Crash Test Report

Barriers International

Running Rail System

Report Prepared by

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21 July 2008

Note: The analyses presented in this report are based on the information available to the author. Should additional information become available, further review and analysis may be required, which may affect the opinions expressed in this report.

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Executive Summary

This testing round evaluates the performance of the post fuses of the Barriers International Running Rail system in the context of chest injury. The secondary purpose is to link this performance with the NCAP crash ratings for the worlds best seat belt systems.

The operation of the Barriers International running rail fuses 12 and 20 in lab conditions is reported.

Test data shows that in theory a fuse identical to the newly modified Barriers International fuse, properly installed on a post free to rotate around the post axis at the connection, will prevent life threatening injury in impacts of 30 km/h. Computer simulation (**Section 5.3**) indicates that this fuse should (in theory) also prevent injuries up to 55 km/h.

Reliability testing is required for each fuse as, to date, a single impact has been conducted to evaluate each one.

With the additional of a reliably operating **Barriers International Fuse 12 or 20** the chances of **all types of chest injury are reduced considerably**. The level of safety attributable to the performance of **Fuse 12 or 20** is in advance of the normally applied acceptability levels for life threatening injury in car crash.

The Barriers international post fuse has the affect of eliminating excessive loading on the jockey by a feature that takes effect quicker than an airbag and is many times simpler in operation. The post releases when hit from a direction that is consistent with a jockey impact.

1 Background and Introduction to the Testing Program

A series of testing rounds relevant to jockey safety at the running rail have been conducted. Tests have been conducted in computer simulation, in a concrete test bed, at a test track, at the racetrack and just recently in lab conditions at Autoliv©. This comprehensive series of tests has covered a range of test environments and impact conditions. The following table identifies the advantages and disadvantages of each test type.

Test Type	Hit Configuration	Injury Potential Evaluated	Data Output	Environment	Dummy	Outcome Assessment	Associated Standard
A. Computer simulation	Head on (high and low), somersault	1. Head 2. Neck 3. Chest	Dummy Accelerations, bending loads etc	Computer generated	Simulated crash test dummy (55 kg)	HIC, NIC, CTI	NHTSA final rules
B. Pull over tests	-	-	Post inclination and Fuse breaking load (kg)	Concrete or racetrack	-	Post characterisation	-
C. Cranbourne test track	Tumbling torso impact	Whole body	Contact time (ms) and speed loss (km/h)	Sandy soil	Ballast (25 kg)	Threat to life from sudden speed loss	-
D. Sandown Racetrack tests	Tumbling torso impact	Whole body	Contact time (ms) and speed loss (km/h)	Curated track turf	Ballast (25 kg)	Threat to life from sudden speed loss	-
E. Autoliv© tests		1. Head 2. Neck 3. Chest	Dummy Accelerations, bending loads etc	Lab conditions	Crash Test Dummy (54 kg)	HIC, NIC, CTI	NHTSA final rules

Table 1: Test types and characteristics.

Post Tests: Chest Impact Testing at Autoliv, Campbellfield [17/7/2008]

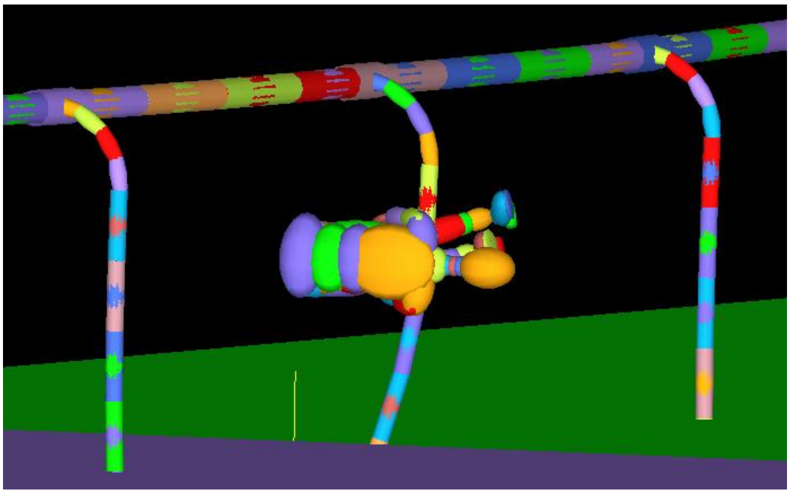

Figure 1: Type A testing used materials testing results from the components of the running rail to build a computer model and testing was conducted entirely in computer simulation. It considered, head-on impact, somersault and leg impacts (above).

