATHER</td>
<td>Rural, major road</td>
</tr>
<tr>
<td>ROAD TYPE</td>
<td></td>
</tr>
<tr>
<td>INTERSECTION TYPE</td>
<td>n/a</td>
</tr>
<tr>
<td>SPEED ZONE</td>
<td>100 km/hr</td>
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</tbody>
</table>

VEHICLE DETAILS

<table>
<thead>
<tr>
<th>TRUCK MODEL</th>
<th>Volvo &amp;Freighter Tautliner semi-trailer</th>
</tr>
</thead>
<tbody>
<tr>
<td>TARE WEIGHT</td>
<td>14800kg</td>
</tr>
<tr>
<td>CROSS WEIGHT</td>
<td>38000kg</td>
</tr>
<tr>
<td>VEHICLE MODEL</td>
<td>Holden Nova</td>
</tr>
<tr>
<td>YEAR</td>
<td>12/1989</td>
</tr>
<tr>
<td>MASS</td>
<td>1040kg</td>
</tr>
</tbody>
</table>

CRASH DETAILS

The car was travelling behind the truck. The truck had to stop suddenly due to a car stopped and turning right in front of the truck. The car ran into the rear of the trailer, with the front of the car penetrating under the under-ride guard, up to its windscreen. The truck driver was unaware of the impact and started to drive away dragging the car behind it, as it was wedged under the rear under-ride guard. From calculations of the estimated load capacity of the rear under-ride bumper on the truck, the equivalent impact speed was estimated to be in the order of 30-40 km/h.

TRUCK DAMAGE

The only damage to the truck was the failure of the bottom vertical supports for the rear under-ride guard. This was a 120mm*60mm*5mm(?) box section which failed due to local buckling and bending. This allowed the car to under-ride the barrier.

VEHICLE DAMAGE

The damage to the car was limited to the front structure. The bonnet was crushed back and folded against the windscreen which though cracked remained intact. There was very little crush at bumper level, but above that the mudguards were crushed where the car wedged under the truck. There was some rearward displacement of the engine resulting in deformation of the firewall. There was no internal damage to the passenger compartment.

SIGNIFICANT INJURIES

Driver: (29y, female) fractured sternum
No passengers

CAUSE OF INJURY

Driver was wearing seat belt.
Injuries consistent with deceleration loading from seat belt.
**DESIGN COMMENT**

**TRUCK DESIGN**:
The significance of this crash was that it highlighted the load limitations and design inadequacies of common under-run barrier designs currently used on semi-trailers. The key points are:

- the 120*60RHS was used about its weak axis, with an equivalent load capacity in bending =68Kn
- this capacity was greatly reduced by the concentrated load from the 80*50 brace, which reacted on the unstiffened flange of the 120*60 box section. The induced local bending effectively reduced the capacity to the order of 18kn.
  (from 68kn)
- in contrast the 80*50mm brace has an axial capacity in excess of 200Kn.

The capacities are significantly lower than the EEC under-run regulations, refer "Calculations of Load Capacity", following.

**VEHICLE DESIGN**: No comments

**ADR's**:
The trailer's compliance plate only showed compliance with ADR 38, which relates to "trailer brake systems". In addition for this trailer compliance with ADR 42.6.1 is also required, but this was not stated on the plate. However, this rear bumper appeared to comply with ADR 42.6 "Rear bumper for Semi-trailers", in that it had a 110mm steel tube bumper which was supported by apparently substantial members. However ADR 42.6 is very ambiguous and non-specific in regard to the load carrying capacity of the supports to the tube. The failure of this bumper is a clear illustration of the inadequacy of this ADR, to provide a design resulting in protection against rear underrun.

**POTENTIAL TRUCK & VEHICLE DESIGN COUNTERMEASURES**

**TRUCK**:
With very few changes to the bumper design (with very little cost and weight change), the capacity could be increased by over 300-400%. By moving the brace down to the bottom of the 120*60 box section, and widening it to 120mm or by adding some small stiffeners the severe weakening of that section would be avoided, allowing it to maintain its full section capacity.

