

Federal Office of Road Safety

**Review of Occupant Protection in
Light Commercial, Off-road and
Forward Control Passenger Vehicles**

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Federal Office of Road Safety

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Abstract

In 1992 a review of the level of occupant protection provided by light commercial and off-road passenger vehicles was commissioned by the Federal Office of Road Safety. This report provides the outcome of that review in general and specifically covers the FORS crash test program which was conducted as part of the standards development program to improve occupant protection provided by off-road passenger vehicles and light commercials. The test program provides a general indication of the safety performance of these vehicles and in summary, supports the application of ADR 69/00 Full Frontal Occupant Protection to Off-road Passenger Vehicles and Light Goods Vehicles which would result in an improvement in the occupant protection levels. This would also shift the focus towards performance based testing of the vehicle occupant protection package as a whole and provide a level of occupant protection equal to that of passenger cars.

Keywords

Occupant protection, crash test, ADR, road safety, 4WD, light commercial, forward control passenger vehicles

Notes

- (1) FORS research reports are disseminated in the interests of information exchange.
- (2) The views expressed are those of the author and do not necessarily represent those of the Commonwealth Government

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Introduction

In 1989, the Federal Office of Road Safety (FORS) commissioned a major study to determine the performance of the Australian Design Rules (ADRs) through examination of real life cases and to recommend the improvements that could be made.

The study was carried out by the Monash University Accident Research Centre (MUARC) as part of a review of passenger car occupant protection and showed that despite the improvements in vehicle safety, occupants were still being injured by contact with parts of the passenger compartment.

The outcome of the review was the introduction of ADR 69/00 for full frontal occupant protection. This will see the fitment of airbags in most passenger cars when the Design Rule is introduced during 1995.

Off-road passenger vehicles and light commercial vehicles are becoming an increasing proportion of the Australian passenger vehicle fleet.

Consequently, a review of the level of occupant protection provided by these vehicles was commenced in 1992. As part of the review, a further study was commissioned with MUARC to examine the occurrence of injuries to occupants of these vehicles.

In parallel, a review group was set up with industry to explore ways to improve the level of occupant protection provided by these vehicles. This included a regulatory impact statement on the costs and benefits of new ADR requirements.

This report provides the outcome of this review in general and specifically covers the FORS crash test program which was conducted as part of the standards development program to improve occupant protection provided by off-road passenger vehicles and light commercials.

Crashed Vehicle Study

The objectives of this study were to examine the extent and patterns of injuries occurring to occupants of off-road passenger vehicles and light commercials and ways to address this trauma.

Examination of the mass database indicated that frontal impacts comprised the majority (55%) of crash types and were similar to earlier findings of 60% for passenger cars.

However, rollovers were strongly over-represented in the crashed vehicle file by comparison with passenger car crashes (under 10%), with 44% of 4WD crashes and a further 27% of utility crashes involving rollovers. Although overseas reports have previously found forward control vans to have a propensity for rollover, this was not supported in the data examined in this study. Since the 4WD models sold in Australia already comply with the only rollover standard available, US Federal Motor Vehicle

Safety Standard 216, research into the behavioural aspects of drivers of these vehicles may provide an insight into the issue of rollover.

The majority of contacts causing injury were with the instrument panel, seatbelts and steering wheel. These components were also the most common contact sources reported for frontal crashes among passenger cars. Consequently, the suggested countermeasures coming out of this study are those suggested from the previous study for passenger cars.

Occupant Protection Review

The outcome of the review was to introduce improved occupant protection requirements by way of new or amended ADRs in three phases.

The first phase was aimed at bringing 4WD and light commercial vehicles up to the same level of occupant protection provided by passenger cars. The ADRs involved in the first phase were promulgated at the end of 1994 and will be introduced progressively from 1996. These requirements include improvements to seatbelts, head restraints, side door strength and the introduction of Centre High Mounted Stop Lamps to some of these vehicles. A regulatory impact statement showed that the proposed requirements were cost beneficial.

The second phase will introduce the performance based requirements of ADR 69/00 for these vehicle categories.

The third phase will introduce further performance based ADRs for offset frontal and dynamic side impact crash protection when these standards are finalised overseas.

Crash Test Program

The extent and pattern of four-wheel-drive and light commercial vehicle occupant injuries occurring in actual road crashes was the focus to the MUARC study.

To assess the level of occupant protection offered by light commercial and off-road passenger vehicles, it was decided to conduct a series of barrier crash tests on a range of these vehicles.

The vehicles selected were representative of popular vehicles in these categories. All were purchased through the Federal Government's fleet vehicle supplier in order to ensure the supply of representative examples.

The crash test program was conducted to the procedures specified in ADR 69/00 Full Frontal Occupant Protection. Test impact velocity was nominally 48 km/h and the approach was perpendicular to the barrier face.

The injury levels were measured by using calibrated 'Hybrid III' test dummies positioned in the front outboard seating positions and restrained by the vehicle's lap/sash seatbelts.

The following primary injury criteria were measured:

Head Injury Criteria (HIC)

Chest deceleration

Chest deflection at the sternum

Axial Femur Loading

In addition, lower leg injury data and neck force/moment data was also measured while lower leg kinematics were recorded on high speed film.

All tests were conducted under the supervision of FORS engineers at the facilities of New South Wales Roads and Traffic Authority's Crashlab. The facility was awarded the test contract through its successful bid at tender.

Outcome of FORS Crash Test Program

The vehicle models tested in the program were built to comply with the current Australian Design Rules for vehicle safety which offer comparable levels of safety to the requirements in force in Europe and Japan.

As expected, the data from the series of tests varied significantly due to the complex nature of this form of testing and the differing configuration of each vehicle. Variations in HIC and femur loading were most pronounced.

It is important to bear in mind that due to this test to test variation, the results of a single test do not form the basis for drawing a sustainable comparison of the safety performance of each vehicle.

The data indicated that while the majority of the injury criteria recorded were at reasonable levels, there is still a degree of development work required by manufacturers to ensure that all series production vehicles comply with the requirements of ADR 69/00.

In summary, this crash test program supports the application of ADR 69/00 Full Frontal Occupant Protection to Off-road Passenger Vehicles and Light Goods Vehicles which would result in an improvement in the occupant protection levels. This would also shift the focus towards performance based testing of the vehicle occupant protection package as a whole and provide a level of occupant protection equal to that of passenger cars.

1. CRASHED VEHICLE STUDY

1.1. Introduction

Four Wheel Drive (4WDs) and light commercial vehicles (including forward control vans) have become increasingly popular as many people choose to drive these vehicles as an alternative to passenger cars. In 1992, for instance, sales involving these vehicles represented 28 percent of those of passenger cars compared with 26 per cent for 1991.

While a number of current Australian Design Rules apply to these vehicles (such as ADR 10/01 for steering column intrusion), these vehicles are not classified as "passenger cars or derivatives" and hence are not subject to the full range of design rules that currently apply to passenger cars in this country.

1.2. Objectives

The objectives of this study were to examine the extent and patterns of injuries occurring to occupants of these vehicles and ways to address this road trauma by way of more stringent regulations.

Three tasks were undertaken to meet these aims. Firstly, a review of main stream occupant protection literature was conducted to highlight previous published findings in this area.

Secondly, an analysis of 6 years of New South Wales tow-away casualty data and 2 years fatality data on the Federal fatal file was then carried out to examine the extent of the problem and patterns of injuries sustained by seriously injured occupants of passenger cars, four-wheel-drives, vans and light trucks or utilities.

Finally, a thorough examination of 140 vehicles which had been written-off as a result of a road crash with another vehicle or a fixed object was undertaken to provide a more detailed picture of the extent of damage, the injuries sustained by the occupants and the sources of these injuries from within or outside the vehicle.

1.3. Crash data

For the 6 years of casualty crashes examined in New South Wales between 1987 and 1992, vans, 4WDs and utilities accounted for roughly 10 per cent of road trauma to vehicle occupants. Furthermore, they were over-represented in both fatal and serious injury crashes on rural roads and in single-vehicle collisions.

4WDs were over-involved in roll-over crashes compared to all other vehicle types and their occupants sustained more serious injuries as a result of these crashes. Drivers of 4WDs involved in casualty or fatal crashes were more likely to be male and aged between 26 and 55 years.

Passenger vans were over-involved in fatal outcomes in head-on crashes at lower speeds and their occupants were more likely to be trapped in the vehicle in these crashes. This is probably because of the more limited crumple space available in these vehicles, thus

making their occupants more vulnerable to severe injury and entrapment in head-on crashes.

1.4. Injury Patterns

The proportion of fatalities for all casualty crashes in NSW between 1987 and 1992 was greatest for occupants of passenger cars, compared with the other vehicle types. Front seat occupants in 4WDs, however, also had exceptionally high fatality rates. Overall, 4WD occupants were more likely to have been uninjured than those from cars, vans and utilities.

Head and head-chest injuries were the most common cause of death for vehicle occupants killed on the fatal file. These injuries were particularly over-represented among passenger car fatalities (42%) and slightly under-represented among 4WD fatalities (38%). This latter group were a little more likely to have sustained a severe spine injury.