Table 1 identifies previous test types and methods. They cover a range of environments and testing methodologies. **Test type A** was conducted entirely in computer simulation (**Figure 1**). It was possible to simulate a large number of impacts, however it was not real world impact so it needed to be validated from the point of view of the characterisation and whole system performance of the running rail.

Figure 2: Test type B was conducted using an instrumented winch attached to the post 700mm from the ground. These tests are useful for characterising the force deflection characteristics of the post and determining the pseudo static cantilever breaking load for any fuses. In the figure, a new style of footing is being trailed. The post was able to manage the loading. The footing turned in the ground at 164.6 kg as seem on the crane scales in the figure.

Test type B (**Figure 2**) was used in characterisation of the post under load and not useful for direct injury potential prediction. The load at which the fuse breaks can be greater or lower than that found in this style of testing which is referred to as pseudo static loading. The loading increases at such a slow rate that it is effectively testing in static conditions. The consequence of a high or low breaking load is a marker for the injury prevention potential, but the ideal breaking load must be established by other means.

Further, the test on the post in a jockey impact scenario is more likely to be a three point bend where the post is restricted below at the ground and above at the rail and loaded in the middle, hence its description as a bend with three loading points. The impact does not generate the pull over style configuration depicted in **Figure 2**.

Figure 3: Type D testing, a ballast dummy is projected into contact with the post. Type C was similar in that a ballast dummy was also used, but the dummy was released in a head on-impact configuration with the post.

Test type C & D (**Figure 3**) did test the post in realistic conditions and speed loss was used as a determinant in conjunction with a star rating system for safety value. The speed loss measure is backed up by a number of reports and research articles (see **Section 6**). It is used by VicRoads in their fact sheet to deter speeding.

1.1 Discussion of Test Types

While the computer simulation in **Test Type A** considered a range of impacts and has potential to consider all conceivable impact scenarios, the analysis focused on high priority head and neck[1] injuries. This top down approach is important for optimised running rail development. A principal of injury prevention is to focus on life threatening injury first, and deal with broken legs and such as a secondary item. In the process of preventing the severe injuries, often the potential for less severe injury is reduced in parallel. Life threatening and debilitating injury make the headlines, but on a day to day basis, these injuries are relatively rare. So additional testing was required to generate a rounded measure of injury prevention potential that does not only consider relatively rare life threatening injuries, but also measures the potential for all types of injury.

To balance a specific assessment of head and neck injury, a general assessment was also conducted as jockeys suffer a range of injuries. **Test Type C & D** assessments considered the general potential for injury at a number of levels of severity to all body parts in a tumbling impact scenario.

After tests **A, B, C & D**, which covered testing in computer simulation and in track conditions, there are three remaining items to consider. These are instrumented testing of the torso, standardisation and reliability testing.

1.2 Test Type E: Instrumented Chest Impact Testing

The resilience of chest to post impact is tested in this round due to the following reasons.

- **Instrumented testing** compliments the (non-instrumented) testing already conducted.
- This testing program can be linked with world **standards** in automotive safety of seatbelts.
- Instrumented testing for chest impact **completes the evaluation of potentially life threatening impacts**, as so far focus has been on the head, neck and whole body and

[1] Previous report on **Test type A** delivered to Racing Victoria Ltd, by the author.

not specifically on the torso (including the chest cavity) which also protects vital internal organs.

- Chest impact is **reliable and repeatable** in lab conditions; in contrast there are intrinsic problems with isolated head and neck injury evaluation with a sled test.

1.2.1 Instrumented Testing

Thus far, testing has been conducted using a marker for injury, which is speed loss due to the impact. This needs to be backed up with detailed instrumented tests which measure injury potential directly in terms of the established injury criteria.