**VEHICLE**: nil.
CASE 17/291

PHOTO 1. Front view of car.
PHOTO 2. View of car, note crumpled windshield and lack of crush at bumper level.
PHOTO 3. View of damaged trailer rear guard
PHOTO 4. Detail of failure of 120 x 65 mm box section at connection & brace.
PHOTO 5. View of rear under-run bumper - undamaged.
PHOTO 6. View of front under-run support.
FIGURE 1a: CASE 17/02/91
REAR IMPACT: Car into Truck. Side elevation view showing car relative to truck.

FIGURE 1b
Side view showing under-ride. Note bend in under-ride guard.
TRUCK RELATED CRASH STUDY
CASE SUMMARY: 117/2/91

REAR UNDER-RUN BARRIER, CALCULATIONS OF LOAD CAPACITY

The following calculations are intended to provide an estimate of the load capacity of the rear under-run barrier for this semi-trailer. The actual section sizes were obtained from the manufacturer. Load tests had not been carried out on the design by the manufacturer.

SUMMARY OF RESULTS

The brace is made up of members with significantly different load capacities, resulting in a far from optimal structure. The following Table summarises the load capacities based on each failure mode. The resultant capacity is of course limited by the lowest failure mode (Cases 1B and 2). Also shown for comparison purposes are the loads specified in the EEC Regulation and loads proposed in the USA by Adiv &Erwin (UMTRI report, 1989).

<table>
<thead>
<tr>
<th>IMPACT TYPE</th>
<th>FAILURE MODE</th>
<th>LOAD CAPACITY (kN) (estimated)</th>
<th>EEC REGS. (kN)</th>
<th>USA (proposed) (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>impact taken at bottom of bumper, full width</td>
<td>1A. cantilever bending of vertical support (120RHS)</td>
<td>110</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>1B. local failure of support flange</td>
<td>16</td>
<td>(200)</td>
<td>(200)</td>
<td></td>
</tr>
<tr>
<td>3. axial capacity of brace</td>
<td>300</td>
<td>consistent with above</td>
<td>consistent with above</td>
<td></td>
</tr>
<tr>
<td>offset impact</td>
<td>2. cantilever bending of 114mm dia.* 4.5mm tube</td>
<td>18</td>
<td>(load applied 300mm from end)</td>
<td>25</td>
</tr>
</tbody>
</table>

CALCULATIONS:

Section Properties Sizes
- verticals 125*65*4mm RHS Yield \( \gamma = 350 \text{MPa} \) \( Z_y = 30.3 \text{E-6 m}^3 \)
- brace 75*50*3mm RHS \( \gamma = 350 \)
- bumper 114OD*4.5mm CHS \( \gamma = 200 \)
- total weight \( \approx 44 \text{kgs (nom.)} \)

I. LOAD CAPACITY OF THE VERTICAL SUPPORTS (126*65RHS)

This is dependent on the failure of the section in bending due to cantilever action, or local overstressing from the concentrated load from the brace.

Assumptions:
- load is horizontal
- load is applied on the tube but near the supports
- failure bending moment \( = M_f = 350 \text{E6*30.3E-6 = 11kNm} \)

TRUCK INVOLVED CRASH STUDY
55
1A. CANTILEVER ACTION:

Bending moment at B
\[ M = P \cdot L_3 \]
\[ P_{\text{max}} = M_{\text{max}} / L_3 = 11 / 0.2 \]
\[ P_{\text{max}} = 55 \text{KN per support} \]

1B. LOCAL BENDING AT B (REACTION FROM BRACE)

Because the bracing section is smaller than the member it supports the reaction is taken on the 4mm flange of the 125RHS, which must then transfer this loading in bending to the webs.

