TRANSPORT RESEARCH LABORATORY

Assessment and test procedures for bull bars

Prepared for Vehicle Standards and Engineering Division, Department of the Environment, Transport and the Regions

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Executive Summary

Off-road vehicles have become popular in recent years and this type of vehicle now forms an increased proportion of the vehicle fleet. In 1998, they represented 4.4% of sales. These vehicles are often fitted with bull bars and this has created safety concerns because of their potential to increase the risk of injuries in accidents with vulnerable road users.

Currently the European Union (EU) is committed to producing a proposal for a pedestrian protection Directive, based on the European Enhanced Vehicle-Safety Committee, Working Group 17 Pedestrian Test Procedure (EEVC Committee, 1998). This is likely to apply to all new cars submitted for safety approval and would require them to provide pedestrian protection effective in accidents at speeds up to 40 km/h. However, it will take some years before a directive is agreed and begins to come into effect and it will not apply to most bull bars unless it is tailored to cater for after market accessories, since they are normally fitted after vehicle approval. In addition, the EEVC procedures have not been specifically developed to regulate bull bars and may require some modifications to make them suitable for testing the safety of bull bars.

The Department of the Environment, Transport and the Regions commissioned TRL to develop a pedestrian protection test procedure, which could be used to assess the injury risk of bull bars. As part of this study TRL investigated the pedestrian protection performance of a range of vehicles both with and without bull bars fitted. These tests were intended to:

a aid the development of a bull bar test method for pedestrian protection;

b determine the performance of current bull bars;

c determine the speed at which a representative sample of vehicles without bull bars can meet the performance requirements of the EEVC pedestrian protection test methods.

In order to determine the relative safety of the vehicles with and without bull bars fitted, tests were carried out over a range of speeds, with the aim of spanning the speed at which the base vehicles passed/failed the EEVC's performance criteria.

Test methods suitable for regulating the pedestrian protection provided by bull bars have been developed, based on the EEVC 40 km/h pedestrian test methods. Reduced test speeds have been established for a bull bar test method that could show if the bull bar matches the safety currently provided by vehicles of the type commonly fitted with bull bars.

All of the steel bull bars tested have been shown to have a very high risk of causing life-threatening brain injuries in impacts with the heads of children or serious injuries to the abdomen and chest of adults and taller children, even in low speed accidents. However, the very limited bull bar accident data makes it impossible to identify whether this is happening in real life. Nevertheless, the tests show that some method of encouraging safer bull bars would be beneficial.

The deformable bull bars tested have been shown to have a very low risk of causing serious and life-threatening injuries in impacts with the heads of children, in accidents at speeds up to 40 km/h. One type of deformable bull bar has shown that as well as protecting the child head it is also possible to provide, femur, pelvis abdomen and chest protection effective in accidents at speeds up to 40 km/h.

To require effective protection it is considered essential that a bull bar test method includes an adult upper legform test and a child headform test for the top parts of the bull bar.

A direct impact of a steel bull bar to a child's head is a worst case situation, which would rarely happen in real life; however, it is likely to result in serious or fatal injury.

If the bull bar test procedure were to be conducted at a speed at which current base vehicles meet the requirement of the EEVC proposal, the test speed would be considerably lower than required in that proposal.

The tests demonstrate that while both steel and deformable bull bars could be produced that gave acceptable results at low speed, the performance of steel bull bars deteriorated very rapidly as the speed of impact increased to a speed where a large proportion of serious injury accidents occur. A low speed test could encourage the less expensive steel bull bars rather than deformable bull bars. It is therefore considered that a low speed test method would bring small real world benefits and be counter-productive.

It has been demonstrated that it is feasible to make bull bars to meet the requirements of a 40 km/h sub-systems test method. Therefore it is recommended that a low speed bull bar approval regulation should not be introduced and that consideration should be given to introducing the 40 km/h bull bar test methods, proposed in this report, as a standard to control bull bars. It is anticipated that a 40 km/h test would result in a significant improvement in real world safety.

1 Introduction

The current popularity of fitting bull bars has created safety concerns because of their potential to increase the risk of injuries in accidents with vulnerable road users.

It may be argued that there is a real benefit in the fitting of bull bars to vehicles used in farming and forestry commission work, due to the nature of the environment in which such vehicles operate. However, currently the majority of off-road vehicles are used as a ‘family car’. Some bull bar manufacturers have responded to the safety concerns by making energy absorbing bull bars, which may well prove to have a reduced risk of pedestrian injury over the non-bull bar equipped vehicle and it would be unreasonable to ban these.

Due to the height of off-road vehicles, the child’s head or chest could be in direct contact with part of a bull bar in an accident. For an adult, the bar’s height would result in direct contact with the upper leg, pelvis, abdomen or chest regions.

If a rigid heavy bull bar is attached to the front of a vehicle, the consequences in the event of a pedestrian impact are likely to be more severe than with a non-equipped vehicle (base vehicle). However, with the limited bull bar accident data available it is difficult to demonstrate a real life increase in injury severity in bull bar accidents. The limited test data currently available suggest that standard steel tube type bull bars are particularly likely to produce serious head injuries in accidents with children if they are hit directly on the head. To-date, no clear-cut child accident of this type has been identified. However, exact details of bull bar accidents are not routinely identified in accident statistics. A study of accidents involving bull bar equipped vehicles (Hardy, 1996), using data acquired in a police survey, found that there was insufficient child data to make an in-depth analysis of such cases.

Currently the European Union (EU) is committed to producing a proposal for a pedestrian protection Directive, based on the European Enhanced Vehicle-Safety Committee, Working Group 17 Pedestrian Test Procedure (EEVC Committee, 1998). This is likely to apply to all new cars submitted for safety approval and would require them to provide pedestrian protection effective in accidents at speeds up to 40 km/h. However, it will take some years before a directive is agreed and begins to come into effect and it will not apply to most bull bars unless it is tailored to cater for after market accessories, since they are normally fitted after vehicle approval. In addition, the EEVC procedures have not been specifically developed to regulate bull bars and may require some modifications to make them suitable for testing the safety of bull bars.

The Department of the Environment, Transport and the Regions commissioned TRL to investigate the performance of a range of vehicles both with and without bull bars fitted. The research programme was planned:

a to determine the impact speed at which a representative range of vehicles to which bull bars are commonly fitted, meet the requirements of the pedestrian protection proposal;

b to determine the pedestrian impact performance of a representative range of steel and deformable plastic bull bars;

c to propose pedestrian test methods which could be considered for UK National Standards for bull bars, with the test severity linked to the performance of a representative range of current vehicles without bull bars;

d to propose pedestrian test methods which could be considered for an EU Directive for bull bars;

e to consider the effectiveness of legislation based on the bull bar test methods produced here.

In order to determine the relative safety of the vehicles with and without bull bars fitted, tests were carried out over a range of speeds, with the aim of spanning the speed at which the base vehicles passed/failed proposed performance requirements. Possible test methods for bull bars, based on the EEVC pedestrian test methods, have been developed. The likely effectiveness of applying these test methods to control bull bar aggressiveness has been considered.

2 Method

The vehicles, with and without bull bars fitted were tested using the EEVC Child Headform, the adult Legform and the adult Upper Legform pedestrian impactors. The test methods were based on variations of the EEVC pedestrian test procedures. The outputs from the impactor instrumentation were recorded throughout the impact and the data were processed in accordance with the EEVC requirements to determine the injury risk.

It was anticipated that a large number of tests would be required to provide the required information for this programme. Therefore, the number of tests to the bumper area, to which most bull bars make little difference, was kept to a minimum.

2.1 Vehicle selection

The aim of the vehicle selection process was to choose vehicles representative of the type commonly equipped with bull bars on UK roads. The choice of vehicle models also took into account the types of bull bars that were available for them so that a wide range of bull bars was available for testing. The vehicle models were also chosen to cover a range of frontal shapes, sizes and construction methods.

The six vehicles selected were:

- Ford Transit.
- Land Rover Defender.
- Mitsubishi Shogun.
- Suzuki Vitara.
- Toyota HiLux.
- Vauxhall Frontera.

2.2 Bull bar selection

The aim of the bull bar selection process was to cover a variety of different styles, materials and methods of construction typical of those currently available. For each vehicle up to three types of bull bar, designed to fit that vehicle, were chosen. Some suppliers were offering what they referred to as ‘Pedestrian Friendly Bull Bars’, so several of these were included, to determine what improvements in protection to pedestrians these might offer over the traditional steel bull bars. Details of the bull bars selected are given in Table 1 (Appendix A) and Figure 1 (Appendix B). The bull bars selected therefore fell into two main types; traditional steel and plastic. The traditional steel bull bars consisted of horizontal steel tubes attached to strong uprights. These uprights were normally steel ‘I’ sections or heavy tubes attached at about bumper level. A limited number of the ‘A’ bar variant of the traditional steel bull bar were also obtained. The plastic bull bars have or appear to have been developed to be ‘pedestrian friendly’ and have a non-metallic deformable composition, at least on the exterior. There were three types of plastic bull bar found to be available and examples of each were tested. They consisted of a moulded solid foam plastic type, a firm plastic ‘U’ section type (closed by a metal frame at the rear) and a stiffer, large-diameter continuous-polymer hollow-tube type. The polymer tube type was produced by filling a mould with resin powder and heating and tumbling the mould in three dimensions. This caused the mould surface to be coated with the molten plastic forming a seamless hollow vessel when cooled.

The traditional steel bull bars are referred to as ‘steel bull bars’ and the three types of plastic bull bar are referred to as ‘deformable bull bars’ throughout the rest of this report.

2.3 Adaptation of the EEVC test method

The EEVC pedestrian test procedures represent a pedestrian accident at 40 km/h. This speed was chosen because studies indicated that it would be practical for vehicles to incorporate sufficient energy absorption within their structure to provide effective protection. Currently, vehicles are not designed to pass the EEVC test procedures and off-road vehicles are normally more robust than cars. Therefore, a range of lower test velocities was used with the intention of spanning the accident speed at which the base vehicles passed/failed the injury criteria. This aided the comparison of relative safety of the base vehicles and their bull bars. Other changes were made to the EEVC test procedures in order to take into account the effects of reducing the impact speed and the additional requirements of testing bull bars. These changes are described below for each impact type. The vehicles with and without the bull bars fitted were marked up as necessary using the EEVC marking up methods. For all bull bars this method identified the top tube of the bull bar as the bonnet leading edge.

2.3.1 Child headform

The EEVC WG17 has recently revised the pedestrian test methods (EEVC Committee, 1998), developed by EEVC WG10 (EEVC Committee, 1994), to exclude the need for child headform tests directly to the bonnet leading edge of tall vehicles such as off-road vehicles and only require assessment with the upper legform impactor. When a bull bar is fitted, the top tube would also be exempt from child head tests by the same rules. However, because of concern about the risk of fatal child head injuries from contacts with the top tube of the bull bar, it was decided to test both it and the bonnet leading edge of the vehicle with the child headform in this test programme. For tests to the top tube of the bull bar, the child headform test locations were selected at a wrap around distance that would result in a central headform contact. This effectively simulates a child of such a stature that the child’s head would hit the top tube in an accident. The wrap around distance was taken from the ground, at a point vertically below the bumper front face, up round the front of the vehicle. For all but vehicle F, the wrap around distance to the bull bar top tube exceeded the 1000 mm minimum distance by which the EEVC test method identifies the start of the child headform test area. Because the top tubes of the bull bars available for vehicle F were at a wrap around distance of about 900 mm, no child headform tests were carried out (children of this stature are mostly very young and accident statistics show that they are rarely at risk).

In order to select test sites on each vehicle, which could be compared with the results of the bull bar tests, the wrap around distance for the bull bars was transferred to the vehicle. Therefore, the sites on the vehicle were effectively the points that the head of a child would hit if the bull bar were not fitted. As there were several bull bars per vehicle model, an average wrap around distance was found for each vehicle. Suitable locations were then chosen along the width of the vehicle to give test points that were representative of the range of structures, avoiding obvious extremes such as the corners of the bonnet. These locations were also chosen with regard to the bull bars obtained for each vehicle model so as to select impact locations that represented the different structures found in typical bull bar designs. Because some of the bull bars were of different styles, the test positions on the bull bar did not always correspond exactly with those on the vehicle. The test speeds were adjusted by iteration, in order to obtain results which span the accident speed at which the base vehicles and the safer bull bars passed/failed the head injury criterion.

The 50° EEVC angle used for child headform impacts may be less appropriate for bull bar impacts which may be more horizontal. This is because the EEVC impact angle has been optimised for car shapes, where the head swings round onto the bonnet top, whereas a bull bar could strike a child directly on the head horizontally, if it is the first contact. It was originally anticipated that mathematical simulation could be used to determine a more appropriate impact angle for the taller vehicles commonly fitted with bull bars. However, initial simulations demonstrated that a more sophisticated human-like model than those available, would have been required for simulating children.

In the absence of suitable information from mathematical simulation, an alternative method was used. This alternative method was based on consideration of bull bar shapes for which the child head impact angle can be deduced. It was concluded that if the bull bar is shaped so that it is canted forwards, as is popular in Australia (**see** Figure 2, Appendix B), then it is possible for the first contact to be between the top tube and a child's head. In this case the impact would be essentially horizontal. Alternatively, if the bull bar is canted backwards, as is more common with European styles, it will have a significant bumper lead, which will result in the first contact being to the legs. This will cause the body to swing around, giving a head impact angle closer to that required by EEVC (50 degrees).

Taking this consideration of kinematics into account, it was concluded that using the fixed EEVC test angle would be suitable for the purpose of exploring the comparative performance of the vehicles, with and without bull bars. The most appropriate angle to use in a test method for approving bull bars is discussed further in Section 4.2.

The vehicles and bull bars were then tested with the child headform at the sites chosen and at the velocities and the angle selected above, using the pedestrian propulsion system. The headform was released to strike the selected points in free flight as required by the EEVC test method. The child headform used was the original phenolic resin version. The revised aluminium child and adult headform versions were not yet available, but they will be designed to conform to the same certification tests. This means that there should be little or no difference between the two versions at results near or below the pass criteria. However at much higher loadings, the thicker skin of the aluminium version may give a lower reading than the phenolic resin version (for the same load).

2.3.2 Upper legform

The upper legform impactor was used for both the bonnet leading edge tests and the bumper tests.

2.3.2.1 Upper legform to bonnet leading edge

The EEVC upper legform test method represents the bonnet leading edge contact in a 40 km/h impact with the side of an adult pedestrian. The shape of the vehicle affects the severity of the bonnet leading edge impact (the velocity, angle and effective pedestrian mass). Therefore, the EEVC test method requires the upper legform impactor test severity to be selected from look-up graphs to find appropriate test velocity, energy and angle for the shape of the vehicle being tested. This is done using measurements of the frontal shapes of the vehicles. (The look-up graphs give energy rather than mass because this results in a more accurate method of specifying test severity. Impactor mass can then be calculated from the required velocity and energy.) For high vehicles of the type fitted with bull bars, the bonnet leading edge strikes very early in the impact, therefore the EEVC test velocity is 40 km/h. The energy for these high vehicles should be of the order of 1500J, but EEVC recommends that the energy is capped at 700J, to keep the crush depth, needed to pass the test, to a practical depth. The impactor mass for tall vehicles can therefore be calculated to be 11.36kg. Using this mass, the test speeds selected for this study were adjusted by iteration in order to obtain results which span the accident speed at which the base vehicles and the safer bull bars passed/failed the upper legform injury criteria. By using a fixed impactor mass of 11.36kg and the alternative velocities, the impact energies were also adjusted accordingly.

The direction of the forces generated in the bonnet leading edge in an impact with a pedestrian are dependent on the vehicle shape and on the impact speed. The EEVC upper legform test method provides the relationship between vehicle shape and impact angle in the form of look-up graphs for a 40 km/h impact (11.1m/s). The EEVC angular data were found experimentally from tests between a range of instrumented cars of different shapes impacting a 50th percentile adult pedestrian dummy. For the bull bar tests additional angle data were required for lower speed impacts and this was found by computer simulation for an impact at 30 km/h (8.33m/s). The simulation used a 50th percentile adult, Hybrid III pedestrian dummy model, significantly modified to respond in a more human-like manner. The simulation generated an adjustment factor for converting the angles appropriate for 11.1m/s impacts to angles appropriate for 8.33m/s impacts. The multiplying factor found from the simulations was 0.721. These new angles were also used at slower speeds, for which simulations were not undertaken.

The bonnet leading edge reference line for a bull bar attached to the vehicle was found using the EEVC mark up method. For all the bull bars tested, this method identified the top tube of the bull bar as the bonnet leading edge. The EEVC bumper lead is defined as the horizontal distance from the bonnet leading edge to the top edge of the bumper (horizontal distance from bonnet leading edge reference line to the upper bumper reference line as defined in EEVC test method). For the vehicles without bull bars, the bonnet leading edge reference line was found to lie on the front edge of the bonnet. The EEVC mark up method for identifying the bumper top edge reference line selected the furthest forward member of the vehicle or the bull bar in the region of the bumper. The upper legform tests to the bull bars and bonnets were to the bonnet leading edge reference line. The impact locations across the width of the bonnet leading edge/bull bar top tube were selected in the same positions as the child headform tests. Bonnet leading edge height and bumper lead dimensions found from the reference lines were used when making use of the EEVC look-up graphs.

2.3.2.2 Upper legform to bumper

The EEVC test method uses a legform impactor for testing the bumper area of most cars. The legform impactor consists of an upper and lower leg section joined by a mechanical knee, and is principally intended for testing cars where the bumper makes its main contact below the knee. The height of the top edge of passenger car bumpers is generally found to be about 500 mm, which for most adults is just below the knee. Indeed, the United Nations Agreement No. 42, details uniform provisions concerning the approval of cars with regard to their front and rear bumpers, which use a test that strikes the bumper area with an impactor, the top edge of which is at 502 mm (United Nations, 1980). Off-road vehicles are a separate class of vehicle, which have high bumpers to clear rough ground. The legform impactor is less suitable for testing these vehicles where the bumper contacts above the adult knee on the femur. Therefore, WG17 has developed an alternative test for high bumpers using the upper legform impactor striking the vehicle at 40 km/h (EEVC Committee, 1998).

A limited number of tests were carried out to the base vehicles using the EEVC upper legform to bumper test method but with the velocity reduced to represent a 30 km/h impact. These tests were mainly to the centre of the bumper width.

2.3.3 Legform to bumper

The legform tests were limited to vehicles D and F to reduce the size of the test programme. Vehicle F was selected because it had a low bumper (lower bumper reference line below 500 mm). Vehicle D, with a high bumper, was selected so that the effect of a steel bull bar with a sump-guard and the effect of a canted forward deformable large diameter tube type bull bar could be explored. The legform tests to these vehicles and their bull bars were performed at 30 and 40 km/h. For each vehicle, one impact location across the vehicle width was chosen for the tests to the bull bars and the vehicle without bull bars so that the results could be compared.

3 Results

The vehicles and bull bars are not identified in the results, since the aim of this project was to provide a range of results to aid the development of a bull bar test procedure to require pedestrian protection, rather than to inform on any particular vehicle or bull bar. Instead, each vehicle and bull bar has a unique identification code. Tables and figures not included in the text can be found in Appendix A and B.