1.2.2 World Standards in Injury Prevention

Conducting torso impact tests at the seatbelt laboratory means that the tests can be accredited within the bounds of NCAP evaluation standards for seat belts. This linkage validates previous testing and allows correlation between our jockey safety testing and standards of automotive testing.

Conducting torso impact tests at the seatbelt laboratory means that the tests can be accredited within the bounds of Euro NCAP, ANCAP and other evaluation standards for seat belts. This linkage validates previous testing and allows correlation between our jockey safety testing and standards of automotive testing.

1.2.3 Chest Impact Tests Completes the Picture

Thoracic injury may have been neglected up until now, however serious injury to the thorax and/or abdomen can be similarly life threatening.

1.2.4 Reliability and Repeatability and Usefulness of Chest Impact as a Standard Impact

Of all the body parts that could contact the post in a standard test, the chest is the most suitable. As 100% success rate might be expected for contact, it is the most likely contact for tumbling jockeys and it also provides scope for neck injury likelihood evaluation.

The torso presents a large contact area which contrasts to the point contact resultant from a head on post contact. A 100% hit rate with tests might be expected in these conditions. This is important where limited time and prototype devices are available.

The torso always contacts the seat belt in frontal car crash. The size of the torso in the context of a jockey's body means that the torso is also much more likely to make contact with the post that the head or neck, so the torso presents a much larger target and is investigated in this round, specifically as higher resolution injury criteria are required to determine specific chest injury likelihood accurately.

Chest contact also includes scope for neck injury evaluation, as when the dummy is loaded on the chest (by a post or seatbelt) whiplash can be induced at the neck. Where a reliable contact is generated on the chest the induced whiplash severity will also be reliable and directly proportional to the loading.

1.2.5 Potential Problems with Head and Neck Contact

Within the constraints of the testing it was not possible to conduct tests specific to the head and neck separately.

Injury to the head and neck has already largely dealt with in **Test Type A** and this involved a head-on impact where both the head and neck was tested.

However, in laboratory conditions it is difficult to set up a reliable contact of the head with a post due to the rounded nature of both items and the required free movement of the dummy. The analogy is the difficulty of controlling contact of two snooker balls. Further, the neck will deflect differently depending on the outcome of the head-on-post (round-on-round) contact.

In theory, advances in helmet design and/or padding on the posts or a combination can prevent head injury. The author believes that ultimately, head injury in the whole racing environment will be prevented with helmet advances, as a safe post will not help a jockey that falls onto the turf and this injury mode is dealt with in a separate study. Many manufacturers stated that the cost of padding makes it unrealistic to include and consequently will rely on the helmet developments. There may be little to gain in pursuit of the fourth star without any padding.

Nevertheless, head form impacts can be conducted separately and some high performance fuses may avert injury without padding being in place.

1.3 Summary of Background and Introduction

In summary, the running rail project has conducted a thorough evaluation of the safety characteristics of the running rail. It has utilised a range of different testing methods, has fostered extensive safety engineering effort and can demonstrate safety outcomes with the collected data in this report.