Head (and head-chest) injuries were the most common cause of death for all killed vehicle occupants in the fatal file. They were particularly over-represented among killed passenger car occupants and slightly under-represented among 4WD fatalities.

In frontal crashes, a fatal chest injury was particularly under-represented among 4WD occupants. However, these occupants were slightly more likely to have sustained a severe spinal injury or other severe injury. Many van occupants sustained severe external injuries which warrants closer examination.

Occupants killed in a 4WD in frontal crashes were more likely to have sustained a severe chest or spinal injury compared to other vehicle's occupants. Moreover, they were twice as likely to have been ejected and less likely to have been entrapped. While this might suggest that these occupants have lower seatbelt wearing rates, it could also indicate that these vehicles provide less ride-down in a crash.

1.5. Injuries and their Sources

The data collected on the source of injury to occupants of 4WDs, vans and utilities was a little sparse because of the minimal number of cases and the low levels of injuries observed as a result of the entrance criteria adopted for the crashed vehicle study. The lack of major injuries in particular was problematic for this study. Nevertheless, some interesting trends were apparent in these data.

Upper limb injury was most common among these relatively minor injured occupants and for front seat occupants, often caused from contact with the steering wheel, instrument panel and side structures, and the seatbelt. Most of the head and chest injuries observed here were relatively minor, caused by contact with the steering wheel or instrument panel, the roof, or from exterior contacts.

Injuries to the thigh, knee and lower leg were also quite frequent and usually the result of instrument panel or floor contacts. Non-severe neck injuries such as whiplash were also quite common.

It was not possible to draw any reliable conclusions regarding injuries and source of injury for rear seat passengers and those unrestrained because these numbers were too small.

1.6. Potential Countermeasures

While the findings are not particularly robust, there were some suggestions of suitable countermeasures to reduce these injuries. Many of these measures have already been suggested from a previous study (CR 95) for passenger cars.

1.6.1. Steering Assembly

The steering wheel and assembly has been shown to inflict injury to drivers of these special purpose vehicles. This is in spite of the fact that most of them (up to 98%) were properly restrained. Steering wheel related countermeasures worthy of consideration include supplementary air bags, belt pretensioners and webbing clamps, padded steering wheels, or no steering wheel at all.

1.6.2. Improved Restraint Systems

The need for improvements to existing seatbelt systems was noted in CR 95 for passenger cars and again highlighted in the injury and contact source findings here. Possible improvements to existing seatbelt systems are better seatbelt geometry, belt pretensioners and webbing clamps, improved front seat design, better positioning of seatbelt stalks, seatbelt interlocks, as well as other incidental belt improvements.

1.6.3. The Instrument Panel

The instrument panel assembly was a well documented problem area for front seat occupants of current generation passenger cars and in this study, too. There are several possible countermeasures currently available to minimise or alleviate these injuries, such as the use of knee bolsters, improved padding, reduced protrusions, and the use of less injurious instrument panel materials.

1.7. The Need for Vehicle Regulations

Special purpose vehicles such as 4WDs, Vans and Utilities are not currently subject to the full set of Australian Design Rules that apply for passenger cars and their derivatives. In particular, the only frontal crash requirement is for these vehicles to comply with ADR 10/01 which specifies maximum steering column intrusion levels. Moreover, there is no current roll-over requirement such as a roof strength test for any passenger vehicle sold in Australia.

Given the increasing use of these vehicles for private use as an alternative to passenger cars, it could be argued that they should also be expected to provide similar levels of occupant protection as passenger cars. Thus, a strong case could be mounted for all these special purpose vehicle types (4WDs, Utilities, and light commercial vans) to be similarly regulated.

In particular, they should at least be required to meet the new dynamic frontal crash performance requirement ADR 69 as well as side impact regulations, either current or proposed for the future.

Given the preponderance of roll-overs among 4WD vehicles, the study suggested that it would seem worthwhile for these vehicles in particular to have to meet a roof strength requirement. This issue was canvassed during the review of four wheel drive and light commercial vehicle occupant protection, by way of an industry survey which indicated that 98% of the four wheel drive models sold in Australia already complied with the US rollover requirement FMVSS 216. FORS will be monitoring research being carried out in the US for a dynamic rollover requirement. In addition, research on behavioural aspects of drivers of these vehicles may provide an insight into their over-involvement in roll-over crashes.

1.8. Further Research and Development

This study has highlighted a number of areas requiring further research. Most notably, these findings would be more robust if more data was available on those seriously injured in crashes involving these vehicles. In addition, the cost-effectiveness of many of these measures needs to be established for these vehicles.

The full report of this study is available from FORS Report CR150 - Vehicle Occupant Protection - Four Wheel Drives, Utilities and Vans.

2. FOUR WHEEL DRIVE AND LIGHT COMMERCIAL VEHICLE OCCUPANT PROTECTION REVIEW

2.1. Background

One of the first issues raised by the National Road Trauma Advisory Council following its formation was that of the level of occupant protection provided by four wheel drive (4WD) and light commercial vehicles.

This issue was forwarded to the Federal Office of Road Safety for consideration. FORS formed a small review group in 1993 with members from the Federal Chamber of Automotive Industries (FCAI) to consider the matter.

The review group set out to bring in occupant protection improvements in three phases. The first stage was to apply those ADRs (where applicable) to bring these vehicles up to the same level as passenger cars. The second stage was to require these vehicles to meet the injury criteria set out in ADR 69/00 for full frontal impact protection. The third phase was to include performance based dynamic side impact and offset frontal impact protection after they had been finalised in the international arena (with suitable lead time).

Preliminary results from the MUARC crashed vehicle study were used to focus on particular issues during the review.

2.2. Summary of Review Outcome

Following the last meeting in July 1994, there was an agreed position reached for the introduction of the first phase of improvements which are summarised in Table 2.1.

Initial agreement was also reached at this meeting on the implementation of the second phase as detailed in Table 2.2. However, industry indicated it had difficulty in meeting these implementation dates for a small number of models and negotiations are continuing.

The crashed vehicle study indicated that 4WDs were over-represented in rollover accidents. This prompted an industry survey which indicated that 98% of the four wheel drive models sold in Australia already complied with the US rollover requirement FMVSS 216. FORS will be monitoring research being carried out in the US for a dynamic rollover requirement.

2.3. Timing

There has been a similar push to improve the occupant protection in these vehicle categories in Japan. Depending on the vehicle type and ADR, some of the proposed new requirements will be introduced either a short time before or a short time after the same regulation is mandated in Japan.

In a number of cases, Japanese manufacturers have voluntarily fitted design improvements to vehicles manufactured for their domestic market. In these cases,

manufacturers have agreed to minimum lead times sufficient to schedule testing and submit test evidence of compliance to the appropriate ADRs.

To achieve these minimum lead times, the agreed position was predicated on having the ADRs gazetted as national standards by the end of 1994. This timing was critical because manufacturers had to schedule certification testing and design change developments for the various ADRs involved. Failure to achieve this time frame would have meant an increase in lead times.

Parliamentary Secretary Neil O'Keefe wrote to his State and Territory colleagues to seek their support for these important initiatives in parallel with the public comment process. They too agreed to 'fast track' the proposed changes.

Industry agreed to a 60 day comment period instead of the usual 90 days.

The package of proposed ADR amendments were sent out for public comment at the end of August 1994 together with a preliminary Regulatory Impact Statement (RIS).

At the Transport Agency Chief Executives meeting in August 1994, members agreed to examine this issue out of session, in parallel with the public comment period, in order to achieve the minimum lead times agreed with industry.

The final Regulatory Impact Statement for the first phase of changes is at Appendix 1.

The ADRs involved in the first phase of improvements were determined as national standards in December 1994 and will begin to come into force during 1996 for these vehicle categories.

TABLE 2.1 - TIMETABLE FOR PHASE 1 IMPROVEMENTS

ADR	MB CATEGORY (Forward Control Pass. Vehicles)	MC CATEGORY (4WD vehicles)	NA CATEGORY (Light Commercials)
4/01 Seatbelts (retractor seatbelts in 2nd row seats)	Already applies	Adopt 1/7/96	Adopt 1/7/96
5/02 Seatbelt Anchorages (for retractor seatbelts in 2nd row seats)	Already applies	Adopt 1/7/96	Adopt 1/7/96
10/01 Steering Column Intrusion	Already applies	Defer to ADR 69/00 in Phase 2	Defer to ADR 69/00 in Phase 2
21/00 Instrument Panel Padding	Defer to ADR 69/00 in Phase 2	Defer to ADR 69/00 in Phase 2	Defer to ADR 69/00 in Phase 2
22/00 Head Restraints	Applies	Applies	Adopt 1/7/96
29/00 Side Door Strength	Adopt 1/7/96 subject to FCAI survey on seating reference height	Adopt 1/7/97 subject to FCAI survey on seating reference height	Examine applicability to single cab utilities and defer remainder to Phase 3
60/00 Centre High Mounted Stop Lamp	Adopt 1/7/96	Adopt 1/7/96	Not Applicable

TABLE 2.2 - TIMETABLE FOR PHASE 2 IMPROVEMENTS

ADR	MB CATEGORY (Forward Control Pass. Vehicles)	MC CATEGORY (4WD vehicles)	NA CATEGORY (Light Commercials)⁽³⁾
69/00 Full Frontal Impact Occupant Protection NEW MODELS	1/7/97	1/7/97	1/7/97 ⁽¹⁾ 1/7/98 ⁽²⁾
69/00 Full Frontal Impact Occupant Protection ALL MODELS	1/7/98	1/7/98	1/7/98 ⁽¹⁾ 1/7/99 ⁽²⁾

(1) Except Forward Control Vans

(2) Forward Control Vans

(3) NA 1 Category only (vehicles up to 2.7 tonnes GVM)

3.**CRASH TEST PROGRAM****3.1. Aim**

This crash test program was carried out to evaluate the extension of Australian Design Rule 69/00 Full Frontal Occupant Protection to Forward Control passenger vehicles, Off-road passenger vehicles and Light Goods vehicles.