3.1 Impact conditions

The impact conditions are listed in Tables 1 to 5. These tables also indicate the origins and sense of the measurements used to report the lateral position of the test sites, along with dimensional information of the bull bars tested.

‘Bull bar code’ refers to the bull bar fitted for a test; definitions of the codes used in subsequent tables are given in Table 1.

Figure 1 shows photographs of the bull bars selected with the test sites superimposed on them.

Figure 3 shows the positions of the test sites superimposed on to photographs of the vehicles.

3.2 Test results

The results of the tests are given in Tables 6 to 9. Table 6 gives the results of the child headform tests, Table 7 the results of the upper legform tests. Table 8 gives the results of the legform tests to the bumper area, with and without bull bars fitted. Table 9 gives the results of the upper legform tests to the bumpers of the vehicles.

Damage to the vehicle bodywork was caused in some of the faster upper legform test to the bull bar top tubes. Overall it was concluded that the steel bull bars offered similar or better protection to the vehicle than the deformable solid foam and firm plastic types. However, it was interesting to note that for Vehicle D the steel bull bar pushed back and produced large dents in the forward faces of both front wings in the 30 km/h test while the large polymer tube type bull bar both passed the upper legform requirements and protected the vehicle from damage in both the 30 and the 40 km/h upper legform tests.

Figures 4 to 12 show the test results graphically with trend lines added. These trend lines for each family of test results were produced using a power equation of the form:

$$y = a \cdot x^{b}$$

Where ‘a’ and ‘b’ were selected to give a best fit to the data points.

Figures 4 to 12 also include injury risks for HIC (Mertz, 1993) and Upper Legform Force and Bending Moments (Rodmell and Lawrence, 1998). The HIC (Head Injury Criterion) is based on experiments on skull fracture associated brain injury. For a given level of HIC, it predicts the proportion of a population that would suffer a potentially life-threatening brain injury. A HIC of 1000 predicts that approximately 18% would suffer such an injury, which is a commonly used threshold as recommended by the EEVC. A HIC of 2000 predicts 90% would suffer such an injury.

Table 10 below gives the speed at which child headform and adult upper legform acceptance criteria are met, taken from the trend lines in Figures 4 to 12, for a range of selection options and also the proportion of accidents which occur at or below each speed.

Table 10 Speed at which child headform and adult upper legform acceptance criteria are met for options a to d and proportion of accidents which occur at each speed

	Child headform test				*Adult upper legform test*		
	Velocity		*Proportion of accidents #*		*Velocity*		*Proportion of accidents #*
Option	*(m/s)*	*(km/h)*	*(%)*		*(m/s)*	*(km/h)*	*(%)*
a	5.2	18.7	40		5.4	19.5	42
b	7.0	25.2	55		6.0	21.6	49
c	7.6	27.4	63		6.1	22.0	50
d	11.1	40.0	86		11.1	40.0	86

 # Proportion of accidents (all injury severity) which occur at or below each speed (Ashton, c1980)

4 Discussion

For the vehicles and bull bars tested in this programme, the child headform and adult upper legform test results show that the injury risk is significantly higher for the steel bull bars than for the vehicles without bull bars, particularly for the child head. Conversely, the results of the tests to the deformable bull bars show significantly lower risk of causing serious or fatal injuries particularly for the child head. The injury risk for steel bull bars was also seen to increase more rapidly with increasing impact speed than it does for the vehicles or the deformable bull bars, particularly for the child head. The child headform results show that children are very likely to suffer life threatening head injuries at speeds as low as 20 km/h if struck directly on the head by a steel bull bar. See Figures 4 to 9 for the headform and upper legform results and trends with speed.

The bumper was tested with the legform and upper legform impactors. However, the limited number of tests in this programme were insufficient to determine clear trends but still provided useful data on the relative performance of the vehicles and bull bars. The bumpers tested all failed the performance criteria in these tests. For the tests with the legform, the bumpers failed because they were too hard and too high, striking at about knee height, they provided no contact below the knee, which caused the knee joint to bend and often to shear in excess of the injury criteria. The addition of a bull bar would normally make very little differences to the performance of the bumper. The only exceptions to this would be for bull bars which replace or reinforce the original bumper. For the tests to the bumper with the upper legform, the bumpers failed because they were all too hard.

The upper legform to bonnet leading edge tests results show that the deformable bull bars gave lower bending moments and force results than either the base vehicles or the steel bull bars. Most of the deformable bull bars were close to meeting the upper legform requirements at 30 km/h and one of the two large diameter polymer tube types met the upper legform requirements at 40 km/h at one lateral position. This bull bar was of the ‘Australian canted forward style’ which resulted in a large gap between the bonnet and the top tube. A large stand off gap will often increase the risk of abdomen and chest penetrative injuries particularly for strong narrow bull bar top tubes; this is discussed further in Section 4.1.2. However, in this case the large gap enabled the bull bar to stroke back and absorb the energy by both flexing and local deformation without contacting the bonnet and bottoming out.

It can be seen from the results that vehicle E gave particularly poor results in the child headform and upper legform tests. This vehicle was examined to determine the cause of these poor results. This examination showed that the front cross member, on which the bonnet lock was mounted, was of an unusual construction. On most vehicles this part is relatively weak and is concealed under the bonnet, but on this vehicle it consisted of a strong box with its front face effectively forming part of the bonnet leading edge. This unusually strong front face was the cause of this vehicle’s poor performance. However, it should be noted that the vehicle was not chosen for this feature, which was identified only after testing. Even for this vehicle, the majority of steel bull bars were worse for the child head. However, one of the bull bars for that vehicle (E7S) was one of two steel bull bars that gave the best results of all the steel bull bars. This bull bar was the only steel bull bar that gave a slightly better result than the base vehicle it belonged to.

It can be seen from the results that, with one exception, the impactor outputs at any particular test point increased with increasing test velocity. The exception was found with a deformable bull bar of the moulded plastic foam type (B3D(SF)). In this case it can be seen that the child HIC increases with speed up to 30km/h and then reduces slightly for the 40km/h test. The cause of this effect has not been investigated, but the HIC calculation is very sensitive to the acceleration time history (shape of the waveform) and the overall displacement characteristics are dependent on both the bull bar’s inertia and local deformation mode. These may have combined to give a slightly better result at 40km/h. Alternatively, the effect could be due to the normal random variations seen between tests.

As already noted, examination of the child headform test results to the steel bull bars shows a very high risk of life threatening child head injuries. Although bull bar accident statistics are not normally recorded, a high level of child fatalities due to head injuries is likely to have been noted. In the absence of a noticeably high child fatality rate, it may appear that there is a disparity between this and the high risk seen in these test results. However, it must be realised that a direct impact to a child’s head is a worst case situation, which is unlikely to happen very frequently in real life. This is because vehicles with bull bars form a very small proportion of the vehicle fleet and the chances of one impacting a child pedestrian of such a height that the head is at top tube level will be low. Even when such an unfortunate combination occurs, first contact would often be below the top tube, to the shoulder, which would often reduce the severity of the head impact.

These test results demonstrate both the need for some method of controlling bull bars and the potential to improve the performance of bull bars by making use of energy absorbing deformable materials. Experience has shown that the introduction of appropriate mandatory performance standards is the most effective way of achieving improved safety without being design restrictive.

As already discussed, the EU is committed to producing a pedestrian protection Directive for cars, but this will take some time to come into effect and it will not apply to most bull bars unless it is tailored to cater for after market accessories, since they are normally fitted after vehicle approval. In addition, the EEVC procedures, on which the Directive will be based, have not been specifically developed to regulate bull bars and may require some modifications to make them suitable for testing the safety of bull bars.

One of the tasks of this research programme is to propose test methods for bull bars that could be used in a standard. These proposals need to reflect the likely pedestrian injury mechanisms and the practical limits of absorbing the pedestrians’ impact energy in the bull bar system. DETR required the research to consider:

- Test methods suitable for a UK National Legislation.
- Test methods suitable for a European Union Legislation.
- Feasibility of a visual in-service examination.

For UK National Legislation it was decided to explore the approach of a test which ensured that the addition of an approved bull bar did not reduce the pedestrian safety aspect below that of the vehicle to which it was attached. The two avenues for a test method that might result in bull bars no worse than the base vehicle were considered to be:

a a bull bar approval test at 40 km/h (speed recommended by EEVC), with the injury risk acceptance criteria adjusted to match the performance of the base vehicles at that speed;

b a bull bar approval test at a reduced speed at which the base vehicle meets the EEVC injury criteria.

Base vehicles for this purpose means current vehicles representative of the type that are commonly equipped with bull bars in the UK, but without bull bars fitted. Option (a) was felt to be unacceptable because it was anticipated that the adjusted acceptance criteria would have to be set at a very high risk of injury, to match the current vehicles. The base vehicles were not tested at the full 40 km/h speed in this test programme, but the trends of the results suggest the adjusted criteria would indeed have an unacceptably high risk of serious or life threatening injury. A bull bar test method at 40 km/h with adjusted injury risk acceptance criteria would result in bull bars that approximately match the performance of current off-road vehicles. However, it would also give approval to bull bars that the test results show to be very likely to cause serious or life threatening injuries. Therefore, option (b) was selected and option (a) was not explored further in this research programme.

From a purely scientific perspective, the velocity for a National test method to match current vehicle performance could be chosen from the following:

a At the speed at which all the base vehicles pass, i.e. at which the worst vehicle passes.

b At the speed at which the average of the base vehicles passes.

c At the speed at which only the worst vehicle failed (one out of the six base vehicles tested).

A further option for a National test method could be:

d At the speed at which the best bull bar passes, limited to no more than 40 km/h.

These values can be read off the trend lines in Figures 4 to 12. Separate values can be found for the child headform and the adult upper legform tests, as shown in Table 10 along with the proportion of accidents

For UK national legislation, suitable test speeds can be read off from Table 10 (above) for each test method. The speed at which each test method passes the criteria is different for the child headform and the upper leg test. Therefore, for each option, different speeds can be required for each test method or one compromise speed could be selected. Clearly, a regulation with reduced test speed (to match the performance of current base vehicles) would be less effective than one at the full 40 km/h.

Any recommendations for a European Legislation for bull bars should be considered alongside the European Commission commitment to draft a pedestrian protection Directive for consideration by the European parliament. This EU draft will be based on the EEVC test methods. If the EEVC test methods were adopted without change, then all new cars would be required to meet the criteria at 40 km/h. Once this legislation is in place for cars, it would be reasonable to also use 40 km/h for testing bull bars. Therefore a test speed of 40 km/h is recommended for a bull bar test method suitable for a European Union Legislation.

4.1 Limitations of the impactors for assessing bull bars

The EEVC test methods were developed for testing cars and not bull bars. The traditional steel bull bars are likely to cause concentrated loads on the test tools and to pedestrians in accidents. The limitations of the test tools are discussed in the following sections. It should be noted that it is not part of this research programme to develop test tools and methods suitable for assessing structures that produce concentrated loads. However, these limitations will be taken into account when discussing the effectiveness of possible bull bar test methods in the following section (Section 4.3).

4.1.1 Limitations of the child headform

The headform impactor and its acceptance criteria of Head Injury Criterion, HIC, have been developed to predict the risk of skull fracture, which are likely to result in life threatening brain injury. The HIC criterion was developed from biomechanical data where the impact to the skull was reasonably well-distributed (flat of forehead against a flat plate). For car structures likely to meet or come reasonably close to meeting the HIC criteria, the headform contact is also very likely to be distributed as the bonnet deforms. Therefore, a rigid impactor, such as the EEVC ones, will give a good indication of the risk of skull fractures for such cars. However, the most common types of bull bars consisting of strong small diameter tubes, when impacting a pedestrian’s head, will produce very localised stresses in the skull. If the contact force is high, this is likely to result in local shattering of the skull, which the rigid impactor will not fully indicate. A headform sensitive to stress concentrations (i.e. a frangible headform) would be better able to respond to different stress distributions, but these headforms have many practical problems which make them unsuitable for legislative use at present.

From the above the following can be concluded:

- Using a rigid headform to assess bull bars made from strong small diameter tubes means that the results will underestimate, to some extent, the risk of skull fractures. However, it can be seen from the test results that, at all but the lowest speed, the steel bull bars cause extremely high levels of HIC for the child headform, well above the acceptance criteria. Therefore, some degree of underestimating the injury risk of this type of bull bar may be acceptable, if the test velocity were sufficiently demanding that it failed the worst examples of this type of bull bar. Tests of this severity might well result in new design solutions that provide a distributed load (this is discussed further in Section 4.3).

4.1.2 Limitations of the upper legform

The upper legform impactor is designed to represent the femur/pelvis of an adult and is instrumented to measure the risk of femur and pelvis fracture. However, depending on vehicle size/shape and pedestrian stature (child stature over a range of ages or adult male and female stature distributions), the bonnet leading edge can contact a wide range of pedestrian body areas/parts. For a sub-system test, it would be impractical to develop test methods and impactors for all these combinations. Therefore, the EEVC working group examined accident data and concluded that for most shapes of vehicle the adult femur and or pelvis is more vulnerable to injury from contact with the bonnet leading edge than the abdomen or chest of children. They concluded that if a vehicle were made to pass an adult upper legform test it would also be safe for children. However, for high vehicles, the bonnet leading edge impact is normally above the height of the adult upper leg. The EEVC working group considered the need for developing additional impactors for these tall vehicles and the practical limitations on providing protection. They concluded that for tall vehicles of normal construction, meeting the upper legform requirements would provide the most protection that it would be practical to provide, with vehicle stiffness of the correct order for impacts to most other pedestrian body parts. Therefore the upper legform test method is also used for testing the bonnet leading edge of tall vehicles.

Bull bars are normally fitted to tall vehicles with the top tube at about the same height as the bonnet leading edge. The top tube of a steel bull bar is normally of small diameter, very strong and stands out from the vehicle bodywork. These factors result in an increased risk of penetrative injuries to the abdomen or chest when compared with the less strong and rounded shapes used for vehicles. The instrumentation outputs of femur bending and total force and the acceptance criteria for the upper legform impactor are aimed at preventing femur and pelvic fractures. These are less suitable for determining the injury risk for narrow shapes such as steel bull bars’ tubes when they strike other pedestrian body parts such as the abdomen and chest. (The top tube diameter and rear clearance are given in Table 1.) It should be noted that the typical 40 mm diameter of a steel bull bar top tube is small enough to fit inside the 45 mm gap typically found between the pelvis and the lower rib of an adult. Biomechanical data for penetrative injuries for the abdomen has been examined and is discussed below. However, no appropriate biomechanical data could be found for the chest. Biomechanical data for the chest could only be found for wide faced impacts. However, it is thought likely that the arguments for the abdomen will apply in principle for the chest, although, the threshold at which injuries start may be slightly higher due to the protection provided by the ribcage.

As already noted, the presence of bull bars is not routinely recorded in accident statistics. Limited data were acquired in a police survey and analysed by Hardy (Hardy, 1996), but there was insufficient detailed information to identify any clear-cut abdomen injuries where the bull bar had penetrated through the gap between the pelvis and the lower rib. However, an accident case has recently arisen where a bull bar top tube did penetrate the gap between the pelvis and the lower rib, in an accident involving a rider of a small motor scooter. Although the accident was apparently at a low speed, the rider suffered serious injuries. Those injuries attributed to the top tube were serious injuries to the liver on the struck side, and rupture of the diaphragm, lung and intestines on the non-struck side, due to internal displacement and pressure waves caused by the impact of the top tube. The abdomen of a person sitting on a scooter is at about the same height as the abdomen of a person walking. Although the presence of the scooter makes the accident different to a pedestrian accident, it is likely that similar injuries would occur in an accident with a pedestrian if the height of the abdomen and bull bar top coincided. Had the vehicle been a car or off-road vehicle without a bull bar, the flatter front-end surfaces and lack of significant protrusions would have prevented the penetration injuries.

Injury criteria have been developed for the abdomen of side impact dummies for assessing features such as arm rests fitted to the interior doors of a car. These criteria are based on the results of cadaver tests against a simulated car armrest, 70 mm wide at an impact velocity of 23 km/h (Janssen, 1986). It should be noted that the armrests tested were positioned to involve both the lower rib and the abdominal gap between the lower rib and the iliac wing of the pelvis. For the comparatively wide impacting face of this type, the injury threshold for serious liver injuries found from the cadaver tests was found to occur at a penetration depth of 28% of the half width of the abdomen and a force of 4.5kN.

The way in which the abdomen, of a living person, responds to penetrative impacts is not fully understood, however, the consensus of expert opinion is that penetration depth and velocity are most significant in causing injuries.

The acceptance criterion for force in the upper legform test is 5kN; this criterion exceeds the force found to cause serious abdomen injuries for the 70 mm wide impact face used in the cadaver tests. The top tube of standard bull bars is narrower than the armrest used in the cadaver tests. Therefore, the bull bar force that will cause serious penetration injury is likely to be lower than the 4.5kN found in the cadaver tests, particularly if the top tube of the bull bar coincides with the most vulnerable gap between the pedestrian’s ribs and the pelvic bones. Therefore, the force criterion for the upper legform test is unsuitable for controlling protection for narrow surfaces, like a steel bull bar top tube, if it is likely to strike the abdomen. Although the upper legform femur bending is sensitive to the load distribution, the femur bending acceptance criterion is also considered to be unsuitable for requiring abdomen protection for contact with a narrow face.

The cadaver tests showed that serious liver injuries occur at a penetration depth of 28% of the half width of the abdomen. For the average male, this would be 39 mm and for a small female it is about 35 mm. The top tube of the bull bars used in this test programme stands off from the front of the vehicles by a distance of between 85 and 200 mm. Some displacement of the bull bar top tube was observed in the upper legform test. Displacement of the bull bar during an abdomen contact would reduce the possible penetration depth. However, in most of the upper legform tests the displacement of the top tube was seen to be small and was insufficient to bring it into contact with the vehicle bodywork even in the higher speed tests where very high forces were recorded. Although there are no data on the force an abdomen contact would generate when struck by a narrow face, such as a bull bar top tube, the cadaver results suggest that it will be significantly lower than that found in the upper legform tests. Even the upper legform tests at the lowest test speed of 20 km/h gave comparatively high forces. Therefore, for a strong and narrow bull bar top tube, the force generated when striking the abdomen will be insufficient to displace the tube a significant distance. Consequently, there is nothing to prevent a narrow tube penetrating to about the full top tube stand-off distance, at which point the pedestrian's body would make contact with the vehicle body work. Even if the tube were free to push back against the vehicle bodywork, the tube diameter (typically 40 mm) would still provide a protuberance sufficient to cause serious abdomen injuries.