2 Impact Test Setup

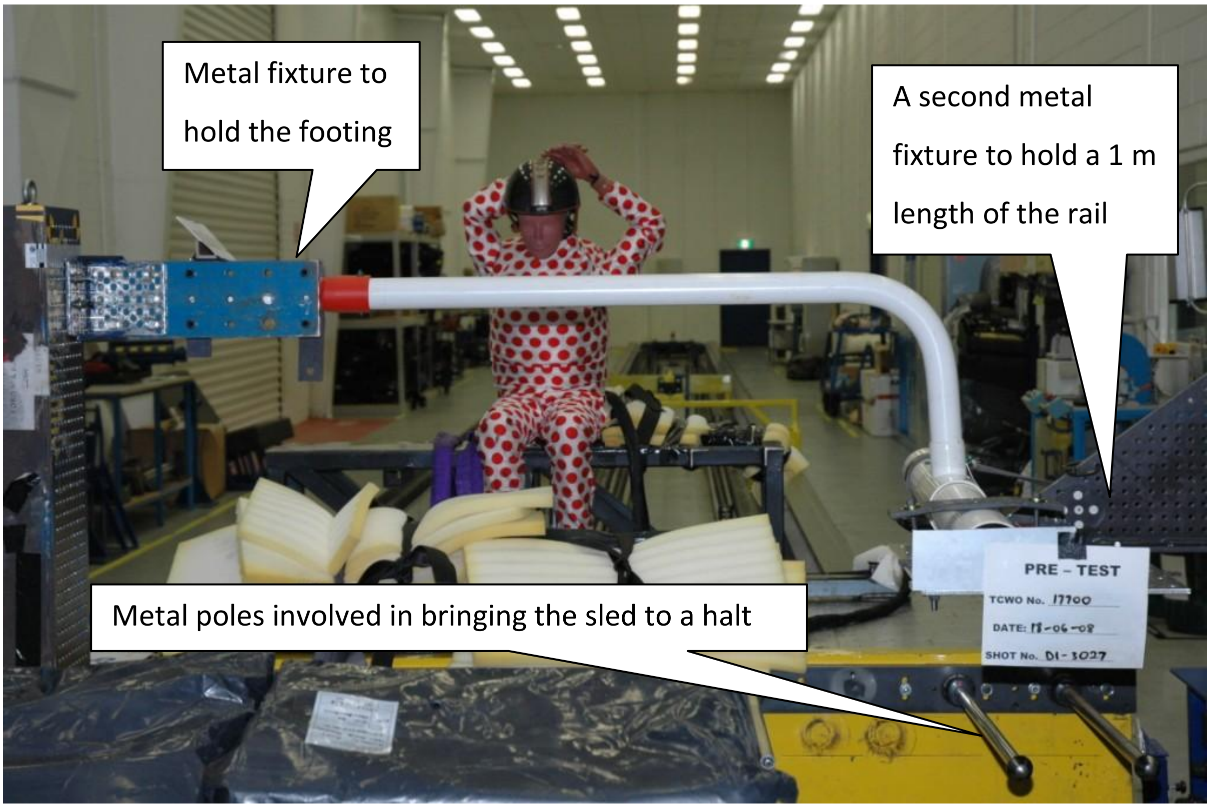

Figure 4: The test setup at the seat belt laboratory at Autoliv, Campbellfield, Victoria. The crash test dummy is seen in the shot wearing a racing helmet, and a biomechanics suit, underneath which is a safety vest. The dummy is lined up for an impact with the Barriers International post.

The tests were conducted at Autoliv© which is a world renowned impact testing facility that conducts hundreds of impact tests each year for major car manufacturers. The facility at Campbellfield, in Victoria includes two test tracks. One is for full scale vehicle impact testing. These tests were conducted on the second test track which is situated in the seat belt laboratory.

Figure 4 depicts the test set up. The dummy is seated on a steel bench with a slick Perspex seat. The dummy is held upright during the acceleration by leaning its back on metal support. It has an umbilical cord extending to a data acquisition system on the platform.

The bungee catapult used to accelerate the dummy extends into the background of the photograph above.

To stop the sled, metal poles (annotated in **Figure 4**) that extend from the front of the sled are driven into constricted plastic sheaths, which are rated to stop the sled with a particular crash pulse. When the platform and bench seat are brought by to a halt by the posts driving into the sheaths, the dummy is free to move directly forward into collision with the post.

A full array of equipment was made available for the testing which included the test sled which is capable of delivering a jockey into collision with a post at 30 km/h with a precision of ±0.1 km/h. The sled passes over a mechanical trip switch which automatically triggers the cameras and data acquisition system for the dummy.

Two high speed colour video cameras were available. One was used to acquire an overhead shot and the second was used for a side view. Suitable illumination equipment was also on hand to provide for the light hungry high speed cameras.

The crash test dummy was chosen to be representative of a jockey. Due to the extensive and comprehensive research required to validate a crash test dummy there is a restricted set of sizes available. The range is referred to as a family. A 95^{th} percentile male is the largest and is representative of a person who is heavier and bigger than 94% of the male population, but smaller than the top 4% of the population. The 50^{th} percentile male is the most commonly used. He is 78 kg and is average height and build. The 5^{th} percentile (female) person in the US population is 54 kg in weight and is chosen as this is the dummy that most closely represents the height and weight of a racing jockey.