Assumptions:
- effective width of the 4mm flange = 100mm
- section modulus = \( fd^2 / 6 \) = 0.1 * 0.004^2 / 6
- failure moment \( M_{\text{max}} = 350 \times 6 \times 2.66 \times 10^7 = 93 \text{Nm} \)

For a box section with two point loads (w), a good estimate of the bending moments at the corners is:
\[ M_1 = 0.015w, \]
(\( a = 24.5 \text{mm}; b = 96.5 \text{mm}; l = 121 \text{mm} \))
\[ w = M_{\text{max}} / 0.015 = 93 / 0.015 \]
\[ w = 6.2 \text{KN} \]

Maximum reaction per support \( \approx 2w = 13 \text{KN} \) (estimated)
(This is the reaction at the brace (B), the equivalent load applied at the lower level (A) is even less)

Equivalent load capacity at A (per support):
For moment equilibrium:
\[ P_a = R \cdot b / 2 / L_1 \]
\[ P_a = 13 \text{KN} \times 350 / 550 \]
\[ P_a = 8.27 \text{KN} \]

2. CANTILEVER BENDING CAPACITY OF THE 114 OD TUBE

This determines the load that can be taken in offset collisions.
Assumptions:
- the maximum bending resistance of the tube
  \( = 200 \times 6 \times 41.6 \times 6 = 8.2 \text{KNm} \)
- the load is taken 300mm in from the edge, leaving a lever arm = 440mm
\[ M = p \times 0.440 \]
\[ P_{\text{max}} = 8.2/0.447 \]
\[ P_{\text{max}} = 18 \text{kN} \]

4. AXIAL COMPRESSION CAPACITY OF THE BRACE

The brace acts as a compression strut, with an effective length of less than 500 mm.

Axial capacity = \( \geq 150 \text{kN} \) (from the AISC Safe Load table)
APPENDIX 2

ADR 42.6 REAR BUMPER FOR SEMI-TRAILERS
42.5.2 Standard Controls for Automatic Transmission

All motor vehicles, except L-group category vehicles, equipped with an automatic transmission shall comply with the following requirements:

42.5.2.1 Lever position

The transmission control lever positions shall be permanently displayed within the driver's compartment of the vehicle.

42.5.2.2 Lever sequence

The sequence of transmission control lever positions shall:

42.5.2.2.1 include a neutral position located between the reverse drive and forward drive positions; and

42.5.2.2.2 in cases where a park position is included such park position shall be located at the end of the sequence, adjacent to the reverse drive position.

42.5.2.3 'Steering Column' mounted transmission control levers (MA vehicles only)

The movement of the control lever from neutral to reverse shall be clockwise except that in case where all control lever positions are to the right of the vertical longitudinal plane through the centre of the steering wheel, the movement of the control lever from neutral to reverse shall be anti-clockwise. A device shall be provided which indicates the transmission position selected. The movement of the indicator shall be generally in the same linear or rotational direction as the movement of the transmission control lever.

42.5.2.4 Transmission control levers mounted other than on the 'Steering Columns' (MA vehicles only)

All control lever positions shall be to the left of the vertical longitudinal plane through the centre of the steering wheel and movement of the control lever from neutral to reverse shall be generally upwards, forward, or to the left according to whether the control lever is constrained to move generally in a vertical, longitudinal or transverse direction.

42.5.2.5 Starter interlock

The engine starter shall be inoperative when the transmission control lever is in any forward or reverse drive position.

42.6 REAR BUMPER FOR 'SEMI-TRAILERS'

42.6.1 Every 'Semi-trailer' shall be provided with a continuous rear bumper which shall be so constructed and located that:

42.6.1.1 with the vehicle unladen, the contact surface of the bumper is not more than 600 mm from the ground;

42.6.1.2 the bumper contact surface is located not more than 600 mm forward of the rear of the vehicle and is painted white;

42.6.1.3 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 shall be considered as meeting the requirements over their width;

42.6.1.4 the member which is, or directly supports, the bumper contact surface is of material having no less strength than steel tubing of 103 mm outside diameter and 8 mm wall thickness; and

42.6.1.5 the structure supporting the member referred to in Clause 42.6.1.4 can transmit no less force than that member can sustain, and provides a continuous force path to vehicle members of a strength consistent with the forces to be sustained.

42.6.2 This Clause shall not apply to 'Semi-trailers' so constructed that:

42.6.2.1 cargo access doors, tailgates or other such structures when closed afford comparable protection; and

42.6.2.2 a vertical plane tangential to the rearmost surface of the rear tyres is 1,555 mm or less from a parallel vertical plane containing the 'rear end' of the 'Semi-trailer'.