From the above, the following can be concluded:

- A strong, narrow, protruding surface such as the top tubes of traditional steel bull bars is the worst type of impact surface for the abdomen or chest. The upper legform test only assesses the strength of the bull bar and is not sufficiently sensitive to its shape to protect the abdomen or chest. The upper legform force criterion is only appropriate for abdomen contact where the contact width is in excess of 70 mm.
- The top tubes of traditional steel bull bars are very likely to cause serious injuries if they strike the abdomen of pedestrians or cyclists, even in comparatively low speed accidents.
- The top tubes of traditional steel bull bars are thought likely to cause serious injuries if they strike the chest of pedestrians or cyclists in moderate speed accidents, although biomechanical data for this type of contact could not be found.
- The upper legform test method is not ideal for assessing the safety of the narrow top tube of traditional steel bull bars if they impact the abdomen or chest, since it would pass some bull bars that are very likely to cause serious injuries. However, some degree of underestimating the injury risk of this type of bull bar may be acceptable, if the test velocity were sufficiently demanding that it failed most examples of this type of bull bar. Tests of this severity might well result in new design solutions that provide a distributed load (this is discussed further in Section 4.3)

4.2 Possible bull bar test methods

As already discussed above, the DETR required TRL to propose test methods for bull bars suitable for use in EU or UK legislation, based on the EEVC methods. Both would use the same test tools. However, the test method suitable for UK National Legislation might be at a lower speed than the EEVC test speed of 40 km/h. Adaptations of the EEVC test methods with regard to speed and use of the child head form test method for the top tube have already been produced in order to carry out this test programme. These adaptations are described in the test method (see Section 2), and are considered suitable for a bull bar test method. Ideally some further consideration should be given to an appropriate angle for the child headform test; however, this will be more sensitive to frontal shape, pedestrian stance and stature than for normal car shapes. This angle is thought to range from horizontal if the bull bar is shaped so that it is canted forward, as is popular in Australia (see Figure 2), through to a maximum of 50 degrees, if the bull bar is canted back, as is more common with European styles. Unless a complicated look up method is produced it may be better to use a pragmatic fixed angle as used in this test programme. This could be chosen to be 50 degrees to be compatible with the EEVC procedure or to be 25 degrees as a more appropriate average between the two extremes.

These modifications to the test methods and the other factors that need to be considered for a bull bar test method are:

- All parts of the bull bar within the 1000 to 1500 mm child wrap around zone should be tested with the child headform. The test angle can be selected from the options discussed above.
- The parts of the bull bar top structure, identified as the bonnet leading edge by the mark up method, should be tested with the upper legform.
- All bull bar designs should be tested on the vehicle they are intended for, because the flexibility of the mountings and interactions with the vehicle front will have a marked effect on the pedestrian safety in most cases. Subtle changes in a bull bar design to make it fit a different vehicle model are very likely to give different results when tested on that new vehicle.
- Ideally, bull bar legislation needs to be included in both assessment of independent technical units as well as whole vehicle approval. This is because they are normally fitted as an after market accessory but can be fitted as part of a whole vehicle approval assessment.

Some bull bars have a bumper section which either replaces the original bumper or covers and reinforces parts of the original bumper. In this case the upper legform to bumper test could be used for high bumpers or the legform test for lower bumpers. However, there are insufficient data from the tests reported here to propose a suitable reduced speed for a test severity intended to match the performance of current vehicles.

The above procedure would result in tests to the top and bottom sections of the bull bar and it would normally be safe to assume that the section in-between is safe. However, bull bars are a very inconsistent type of structure and it may be considered necessary also to test some parts not covered by the above method such as the mid parts of the uprights or mid horizontal tubes. In this case it is difficult to propose a scientific test. However, pragmatic test, methods might be to use the upper legform test for high bumpers and/or the child headform test for these parts, perhaps at the discretion of the regulating authorities.

4.3 Effectiveness of possible bull bar test methods

The only significant difference between the test methods discussed above is the test speed. For the proposed European legislation, the test speed proposed is 40 km/h and a further three, lower speeds have been examined for potential national legislation. As discussed earlier, legislation at a reduced test speed would be less effective.

The effectiveness of the test methods, at these different test speeds, can be judged by considering:

- the physical properties of the current types of bull bars, which affect and limit their performance in the pedestrian tests and in real life accidents;
- the types of new or modified bull bar designs that might be made to meet the requirements of bull bar test methods, at the different test speed options and for each type of bull bar construction. The test results for current bull bar designs can be used to provide some insight into possible design solutions;
- the effect of design changes to comply with a low speed bull bar approval test requirement in real life accidents at higher speeds;
- the limitations of the child headform and adult upper legform test methods when used for steel bull bars;
- the distribution of impact speed in pedestrian accidents.

Six possible modes of absorbing impact energy can be identified for bull bar structures:

- Friction pivots at the bull bar lower mounting points, in the vicinity of the bumper, allowing the bar to move towards the vehicle. (ie pivoting about clamping bolts in oversize holes.)
- Pivots at the lower mountings (free or frictional) with energy absorbing upper struts to the vehicle bodywork.
- Flexing of the main upright members of the bull bar.
- Local deformation of the bull bar materials at the impact location.
- Transferring impact energy into motion of bull bar elements (i.e. overcoming the inertia of bull bar components).
- Deformation of the vehicle structure by the bull bar interacting with the vehicle bodywork.

A combination of these modes can be used to provide pedestrian protection, but it is necessary for the contact force to remain below the injury threshold throughout the impact. Deformation of the vehicle structure was seen in earlier tests (Lawrence and Hardy, 1992). In these tests, it was found that this solution was unsuitable because the stiff bull bar structure bridged the vehicle front, distributing the load, and caused very high forces in the upper legform test.

4.3.1 Effectiveness for the child headform tests

4.3.1.1 Steel bull bars

For the steel bull bars tested, the injury risk for the child head can be seen to increase rapidly with impact velocity. At a nominal test speed of 20 km/h, all but one of the steel bull bar test results were found to exceed the recommended maximum of HIC 1000 by a considerable margin, giving a very high risk of a fatal injury (see Figure 4). The steel bull bars could be seen to flex or pivot to some extent at or near their mounting points. Local deformation of the steel bull bar tubes at the impact point was seen to be very small. Examination of the physical properties of the steel bull bars suggests the energy of the headform impact would be absorbed primarily by a combination of overcoming the inertia of the top tube and the flexing or pivoting at the lower mountings. Initially the contact force would be primarily due to the headform overcoming the inertia of the top tube assembly and starting to push it back. Further energy would then be absorbed in a second phase by movement at the lower mountings. This movement at the mountings was most noticeable with the bull bar that gave the lowest HIC values, out of the steel bull bars (bull bar E7S on vehicle E). However, it should be noted that this bull bar, which passed the HIC 1000 requirement in the low speed test at about 20 km/h, gave a 74% risk of life threatening injury in an impact at only 25 km/h. The compliance of the flesh on the headform impactor would provide some contribution to reducing the HIC value in a low speed test, but the 7.5 mm flesh thickness would soon ‘bottom out’ at higher speeds. This high rate of increase in the risk of life-threatening brain injuries with speed for this bull bar (E7S), is in this case matched by the vehicle to which it is mounted (E), which had a particularly strong bonnet leading edge box design. All the other base vehicles tested had a much lower rate of increase.

Steel bull bars designed to be pedestrian friendly have been tested in the past (Lawrence and Thornton, 1996). These pedestrian friendly bull bars were designed to make use of the same principles of reduced mass and hinging at the lower mountings in a more controlled way, which caused bull bar E7S to give good results in the low speed test in this test programme. These pedestrian friendly designs gave very good results in these earlier child headform tests, at 24 km/h, and could possibly be made to meet the HIC requirement at speeds up to about 30 km/h. It is possible that this hinged design may become popular with steel bull bar manufacturers if a low speed approval test method were introduced. However, the energy of an impact increases rapidly with speed and will have almost doubled as the impact speed increases from 30 to 40 km/h. It is thought likely that the inertial forces with this hinged design would become unacceptable at higher impact speeds. It is also likely, at higher impact speeds, that the system used to control the rearward stroke of the bull bar would absorb insufficient energy to provide protection causing the bull bar to ‘bottom out’ against the vehicle body work giving high forces. It is therefore anticipated that all steel bull bars made to meet a low speed approval test method would have a high rate of increase in injury risk with speed.

A further option to make steel bull bars more pedestrian friendly, is to improve their ability to deform locally. However, the lack of any significant dents in the tubes of the steel bull bars tested show that the tubes are currently far too strong to deform at a safe force. The tubes could be made to deform at a lower force by reducing the wall thickness, increasing the tube diameter, changing the steel to one with a lower yield strength or a combination of these. However, to provide suitable protection, the change in strength would have to be large and these changes would also make it more difficult to bend the tube to shape. Ultimately, there are practical limits on tube diameter and wall thickness that can be bent and it is thought that these would exclude steel tube of sufficiently large diameter and small wall thickness to deform locally at the force level required for head protection. The possibility of using different materials, such as copper, or different types of construction, to improve the local deformation properties of metal tube bull bars could be explored.

For steel/metal bull bars it is considered that the above methods of absorbing energy (the hinged bar and the locally compliant tube) are the most feasible methods of producing bars to pass a pedestrian test method at speeds up to 30 km/h. However, it is thought to be difficult to produce a viable steel/metal tube design that would meet the requirements of a 40 km/h test and it may be more feasible to switch from steel to deformable materials if the test speed were 40 km/h.

It is anticipated that a hinged steel bull bar design would be the most popular solution to meet a low speed, child headform approval test. This solution is likely to have a high rate of increase in the risk of life threatening head injury with speed. This means that low speed approved steel bull bars would be safe in low speed accidents but have a very high risk of causing life threatening child head injuries in accidents at higher speeds. In addition, because the injury risk from steel bull bars is likely to increase more rapidly than that of the base vehicle, a low speed approved bull bar would also be more dangerous than the base vehicles in accidents above the test speed. Because the proportions of accidents which occur at low speeds is small, a low speed approval test method would result in steel bull bars with effective protection for only a small proportion of pedestrian accidents. The proportions of accidents for each speed option are given in Table 10 of Section 4. With a regulation in place bull bar manufacturers are likely to design to exceed the minimum regulation requirements. However, because the test results show that unlike deformable bull bars, steel bull bars have a high rate of increase in injury risk with respect to speed, the additional benefits likely to accrue for designs which exceed the requirements, are likely to be small for steel bull bars and large for deformable bull bars.

4.3.1.2 Deformable bull bars

For the deformable bull bars tested, the injury risk for the child head can be seen to increase slowly with impact velocity. At the test speeds of 20, 25 and 30 km/h, they were all found to be well within the recommended maximum of HIC 1000, giving a very low risk of a fatal injury. Even at the highest test speed of 40 km/h, one passed the HIC requirement and the rest only exceeded it by a small margin, the worst giving an injury risk of just under 50% (see Figure 4). It is anticipated that little effort would be required to make all deformable bull bars pass at 40 km/h.

The deformable bull bars of the solid foam plastic type and the firm plastic ‘U’ type appeared to absorb energy mainly by local deformation although some flexing of the rest of the structure was seen. For the large-diameter continuous-polymer hollow-tube type, the energy appeared to be absorbed by a combination of the whole bull bar structure flexing and local deformation. The high level of local compliance seen with the deformable bull bars means that the mass and inertia of the bull bar material involved in the head impact is small. This combined with an appropriate force deflection characteristic is thought to be the main reason for the very low rate of increase in HIC values with speed seen in the test results. This low sensitivity to speed means that deformable bull bars tested at one speed may well still be safe for many of the stronger pedestrians in accidents at higher speeds, particularly if the bull bars exceed the minimum requirement. The deformable bull bars have demonstrated the practicality and feasibility of meeting a 40 km/h test and, if it became mandatory, would provide protection in at least 86% of pedestrian accidents (see Figure 4 and Table 10).

The manufacturers’ publicity material for the deformable bull bars selected for testing in this test programme suggests that all were designed with pedestrian protection in mind and all have been tested by the manufacturer, to the EEVC child headform test method at 40 km/h. It should be noted that although the bars tested by the manufacturers were not necessarily exactly the same versions tested in this programme, they were of similar construction and in at least one case the tests were conducted with a different headform test angle. These deformable bull bar results therefore give some indication of the improvements that have already been achieved with the aid of a non-mandatory EEVC child test method at 40 km/h. It is thought that the switch to deformable materials is due to the demands of meeting a 40 km/h test. It should be noted that the investment costs to produce deformable bull bars are likely to be more than those for steel bull bars. The concern of both vehicle manufacturers and the public about the safety of steel bull bars has led to a demand for pedestrian friendly bull bars. Therefore, currently plastic bull bars have had a marketing advantage if they have been shown to be pedestrian friendly by meeting the 40 km/h requirements of EEVC. The introduction of an approval test at a lower speed might well remove the incentive to produce deformable bull bars. This is because deformable bull bars would then be competing with lower cost steel bull bars which could also be sold as ‘approved pedestrian friendly’ despite the steel bull bars offering less effective protection.

As has already been discussed, the EEVC test methods are not intended for bull bars. For high vehicles, the EEVC test methods only require the bonnet leading edge area to be tested with the upper legform impactor, although child headform tests are required close to the bonnet leading edge. This compromise is considered appropriate for approval tests to normal vehicle constructions. This is because a vehicle that meets the legform requirement will provide local deformation and low inertia. Although the stiffness required by the upper legform test might not be ideal for the child head, it will provide improved protection over that currently provided by most off-road vehicles. Also the deformation area required to meet the child head requirement in tests adjacent to the bonnet leading edge, is very likely to impinge on the bonnet leading edge area, testing the bonnet leading edge to the child head requirement to some extent. However, steel bull bars have high inertia and provide little local deformation and therefore the headform results show a very high child head injury risk. Because the bull bar does not form part of a continuous bonnet structure, adjacent child head tests on the bonnet top will place no child headform demands on the bull bar. Taking this into account, the test results show that for testing bull bars, especially steel bull bars, a child headform test is also necessary.

4.3.1.3 Summary of effectiveness for the child headform test

- If the EEVC test method were applied to bull bars without modification only an upper legform test would be required for the top tube. However, the test results show that a child headform test is essential for bull bars.
- A low-speed child headform bull bar test method is unlikely to be effective. It would most likely result in predominately steel bull bar designs. These approved bull bars would still have a very high risk of causing life threatening child head injuries, over the speed range at which the majority of accidents occur.
- A low-speed child headform bull bar test method may be counter-productive. Deformable bull bars have been shown to provide high levels of protection for the child head. The introduction of an approval test at a lower speed might well remove the marketing incentive to produce deformable bull bars.
- A high-speed, 40 km/h, child headform bull bar test method is likely to prove effective. It would most likely result in predominately deformable bull bar designs. These deformable bull bars would have a low risk of causing life threatening child head injuries, over the speed range at which the majority of accidents occur.

4.3.2 Effectiveness for the upper legform test

The results for the upper legform test show a similar pattern to those found with the child head test. However, the difference between the vehicle and the steel and deformable bull bars is less marked, particularly for the force results. The difference between the injury severity risk for the force and bending results is due to the bending output being sensitive to the load concentration caused by the steel bull bars.

The hinged bull bar design for steel bull bars described above is also likely to be a popular solution to meet a low speed upper legform approval test. These designs would most probably feature a narrow, protruding top tube. The height of the top tube most commonly coincides with the height of the adult femur, pelvis, abdomen or chest. The limitations of the upper legform test method for the contacts between a bull bar top tube and the abdomen and chest of a pedestrian have been discussed in Section 4.1.2. It was concluded that the upper legform test is unsuitable for requiring abdomen and chest protection for narrow contact surfaces. Therefore a low speed upper legform bull bar test method would provide little effective protection in accidents where the top tube made contact with the abdomen or chest. Thus low speed approved bull bars would have a very high risk of causing serious or life threatening abdomen and chest injuries, even in low speed accidents. However, as with the child head, it will be difficult to produce a viable steel/metal tube design that would meet the requirements of a 40 km/h upper legform test. Therefore, it will be more feasible to switch to deformable materials if the test speed were 40 km/h, which would be more suitable for protection of the chest and abdomen. This is discussed further in the final paragraph of this section.

The upper legform test method was designed to require appropriate protection when the impact is to the adult femur or pelvis (at a higher speed of 40 km/h). Therefore, an upper legform test method for bull bars will provide effective protection in accidents where the bull bar coincides with the femur and pelvis. If a 40 km/h speed is chosen for the upper legform test then it is likely to provide effective femur and pelvis protection over the speed range at which the majority of accidents occur. The range of heights of the top of the bull bars can be seen in the ‘BLE height’ column of Table 3. The height of the bull bar can be seen to range from 860 to 1150 mm. This can be compared with the iliac crest (bony part at side of pelvis) heights for 5th, 50th and 95th percentile men of 965, 1041 and 1118 mm respectively and for women 876, 953 and 1029 mm respectively (derived from Gaebler, 1964). This comparison shows that for many adults the bull bar contact will be to the femur or pelvis and for these cases an upper legform test will be effective. In general only the smaller adult and larger children will be at risk of chest and abdomen contact from the upper parts of the bull bar (smaller children will be hit on the head). However, the highest the bull bars seen in this programme exceeded the height of the Iilac crest for 50th percentile males and 95th percentile females.

The combination of upper legform impactor mass and the force acceptance criteria mean that to protect the femur and pelvis (and the abdomen and chest for wide bull bar contact faces) a larger crush depth is required than for the child headform. Therefore it is essential that any bull bar test method also includes an upper legform test.

Because of the practical constraints, stroke in excess of that required to meet the minimum test requirement will be limited. Therefore, a hinged system is very likely to ‘bottom out’ in accidents with adults at higher speeds. The risk of injury to the femur, pelvis, abdomen and chest when a hinged system ‘bottoms out’ against the vehicle will be high. This ‘bottoming out’ effect was seen in tests by Lawrence to a prototype bull bar and was seen to cause very high forces because the bull bar spread the load across the width of the vehicle (Lawrence and Hardy, 1992). Therefore, a low speed upper legform approval test is likely to encourage design solutions which are only effective for contacts with the adult femur and pelvis in the small proportion of accidents occurring at low speeds.

Conversely it is anticipated that design solutions to absorb the energy of a 40 km/h upper legform test would deform locally. A deformable bull bar would provide a more distributed load over a wide area. If the contact width is in excess of 70 mm then it would overcome the limitation of the upper legform test for protecting impacts to the abdomen and chest. It is known that some of the deformable bull bars tested have only been designed to meet the child headform requirement. Nevertheless, the results from the tests to the deformable bull bar made from large diameter polymer tube (test code 115) show that it is possible to meet the requirements of a 40 km/h upper legform test. The low force and large deformed contact width of this large tube was thought to be sufficient to prevent abdomen and chest injuries. Therefore, for this design of bull bar, a high-speed, 40 km/h, adult upper legform bull bar test method is also likely to be effective for the abdomen and chest over the speed range at which the majority of accidents occur.