3.2. Background

In the mid 1980s a study was carried out to assess the safety of Forward Control Passenger Vehicles (FCPVs) by conducting a series of 9 frontal barrier crash tests on existing vehicle designs. As a result of this study a number of ADRs, which at that time applied only to passenger cars, were extended to FCPVs. Included among these design rules was ADR 10 Steering Columns which tests certain occupant protection features in the frontal barrier crash test.

Also as a result of the test program, other occupant protection features were introduced or enhanced to bring the level of protection offered by FCPVs into line with that of passenger cars. The list of features included seat strength, seatbelts, seatbelt anchorages, child restraint anchorages and head restraints. The introduction of those requirements placed Australia in the forefront of safety requirements for FCPVs in the world.

More recently, the Federal Office of Road Safety completed a review of passenger car occupant protection. One component of which involved the crash testing of a number of passenger cars marketed in Australia. The aim of the FORS crash test program at that time was to provide test data for use in comparison to documented occupant injuries and their cause while evaluating means by which to improve occupant protection in passenger cars.

An outcome of this review was the introduction of Australian Design Rule 69/00 - Full Frontal Occupant Protection. This design rule is a performance based standard which sets injury parameters measured by instrumented dummies in a barrier crash test.

Currently the legislation of ADR 69/00 mandates minimum occupant protection levels in passenger cars manufactured from 1 July 1995. The rule does not apply to other non-passenger car vehicles commonly used for personal transport.

Lately a number of alternative passenger vehicles which are categorised as Off-road Passenger Vehicles and Light Goods Vehicles have risen in popularity. Such vehicles commonly spend most of their time operating in conditions similar to passenger cars, with many models providing comfort levels commensurate with passenger cars.

Using the same methodology as the review of passenger car occupant protection, a review of off-road passenger vehicles, light goods and forward control passenger vehicles was commenced in 1992. The third stage of the review included a series of crash tests of selected models under controlled conditions to compare the crash test outcome for the occupants of these vehicles with the documented occupant injuries in the crashed vehicle study.

For these vehicles, crash testing required by the Australian Design Rules, and the regulations enforced in other countries except the USA, assesses rearward displacement of the steering column. In order to shift the focus from component based testing to assessment of the total occupant protection package performance, the series of tests conducted in this program examined the likelihood of injury to occupants using instrumented test dummies. Using the requirements of ADR 69/00, six vehicles were tested, three off-road passenger vehicles and three light commercial utility vehicles.

3.3. Test Procedure

3.3.1. Introduction

All tests in this program were conducted at the New South Wales Roads Traffic Authority Crashlab and were carried out in accordance with the test procedure specified in Australian Design Rule 69/00 Full Frontal Impact Occupant Protection (ADR 69/00). However, as ADR 69/00 is applicable only to passenger cars, the test mass used for the four-wheel-drive (off road) and light commercial vehicles was as specified by the United States Federal Motor Vehicle Safety Standard 208 (FMVSS 208).

The test vehicles were equipped with 'Hybrid III' test dummies restrained in outboard front seating positions and subjected to a full frontal crash test at a nominal speed of 48 km/h. A full copy of ADR 69/00 and an extract from FMVSS 208 are at Appendices 2 and 3 respectively.

Instrumentation parameters and other detailed information not included in ADR 69/00 or FMVSS 208 were obtained from Documents:-

- TP-208-08 Laboratory Test Procedure for FMVSS No. 208 "Occupant Crash Protection" published by the US Department of Transportation as test procedures to be used by their contractors for audit testing to FMVSS 208.
- Test Facility Inspection Manual procedure 69/00-9-1 "Full frontal Occupant Protection" published by the Department of Transport as a guide to officers for inspection audits of test facilities testing to ADR 69/00.

3.3.2. Test Requirements

3.3.2.1. Injury Parameters

The injury parameters set out in ADR 69/00 were used, viz:

- **Head Injury Criterion (HIC)** measured by accelerometers in the test dummy's head. The value is the maximum cumulative integration of acceleration using the expression:

$$\left[\frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} a \, dt \right]^{2.5} (t_2 - t_1)$$

where a is the resultant acceleration expressed as a multiple of the acceleration due to gravity, and t_1 and t_2 are any two points in time during the

crash which are separated by not more than 36 milliseconds. The limit specified in ADR 69/00 is 1000. Refer Figure 3.1.

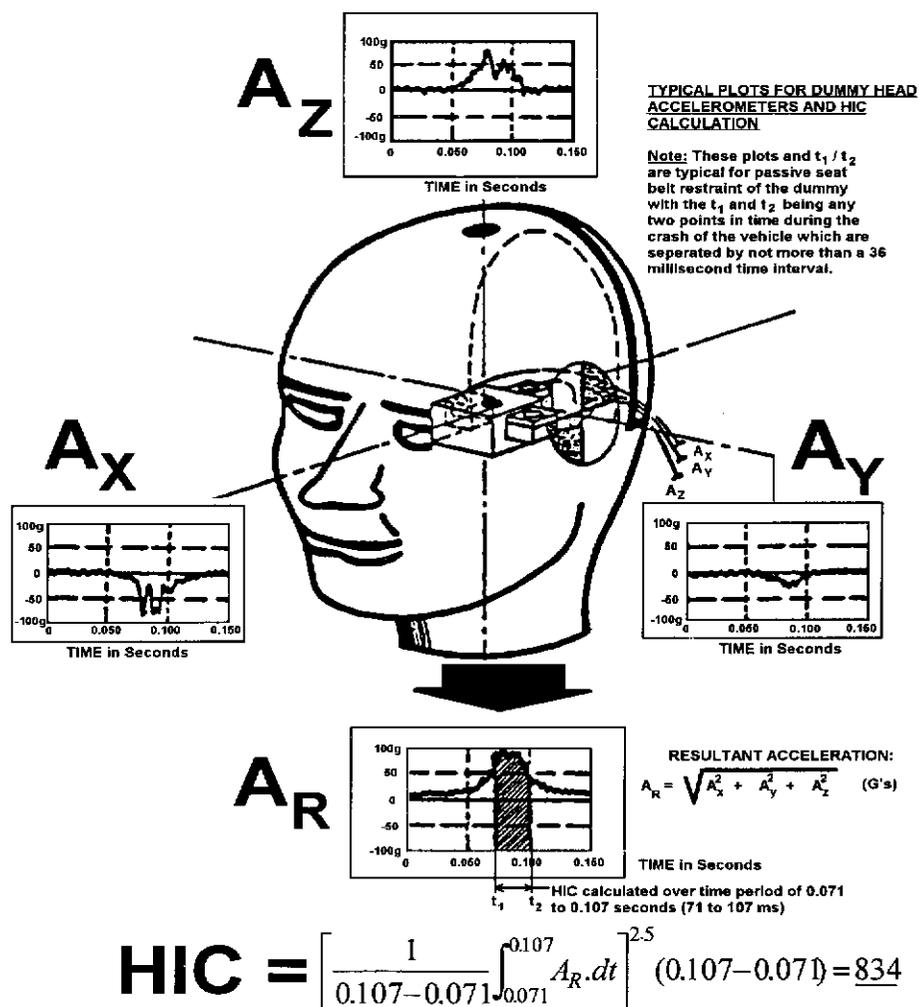


Figure 3.1. Head Injury Criteria

- **Chest Deceleration** measured by accelerometers in the test dummy's chest. The limit specified in ADR 69/00 is 60g except for intervals whose cumulative duration is not more than 3 milliseconds. In this expression, "g" is the acceleration due to gravity.
- **Compression Deflection of the Sternum** measured relative to the spine by a chest mounted rotary potentiometer. The deflection limit specified in ADR 69/00 is 76.2 mm.
- **Femur Load** measured by load cells as the force transmitted axially through the upper leg. The limit specified in ADR 69/00 is 10 kN.

These injury parameters provide an indication of the likelihood of serious or fatal injuries to vehicle occupants.

In addition to the injury criteria, there was a requirement that all portions of the test dummies remain within the vehicle passenger compartment during the crash test.

3.3.2.2. Impact Velocity

The impact velocity requirements of ADR 69/00 are that the test vehicle strike the barrier at 48 km/h. In accordance with ADR 69/00 Clause 5.1.1, vehicles impacted at velocities above 48 km/h are deemed to comply with the rule provided all injury criteria are met.

3.3.2.3. Test Vehicles

The program tested three off-road passenger vehicles and three light goods vehicles. They were selected as representative of popular vehicles in these categories.