Appendix A includes some additional information on the dummy as regards injury criteria and the vest worn by the dummy during testing.

2.1 Output Data Types and Analyses

The testing produced three types of data:

- Photographs of the test setup were taken before and after each impact test. These are not analysed in great detail in this report as the mechanics of the impact ***during the impact*** are of primary importance and not the pre-test situation and post-test outcome. Nevertheless, they provide a vital visual record of the test setup should manufacturers like to trace the particular setup for each test. The test outcome is similarly documented with the post-test photographs.

- High speed video recordings were also made to record the interaction of the jockey with the post in great visual detail. Two cameras were used, one providing a side view and the second an overhead view. This vision data from each impact is of particular interest and is analysed in **Section 3**.

- The test dummy is an instrument for collecting data on the forces experienced during the impact. Sensors embedded in the dummy record forces and bending moments on the body at a number of locations associated with vital organs and prominent modes of injury. Crash test dummy data is received from the crash test reports and this data is analysed in **Section 4**.

2.2 Associated Predictive Simulations

The post is characterised in crash tests. This means that the key parameters that govern the performance of the post can be extracted from the crash tests. With this extracted data it is possible to look at variations on the impact configurations and make predictions of the performance in these areas.

For example, tests are limited to 30 km/h due to risk to the instrumentation. This begs the question: What is the performance like at higher speeds? With each crash test, associated computer simulation can be used as a predictor of performance where one parameter of the system is changed.

A series of computer simulations were conducted to determine the effect of a number of factors on tests outcomes. The factors investigated were the effect of the contact duration of the jockey on the post (**Section 5.2**), impacts at increased speed (**Section 5.3)**, the operation where no fuse was present (also **Section 5.3)** and the operation of the railing connection (**Section 0)**.

Based on all the test data and analyses conclusions are then drawn.

3 Measurements from the High Speed Video

Figure 5 & **Figure 6** are included here to show the capture of the high speed video cameras above and to the side of the impact. **Appendix B** shows a full sequence of key moments (salient events) during the simulation where particular events occur and features in the video are tracked or measured.

The reader is encouraged to view the video clips and track forward and backward to see the action, timing and consequences of the post release. While in the opinion of the author, all key measurements have been made, further measurement is possible with the collected footage.