4.3.2.1 Summary of effectiveness for the adult upper legform test

- For many adults the bull bar contact will be to the femur or pelvis and for these cases an upper legform test will be effective.
- In general only the smaller adult and larger children will be at risk of chest and abdomen contact from the upper parts of the bull bar. However, the highest bull bars are likely to strike the abdomen or chest of all but the taller adult males.
- It is essential that any bull bar test method include an upper legform test as well as a child headform test, because the energy absorbing capacity required to protect is different for each body part.
- A low-speed adult upper legform bull bar test method is very unlikely to be effective for impacts to the abdomen or chest. It is most likely to result in predominately steel bull bar designs. These approved steel bull bars would have a very high risk of causing serious or life threatening abdomen and chest injuries even in low speed accidents.
- A high-speed, 40 km/h, adult upper legform bull bar test method is likely to be effective. It would most likely result in predominately deformable bull bar designs. These approved bull bars would have a low risk of causing serious or life threatening femur, pelvis, abdomen and chest injuries, over the speed range at which the majority of accidents occur.
- A low speed adult upper legform bull bar test method is unlikely to provide effective protection where the top tube strikes the femur or pelvis except in low speed accidents. At the high speeds at which the majority of accidents occur, an approved bull bar would still have a very high risk of causing serious femur or pelvis injuries.
- A low-speed adult upper legform bull bar test method may be counter-productive. The introduction of an approval test at a lower speed might well remove the marketing incentive to produce safer deformable bull bars.

4.4 Practicality of a ‘visual’ test method

The test methods outlined above in Section 4.2 will obviously be expensive and TRL were requested to consider if the aggressiveness of bull bars could be judged by observing their mass, shape, material and construction. The potential of visual inspection method was examined by comparing the physical properties of the bull bars with their test results.

Good and bad results were found for bull bars of both heavy and light mass. It was therefore concluded that bull bar mass was not a good indicator of performance. Similar bull bar shapes were often found to give different results and different shaped bull bars often gave similar results. It was therefore concluded that bull bar shape was not a good indicator of performance. The examples listed below in Table 11, extracted from the headform results in Table 6, illustrate this point.

Bull bar material and construction were the only clear links between the physical properties and the injury risk, demonstrated by the differences in results for the steel tube versus deformable plastic materials (see Figures 4 to 12). However, regulating by material type and not performance could be seen as discriminatory because it may well be possible to make safe steel bull bars, for instance by making them from pressed sheet steel. Excluding one particular material may also result in the use of an alternative dangerous material and could result in uncertainty when steel parts are used in combination with deformable materials.

It was therefore concluded that a visual assessment test method for bull bars would be impractical. Based on testing experience, it is also very likely to be similarly difficult to judge the aggression of base vehicles with a visual assessment test method.

Table 11 Examples of headform results

	Test codes at nominal test velocity			*HIC at nominal test velocity*		
Bull bar shape	*20 km/h*	*30 km/h*	*Bull bar material*	*20 km/h*	*30 km/h*	*Mass (kg)*
‘A’-bar	1	3	Steel	2415	6202	7
‘A’-bar	13	15	Deformable plastic	87	401	6.5
‘A’-bar	55	57	Steel	980	3327	8.5
‘Traditional’-bar	4	6	Steel	2901	7015	22
‘Traditional’-bar	24	26	Steel	1663	5720	14.5
‘Traditional’-bar	N/A	36	Deformable plastic	N/A	759	24.5
‘Traditional’-bar	52	54	Deformable plastic	253	694	17

5 Summary

1 A direct impact of a steel bull bar to a child's head is a worst case situation, which will rarely happen in real life. Nevertheless, when it occurs, the test results show that a steel bull bar has a very high risk of life threatening child head injuries even in low speed impacts and is more likely to cause a fatal head injury than a vehicle without a bull bar.

2 One of the vehicles tested, Vehicle E, was found to give particularly poor results in the pedestrian sub-systems tests. This was attributed to an unusually strong method of construction. Even for this vehicle, the majority of steel bull bars were worse for the child head. However, one of the bull bars (E7S) for that vehicle (E) was one of two steel bull bars that gave the best results of all the steel bull bars. This bull bar was the only steel bull bar that gave a slightly better result than the base vehicle it belonged to.

3 The test results for the deformable bull bars show that it is possible to provide pedestrian protection effective at speeds up to at least 40 km/h, for the child head and the femur, pelvis, abdomen and probably for the chest of the adult or larger child.

4 The deformable bull bar test results give some indication of the improvements that have already been achieved with the aid of a non-mandatory EEVC test method at 40 km/h.

5 For many adults the bull bar contact will be to the femur or pelvis and for these cases an upper legform test will be effective.

6 In general only the smaller adult and larger children will be at risk of chest and abdomen contact from the upper parts of the bull bar. However, the higher bull bars are likely to strike the abdomen or chest of all but the taller adult males.

7 The test results and biomechanical considerations show that the top tubes of traditional steel bull bars are very likely to cause serious injuries if they strike the abdomen of pedestrians or cyclists, even in comparatively low speed accidents. However, the very limited bull bar accident data makes it impossible to identify whether this is happening in real life. Such top tubes are also thought likely to cause serious injuries if they strike the chest of pedestrians or cyclists in moderate speed accidents, although biomechanical data for this type of chest contact could not be found.

8 The test results for the steel and deformable bull bars demonstrate both the need for some method of controlling bull bars and the potential to improve the performance of bull bars by making use of energy absorbing deformable materials.

9 It is considered essential that any bull bar test method include an upper legform test as well as a child headform test, because the energy absorbing capacity required to protect these body parts is different.

10 The speed at which the selected vehicles, without bull bars, can meet the requirements of the EEVC pedestrian protection test method has been found for the child head and adult upper leg. Proposals for low speed test methods based on this have been produced. Clearly, a UK standard with reduced test speed would be less effective than one at the full 40 km/h. A low speed bull bar approval test is thought likely to result in the following disadvantages:

- It is anticipated that a hinged steel bull bar design would prove the most popular solution to meet the requirements of a low-speed bull bar test method using the child headform and the adult upper legform. Low speed approved bull bars using this design principle would have a very high risk of causing serious or life threatening injuries at the higher speeds where a large proportion of pedestrian accidents occur.
- A low speed bull bar approval test is thought likely to encourage the production of steel designs with a higher rate of increase, with speed, in the risk of injuries than the base vehicle. This would mean that approved steel bull bars would only be safe in the small proportion of accidents, which occur at low speed. However, they would be very likely to cause life-threatening injuries and be more dangerous than the base vehicles in accidents above the test speed.
- It is anticipated that the additional benefits likely to accrue for designs, which exceed the requirements of a low speed approved test, are likely to be small for steel bull bars and large for deformable bull bars.
- A low speed approval test would under estimate the risk of fatal and serious child head, adult abdomen and adult chest injuries when testing any strong narrow designs of steel tube bull bar.
- Steel bull bars made to meet a low speed approval test requirement could then be sold as 'approved pedestrian friendly' despite only offering protection effective in a small proportion of accidents.
- The deformable bull bars tested provide enhanced protection at up to 40 km/h. It should be noted that the investment costs to produce deformable bull bars are likely to be more than those for steel bull bars. Therefore, the introduction of an approval test at a lower speed might well remove the marketing incentive to produce deformable bull bars, which are usually marketed as pedestrian friendly, unlike steel ones.

11 The EU is committed to producing a pedestrian protection Directive for cars, but this will take some time to come into effect and it will not apply to most bull bars unless it is tailored to cater for after-market accessories, since they are normally fitted after vehicle approval. In addition the EEVC procedures, on which the Directive will be based, have not been specifically developed to regulate bull bars and may require some modifications to make them suitable for testing the safety of bull bars.

12 Proposals for a 40 km/h bull bar test method have been produced based on the EEVC test methods. These test methods are thought suitable for inclusion in an EU directive to control bull bars.

13 Both the child headform and the adult upper legform tests have some limitations in measuring the 'real' injury risk when testing bull bars made from strong small diameter tubes. Despite this, a high speed (40 km/h) test would still be demanding and it is thought to be difficult to produce a viable traditional tube design that would meet the requirements. Therefore, a 40 km/h approval test is very likely to result in manufacturers using new design solutions that provide a distributed load, such as the deformable bull bars.

14 For high vehicles the EEVC test methods do not require child headform tests to the bonnet leading edge, although child headform tests are required at positions close to it. This compromise is considered appropriate for approval tests to normal vehicle constructions but not for bull bars. Taking into account the differences between bull bar and vehicle construction and the test results, it has been concluded that, for testing bull bars, especially steel bull bars, a child headform test is also essential.

15 The potential of a visual inspection method was examined. The only clear link between the physical properties and the injury risk was for the steel tube versus plastic materials. However, regulating by material was not thought to be acceptable and it could result in uncertainty e.g. when steel parts are used in combination with deformable materials.

16 It was interesting to note that for vehicle D the steel bull bar failed the upper legform test requirements and did not protect the vehicle body work in a 30 km/h test. In contrast, the large polymer tube type bull bar protected the vehicle from damage in both the 30 and the 40 km/h upper legform tests and passed the upper legform requirements.

6 Conclusions

1 Test methods suitable for regulating the pedestrian protection provided by bull bars have been developed, based on the EEVC 40 km/h pedestrian test methods.

2 Reduced test speeds have been established for a bull bar test method that matches the performance currently provided by vehicles of the type commonly fitted with bull bars. However, to be effective, a bull bar standard would have to be more stringent than current vehicles' performance.

3 A selection of representative vehicles and bull bars have been tested using an adaptation of the EEVC pedestrian protection test procedure.

4 The steel bull bars tested have been shown to have a very high risk of causing serious and life-threatening injuries in impacts with the heads of children and the abdomen and chest of adults and taller children, even in low speed accidents. However, the very limited bull bar accident data makes it impossible to identify whether this is happening in real life. Nevertheless, the tests show that some method of encouraging safer bull bars would be beneficial.

5 The deformable bull bars tested have been shown to have a very low risk of causing serious and life-threatening injuries in impacts with the heads of children, in accidents at speeds up to at least 40 km/h. One type of deformable bull bar has shown that as well as protecting the child head it is also possible to provide femur, pelvis abdomen and chest protection effective in accidents at speeds up to 40 km/h.

6 A direct impact of a steel bull bar to a child's head is a worst case situation, which will rarely happen in real life; however, when it occurs, it is likely to result in serious or fatal injury.

7 To require effective protection it is considered essential that a bull bar test method includes an adult upper legform test and a child headform test for the top parts of the bull bar.

8 A low speed test could encourage bull bars that gave acceptable results at low speed but with a performance that deteriorated very rapidly as the speed of impact increased. They could therefore be very dangerous at the speeds where a large proportion of serious injury accidents occur.

9 It is considered that a reduced speed bull bar test method, that matches the performance provided by current vehicles (of the type commonly fitted with bull bars) would be at such a low speed that it would be counter-productive.

7 Recommendation

A low speed bull bar approval regulation should not be introduced because it will bring small real world benefits and may prove to be counterproductive in many respects.

It has been demonstrated that it is feasible to make ball bars to meet the requirements of a 40 km/h sub-systems test method. Therefore it is recommended that consideration should be given to introducing the 40 km/h bull bar test methods, proposed in this report, to control bull bars. It is anticipated that a 40 km/h regulation would result in a significant improvement in real world pedestrian safety.

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Appendix A: Tables

Table 1 Bull bar information

Bull bar code	Bull bar mass (kg)	Bull bar material		*Upper legform to bonnet leading edge test*		
				Lateral test position (mm)	*Bull bar top tube dimensions (mm)*	*Bar to bonnet distance (mm)*
F1S	25	Steel, profile		N/A	N/A	N/A
C2S	24	Steel, profile		282	80# / 40*	150
B3D(SF)	6.5	Deformable, Foam		90	50#	100
B4S	22.5	Steel, profile		90 550	∅40 ∅40	100 100
B5S	14.5	Steel, tubular		325	∅60	110
E6D(U)	17	Deformable, U section		250	60#	110
E7S	8.5	Steel, tubular		90	∅50	215
E8S	21.5	Steel, tubular		260	80# / 40*	200
D9S	14.5	Steel, tubular		90	∅60	90
A10S	7	Steel, tubular		130	∅65	85
A11S	22	Steel, profile		582	∅40	170
C12D(P)	24.5	Deformable, polymer		282	∅75	175
D13D(P)	19	Deformable, polymer		90 335	∅70 ∅70	260 260

∅ indicates tube diameter
** indicates width of upright (for a non tubular section of the bar)*
 # indicates depth at upright (for a non tubular section of the bar)
'Bar to bonnet distance' is the shortest distance from the front of the tube at impact point to the bonnet.
Steel, profile indicates that the main uprights are made from an 'I' section.
Steel, tubular indicates that the main uprights are made from a tube section.

Bull bar codes for subsequent tables:

The letter at the start of the code refers to the vehicle that the bull bar is fitted to, from A to F.

The number following refers to the bull bar number (see Figure 1).

The letter following refers to the material of the bull bar, either Steel, 'S' or a Deformable material, 'D'.

If the material is deformable, then the letter in brackets refers to the type of deformable bull bar (See Section 2.2 for more detailed descriptions of the deformable types):

'(SF)' indicates a moulded solid foam plastic construction.

'(U)' indicates a firm plastic U-section construction (closed by a metal frame at the rear).

'(P)' indicates a large-diameter continuous-polymer hollow-tube construction.

Origins and sense of lateral test position:

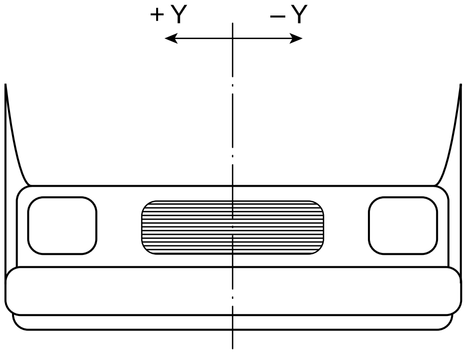


Table 2 Headform test conditions

Test code	Vehicle code	Bull bar code	Bull bar mass (kg)	Wrapround distance to test point (mm)	Lateral test position (mm)	Nominal test velocity (km/h)	Achieved impact velocity (m/s)	Achieved impact velocity (km/h)	Child head form mass (Kg)	Child head form energy (J)
1	A	A10S	7	1160	130	20	5.87	21.1	2.5	43
2	A	A10S	7		130	25	7.12	25.6	2.5	63
3	A	A10S	7		130	30	8.46	30.5	2.5	89
4	A	A11S	22	1160	582	20	5.61	20.2	2.5	39
5	A	A11S	22		582	25	6.94	25.0	2.5	60
6	A	A11S	22		582	30	8.39	30.2	2.5	88
7	A	None		1140	-130	20	5.52	19.9	2.5	38
8	A	None			582	20	5.58	20.1	2.5	39
9	A	None			130	25	6.97	25.1	2.5	61
10	A	None			582	25	7.07	25.5	2.5	62
11	A	None			130	30	8.30	29.9	2.5	86
12	A	None			582	30	8.30	29.9	2.5	86
13	B	B3D(SF)	6.5	990	90	20	5.45	19.6	2.5	37
14	B	B3D(SF)	6.5		90	25	6.82	24.6	2.5	58
15	B	B3D(SF)	6.5		90	30	8.35	30.1	2.5	87
16	B	B3D(SF)	6.5		90	40	11.17	40.2	2.5	156
17	B	B4S	22.5	1020	550	15	4.2	15.1	2.5	22
18	B	B4S	22.5		550	20	5.54	19.9	2.5	38
19	B	B4S	22.5		550	20	5.58	20.1	2.5	39
20	B	B4S	22.5		550	25	6.99	25.2	2.5	61
21	B	B4S	22.5		90	25	7.10	25.6	2.5	63
22	B	B4S	22.5		90	30	8.37	30.1	2.5	88
23	B	B4S	22.5		550	30	8.41	30.3	2.5	88
24	B	B5S	14.5	1060	325	20	5.37	19.3	2.5	36
25	B	B5S	14.5		325	25	6.72	24.2	2.5	56
26	B	B5S	14.5		325	30	8.31	29.9	2.5	86
27	B	None		1020	325	20	5.60	20.2	2.5	39
28	B	None			-90	20	5.80	20.9	2.5	42
29	B	None			-325	25	6.88	24.8	2.5	59
30	B	None			90	25	7.00	25.2	2.5	61
31	B	None			-325	30	8.29	29.9	2.5	86
32	B	None			550	30	8.32	30.0	2.5	87
33	B	None			90	30	8.32	30.0	2.5	87
34	C	C2S	24	1130	90	25	6.96	25.1	2.5	61
35	C	C2S	24		90	30	8.36	30.1	2.5	87
36	C	C12D(P)	24.5	1050	90	30	8.32	30.0	2.5	87
37	C	C12D(P)	24.5		90	40	11.02	39.7	2.5	152
38	C	None		1120	90	25	7.03	25.3	2.5	62
39	C	None			90	30	8.320	29.9	2.5	87
40	C	None			-282	30	8.43	30.3	2.5	89

Continued ....