Listed below are the vehicles tested and their corresponding test mass and indication of their drive configuration.

Barrier Test No.	Vehicle Make / Model	Test Mass	Drive
B4026	Mitsubishi Pajero	2158.0 kg	4WD
B4025	Suzuki Vitara	1458.0 kg	4WD
B4029	Toyota Landcruiser	2521.7 kg	4WD
B4028	Holden Rodeo	1641.0 kg	RWD
B4027	Mitsubishi Triton	1584.2 kg	RWD
B4030	Toyota Hilux	1580.9 kg	RWD

The vehicles were ordered through the Federal Government's Department of Administrative Services so as to assure that they were representative of series production. Further, each vehicle was uniquely marked, their Vehicle Identification Numbers were recorded, and they were held in a secure area prior to test. The specifications of each vehicle are at Appendix 4.

3.3.2.4. Vehicle Preparation

On receipt, each vehicle was checked for delivery damage and configuration correctness. Fluids were then added to specified levels prior to the vehicle being weighed in the "unloaded delivered weight" condition.

To install the necessary instrumentation, the modifications listed below were carried out. These were not considered to critically effect the crash performance of the vehicles.

- Rear Bumper Plastic Facias were removed

- A compressed air operated abort device, which applies the vehicles service brakes, was installed
- Cut-outs were made in the front doors to allow positioning of high speed cameras for recording the dummies' lower leg trajectory. The side intrusion beams, where fitted, were not modified
- To allow the routing of test dummy data cables, cut-outs were made in the cab rear panels for vehicles B4027 and B4028 while the rear window of vehicle B4030 was removed
- Rear seats, where applicable, were removed to allow the fitting of data acquisition equipment
- Load cells were fitted to the restraint system to measure the seatbelt webbing loads

Where necessary, ballast was added and positioned to achieve the correct test mass at the correct vehicle attitude.

To aid in the analysis of the crash test, targets were positioned on the vehicle body.

The final preparation of each test vehicle prior to test was carried out in the laboratory's preparation shed which is controlled for temperature and humidity.

3.3.2.5. Records

Pre-Test Records. A pre-test photographic record was made of the vehicle and positioned test dummies. This sequence of photographs allows for comparison of the pre and post test condition of both the vehicle structure and the test dummy head, torso and lower leg position.

Measurements were taken of the vehicle and test dummy position relative to vehicle datum points. This information is necessary in the event of retest.

Measurement data and photographs for the pre-test condition are provided in Appendix 5 and Appendix 6 respectively.

Post-Test records. A post-test photographic record was made complementing the pre-test sequence. In addition, areas indicating test dummy contact such as contact with the steering wheel, glove compartment and under dash panels were photographed. The areas of test dummy contact are evident by the presence of chalk marks on the vehicle interior. The colour of the marking corresponds to the contact point on the test dummy.

Measurements were taken of the vehicle underbody, passenger compartment and seatbelt anchorage point deformation for comparison to the pre-test condition.

Measurement data plus dummy contact points and photographs for the post-test condition are provided in Appendix 5 and Appendix 6 respectively.

3.3.2.6. High Speed Photography

Both on and off-board high speed cameras were used to record the test dummy trajectory during the test. The cameras were positioned as follows:

- Overview RHS - full length
- Close-up RHS - driver
- On-board RHS - driver's lower leg kinematics
- Overview LHS - full length
- Close-up LHS - passenger
- On-board LHS - passenger's lower leg kinematics
- Front through windscreen

The cameras used 16 mm high speed film and were operated at frame speeds between 800 and 1000 frames per second.

A "time zero" flash on the vehicle and an LED timing board were used to indicate the timing point of initial vehicle impact with the barrier.

3.4. Test Equipment

3.4.1. Barrier Test Facility

The six barrier crash tests were conducted at the Roads Traffic Authority Crashlab facility located in the Sydney suburb of Rosebery. This laboratory is wholly owned and operated by the New South Wales state government.

Crashlab is accredited by the National Association of Testing Authorities and holds AS 3901 accreditation.

The test contract was awarded to Crashlab following an open tender process.

3.4.1.1. Barrier

The Crashlab barrier facility is designed to comply with the requirements of Society Automotive Engineers' standard J850 "Fixed Rigid Barrier Collision Tests".

The barrier collision site is under cover and constructed from reinforced concrete at a mass of approximately 55 tonnes. Mounted on a 1.5 m concrete slab which in turn is anchored by concrete piles to the rock foundation, the barrier and foundations constitute a total mass of approximately 400 tonnes.

Leading up to the impact test area is a 145 metre precision approach track. The smoothness and flatness of the track facilitates self steering of the test vehicle and ensures the accurate positioning of the test dummies is not disturbed during the vehicle's approach to the barrier.

Located at the far end of the approach track is a test vehicle preparation shed which provides an environment controlled for temperature and humidity complying with the requirements of ADR 69/00.

3.4.1.2. Propulsion System

The vehicle propulsion system consists of a continuous tow cable driven by a 375 kW direct current electric motor. This system can accelerate the test vehicle from standstill at a pre-determined acceleration up to a specified test velocity. Maintenance of the approach acceleration and test velocity is achieved through the use of computer control up until the point of release 0.5 m from the impact surface. The primary measurement of the impact velocity is attained by measuring the tow cable velocity just prior to release while a secondary measure is taken via the use of an amphotometer placed at the barrier.

Tracking control of the test vehicle while under tow is achieved by the use of a monorail guidance system. Running on this monorail system, a specially designed tow skate is used which is designed to release the test vehicle 0.5 m from the crash barrier face and detach itself from the tow cable prior to impact. This feature is used to ensure that the vehicle is no longer subject to the towing device just prior to impact.

3.4.1.3. Data Acquisition

The acquisition of crash test data is performed using a hybrid system developed by Crashlab. This equipment predominantly uses a 10 kHz sample frequency per channel. Currently the test facility has the capacity to run 76 data acquisition channels.

3.4.2. Test Dummies

The crash test dummies used in both the driver's and front passenger's seating positions were 'Hybrid III' models. The 'Hybrid III' is an anthropomorphic test dummy which conforms to the requirements of US Federal Motor Vehicle Regulation No. 572, Test Dummy Specifications - Anthropomorphic Test Dummy for Applicable Test Procedures, Subpart E - Hybrid III Test Dummy - 50th Percentile Male, published by the United States National Highway Traffic Safety Administration. Figure 3.2 shows the general instrumentation layout for the Hybrid III dummy.

The Dummies used were Serial No.489D (Driver) and No.043P (Passenger).

Both dummies were calibrated prior to the commencement of the test program while performance verification tests were carried out prior to each barrier test. Calibration and performance verification tests were conducted by Crashlab in their test dummy calibration laboratory. Where a test dummy verification test showed damage had occurred, the affected parts were replaced and another calibration performed.

The Dummies used were fitted with the following primary instrumentation to measure the specified injury criteria:

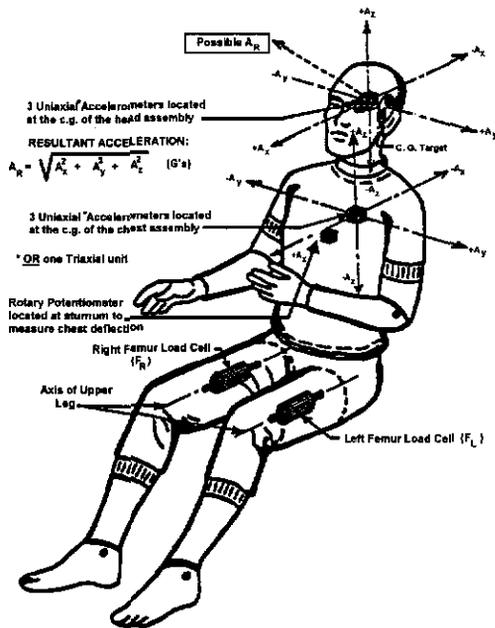


Figure 3.2 Typical Location of Load Cells and Accelerometers in Part 572 Subpart E Test Dummy

- One array of three uniaxial accelerometers in the head to measure orthogonal accelerations;
- One array of three uniaxial accelerometers in the upper thorax to measure orthogonal accelerations;
- One rotary potentiometer in the upper thorax to measure sternum compression relative to the spine;
- One load cell in each femur to measure the axial compressive loading of the femur;

After completion of calibration/verification tests the test dummies were clothed and allowed to undergo a stabilisation period at a specified temperature and humidity prior to being placed in the test vehicle. Positioning of the test dummies in the test vehicles was as specified by the test procedures in ADR 69/00. The test dummy limb joints were set at the minimum loading required to keep them in place (nominally 1g). Further care was taken to ensure:

- That the umbilical cables would not prevent the test dummy from moving freely during the test;
- That the sash portion of the seatbelt lay as straight as possible. This involved lightly supporting the mass of the seatbelt load cells by suspending them from the vehicle structure using light nylon thread;
- Correct positioning of the test dummy's legs.

3.4.3. Location of Additional Transducers and Load Cells

Additional instrumentation was installed to gather base data for use in any subsequent development work.