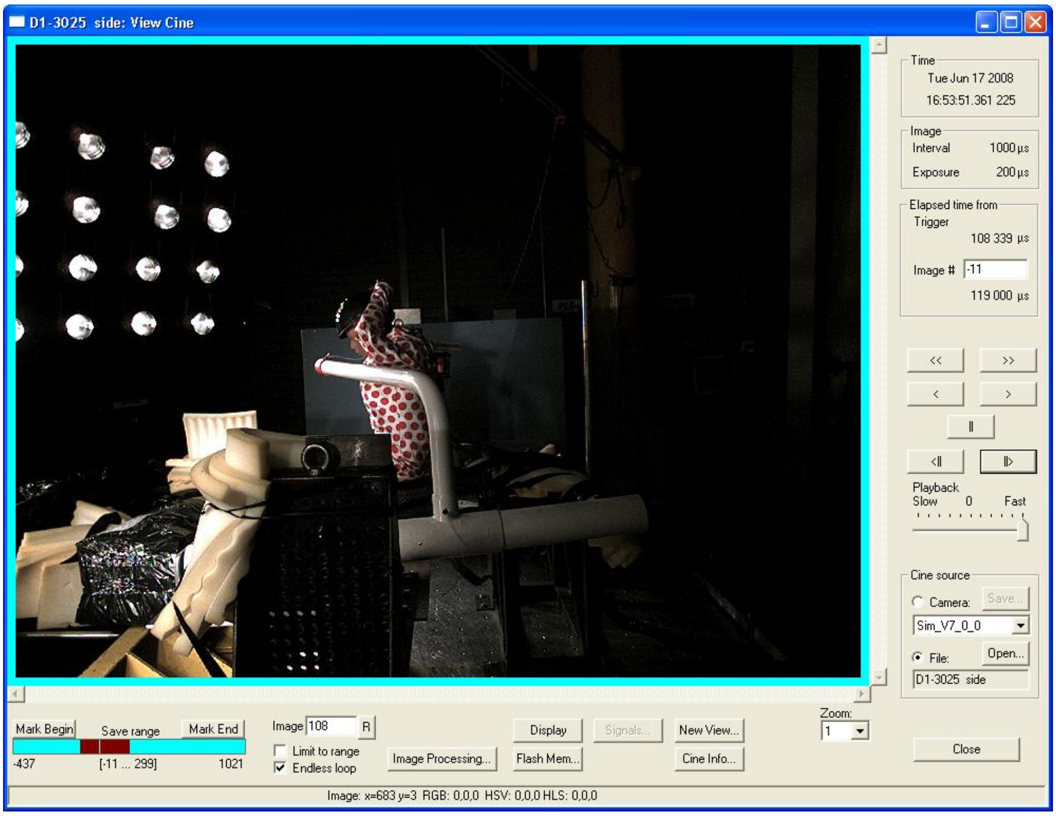

Figure 5: The side view high speed motion capture. The green peg at the rail connection has just broken. This has occurred 28 milliseconds after the initial fuse break at the bottom of the post.

3.1 Salient Events

The aspects of the video recorded sequence that are of interest are referred to as salient events. This list of events includes:

- the instant of contact of the chest with the post
- the time elapsed between first contact and the fuse break
- the maximum deflection of the post when the fuse breaks
- the total duration of the chest loading
- the speed change due the entire contact

The speed loss is measured by tracking the leading or forward edge of the helmet during the impact sequence. Any feature can be tracked such as a particular dot on the biomechanics suit, the back of the dummy and any readily identifiable feature point. The front of the helmet is convenient in this case as it is visible in both cameras, is readily identified and not visually obscured during the impact like parts of the chest itself.

The vital matter in terms of linking with previous tests in the track environment is the correlation of loss of speed during the impact and injury measures and this is addressed in the next section.

3.2 Using the CineView Video Player

The Video player for the output files is included with the crash test data. It is installed by running the installation package and following the instructions.