Table 2 (Continued) Headform test conditions

Test code	Vehicle code	Bull bar code	Bull bar mass (kg)	Wrapround distance to test point (mm)	Lateral test position (mm)	Nominal test velocity (km/h)	Achieved impact velocity (m/s)	Achieved impact velocity (km/h)	Child head form mass (Kg)	Child head form energy (J)
41	D	D9S	14.5	1160	600	20	5.64	20.3	2.5	40
42	D	D9S	14.5		600	25	6.96	25.1	2.5	61
43	D	D9S	14.5		600	30	8.31	29.9	2.5	86
44	D	D13D(P)	19	1030	335	25	6.94	25.0	2.5	60
45	D	D13D(P)	19		335	30	8.26	29.7	2.5	85
46	D	D13D(P)	19		335	40	11.05	39.8	2.5	153
47	D	None		1070	335	25	7.00	25.2	2.5	61
48	D	None			-200	30	8.24	29.7	2.5	85
49	D	None			-335	30	8.34	30.0	2.5	87
50	D	None			90	30	8.38	30.2	2.5	88
51	D	None			-90	30	9.29	33.5	2.5	108
52	E	E6D(U)	17	970	260	20	5.51	19.8	2.5	38
53	E	E6D(U)	17		260	25	6.96	25.1	2.5	61
54	E	E6D(U)	17		260	30	8.38	30.2	2.5	88
55	E	E7S	8.5	1000	90	20	5.62	20.2	2.5	39
56	E	E7S	8.5		90	25	6.95	25.0	2.5	60
57	E	E7S	8.5		90	30	8.40	30.2	2.5	88
58	E	E8S	21.5	960	260	20	5.70	20.5	2.5	41
59	E	E8S	21.5		260	20	6.01	21.6	2.5	45
60	E	E8S	21.5		260	25	6.93	24.9	2.5	60
61	E	E8S	21.5		260	30	8.37	30.1	2.5	88
62	E	None		980	605	15	4.33	15.6	2.5	23
63	E	None			605	20	5.64	20.3	2.5	40
64	E	None			260	20	5.80	20.9	2.5	42
65	E	None			605	25	6.80	24.5	2.5	58
66	E	None			-260	25	6.95	25.0	2.5	60
67	E	None			605	30	8.16	29.4	2.5	83
68	E	None			-260	30	8.24	29.7	2.5	85
69	E	None			90	30	8.33	30.0	2.5	87

Table 3 Upper legform to bonnet leading edge/top tube test conditions

Test code	*Vehicle code*	*Bull bar code*	*Bull bar mass (kg)*	*Lateral test position (mm)*	*Impact angle (°)*	*Nominal test velocity (km/h)*	*Achieved impact velocity (m/s)*	*Achieved impact velocity (km/h)*	*BLE height (mm)*	*Bumper lead (mm)*	*Upper legform Mass (kg)*	*Upper legform energy (J)*
70	A	A10S	7	130	12.3	20	5.31	19.1	1150	80	11.36	160
71	A	A10S	7	130	12.3	25	6.85	24.7	1150	80	11.36	267
72	A	A10S	7	130	12.3	30	8.41	30.3	1150	80	11.36	402
73	A	A11S	22	582	10.8	20	5.27	19.0	1040	50	11.36	158
74	A	A11S	22	582	10.8	20	5.44	19.6	1040	50	11.36	168
75	A	A11S	22	582	10.8	25	6.79	24.4	1040	50	11.36	262
76	A	A11S	22	582	10.8	30	8.35	30.1	1040	50	11.36	396
77	A	None		-130	17.0	20	5.66	20.4	1136	128	11.36	182
78	A	None		582	17.0	20	5.66	20.4	1136	128	11.36	182
79	A	None		130	17.0	25	6.86	24.7	1136	128	11.36	267
80	A	None		582	17.0	25	6.86	24.7	1136	128	11.36	267
81	A	None		130	17.0	30	8.33	30.0	1136	128	11.36	394
82	A	None		582	17.0	30	8.33	30.0	1136	128	11.36	394
83	B	B3D(SF)	6.5	90	12.3	20	5.52	19.9	970	50	11.36	173
84	B	B3D(SF)	6.5	90	12.3	25	6.92	24.9	970	50	11.36	272
85	B	B4S	22.5	90	10.8	20	5.46	19.7	985	45	11.36	169
86	B	B4S	22.5	550	10.8	20	5.52	19.9	985	45	11.36	173
87	B	B4S	22.5	90	10.8	25	6.84	24.6	985	45	11.36	266
88	B	B4S	22.5	550	10.8	25	6.90	24.9	985	45	11.36	271
89	B	B4S	22.5	550	10.8	30	8.32	30.0	985	45	11.36	393
90	B	B4S	22.5	90	10.8	30	8.38	30.2	985	45	11.36	399
91	B	B5S	14.5	325	14.4	20	5.70	20.5	1050	100	11.36	185
92	B	B5S	14.5	325	14.4	25	6.85	24.7	1050	100	11.36	267
93	B	B5S	14.5	325	14.4	30	8.41	30.3	1050	100	11.36	402
94	B	None		-550	16.0	20	5.59	20.1	993	87	11.36	177
95	B	None		325	16.0	20	5.65	20.3	993	87	11.36	181
96	B	None		325	16.0	20	6.30	22.7	993	87	11.36	225
97	B	None		-550	16.0	25	6.65	23.9	993	87	11.36	251
98	B	None		325	16.0	25	6.78	24.4	993	87	11.36	261
99	B	None		90	16.0	30	8.29	29.8	993	87	11.36	390
100	B	None		325	16.0	30	8.30	29.9	993	87	11.36	391
101	B	None		550	16.0	30	8.30	29.9	993	87	11.36	391
102	C	C2S	24	282	7.2	25	6.98	25.1	1100	50	11.36	277
103	C	C2S	24	282	7.2	30	8.42	30.3	1100	50	11.36	403
104	C	C12D(P)	24.5	282	12.0	30	8.42	30.3	1043	66	11.36	403
105	C	C12D(P)	24.5	282	16.7	40	10.75	38.7	1043	66	11.36	656
106	C	None		282	12.0	25	6.94	25.0	1012	65	11.36	274
107	C	None		90	12.0	30	8.40	30.2	1012	65	11.36	401
108	C	None		-282	12.0	30	8.47	30.5	1012	65	11.36	407

Continued ....

Table 3 (Continued) Upper legform to bonnet leading edge/top tube test conditions

Test code	*Vehicle code*	*Bull bar code*	*Bull bar mass (kg)*	*Lateral test position (mm)*	*Impact angle (°)*	*Nominal test velocity (km/h)*	*Achieved impact velocity (m/s)*	*Achieved impact velocity (km/h)*	*BLE height (mm)*	*Bumper lead (mm)*	*Upper legform Mass (kg)*	*Upper legform energy (J)*
109	D	D9S	14.5	90	17.3	20	5.52	19.9	1100	190	11.36	173
110	D	D9S	14.5	90	17.3	25	6.97	25.1	1100	190	11.36	276
111	D	D9S	14.5	90	17.3	30	8.23	29.6	1100	190	11.36	385
112	D	D13D(P)	19	90	12.3	25	7.02	25.3	1035	56	11.36	280
113	D	D13D(P)	19	90	12.3	30	8.29	29.8	1035	56	11.36	390
114	D	D13D(P)	19	335	12.3	30	8.35	30.1	1035	56	11.36	396
115	D	D13D(P)	19	90	17.0	40	10.99	39.5	1035	56	11.36	685
116	D	None		90	19.0	20	5.43	19.5	1013	178	11.36	167
117	D	None		90	19.0	25	6.72	24.2	1013	178	11.36	256
118	D	None		200	19.0	30	8.35	30.1	1013	178	11.36	396
119	D	None		335	19.0	30	8.35	30.1	1013	178	11.36	396
120	D	None		-90	19.0	30	8.39	30.2	1013	178	11.36	400
121	E	E6D(U)	17	260	25.2	20	5.60	20.2	860	153	11.36	178
122	E	E6D(U)	17	260	25.2	25	6.95	25.0	860	153	11.36	274
123	E	E6D(U)	17	260	25.2	30	8.54	30.7	860	153	11.36	414
124	E	E7S	8.5	90	17.3	20	5.67	20.4	1000	125	11.36	183
125	E	E7S	8.5	90	17.3	25	6.83	24.6	1000	125	11.36	265
126	E	E7S	8.5	90	17.3	30	8.30	29.9	1000	125	11.36	391
127	E	E8S	21.5	260	14.4	20	5.55	20.0	900	50	11.36	175
128	E	E8S	21.5	260	14.4	25	6.93	24.9	900	50	11.36	273
129	E	E8S	21.5	260	14.4	30	8.33	30.0	900	50	11.36	394
130	E	None		-595	22.0	15	4.45	16.0	953	246	11.36	113
131	E	None		-595	22.0	20	5.26	18.9	953	246	11.36	157
132	E	None		-90	22.0	20	5.68	20.4	953	246	11.36	183
133	E	None		-595	22.0	25	6.69	24.1	953	246	11.36	254
134	E	None		90	22.0	25	6.84	24.6	953	246	11.36	266
135	E	None		-90	22.0	30	8.05	29.0	953	246	11.36	368
136	E	None		-595	22.0	30	8.19	29.5	953	246	11.36	381
137	E	None		260	22.0	30	8.40	30.2	953	246	11.36	401
138	F	F1S	25	90	17.7	30	8.31	29.9	880	78	11.36	392
139	F	None		610	22.0	25	7.33	26.4	900	123	11.36	305
140	F	None		-90	22.0	30	8.31	29.9	900	123	11.36	392
141	F	None		610	22.0	30	8.31	29.9	900	123	11.36	392

Table 4 Legform test conditions

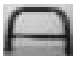
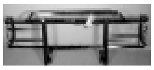
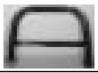
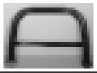
Test code	*Vehicle code*	*Bull bar code*	*Bull bar mass (kg)*	*Lateral test position (mm)*	*Nominal test velocity (km/h)*	*Achieved impact velocity (m/s)*	*Achieved impact velocity (km/h)*
142	D	D9S	14.5	90	30	8.20	29.5
143	D	D13D(P)	19	90	30	8.35	30.1
144	D	D13D(P)	19	90	30	10.75	38.7
145	D	None		90	30	8.35	30.1
146	F	F1S	25	635	30	7.94	28.6
147	F	F1S	25	-635	30	8.23	29.6
148	F	None		635	30	8.32	30.0

Base of legform at ground level at impact.

Table 5 Upper legform to bumper test conditions

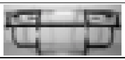
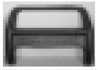
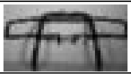
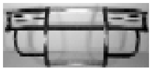
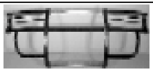
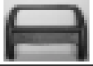
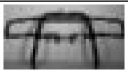
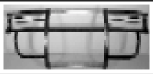
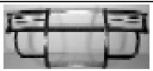
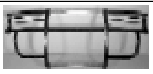
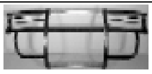
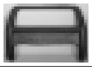
Test code	*Vehicle code*	*Bull bar code*	*Lateral test position (mm)*	*Bumper lower reference Line*	*Bumper upper reference Line*	*Impactor mass (kg)*	*Impactor energy (J)*	*Nominal impact velocity (km/h)*	*Achieved impact velocity (m/s)*	*Achieved impact velocity (km/h)*
149	A	None	0	514	610	9.50	328.8	30	8.32	30.0
150	B	None	0	628	709	9.50	326.4	30	8.29	29.8
151	C	None	0	677	750	9.50	326.4	30	8.29	29.8
152	D	None	0	533	688	9.50	331.2	30	8.35	30.1
153	D	None	710	533	688	9.50	331.2	30	8.35	30.1
154	E	None	0	532	605	9.50	331.2	30	8.35	30.1
155	F	None	0	437	569	9.50	328.8	30	8.32	30.0

Table 6 Headform test results

Test code	*Vehicle code*	*Bull bar code*	*Bull bar mass (kg)*	*Bull bar photo*	*Lateral test position (mm)*	*Nominal test velocity (km/h)*	*Achieved impact velocity (m/s)*	*Achieved impact velocity (km/h)*	*HIC*
7	A	None			-130	20	5.52	19.9	356
8	A	None			582	20	5.58	20.1	782
1	A	A10S	7		130	20	5.87	21.1	2415
4	A	A11S	22		582	20	5.61	20.2	2901
9	A	None			130	25	6.97	25.1	748
10	A	None			582	25	7.07	25.5	1175
2	A	A10S	7		130	25	7.12	25.6	4854
5	A	A11S	22		582	25	6.94	25.0	5150
12	A	None			582	30	8.30	29.9	1590
11	A	None			130	30	8.30	29.9	1815
3	A	A10S	7		130	30	8.46	30.5	6202
6	A	A11S	22		582	30	8.39	30.2	7015

Continued ....

Table 6 (Continued) Headform test results

Test code	*Vehicle code*	*Bull bar code*	*Bull bar mass (kg)*	*Bull bar photo*	*Lateral test position (mm)*	*Nominal test velocity (km/h)*	*Achieved impact velocity (m/s)*	*Achieved impact velocity (km/h)*	*HIC*
17	B	B4S	22.5		550	15	4.20	15.1	1119
13	B	B3D(SF)	6.5		90	20	5.45	19.6	87
28	B	None			-90	20	5.80	20.9	403
27	B	None			325	20	5.60	20.2	416
24	B	B5S	14.5		325	20	5.37	19.3	1663
18	B	B4S	22.5		550	20	5.54	19.9	2284
19	B	B4S	22.5		550	20	5.58	20.1	2695
14	B	B3D(SF)	6.5		90	25	6.82	24.6	227
30	B	None			90	25	7.00	25.2	619
29	B	None			-325	25	6.88	24.8	643
25	B	B5S	14.5		325	25	6.72	24.2	3001
21	B	B4S	22.5		90	25	7.10	25.6	4605
20	B	B4S	22.5		550	25	6.99	25.2	4632
15	B	B3D(SF)	6.5		90	30	8.35	30.1	401
31	B	None			-325	30	8.29	29.9	958.3
32	B	None			550	30	8.32	30.0	1017
33	B	None			90	30	8.32	30.0	1348
26	B	B5S	14.5		325	30	8.31	29.9	5720
23	B	B4S	22.5		550	30	8.41	30.3	6898
22	B	B4S	22.5		90	30	8.37	30.1	7074
16	B	B3D(SF)	6.5		90	40	11.17	40.2	325

Continued ....

Table 6 (Continued) Headform test results

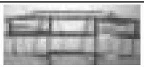
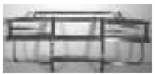
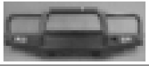
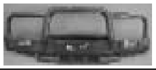
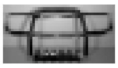
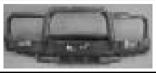
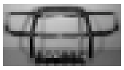
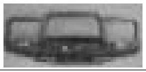
Test code	*Vehicle code*	*Bull bar code*	*Bull bar mass (kg)*	*Bull bar photo*	*Lateral test position (mm)*	*Nominal test velocity (km/h)*	*Achieved impact velocity (m/s)*	*Achieved impact velocity (km/h)*	*HIC*
38	C		None		90	25	7.03	25.3	733
34	C	C2S	24		90	25	6.96	25.1	1730
36	C	C12D(P)	24.5		90	30	8.32	30.0	759
40	C	None			-282	30	8.43	30.3	954
39	C	None			90	30	8.32	29.9	1178
35	C	C2S	24		90	30	8.36	30.1	2376
37	C	C12D(P)	24.5		90	40	11.02	39.7	1432
41	D	D9S	14.5		600	20	5.64	20.3	1351
44	D	D13D(P)	19		335	25	6.94	25.0	324
47	D	None			335	25	7.00	25.2	750
42	D	D9S	14.5		600	25	6.96	25.1	2877
45	D	D13D(P)	19		335	30	8.26	29.7	600
50	D	None			90	30	8.38	30.2	1145
48	D	None			-200	30	8.24	29.7	1334
49	D	None			-335	30	8.34	30.0	1643
51	D	None			-90	30	9.29	33.5	2030
43	D	D9S	14.5		600	30	8.31	29.9	4220
46	D	D13D(P)	19		335	40	11.05	39.8	1190

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Table 6 (Continued) Headform test results

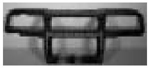
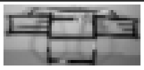
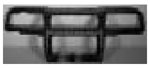
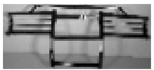
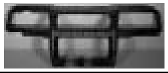
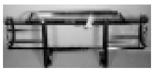
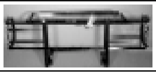
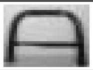
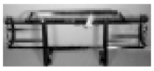
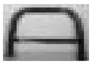
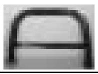
Test code	*Vehicle code*	*Bull bar code*	*Bull bar mass (kg)*	*Bull bar photo*	*Lateral test position (mm)*	*Nominal test velocity (km/h)*	*Achieved impact velocity (m/s)*	*Achieved impact velocity (km/h)*	*HIC*
62	E	None			605	15	4.33	15.6	608
52	E	E6D(U)	17		260	20	5.51	19.8	253
64	E	None			260	20	5.80	20.9	960
55	E	E7S	8.5		90	20	5.62	20.2	980
63	E	None			605	20	5.64	20.3	1148
58	E	E8S	21.5		260	20	5.70	20.5	3226
59	E	E8S	21.5		260	20	6.01	21.6	3857
53	E	E6D(U)	17		260	25	6.96	25.1	442
66	E	None			-260	25	6.95	25.0	1154
56	E	E7S	8.5		90	25	6.95	25.0	1747
65	E	None			605	25	6.80	24.5	1991
60	E	E8S	21.5		260	25	6.93	24.9	4702
54	E	E6D(U)	17		260	30	8.38	30.2	694
68	E	None			-260	30	8.24	29.7	1828
69	E	None			90	30	8.33	30.0	1857
67	E	None			605	30	8.16	29.4	3151
57	E	E7S	8.5		90	30	8.40	30.2	3327
61	E	E8S	21.5		260	30	8.37	30.1	6813

Table 7 Upper legform test results (bonnet leading edge)

Test code	*Vehicle code*	*Bull bar code*	*Bull bar mass (kg)*	*Bull bar photo*	*Nominal test velocity (km/h)*	*Achieved impact velocity (m/s)*	*Achieved impact velocity (km/h)*	*Maximum sum of forces (kN)*	*Maximum bending moment (Nm)*
78	A	None			20	5.66	20.4	3.90	260
73	A	A11S	22		20	5.27	19.0	3.34	260
74	A	A11S	22		20	5.44	19.6	3.56	286
77	A	None			20	5.66	20.4	4.00	295
70	A	A10S	7		20	5.31	19.1	5.26	441
80	A	None			25	6.86	24.7	4.85	337
79	A	None			25	6.86	24.7	5.63	412
75	A	A11S	22		25	6.79	24.4	6.20	507
71	A	A10S	7		25	6.85	24.7	8.30	711
82	A	None			30	8.33	30.0	5.80	409
81	A	None			30	8.33	30.0	8.40	628
72	A	A10S	7		30	8.41	30.3	9.93	867
76	A	A11S	22		30	8.35	30.1	10.57	873

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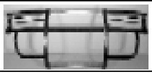
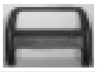
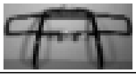
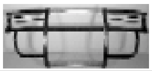
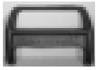
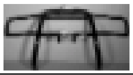
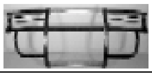
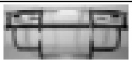
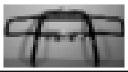
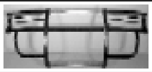
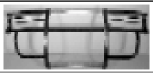
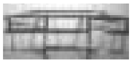
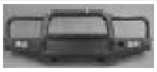
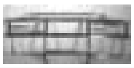
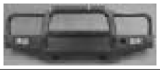
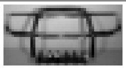
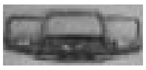
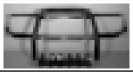
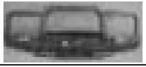
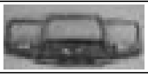
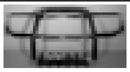
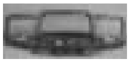
Continued ....

Table 7 (Continued) Upper legform test results (bonnet leading edge)

Test code	*Vehicle code*	*Bull bar code*	*Bull bar mass (kg)*	*Bull bar photo*	*Nominal test velocity (km/h)*	*Achieved impact velocity (m/s)*	*Achieved impact velocity (km/h)*	*Maximum sum of forces (kN)*	*Maximum bending moment (Nm)*
95	B	None			20	5.65	20.3	3.78	250
94	B	None			20	5.59	20.1	4.21	260
86	B	B4S	22.5		20	5.52	19.9	3.49	262
83	B	B3D(SF)	6.5		20	5.52	19.9	3.27	266
91	B	B5S	14.5		20	5.70	20.5	4.20	282
96	B	None			20	6.30	22.7	4.29	292
85	B	B4S	22.5		20	5.46	19.7	5.06	439
98	B	None			25	6.78	24.4	5.06	341
84	B	B3D(SF)	6.5		25	6.92	24.9	4.35	344
97	B	None			25	6.65	23.9	5.45	348
92	B	B5S	14.5		25	6.85	24.7	5.31	367
88	B	B4S	22.5		25	6.90	24.9	5.01	394
87	B	B4S	22.5		25	6.84	24.6	7.14	617
100	B	None			30	8.30	29.9	5.90	383
99	B	None			30	8.29	29.8	5.98	408
101	B	None			30	8.30	29.9	6.84	450
93	B	B5S	14.5		30	8.41	30.3	8.31	579
89	B	B4S	22.5		30	8.32	30.0	7.98	620
90	B	B4S	22.5		30	8.38	30.2	9.63	831

Continued ....