3.4.3.1. Additional Instrumentation fitted to Test Dummies

The secondary instrumentation, additional to that used for measuring injury criteria specified in ADR 69/00, consisted of the following:

- One array of three uniaxial accelerometers fitted in the pelvic cavity of both driver and passenger side dummies to measure deceleration in his region;
- One six axis load cell fitted to the neck of both driver and passenger side dummies to measure neck forces and moments in and about the X, Y, and Z axis;
- Two strain gauge load transducers fitted to each driver's knee clevis assembly measuring axial loading in each component;
- One twin axis upper tibia load cell fitted to each driver's lower leg assembly measuring moments about the X and Y axis;
- One tri axis lower tibia load cell fitted to each driver's lower leg assembly measuring axial force in the Z axis, shear force in the Y axis and the moment about the X axis.

3.4.3.2. Seatbelt Assembly

Two load cells were fitted to each front outboard seatbelt assemblies to measure belt loadings during impact. These were positioned on the webbing near the outer lap anchorage and the upper sash point.

Care was taken to position the transducers so they did not affect test dummy trajectory, especially in the area of the lower ribs and iliac crest.

3.4.3.3. Vehicle Structure

A three axis accelerometer was fitted to the vehicle to measure the deceleration pulse of the occupant space. It was placed on the vehicle body at the base of the "B-Pillar".

3.5. Test Results

This section provides a summary of the test series results. Detailed results of each test are contained in Appendices 5 to 8.

3.5.1. Test Vehicle Velocity

The vehicle impact velocity specified by ADR 69/00 is 48 km/h. Actual measured velocities were slightly above this figure to allow for measurement uncertainty. Measured impact velocities are detailed below:

<u>Vehicle</u>	<u>Impact Velocity (km/h)</u>
B4025	48.1
B4026	48.4
B4027	48.1
B4028	48.4
B4029	48.1
B4030	48.4

The resultant B-Pillar crash pulses for each test vehicle are given in Appendix 7.

3.5.2. Head Injury Criteria (HIC)

The HIC36 values ranged from 709 to 1167 for the driver's side and 471 to 1379 for the passenger's side.

Generally the HIC value was lower for the passenger than for the driver. This reflected driver head contact with the steering assembly whereas passenger head contact was minimal in most cases.

Contrary to this trend were the HIC values for B4025. For this test the recorded passenger side HIC was considerably higher than for the driver's side. This was due the test dummy's head striking its lower thigh.

The HIC15 values ranged from 569 to 1150 for the driver's side and 212 to 641 for the passenger's side.

For the HICs calculated over this shorter time interval, all passenger HIC values were lower than the driver HIC values. Again the trend is likely due to minimal passenger head contact.

The significant difference observed on comparison of the HIC 36 to HIC 15 figures is the reduction in passenger HIC where either no contact was made or contact was with the dummy's thigh flesh. The passenger HIC 15 value for B4025, for example, is 54% lower than the corresponding HIC 36 while the driver value for the same vehicle is 8% lower. (refer to Table 3.2)

3.5.3. Chest Deceleration

The chest deceleration values ranged from 43 to 69g for the driver's side and 37 to 54g for the passenger's side.

For all but one vehicle, the chest deceleration was greater for the driver than for the passenger. This was generally due to driver contact with the steering wheel.

3.5.4. Compression Deflection of the Sternum

The measurements of compression deflection of the sternum ranged from 39 to 57 mm for the driver's side and 33 to 46 mm for the passenger's side.

In all cases, the deflection measurements for the driver were greater than those for the passenger. This is also attributed to driver contact with the steering wheel.

3.5.5. Femur Loads

All measured femur axial loads fell below 6 kN. There seemed to be no distinct trend indicating whether the drivers side or passenger side exhibited higher average loadings.

The two highest loads measured were as follows:

- 5.2 kN measured for the driver left femur of vehicle B4025 which appeared to have contacted an area of the lower dash supported by a mounting bar
- 3.8 kN measured for the passenger right femur of vehicle B4029 which appeared to have contacted an area of the glove box supported by a mounting bar

However it must be noted that these measured loads are well below the ADR 69/00 limit of 10 kN indicating that a serious femur injury was unlikely.

HIC, chest deceleration, compression deflection and femur load data is given in Table 3.1.

3.5.6. Lower Leg Loads

Hybrid III instrumented lower legs fitted to the driver side dummies enabled the gauging of loads through the tibia shaft and knee clevis. Measurements taken were of axial loading on both sides of each knee clevis assembly, tibia shaft upper and lower moments M_x and M_y and tibia shaft axial loading.

Clevis tensile loads ranged from 300 N to 700 N while compressive loads ranged from 600 N to 1900 N. No unusually high loadings were observed.

Tibia shaft maximum moments ranged from 60 Nm to 356 Nm. Vehicle B4025 exhibited maximum moments at the upper end of this range for both left and right lower legs. This observation is coincident with the higher driver side femur loads of the same vehicle discussed above.

Compressive loads on the tibia shaft ranged from 0.8 Nm to 3.8 Nm. Again no unusually high loadings were observed while the magnitude of each load roughly correlated to the clevis loadings as would be expected.

Lower leg load data is given in Table 3.3.

3.5.7. Neck Loads and Moments

The Hybrid III instrumented necks fitted to driver and passenger side dummies enabled the gauging of loads through the neck during the vehicle impact. The primary measurements taken were flexion and extension moments about the Y axis, tensile and compressive axial loadings and fore and aft shear forces along the X axis.

Neck extension moments ranged from 19 Nm to 265 Nm with the maximum figure measured for the driver of vehicle B4025. Neck flexion moments ranged from 13 Nm to 139 Nm with the maximum figure measured for the passenger of vehicle B4025. In most cases the passenger moments for flexion and extension were higher than those of the driver. It was found that there was no substantial alignment between the neck moments and the incidence of high HIC readings.

Neck tensile and compressive forces ranged from 1.9 kN to 4.3 kN and 0.015 kN to 2.0 kN respectively. The incidence of above average tensile neck loading appeared to coincide with an above average (higher) HIC reading though no correlation of HIC data to neck compressive force data was evident.

Neck fore and aft shear forces ranged from 0.1 kN to 0.7 kN and 0.6 kN to 4.8 kN respectively. In all cases, the neck shear forces in the aft direction were greater than in the fore direction as expected.

Neck load and moment data is given in Table 3.3.

3.5.8. Seatbelt Loads

Seatbelt loads measured at points on both the lap and sash portions of the seatbelt are given in Table 3.3. In summary, peak lap belt loads ranged from 4.4 kN to 8.4 kN for the driver's side and from 4.3 kN to 9.0 kN for the passenger's side. Sash belt peak loads ranged from 6.6 kN to 8.1 kN for the driver's side and from 6.6 kN to 8.3 kN for the passenger's side. Depending on the vehicle seating package configuration, the incidence of low lap belt loadings in some cases coincided with above average femur loads.

During the conduct of the test no seatbelt failures were observed. All seatbelt retractors were observed to have locked during impact while post test inspections revealed all seatbelt release buckles were operative without excessive force.

Seatbelt anchorages in most cases showed loading deformation. However no failures were observed. Measurements of deformation can be found at Appendix 5.

3.5.9. Examination of Results

3.5.9.1. Injury Threshold

In order to gauge the probability of occupant injury, the 'Injury Assessment Values' developed by Mertz and specified in FMVSS 208 and ADR 69/00 are used. According to Mertz, dummy response measurements falling below certain developed limits indicate that corresponding occupant injuries are considered unlikely. The limits developed by Mertz¹ and specified in the above mentioned regulations are as follows:

- HIC not greater than 1000
- Chest/spine acceleration not greater than 60g for more than 3 ms

¹ Mertz, H. J., *Injury Assessment Values used to Evaluate Hybrid III Response Measurements, Safety and Crashworthiness Systems*, Current Product Engineering, General Motors Corporation, February 1984.

- Chest compression not greater than 50 mm for sash loading, and not greater than 75 mm for distributed frontal chest loading
- Axial compressive femur loads not exceeding that described by the time dependant injury assessment criterion for distributed knee loading given in Figure 3.3. Note that this criterion has been specified in FMVSS 208 and ADR 69/00 such that the maximum femur loading shall be no greater than 10 kN

By studying the resultant data of each vehicle and applying the 'Injury Assessment Values', the following observations can be made:

- A "significant" head injury is unlikely to occur to the driver and front outboard passenger of any of the vehicles tested except for the driver in B4026 and the front outboard passenger of vehicle B4025. However, note the high HIC figure for B4025 has occurred due to the dummy head contact with its right thigh and not the vehicle structure. The HIC values for the driver are approaching the threshold for vehicles B4025 and B4030 while for the remaining vehicles, both driver and front outboard passenger HICs fall 20% or greater below the threshold.
- A "significant" thoracic organ injury due to gross chest/spine acceleration is unlikely to occur to the driver and front outboard passenger of any of the vehicles tested except for the driver in vehicle B4025 while the value for the front outboard passenger of the same vehicle is approaching the threshold.
- A "significant" thoracic organ injury due to chest compression from the sash belt is unlikely to occur to the driver and front outboard passenger of any of the vehicles tested. All values recorded fell 20% or greater below the threshold.
- A "significant" liver and/or spleen injury due to shoulder belt loading of the lower lateral part of the rib cage is unlikely to occur to the driver and front outboard passenger of any of the vehicles tested.
- A "significant" leg injury is unlikely to occur to the driver and front outboard passenger of any of the vehicles tested. All values recorded fell 20% or greater below a 10 kN threshold.