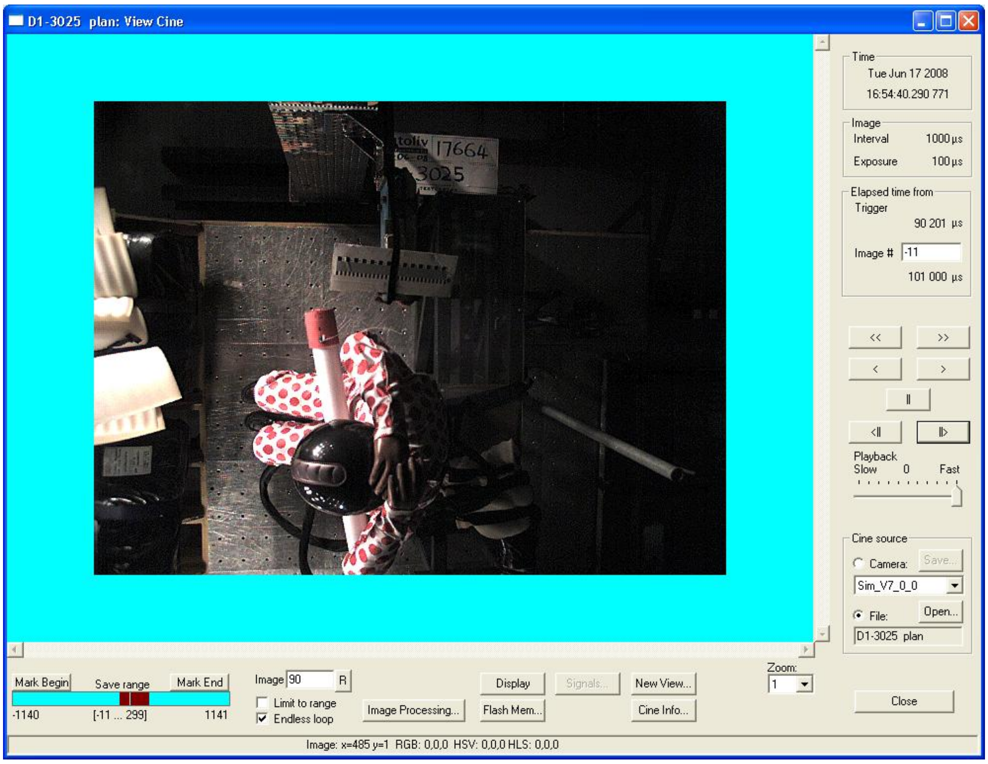

Figure 6: A video still from the overhead high speed video camera, where the fuse has broken and the contact on the chest appears to have been just about released.

Figure 6 shows the view from the overhead high speed video camera. It depicts the approach of the dummy to the post. The date and time of the impact is reported in the top right hand corner and moving down the right edge of the graphical user interface (window); the frame rate is identified as every 1 ms (1000 µs), the exposure for the camera at 0.1 ms; along with the time at which the start record trigger engaged the camera system. The time elapsed from a particular frame (image # -11 is this case) is also reported at 101 ms. The video player controls are evident with file access below that.

At the bottom left, the captured video is -1140 ms to +1141 ms (2.281 seconds). However, the relevant events occur only in a small portion of the captured footage, so a region of interest is highlighted in red, from time point -11 to time point 299 ms. Other display and video settings can be adjusted in the neighbouring frame.

3.3 Key Measurements from the Video Footage

Parameters associated with the salient events are recorded systematically for each video recorded impact sequence. The measurements were all made on the overhead camera.

The overhead view was chosen for measurements as the calibration plate (which appears black and white in Figure 6) appeared larger in the overhead view which leads to more accurate measurements. The length of the calibration plate as it appears in the view is measured in terms of pixels in the view. This is used as a marker for all subsequent distance measurements in the video sequence. The sled platform is also visible in the view and holes are drilled in a 10 cm grid pattern. This can also be used for measurement where the sled has come to rest and the distance from the camera to the object and the object to the platform is already known.

Similarly, measurements of all salient events can be made on the side view as a rough verification check, however due to the smaller size of the calibration plate in the view all measurements will be lower accuracy than on the overhead view.

	BI-3025	BI-3026
Fuse code	12	20
Time to break (ms)	10	14
Chest contact duration (ms)	21	26
Max bend (cm)	2.19	4.14
Speed lost (km/h)	2.17	4.05
Star Rating	***	***

Table 2: Salient measurements from the video footage

From the video based measurements (Table 2) it is clear that there is a correlation between fuse code and speed loss. Each reported impact received a three star rating (maximum). Three stars are awarded where the speed loss is less than 8km/h, due to the fact that the speed loss of that range cannot be associated with any pedestrian impact events where life threatening injuries were suffered.