Table 7 (Continued) Upper legform test results (bonnet leading edge)

Test code	*Vehicle code*	*Bull bar code*	*Bull bar mass (kg)*	*Bull bar photo*	*Nominal test velocity (km/h)*	*Achieved impact velocity (m/s)*	*Achieved impact velocity (km/h)*	*Maximum sum of forces (kN)*	*Maximum bending moment (Nm)*
106	C	None			25	6.94	25.0	5.40	370
102	C	C2S	24		25	6.98	25.1	7.89	511
104	C	C12D(P)	24.5		30	8.42	30.3	3.11	214
107	C	None			30	8.40	30.2	6.40	437
108	C	None			30	8.47	30.5	6.30	443
103	C	C2S	24		30	8.42	30.3	9.80	624
105	C	C12D(P)	24.5		40	10.75	38.7	6.80	504
109	D	D9S	14.5		20	5.52	19.9	5.14	170
116	D	None			20	5.43	19.5	4.02	269
112	D	D13D(P)	19		25	7.02	25.3	2.68	230
110	D	D9S	14.5		25	6.97	25.1	7.10	302
117	D	None			25	6.72	24.2	5.49	382
114	D	D13D(P)	19		30	8.35	30.1	5.02	147
113	D	D13D(P)	19		30	8.29	29.8	2.06	163
120	D	None			30	8.39	30.2	7.80	396
118	D	None			30	8.35	30.1	6.08	412
111	D	D9S	14.5		30	8.23	29.6	9.30	446
119	D	None			30	8.35	30.1	6.20	525
115	D	D13D(P)	19		40	10.99	39.5	3.23	296

Continued ....

Table 7 (Continued) Upper legform test results (bonnet leading edge)

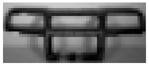
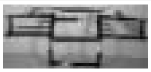
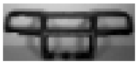
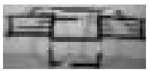
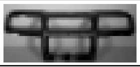
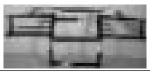
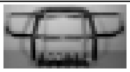
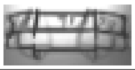
Test code	*Vehicle code*	*Bull bar code*	*Bull bar mass (kg)*	*Bull bar photo*	*Nominal test velocity (km/h)*	*Achieved impact velocity (m/s)*	*Achieved impact velocity (km/h)*	*Maximum sum of forces (kN)*	*Maximum bending moment (Nm)*
130	E	None			15	4.45	16.0	3.83	218
121	E	E6D(U)	17		20	5.60	20.2	3.31	109
124	E	E7S	8.5		20	5.67	20.4	2.94	239
131	E	None			20	5.26	18.9	4.60	241
132	E	None			20	5.68	20.4	4.80	303
127	E	E8S	21.5		20	5.55	20.0	5.35	361
122	E	E6D(U)	17		25	6.95	25.0	5.17	142
125	E	E7S	8.5		25	6.83	24.6	3.69	305
133	E	None			25	6.69	24.1	6.98	345
134	E	None			25	6.84	24.6	5.80	386
128	E	E8S	21.5		25	6.93	24.9	8.22	565
123	E	E6D(U)	17		30	8.54	30.7	6.09	150
126	E	E7S	8.5		30	8.30	29.9	4.06	333
135	E	None			30	8.05	29.0	6.98	433
137	E	None			30	8.40	30.2	7.90	497
136	E	None			30	8.19	29.5	8.66	499
129	E	E8S	21.5		30	8.33	30.0	11.04	762
139	F	None			25	7.33	26.4	5.10	303
140	F	None			30	8.31	29.9	4.90	249
141	F	None			30	8.31	29.9	6.80	339
138	F	F1S	25		30	8.31	29.9	8.13	698

Table 8 Legform test results

Test code	*Vehicle code*	*Bull bar code*	*Bull bar mass (kg)*	*Bull bar photo*	*Nominal test velocity (km/h)*	*Achieved impact velocity (m/s)*	*Achieved impact velocity (km/h)*	*Maximum shear displacement (mm)*	*Maximum knee bending angle (°)*	*Maximum leg acceleration (g)*
144	D	D13D(P)	19		30	10.75	38.7	8.13	4.66	149
143	D	D13D(P)	19		30	8.35	30.1	5.87	7.61	165
142	D	D9S	14.5		30	8.20	29.5	7.92	8.40	261
145	D	None			30	8.35	30.1	7.82	6.15	229
148	F	None			30	8.32	30.0	1.55	19.98	170
146	F	F1S	25		30	7.94	28.6	6.61	6.77	185
147	F	F1S	25		30	8.23	29.6	6.47	8.25	184

Base of legform at ground level at impact

Table 9 Upper legform to bumper test results

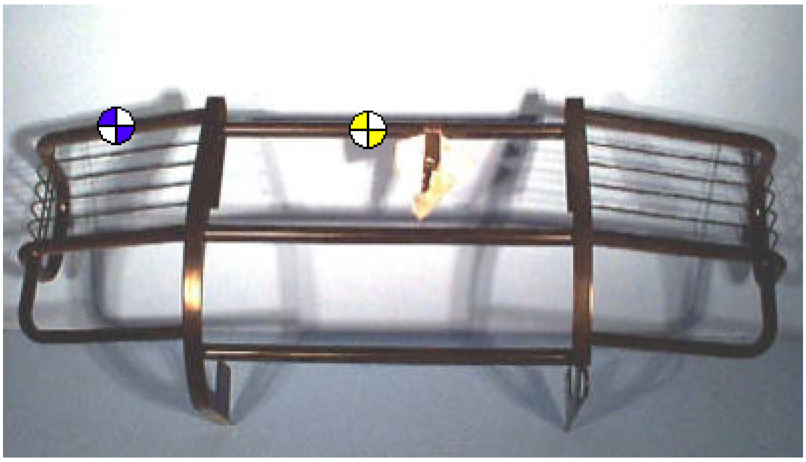
Test code	*Vehicle code*	*Bull bar code*	*Lateral test position (mm)*	*Nominal impact velocity (km/h)*	*Achieved impact velocity (m/s)*	*Achieved impact velocity (km/h)*	*Maximum sum of forces (kN)*	*Maximum bending moment (Nm)*
149	A	None	0	30	8.32	30.0	16.50	1056
150	B	None	0	30	8.29	29.8	6.90	540
151	C	None	0	30	8.29	29.8	5.40	417
153	D	None	710	30	8.35	30.1	6.12	387
152	D	None	0	30	8.35	30.1	12.50	892
154	E	None	0	30	8.35	30.1	7.70	611
155	F	None	0	30	8.32	30.0	5.30	280

Appendix B: Figures

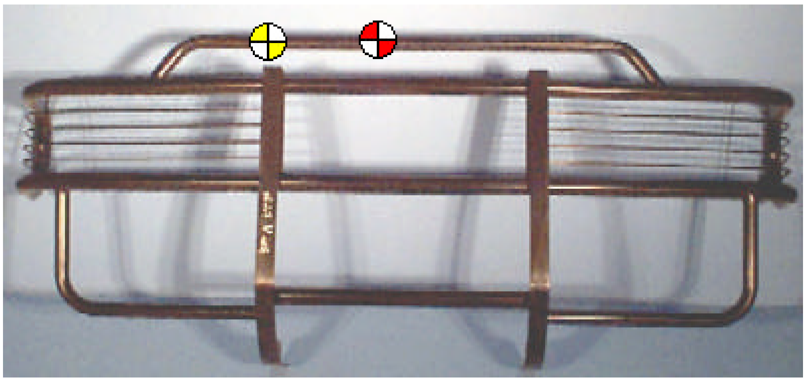
FIGURE 1– Bull Bars with impact locations

Impactor key for targets:	RED	Child Headform
	YELLOW	Upper Legform to Bonnet Leading Edge
	GREEN	Upper Legform to Bumper
	BLUE	Legform

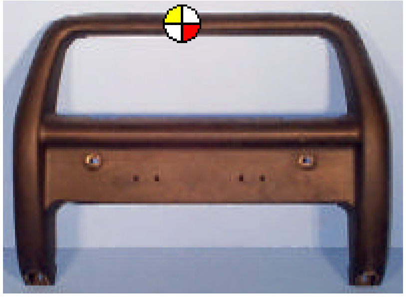
Note: When various impactors have been used at the same location, the target contains more than one colour.



Bull Bar 1 (F1S)

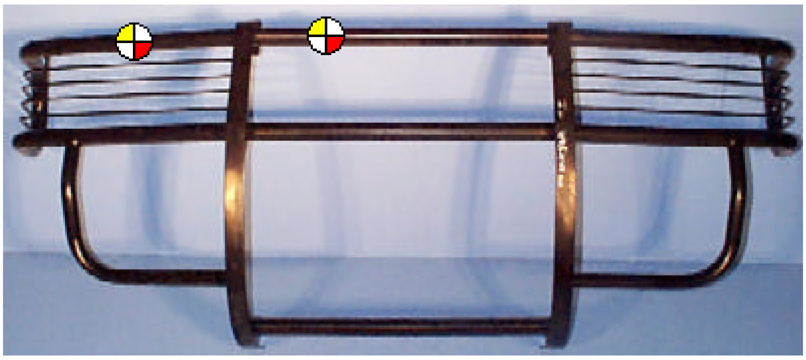


Bull Bar 2 (C2S)

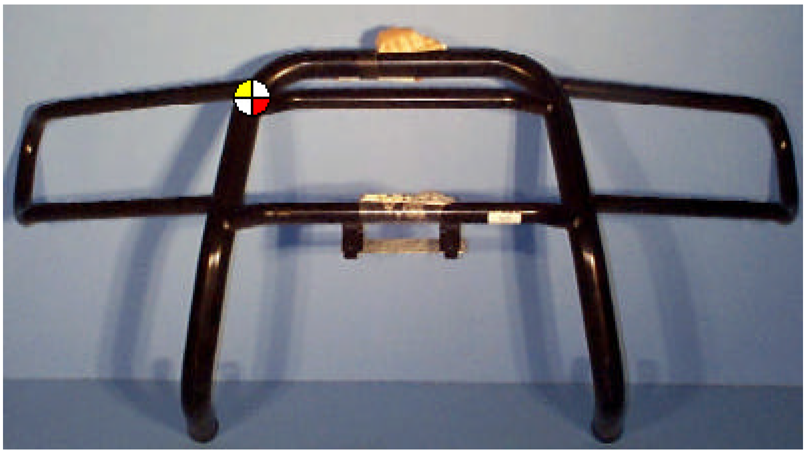


Bull Bar 3 (B3D(SF))

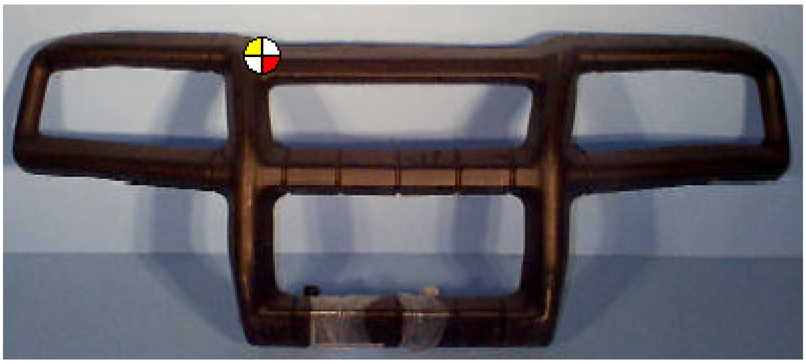
FIGURE 1(continued) – Bull Bars with impact locations



Bull Bar 4 (B4S)

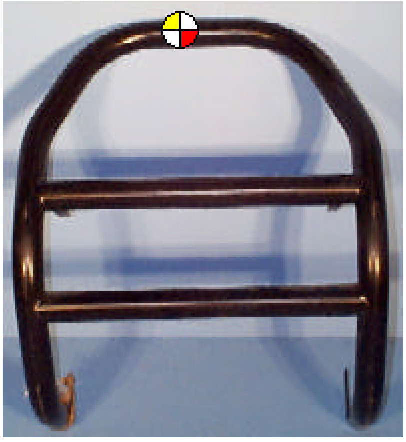


Bull Bar 5 (B5S)

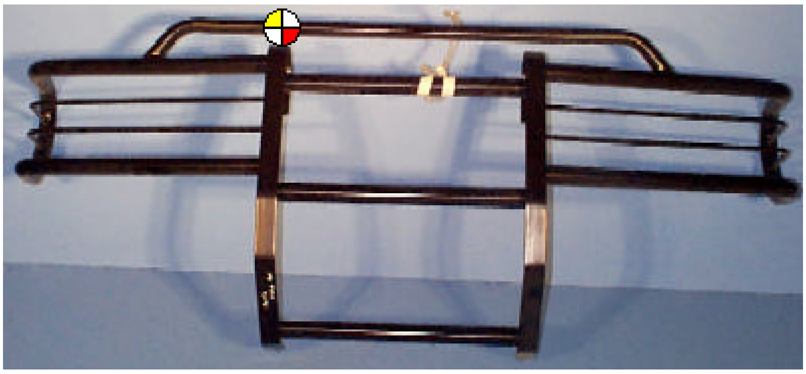


Bull Bar 6 (E6D(U))

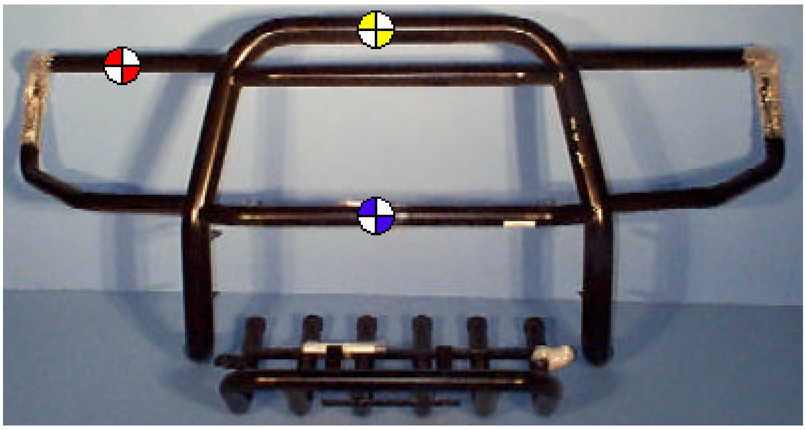
FIGURE 1 (continued) – Bull Bars with impact locations



Bull Bar 7 (E7S)



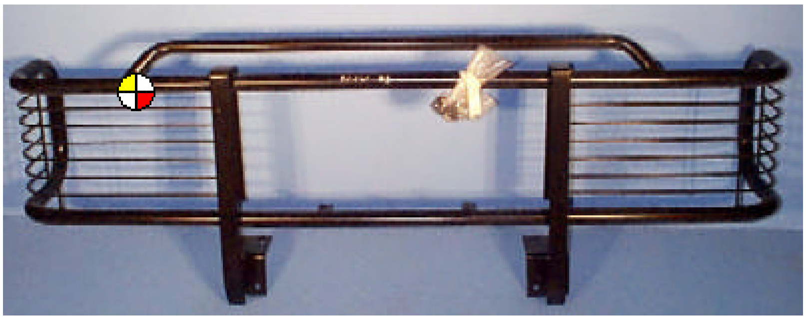
Bull Bar 8 (E8S)



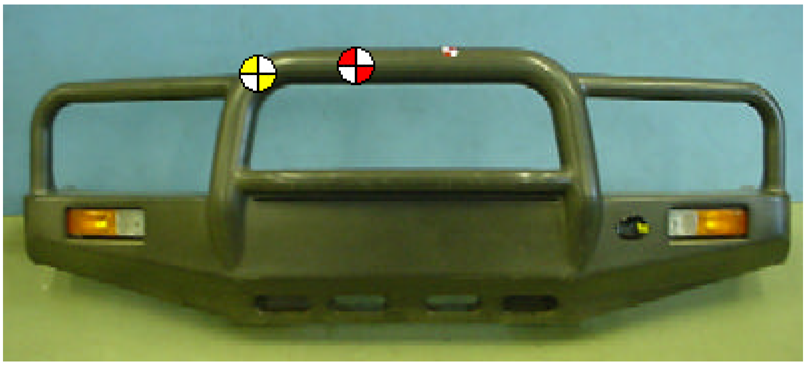
Bull Bar 9 (D9S)

FIGURE 1 (continued) – Bull Bars with impact locations

Bull Bar 10 (A10S)



Bull Bar 11 (A11S)



Bull Bar 12 (C12D(P))

Bull Bar 13 (D13D(P))

FIGURE 2

Typical Australian Canted Forward Bull Bar

FIGURE 3 — Base Vehicles with impact locations

Impactor key for targets:		
	Red	Child Headform
	Yellow	Upper Legform to Bonnet Leading Edge
	Green	Upper Legform to Bumper
	Blue	Legform

When various impactors have been used at the same location, the target contains more than one colour

FIGURE 3 (Continued) — Base Vehicles with impact locations

FIGURE 3 (Continued) — Base Vehicles with impact locations

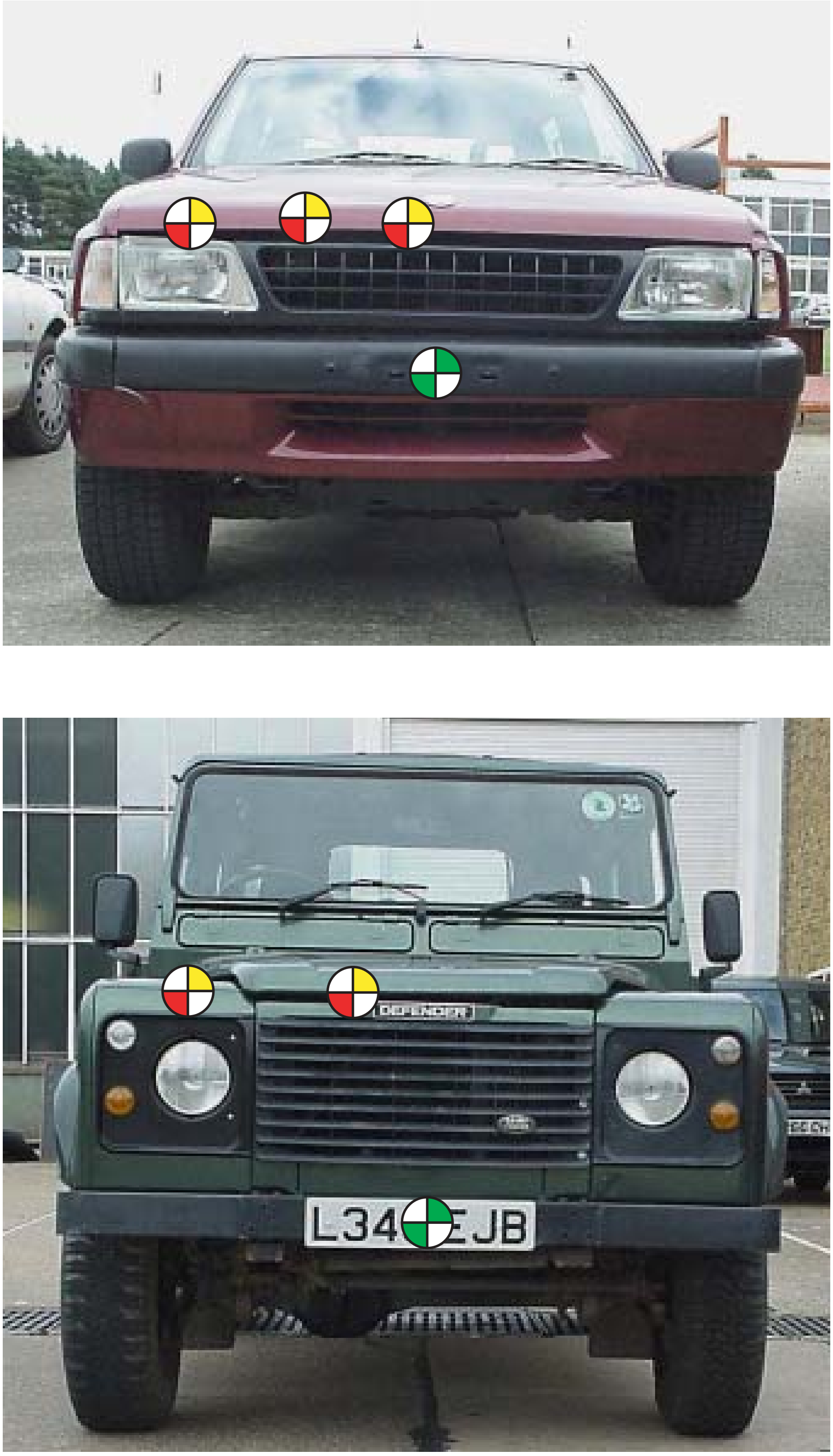


FIGURE 4

Bull bar test programme Child Headform results showing trends (power curves)
Red (squares) = steel bars, Black (circles) = base vehicles, Blue (triangles) = deformable bars