As specified by Mertz and related to the AIS (Abbreviated Injury Scale) published by the American Association for Automotive Medicine, a "significant" injury in this context includes:

- Serious injuries (AIS = 3)
- Reversible brain concussion
- Bone fractures

- Major injuries
 - life threatening injuries (AIS > 3)
 - brain damage
 - thoracic and abdominal organ damage
 - permanent impairment injuries (AIS ≥ 2)
 - spinal cord damage
 - knee joint damage

In addition to the injury assessment values described above, Mertz developed values for the assessment of neck and lower leg injuries. Although these values are not specified in either FMVSS 208 or ADR 69/00 they are of merit for indicating the probability of neck and lower leg injuries. For occupant injuries to be considered unlikely, bounds for the injury assessment values are specified as follows:

- Neck flexion moment less than 190 Nm
- Neck extension moment less than 57 Nm
- Axial neck tensile loadings for all durations to fall below the curve described by the time dependant injury assessment criterion given in Figure 3.4.
- Axial neck compressive loadings for all durations to fall below the curve described by the time dependant injury assessment criterion given in Figure 3.5.
- Fore and aft neck shear forces for all durations to fall below the curve described by the time dependant injury assessment criterion given in Figure 3.6.
- Combined bending and axial compressive loading of the leg, defined by the following equation, not to exceed 1:

$$\frac{M}{M_c} + \frac{P}{P_c} = 1$$

where $M_c = 225 \text{ Nm}$

$P_c = 35.9 \text{ kN}$

M is the resultant bending moment

P is the corresponding axial compressive force

- Medial and lateral tibial plateau compressive forces to be less than 4000 N

Figure 3.3 Time Dependant Assessment Criterion for Distributed Knee Loading*

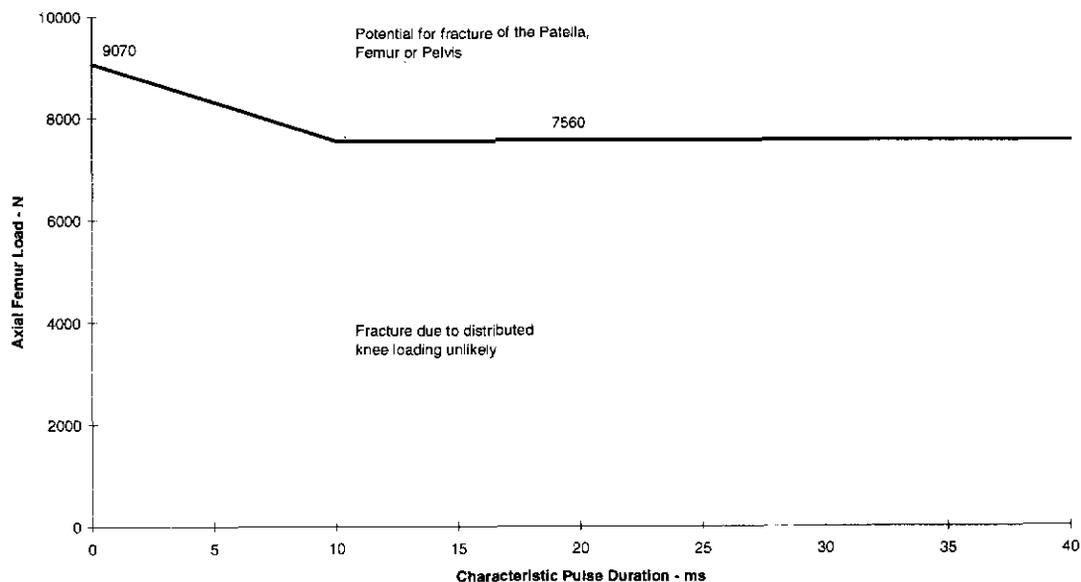


Figure 3.4 Injury Assessment Criterion for Axial Neck Tension Loading*

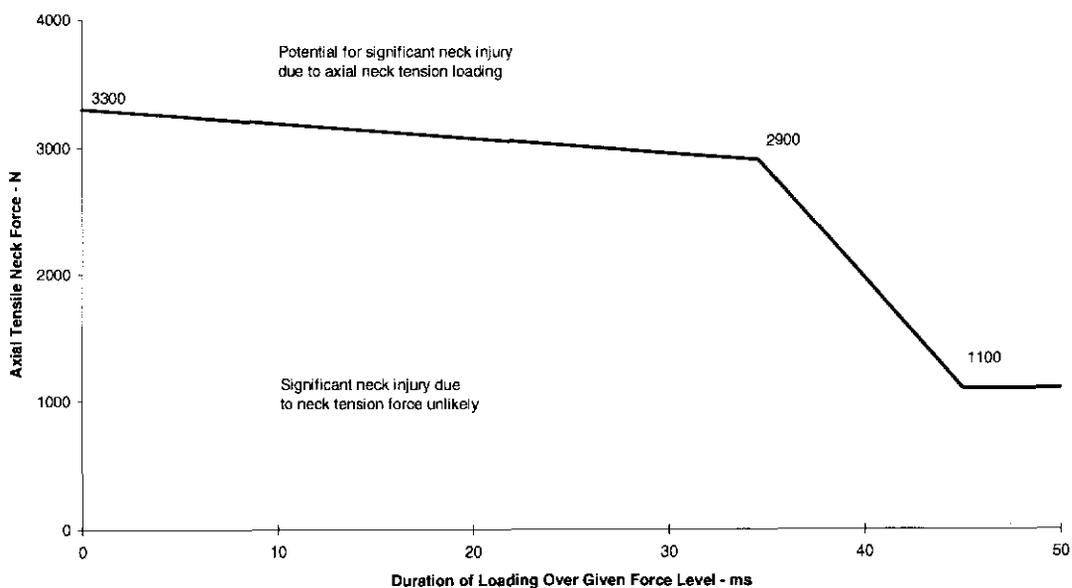


Figure 3.5 Injury Assessment Criterion for Axial Neck Compression Loading*

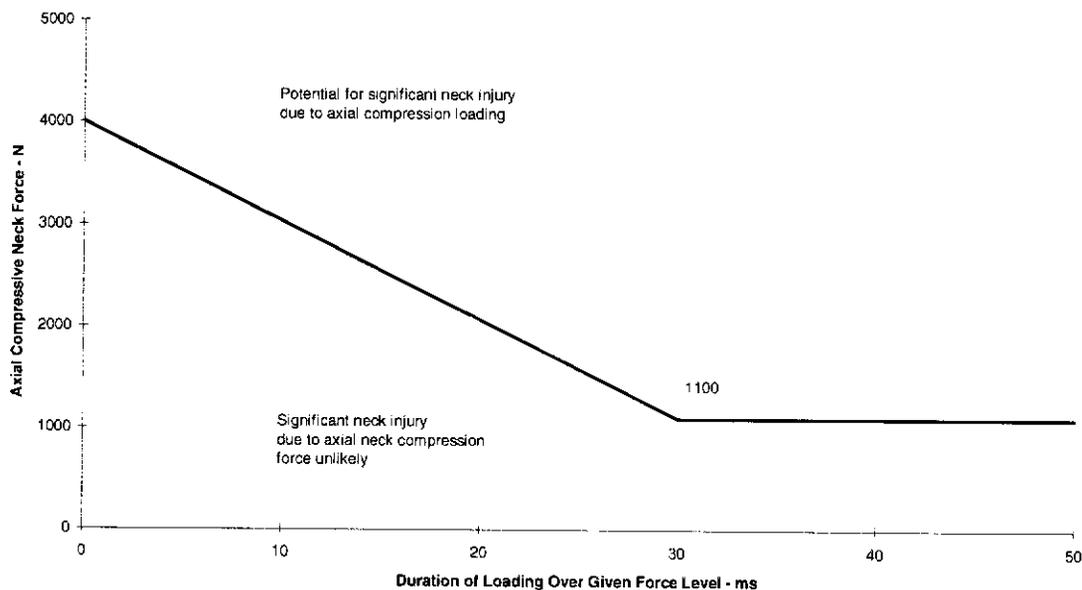
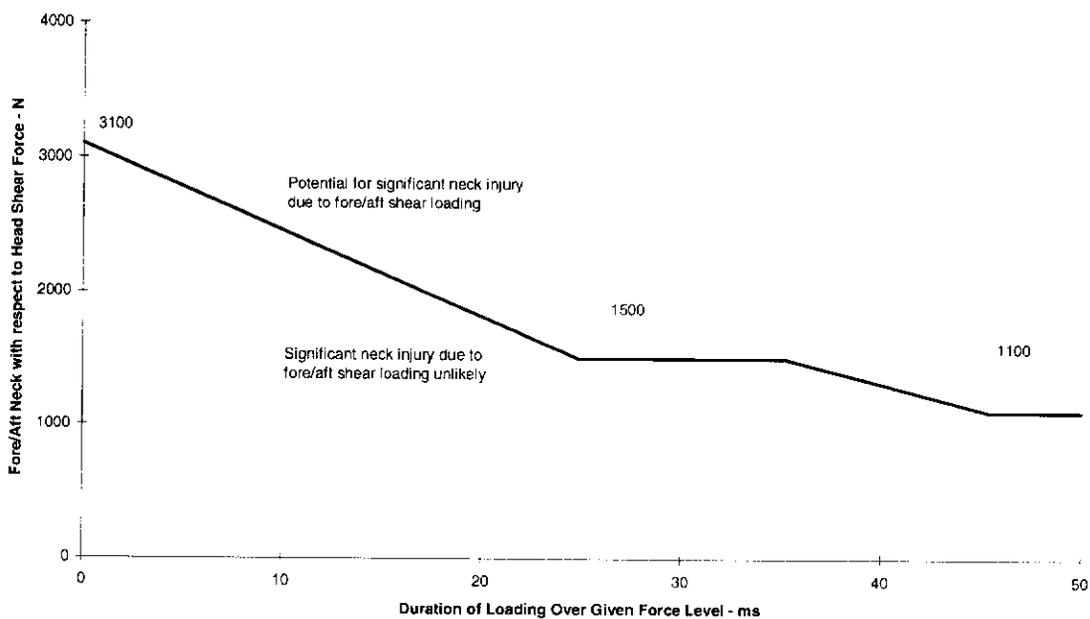