42.7 ELECTRICAL WIRING, CONNECTIONS & INSTALLATIONS

42.7.1 The wiring of electrical equipment other than the high tension ignition wiring shall:

42.7.1.1 be supported at intervals of not more than 600 mm, except that this requirement shall not apply in the case of any 'Pole-type Trailer' which is so constructed that the length of the pole forward of the trailer frame can be adjusted;

42.7.1.2 be insulated at joints;

42.7.1.3 be located in such a position that it cannot become overheated, cannot contact moving parts, nor constitute a fire hazard owing to its proximity to the fuel system; and

42.7.1.4 be protected from chafing. The edge of all holes in metal through which the wiring passes shall be rolled or bushed with a grommet of rubber or other equivalent insulating material.

42.7.2 Electrical Connections

42.7.2.1 The electrical connectors between motor vehicles and trailers, for the purpose of operating the prescribed vehicle lighting and signalling shall comply with Australian Standard 2513-1982, "Electrical Connections for Trailer Vehicles".

42.7.2.2 Every trailer shall be equipped with an electrical conductor independent of the trailer...
APPENDIX 3

SWEDISH UNDER-RUN PROTECTION REGULATIONS (1981)
VEHICLE SECTION 01 UNDERRIDE PROTECTION

TSVFS 1981:3 CONTROL NO. 3

Note:
Regulations are indicated with an asterisk (*) to the left of the text. General recommendations do not have such markings.
REGULATIONS CONCERNING SPECIAL UNDERRIDE PROTECTION

Basic Regulations in the Vehicle Announcement (1972:595)

- Section 11
  A car must have the following equipment.
  - Equipment
    Further details

- Underride Protection
  In the event of another vehicle colliding with the car from behind, this protection must as far as possible prevent the colliding vehicle from getting in under any part protruding from the car. Only needed on a truck/lorry with a total weight exceeding 3.5 t. Not required on a truck/lorry having a device for towing a trailer or where the protection may cause considerable inconvenience because of the design or purpose of the vehicle.

- Section 22
  A trailer towed by a car must have the following equipment.
  - Equipment
    Further details.

- Underride Protection
  In the event of another vehicle colliding with the trailer from behind, this protection must as far as possible prevent the colliding vehicle from getting in under any part protruding from the trailer. Is not required on a trailer having a total weight which does not exceed 3.5 t, or on a trailer where the protection would cause considerable inconvenience due to the design or purpose of the trailer.
Basic Regulations in the Announcement (1972:605) about the

Introduction of New Road Traffic Legislation

Section 47

11. The regulations in Sections 11 and 22 of the Vehicle Announcement (1972:595) about underride protection apply in the question of a truck/lorry, which is described as model 1972 or earlier at the registration or type survey, or with regard to a trailer which has been presented for registration survey before January 1, 1973, or in respect of which a type certificate has been issued before that date, as from the time and to the extent decided by the National Road Safety Board.

If there are very good reasons to do so, the National Road Safety Board may make exceptions from the regulations mentioned in the first paragraph regarding certain types of vehicles.

The Regulations Laid Down by the National Road Safety Board

By virtue of Sections 102 and 104 of the Vehicle Announcement (1972:595) and Section 47, 11th Announcement (1972:605) regarding the introduction of a new Road Traffic Legislation, the National Road Safety lays down the following.

1. Requirements

1.1. The underride protection must be of a design which has been tested according to the regulations in Paragraph 2. The underride protection must be so made that the requirements in Paragraphs 1.1.1. or 1.1.2. are met when the protection is tested.

1.1.1. If the underride protection is positioned in front of the rearmost limitation of the vehicle, the protection must not be deformed so that the centre of the point of attack of the test force is more than 400 mm in front of the plane of limitation.
1.1.2. If the underride protection constitutes the rearmost limitation of the vehicle, the protection must not be deformed so that the centre of the point of attack of the test force is moved more than 400 mm from the original position.

1.2. The underride protection must stretch so far out to the sides that the distance from the outermost part of the protection to the outermost plane of limitation does not exceed 200 mm and is not less than 100 mm.

1.3. The underride protection must have such a position heightwise that the distance from the lower limitation of the protection down to the ground when the vehicle is unladen does not exceed 550 mm. Regarding trucks/lorries with a supporting axle which can be lifted up, the distance may, however, when the vehicle is unladen and the axle is lifted up, be maximum 650 mm.