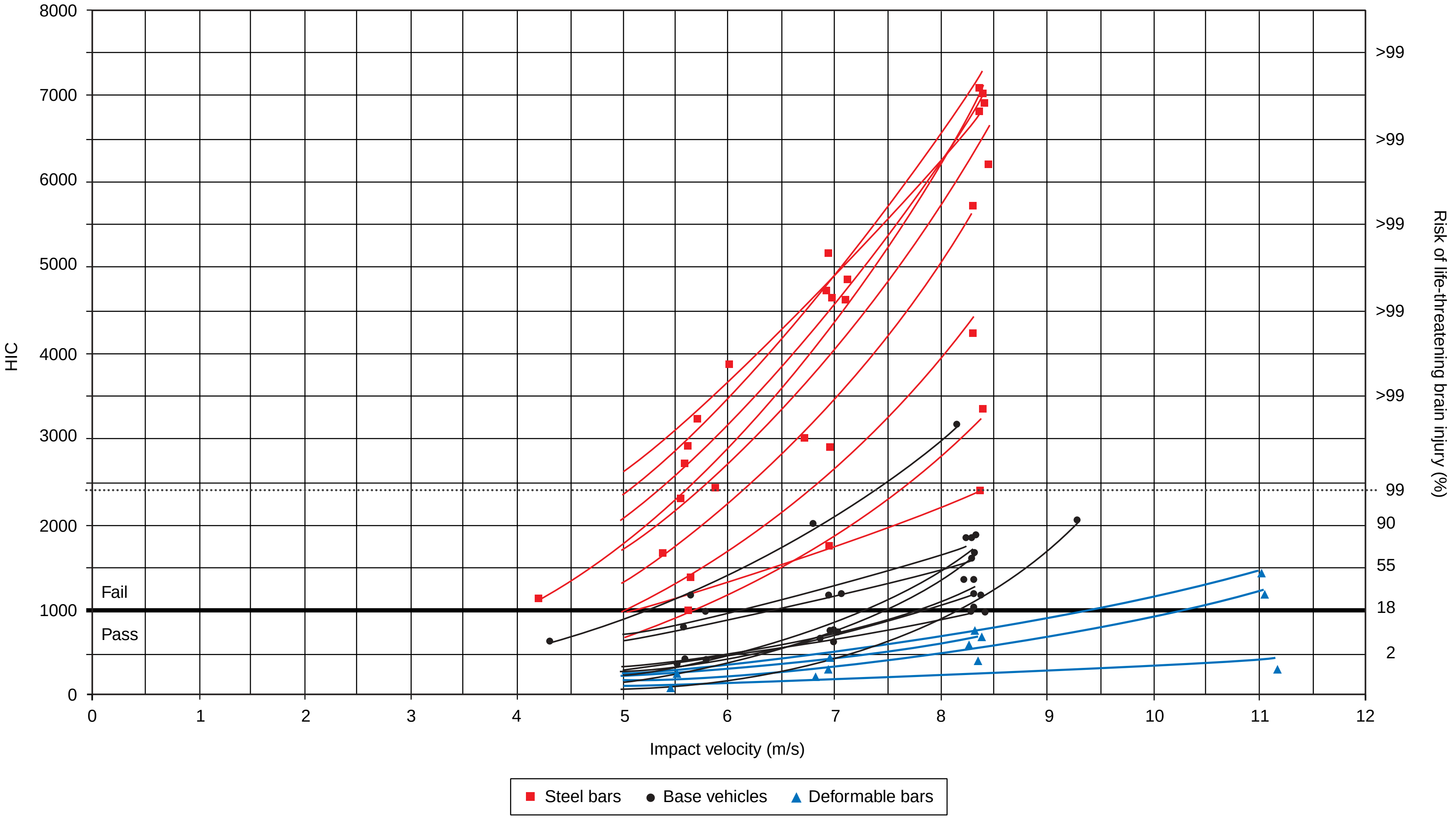


FIGURE 5

Bull bar test programme Child Headform results showing average trends (power curves)

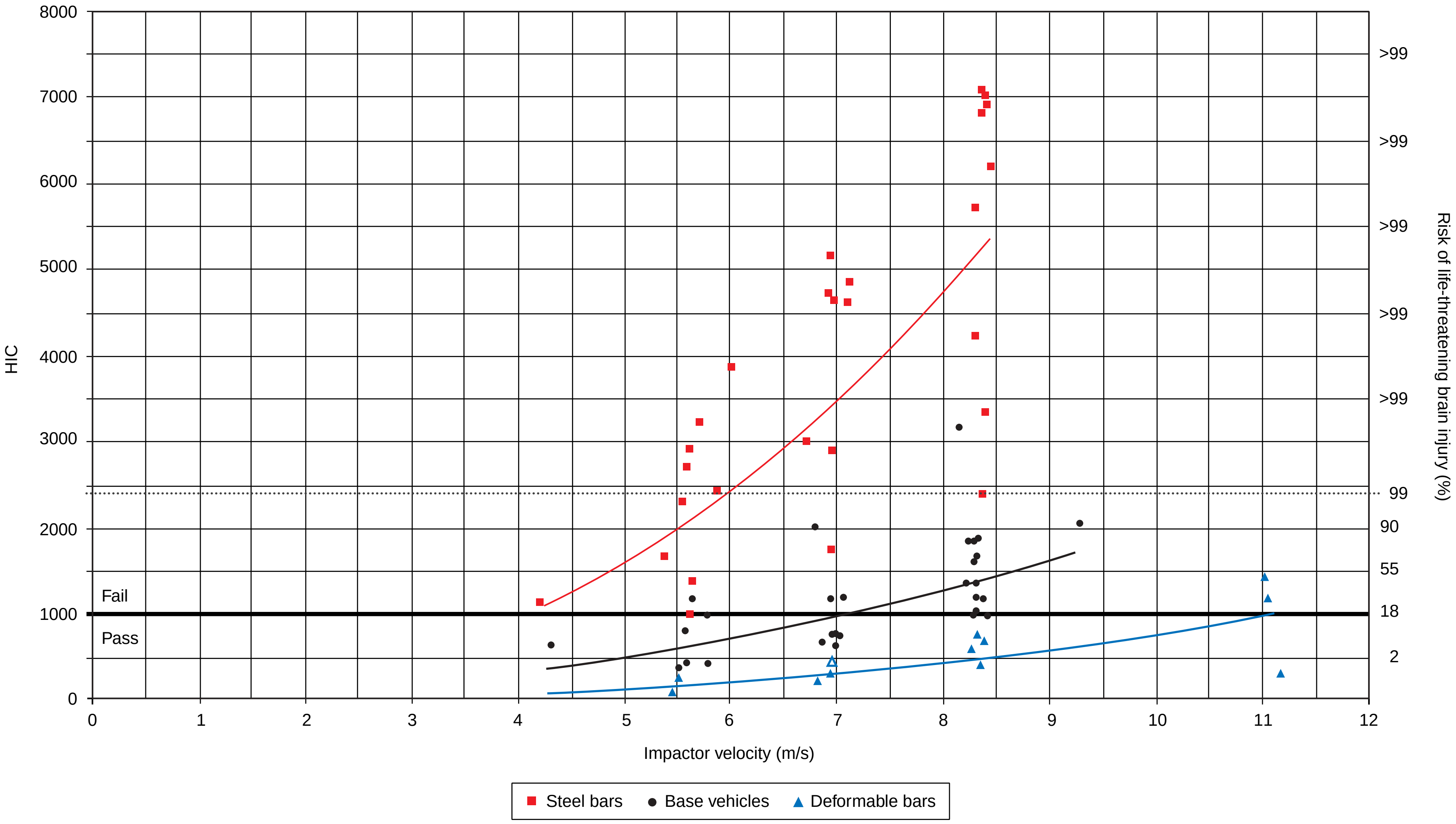


FIGURE 6

Bull bar test programme Child Headform results showing average base vehicle trend (power curves) with worst vehicle removed

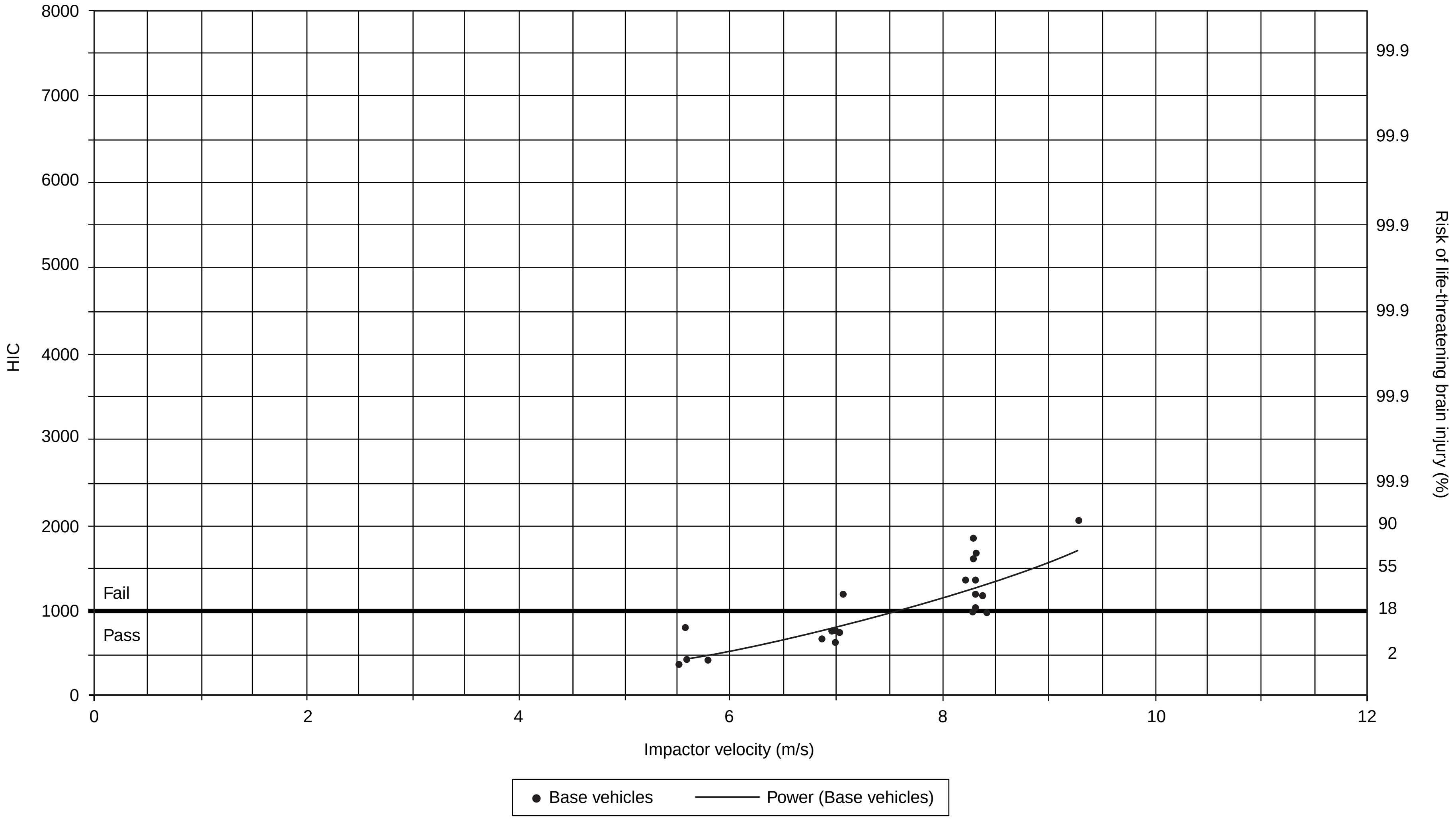


FIGURE 7

Bull bar test programme Upper Legform Force results showing trends (power curves)
Red (squares) = steel bars, Black (circles) = base vehicles, Blue (triangles) = Deformable bars

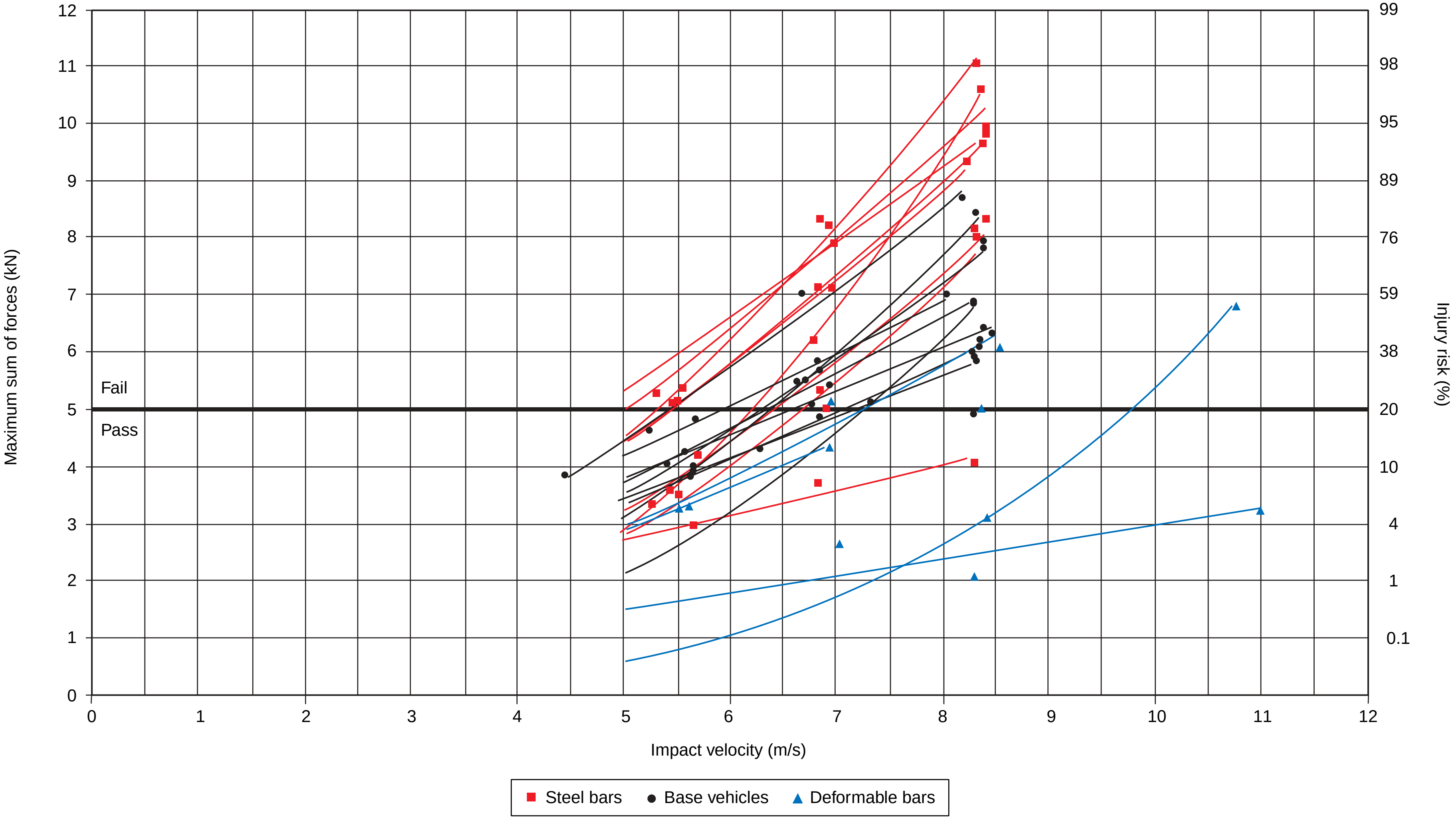


FIGURE 8

Bull bar test programme Upper Legform Force results showing average trends (power curves)