Figure 3.6 Injury Assessment Criterion due to Fore/Aft Neck Loading with respect to Head Shear Force*



* Source: Mertz, H. J., "Injury Assessment Values Used to Evaluate Hybrid III Response Measurements", Safety and Crashworthiness Systems, Current Product Engineering, General Motors Corporation, February 1984.

By relating these additional criterion to the measured data of each vehicle and applying the 'Injury Assessment Values', the following observations can be made:

- A "significant" neck injury due to neck flexion is unlikely to occur to the driver or front outboard passenger of any of the vehicles tested. The neck flexion moments measured were all 20% or greater below the threshold.
- A "significant" neck injury due to neck extension is unlikely to occur to the driver or front outboard passenger of vehicles B4026, B4028 and B4029. Neck extension moments measured for both the driver and front outboard passenger of vehicles B4025 and B4030 and the front outboard passenger of vehicle B4027 indicated potential for a "significant" neck injury.
- A "significant" neck injury due to tensile or compressive forces is unlikely to occur to the driver or front outboard passenger of any vehicle except for the drivers in vehicles B4025, B4026 and B4030. For these vehicles neck tensile forces exceeded the upper limit of 3.3 kN indicating potential for a "significant" neck injury to the driver. All other measured loads were found to fall below the force/duration curve given in Figure 3.4. The neck compressive forces measured for the driver and front outboard passenger for all vehicles were well below the of 4 kN threshold while no force measurements were found to fall above the curve given in Figure 3.5 and sustained for the corresponding duration.
- A "significant" neck injury due to neck fore or aft shear forces is unlikely to occur to the driver or front outboard passenger of any vehicle except for the driver of vehicle B4025. For this vehicle the neck shear force in the aft direction exceeded 3.1 kN indicating potential for a "significant" neck injury to the driver. The neck shear forces measured in the fore direction for the driver and front outboard passenger of all vehicles tested were well below the 3.1 kN threshold while no force measurements were found to fall above the curve given in Figure 3.6 and sustained for the corresponding duration.
- A "significant" lower leg injury due to combined bending and axial compressive loading is unlikely to occur to the driver in any of the vehicles tested except for vehicle B4025. In this vehicle the value for the expression given above exceeded 1 for both the left and right legs indicating potential for a "significant" leg injury.
- A "significant" leg injury at the medial and lateral tibial plateau due to compressive loading is unlikely to occur to the driver in any of the vehicles tested. In all cases the measured loads were below the 4 kN threshold.

Further to this discussion it must be noted that the use of the Injury Assessment Values and Injury Threshold Levels developed by Mertz have their limitations. Not all types of significant injuries that an occupant may experience are included while the dummy is only instrumented to measure limited data. In addition, the

data collected corresponds only to the collision specified in the test procedure and therefore can not be applied to collisions of differing severities or crash modes. Occupants of different ages and physical condition will also have varying injury tolerances.

Consequently it cannot be stated that an occupant will not experience a significant injury in a vehicle where a measured dummy response fell below the injury threshold. Equally, it cannot be stated that an occupant will experience a significant injury in a vehicle where a measured dummy response fell above the injury threshold. Relating the measured dummy responses to the Injury Assessment Values and Injury Threshold Levels is therefore intended only as a guide for assessing the potential for occurrence of significant injuries to occupants.

3.5.9.2. Non-Contact Head Injury Criteria

Table 3.2 provides the HIC values calculated using both 15 ms (HIC15) and 36 ms (HIC36) integration periods.

Analysis of data by the US National Highway Traffic Safety Administration (NHTSA) has indicated that there was no risk of belted occupants in a frontal crash suffering serious head injury in non-contact crashes, but they might be subject to a risk of neck injuries.

Hybrid II or Hybrid III can currently be used for certification to ADR 69/00. Hybrid III is a more biofidelic test device and would generally result in a better designed restraint system.

However the mere fact that Hybrid III has a more biofidelic neck, which Hybrid II does not, can cause misleading HIC figures in non-contact crashes. In non-contact crashes, the dummy head trajectory is such that the triaxial head accelerometer can record a high overall deceleration. This can be explained as follows:

In the initial ride down phase when the belt engages, the head moves forward and starts to decelerate with a high x-axis (longitudinal) deceleration. As the head rotates further and the dummy's face is pointing toward the ground, the z-axis is now pointing in the longitudinal direction and records a high deceleration along this axis as the dummy's motion is arrested by the restraint. The high resultant deceleration gives a high HIC36 figure even though a hard impact, high level deceleration event such as contact with the dashboard or steering wheel has not occurred.

For this reason a proposal to provide two alternatives to measuring HIC in non-contact events when using the Hybrid III is currently being considered for inclusion in ADR 69/00. These two alternatives are:

- A neck injury criteria which measures the neck tensile force in the inferior-superior (z) axis (vertical) with an injury threshold limit of 3300N (see Figure 3.4).
- A HIC15 limit of 700 which is currently being considered by Transport Canada. Research has shown that when a hard head impact occurs, the HIC number is the same or similar whether it is calculated over a 36 ms or 15 ms time interval.

Using the above two criteria when comparing the HIC15 figures in Table 3.2 with the neck tensile forces (Z) in Table 3.3 for both driver and passenger, it is seen that HIC15 appears to be a good predictor of neck injury in both contact and non-contact events.

3.5.9.3. Head to Knee Contact

As mentioned above, the Hybrid III's head and neck are more representative of human response than that of the Hybrid II. However, the Hybrid III head/neck assembly does not totally replicate human head/neck trajectory in a frontal crash situation.

Volunteer testing at low level decelerations has shown that the initial motion of a human head is translational in the longitudinal direction which is then followed by rotation as the neck flexes forward. The Hybrid III dummy's head starts to rotate immediately without this initial forward translation.

This difference in response ultimately affects the trajectory of the head. As part of the advanced dummy research, a new head/neck assembly that is better capable of reproducing this translational response is being developed.

The construction of the Hybrid dummies is such that the area of the thigh near the knee joint is much more solid than that of a human. Therefore, impacts in this area produce non-biofidelic responses when compared to a human.

For these two reasons, interpretation of HIC numbers resulting from head to knee strikes should be treated with great caution and must be backed up with proper analysis of the high speed film and other crash data.

3.5.9.4. Test Data Variability

For the six vehicles tested, the resultant data varied significantly. This was to be expected due to the complex nature of the testing involved and the difference in vehicle size, design and configuration.

Of the variations observed, the most noted were for femur loads and head injury criteria. A standard deviation of 1.8 kN was observed for femur loads recorded for the drivers left side leg while a standard deviation of 1.1 kN was observed for the passenger right side leg. Variation of this magnitude was most likely due to differing design configurations of the lower inboard dash area in conjunction with the differing dummy trajectory kinematics.

The standard deviation of the 36 ms Head Injury Criteria data was 304 and 150 for the passenger side and driver side respectively. The magnitude of the variation on the passenger side may be explained by the relatively high HIC of 1379 recorded for vehicle B4025 where the dummy's head hit its thigh. This particular reading represents a 95% variation on the mean HIC for the passenger side and somewhat skews the distribution of data.

3.5.10. Summary of Results

Individual injury criteria are listed in Table 3.1 while a graphical representation of this data from all test vehicles for each injury criteria is contained in Appendix 8.

Additional key data including neck loads, pelvic deceleration, seatbelt loads and lower leg loads are listed in Table 3.3.

It must be remembered that the above comments may change if further tests are conducted due to the following factors:

- Data has been measured and recorded from only one test per vehicle.
- The results for some vehicles are close to or above the injury criteria threshold values.