1.4. The underride protection may have an opening if this is necessary because of certain equipment, for example, a connecting device fitted to the vehicle. However, the width of such an opening must be maximum 600 mm.

1.5. The transverse beam of the underride protection must have a vertical cross-section with a height of at least 100 mm.

2. Testing

2.1. When testing an underride protection the protection must be fixed in the way it is to be fixed onto the vehicle. If the underride protection is fitted to the vehicle, then this must be firmly anchored to the ground.

2.2. A static loading test to be carried out according to Paragraphs 2.3. and 2.4. The forces must be directed parallel to the longitudinal axis of the vehicle and must be transferred to the underride protection with plates hinged in all directions of size 300 x 100 mm.

The lower longitudinal side of the plates must, if possible, be at the same level as the lower limitation of the transverse beam of the underride protection. However, if the beam has a cylindrical surface and a horizontal centre line, the plates must be so positioned that the point of attack of the forces pass through the centre line.

2.3. Two forces, each one corresponding to half the total weight of the vehicle, however, maximum 100 000 N (10 200 kp) are applied symmetrically to the transverse beam of the underride protection with a mutual distance between them of at least 700 mm and maximum 1 000 mm, measured between the centre points of the plates given in Paragraph 2.2. The forces need not be applied simultaneously.
2.4. A force corresponding to 1/8 of the total weight of the vehicle, however, maximum 25 000 N (2 550 kp) is applied to the transverse beam of the underride protection on that part evaluated to be the weakest, however, at least 300 mm inside the outer plane of limitation of the vehicle.

3. Exceptions

3.1. Underride protection is not necessary on a truck/lorry of model 1972 or earlier, nor on a trailer which has been surveyed for registration before January 1, 1973 or in respect of which a type certificate was issued before that date.

3.2. Underride protection is not required on

- vehicles designed with a great height above the ground, mainly intended to be used in the terrain.
- truck/lorry used by national or municipal fire brigades for salvaging operations.
- truck/lorry chassis in transit from the manufacturer or retailer to the body building firm.
- vehicles specially fitted out for rescuing and towing damaged vehicles and having a fixed suspension device.

3.3. Underride protection is not needed on a vehicle having a body, chassis or some other permanent part with such an external shape that this on the whole corresponds to a separate underride protection.

3.4. Irrespective of Paragraph 1.2. any vehicle described as model 1982 or earlier at the registration or type survey and having a width greater than 250 cm, must have an underride protection as stipulated for vehicles with a width of maximum 250 cm.

3.5. Irrespective of Paragraph 1.2. a vehicle with a loading crane fitted at the rear or having equipment for such a crane which can be removed, must have an underride protection, the outermost part of which is more than 200 mm from the outermost line of limitation of the vehicle if the protection is at least 1 800 mm wide. If a crane is fitted, the measurement of 400 mm according to Paragraphs 1.1.1. or 1.1.2. may be exceeded if the protection is positioned as far to the rear of the vehicle as technically possible.
3.6. A vehicle with tipper towards the rear, a loose loading platform or with arrangements for a snow plough, road surfacing machine, or a gritting device, may, irrespective of the fact that the measurement 400 mm in Paragraphs 1.1.1. or 1.1.2., is exceeded, be approved if the underride protection consists of an approved pulling bar or similar device underneath. However, the measurement must not be exceeded by more than is necessary.

3.7. Other questions regarding exemptions from these regulations for certain vehicles, certain types of vehicles or certain groups of vehicles will be considered by the National Road Safety Board on application.

4. Checking that Requirements are Met

The person presenting the vehicle at a type or registration survey must present a certificate from the vehicle manufacturer, the manufacturer of the underride protection or a testing institute to the effect that the underride protection fitted to the vehicle meets the requirements laid down in these regulations.

These Regulations come into effect on March 1, 1981, and the Regulations regarding frames or supporting parts of car bodies (Sheet 01-01-01-01, 01-01-01-02, 01-02-01-01, 01-02-02-01 and 01-05-02-01 of Vehicle Regulations) and Regulations about underride protection (F 31-1972) shall cease to be valid.