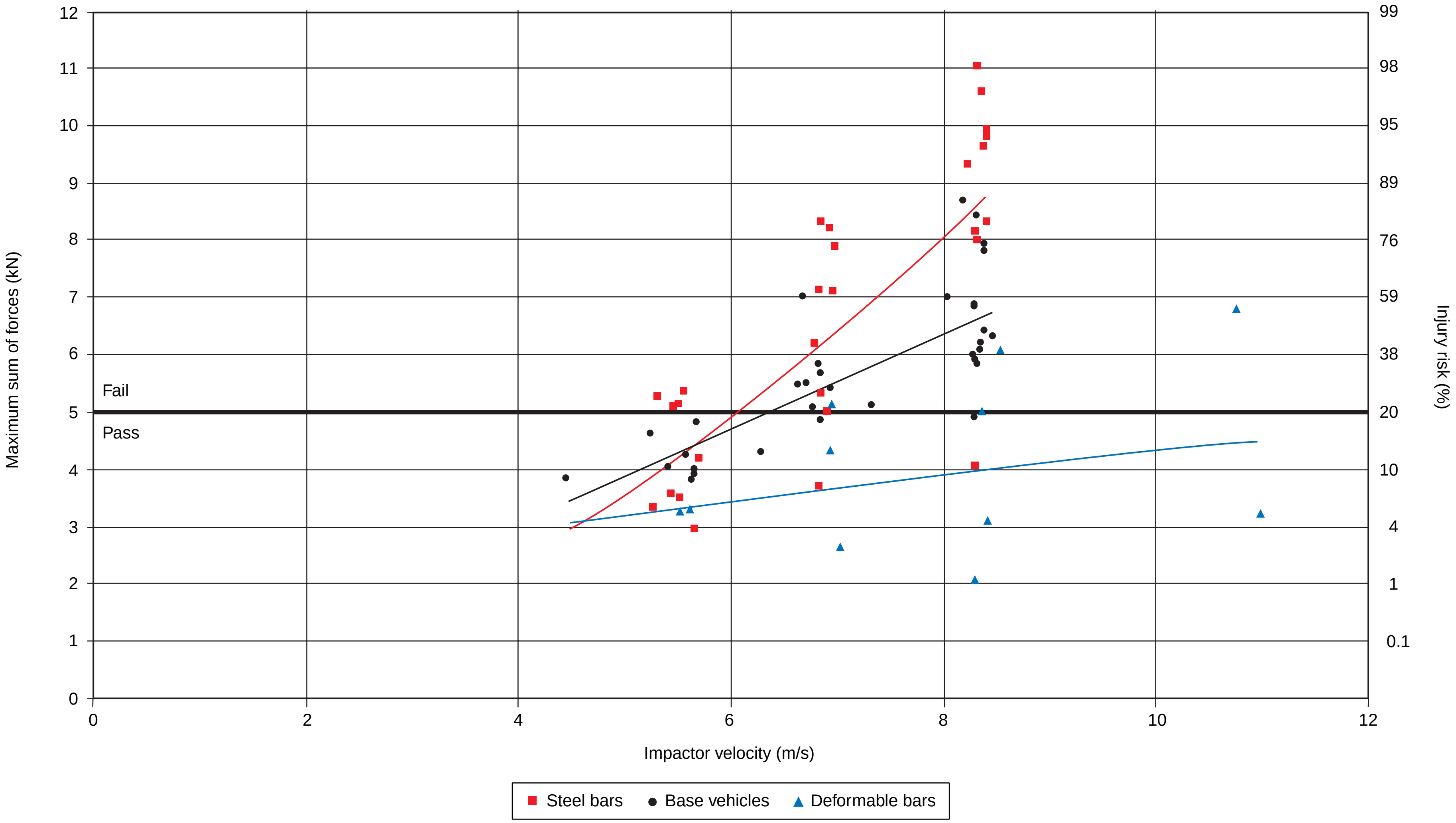


FIGURE 9

Bull bar test programme Upper Legform Force results showing average base vehicle trend (power curve) with worst vehicle removed

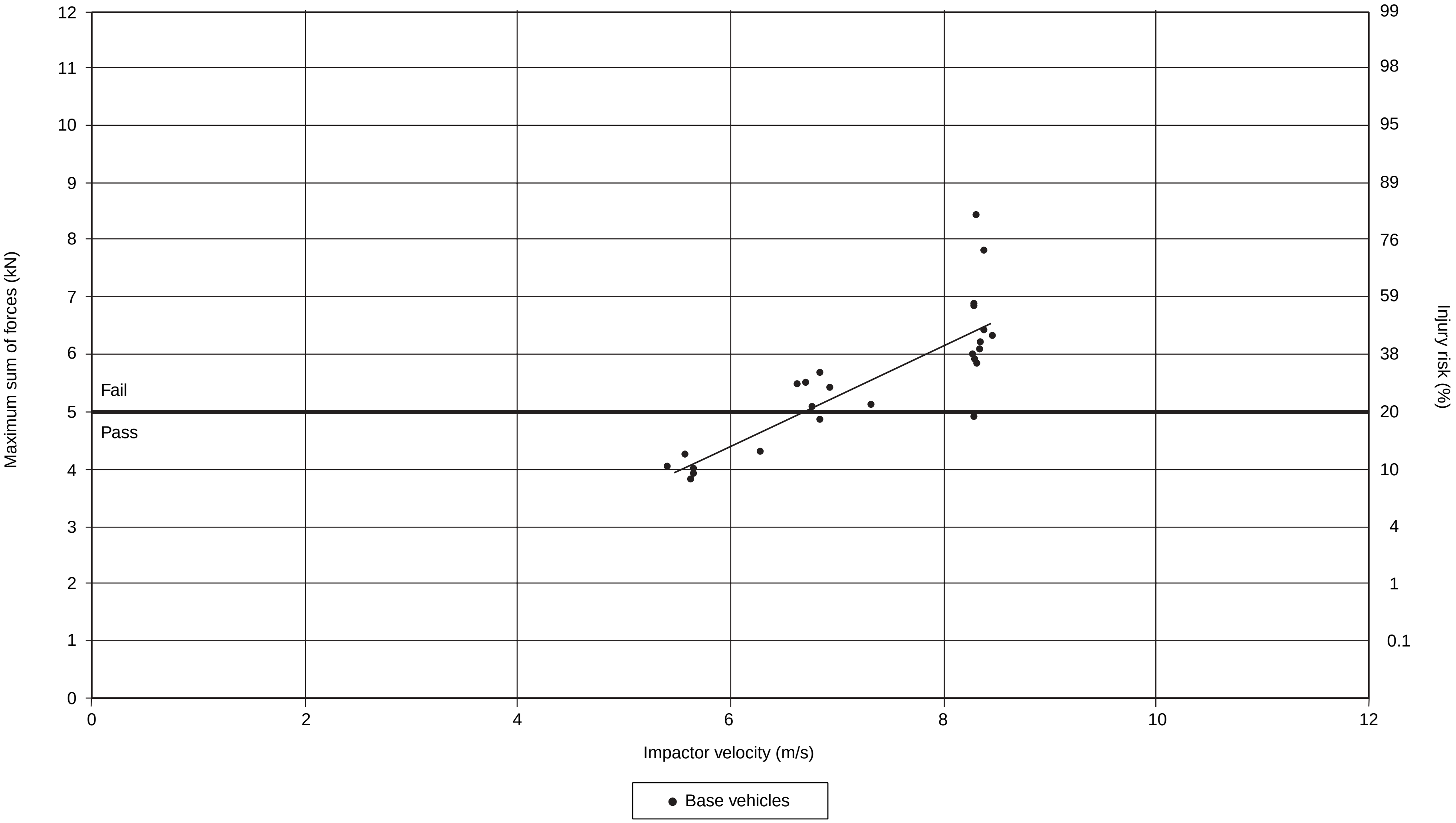


FIGURE 10

Bull bar test programme Upper Legform Bending Moment results showing trends (power curves) Red (squares) = steel bars, Black (circles) = Base vehicles, Blue (triangles) = Deformable bars

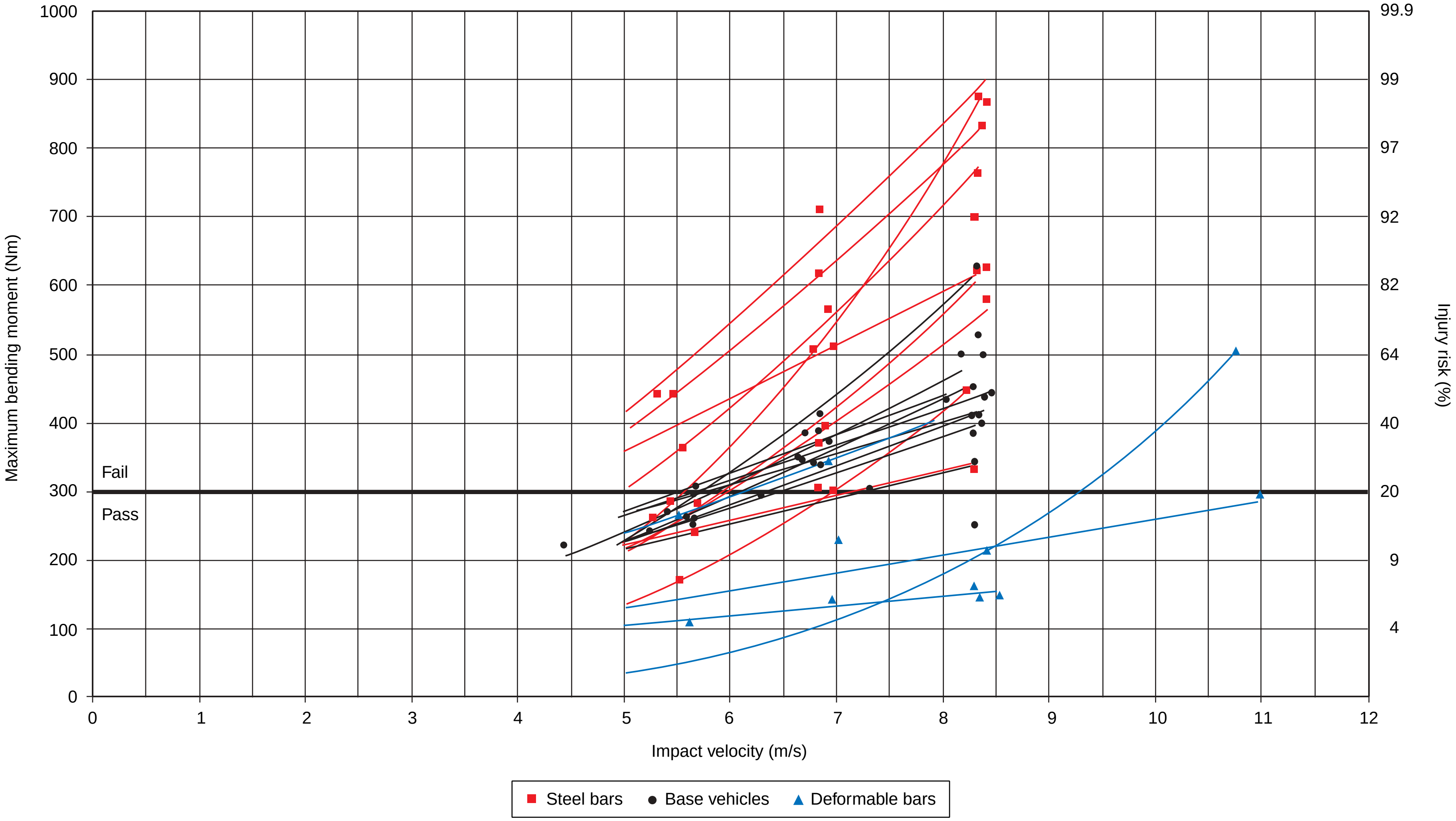


FIGURE 11

Bull bar test programme Upper Legform Bending Moment results showing average trends (power curves)

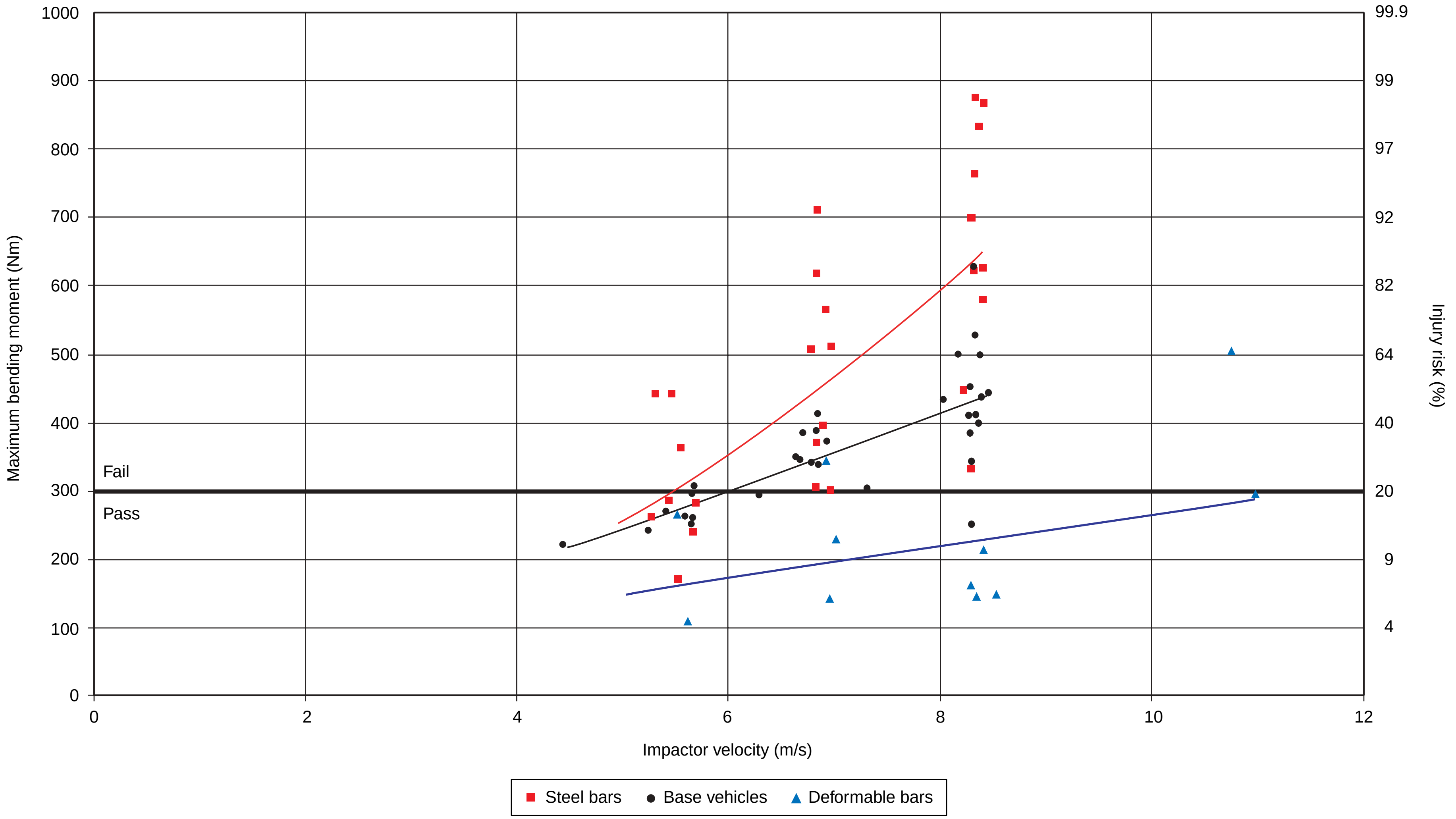
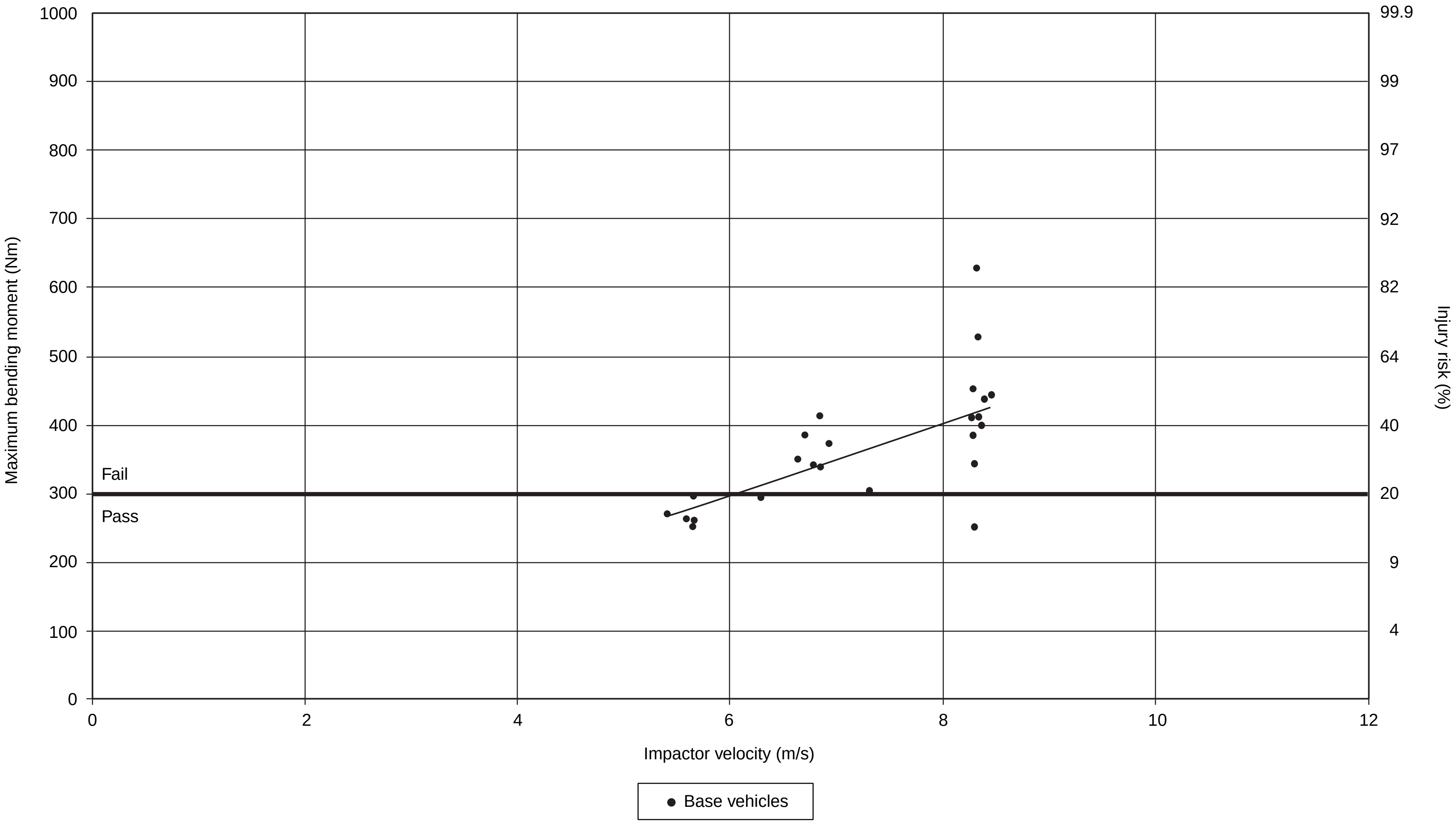


FIGURE 12

Bull bar test programme Upper Legform Bending Moment results showing average basevehicle trend (power curve) with worst vehicle removed



Abstract

Off-road vehicles have become popular in recent years and this type of vehicle now forms an increased proportion of the vehicle fleet. In 1998, they represented 4.4% of sales. This type of vehicle is often fitted with bull bars and this has created safety concerns because of their potential to increase the risk of injuries in accidents with vulnerable road users.

The Department of the Environment, Transport and the Regions commissioned TRL to develop pedestrian protection test methods for bull bars suitable for use in a regulation or standard. As part of this project TRL investigated the pedestrian protection performance of a range of vehicles both with and without bull bars fitted.

The full report describes the test methods developed and discusses the limitations and effectiveness of their use in legislation and also presents and discusses the results of the test to the vehicles with and without bull bars fitted.

Related publications

TRL243 *A study of accidents involving bull bar equipped vehicles* by B J Hardy. 1996 (price £25, code E)

CT47.2 Pedestrian accident studies update (1997-1999) *Current Topics in Transport: selected abstracts from TRL Library's database* (price £20)

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