Table 3.1 Injury Criteria Data

		HIC (36 ms)	Chest Decel. at 3 ms (g)	Chest Comp. (mm)	Femur Comp. Load	
					Left	Right
B4025	Driver	945.1	69.3	57.4	5.2	1.8
	Passenger	1379.0	54.2	45.7	0.6	0.6
B4026	Driver	1167.1	46.2	53.9	0.8	0.7
	Passenger	628.3	48.2	43.7	0.7	1.3
B4027	Driver	791.4	42.5	39.3	0.8	0.9
	Passenger	471.4	40.1	38.5	1.1	0.6
B4028	Driver	708.9	48.5	42.0	0.2	0.4
	Passenger	612.8	43.0	39.7	0.7	0.6
B4029	Driver	773.8	43.1	44.4	3.0	2.8
	Passenger	573.2	37.4	33.7	2.3	3.8
B4030	Driver	881.1	51.0	43.5	0.7	3.0
	Passenger	589.0	46.3	33.3	1.4	1.9
ADR 69/00		1000.0	60.0	76.2	10.0	10.0

Table 3.2 Contact (HIC 36) and Non-Contact (HIC 15) Head Injury Criteria Data

	HIC (36 ms)		HIC (15 ms)		Comment
	Driv	Pass	Driv	Pass	
B4025	945.1	1379.0	871.6	641.0	Driver head contact with upper rim and hub of steering wheel. Passenger head contact with right knee, dash and chest.
B4026	1167.1	628.3	1150.1	386.9	Driver head contact with steering wheel hub centre. No Passenger head contact was made.
B4027	791.4	471.4	568.7	211.9	Driver head contact with rim and hub of steering wheel. No passenger head contact was made in forward motion, crown contact with roof on rebound.
B4028	708.9	612.8	689.9	363.0	Driver head contact with upper rim and hub of steering wheel. Passenger head contact with right knee.
B4029	773.8	573.2	623.7	299.7	Driver head contact with upper rim and hub of steering wheel. Passenger forehead and nose contact with dash.
B4030	881.1	589.0	782.4	324.5	Driver head contact with steering wheel rim and hub centre. Slight Passenger forehead contact with right thigh.

Table 3.3 Neck Moment, Pelvic Deceleration, Seatbelt and Lower Leg Loads

Test Vehicle Dummy Seating Position	B4025		B4026		B4027		B4028		B4029		B4030		Mertz
	Driv	Pass	Driv	Pass	Driv	Pass	Driv	Pass	Driv	Pass	Driv	Pass	
Neck Extension Moment Y (Nm)	264.6	66.2	33.9	37.5	35.3	57.7	19.6	40.9	36.1	28.5	65.8	78.1	< 57
Neck Flexion Moment Y (Nm)	48.2	138.4	13.5	87.9	53.9	79.2	20.6	93.5	81.8	62.8	24.4	95.7	< 190
Neck Moment Resultant - max (Nm)	264.8	141.0	34.3	88.5	55.3	79.8	33.7	95.1	83.3	63.2	66.6	96.6	
Neck Moment Resultant - (3ms) (Nm)	228.7	132.3	32.6	88.0	52.2	78.7	30.9	93.7	79.4	60.2	63.5	95.3	
Neck Tensile Force Z (kN)	4.3	3.2	3.8	2.6	2.2	2.0	3.1	2.6	2.3	1.9	4.3	2.3	< 3.3 *
Neck Compressive Force Z (kN)	0.3	0.3	0.8	0.7	0.3	0.8	0.1	0.0	0.2	0.1	0.6	2.0	< 4.0 *
Neck Shear Force - Fore (kN)	0.3	0.1	0.7	0.3	0.5	0.1	0.6	0.1	0.5	0.1	0.1	0.3	< 3.1 *
Neck Shear Force - Aft (kN)	4.8	2.5	0.8	1.5	0.6	1.4	0.7	1.6	0.7	0.6	1.0	1.6	< 3.1 *
Neck Force Resultant - max (kN)	6.4	3.5	3.8	2.9	2.3	2.2	3.1	2.9	2.3	2.0	4.3	2.5	
Neck Force Resultant - (3ms) (kN)	5.8	3.4	3.6	2.8	2.2	1.2	2.6	2.8	2.2	1.8	3.7	2.5	
Pelvic Deceleration - max (g)	80.9	54.4	54.3	62.8	46.1	43.8	55.3	51.8	55.9	44.6	68.2	67.4	
Seatbelt force - Lap (kN)	7.5	9.0	8.4	8.9	7.2	8.0	7.6	7.1	4.4	4.3	7.8	8.3	
Seatbelt force - Sash (kN)	6.6	8.3	8.1	7.7	6.7	7.1	7.1	7.0	6.8	6.6	7.4	7.4	
Left Upper Tibia - left clevis Z (kN)	-1.0		-0.7		0.3		-0.6		-0.9		-0.9		< 4.0
Left Upper Tibia - right clevis Z (kN)	-1.0		-0.9		-1.4		-1.0		-0.9		-1.2		< 4.0
Right Upper Tibia - left clevis Z (kN)	0.5		0.7		-1.0		-0.6		-0.9		-1.0		< 4.0
Right Upper Tibia - right clevis Z (kN)	-1.3		-1.0		-1.9		-1.7		-1.8		-1.5		< 4.0
Maximum Left Tibia Moment (Nm)	355.9		60.6		81.4		98.2		73.8		104.1		
Maximum Right Tibia Moment (Nm)	275.2		62.7		120.3		93.2		93.6		89.5		
Left Lower Tibia Compressive Force Z (kN)	2.5		0.8		2.7		1.5		2.3		3.0		
Right Lower Tibia Compressive Force Z (kN)	2.0		1.1		3.8		2.5		3.5		3.1		
Combined bending and axial compressive loading of left leg (Tibia Index)	1.7		0.3		0.4		0.5		0.4		0.5		< 1
Combined bending and axial compressive loading of right leg (Tibia Index)	1.3		0.3		0.6		0.5		0.5		0.5		< 1

* Refer to Figures 3.4, 3.5 and 3.6

3.6. Discussion

Motor vehicle crash testing in itself is complex by nature. Not only are there many interrelated variables affecting the test outcome but the relationships between these variables are often unknown. Due to this complexity, test results from vehicles of similar structure often vary considerably. Test to test variability can often be in the order of plus or minus 20%. For this reason, the test results from this crash test program do not form a basis for drawing a sustainable comparison of the safety performance of each vehicle.

Bearing these issues in mind, the following comments can be provided. Of the six vehicles tested, two were found to have exceeded the injury criteria limits imposed on Passenger Cars through ADR 69/00. These two vehicles, B4025 and B4026, exceeded the HIC limit of 1000 for passenger and driver respectively. The chest deceleration limit of 60g was also exceeded for the driver of vehicle B4025.

All of the six vehicles tested had a separate chassis as opposed to monocoque construction. A review of the crash pulses measured at the B-pillar of the vehicle's body show a much earlier onset of crash forces when compared with passenger cars together with a higher peak deceleration. This is the result of the lack of specific crumple zones in the vehicle structure. On the last vehicle tested, B4030, an extra accelerometer was mounted on the chassis to examine whether the mounting system of the cab to the chassis introduced any attenuation of the crash pulse (refer Appendix 7). It was found that the crash pulse was attenuated by some 64% and indicated that the effect provides manufacturers with some opportunity of tuning the dummy kinematics by using the cabin/chassis mounting system.

Generally the results demonstrated that there is scope for improvement of the occupant protection offered in the vehicles tested. The tests also indicated that it is possible to design this type of vehicle to meet the ADR 69/00 criteria. If the ADR 69/00 requirements were to be imposed on these vehicles, further development work would be required in order for manufacturers to gain confidence that all production vehicles met the standard.

3.7. Conclusion

The crash test program was carried out to evaluate the possible extension of Australian Design Rule 69/00 Full Frontal Occupant Protection applicability to Off-road Passenger vehicles and Light Goods vehicles. The vehicle models tested in the program were built to comply with the current Australian Design Rules for vehicle safety which offer comparable levels of safety to the requirements in force in Europe and Japan.

During the conduct of the tests no body structural or seatbelt failures occurred. In addition, no unexplainably high measures of injury criteria greatly exceeding the ADR 69/00 limits were observed.

Highlighted by the injury criteria results measured, this crash test program has indicated that the application of ADR 69/00 to these vehicles would result in a significant improvement in occupant protection levels provided by Off-road Passenger vehicles and Light Goods vehicles. Although not included in this crash test program, it is envisaged that this would also hold for Forward Control passenger vehicles.

Currently the primary vehicle safety features relating to occupant protection for these vehicle categories is specified through individual performance requirements for individual components.

The application of ADR 69/00 to these vehicle categories would shift the focus toward performance based testing of the vehicle safety system as a whole and in summary would therefore bring the level of occupant protection equal to that of passenger cars.

4.**OUTCOME OF REVIEW**

The outcome of the review was to gradually introduce cost-effective improvements to occupant protection in four wheel drive passenger vehicles, light commercial vehicles and forward control passenger vans.

The first stage of improvements will be introduced progressively from 1996 and bring the requirements for these vehicles up to the level currently applied to passenger cars.

The second stage will introduce the performance based requirements of ADR 69/00 for full frontal crash protection to these vehicles. It is expected that this will see the introduction of airbags in the same way as for passenger cars.

The final improvements will be the introduction of dynamic side and offset frontal impact performance requirements to these vehicles once these standards are finalised in the international arena.

5.

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