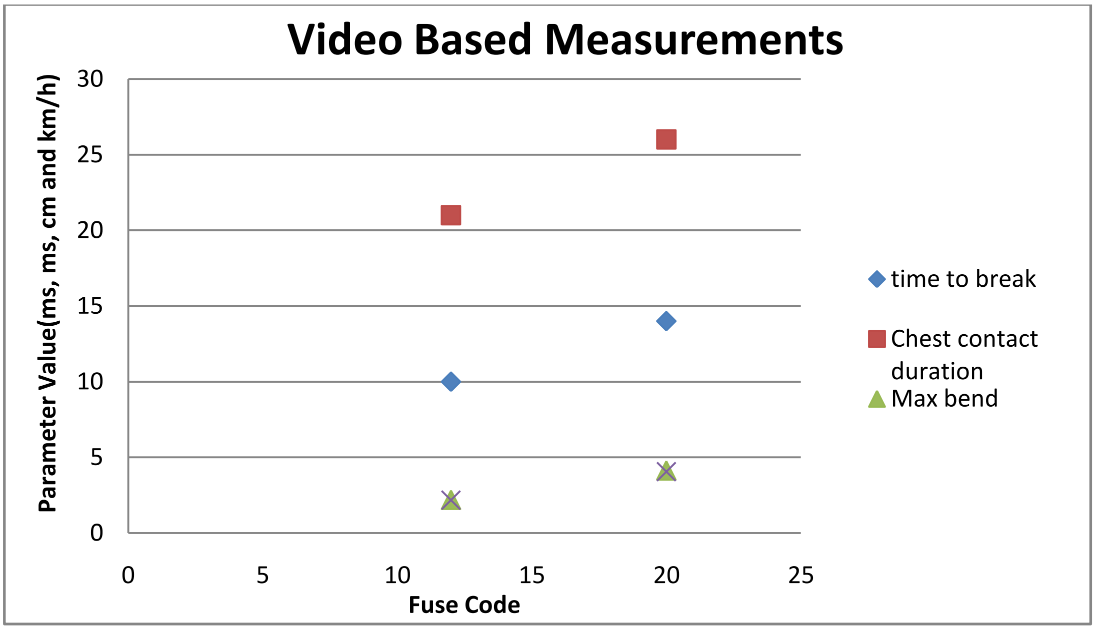

Figure 7: Data for fuses 12 and 20 indicates what appears to be a linear relationship between code number and salient event parameters.

It seems clear that fuses that broke quickly lead to better outcomes in terms of speed lost.

There was some give or flexibility available in the metal fixture used in tests and this is correlated with the compliance of curated turf in which the footing will normally sit. A properly operating fuse that breaks rapidly will not lead to any excessive loading on the post or footing. From this point of view, lab test results should indicate racetrack performance. In other words, a rapid clean break of the fuse should avoid any potential problems in the lab and at the racetrack.

The fuses appear to break quickly. The speed loss is low, in fact it has a three star rating and it follows that no life threatening injury is produced.

This is the basis of the previous testing rounds, yet we need to confirm that a crash test dummy will tell the same story. Crash Test Dummies are backup up by extensive validation and trusted by scientists as the best available measurement instrument for injury potential, so it will be possible to verify the use of speed loss as a predictor of injury because a crash test dummy was used in these tests.

The following section will investigate the injury data that is produced from the recorded forces and bending moments in the crash test dummy instrumentation, to verify that no injurious forces were recorded in the crash test dummy during these impacts.

4 Data from the Crash Test Dummy

Section 3 identified that the loss of speed can be reduced to less than 8 km/h with the introduction of a fuse. This leads to an immeasurably small likelihood of life threatening injury and moderate injury in an extended experience of post impacts. The video analysis also showed that shorter contact times on the body result from a correctly operating fuse. In this section, a summary of the crash test dummy data is reported in the context of limit values of each parameter. Each injury parameter is then explained in more detail.

The limit values for impact parameters are based on a range of data from cadaver tests that is already available. The cadavers were subjected to impacts and the particular levels of shock, force and chest compression was recorded. Injuries identified in subsequent autopsies or medical examinations were considered in the context of the severity of the impact and correlated with particular values of the recorded parameters for the impact.

The recorded data from the crash test dummy is considered in light of these established limit values for injury.

4.1 Summary of Autoliv Dummy Test Results

This section presents all the injury measures from the dummy in one table (**Table 3**) and one graph (**Figure 8**). These results correlate with the video based measurements presented in **Section 3**.

	Units	Limit Value	BI 25		BI 26	
Fuse code			12		20	
Forces	g	60	13.5	(0.23)	16.7	(0.28)
Compression	mm	22	14.5	(0.66)	8.4	(0.38)
VC	m/s	0.5	0.12	(0.24)	0.05	(0.10)
CTI	-	1	0.36	(0.36)	0.33	(0.33)
NIC compression	kn	3.3	0.04	(0.01)	0.05	(0.02)
NIC bending	nm	57	22.8	(0.40)	22.3	(0.39)
HIC	-	1000	11	(0.01)	14	(0.01)

Table 3: Summary table of results for all injury criteria for tests on fuses 12 and 20. The normalised values are included in brackets (as a fraction of the limit value)

Each injury measure in **Table 3,** has its own units and threshold and all injury criteria values have been normalised by dividing by the injury threshold. The normalised data are graphed in **Figure 8**. Any bar of height greater than 1 represents a concern in terms of injury. None of the measured injury criteria returned values greater than one, which means that the acceptability threshold is never exceeded.

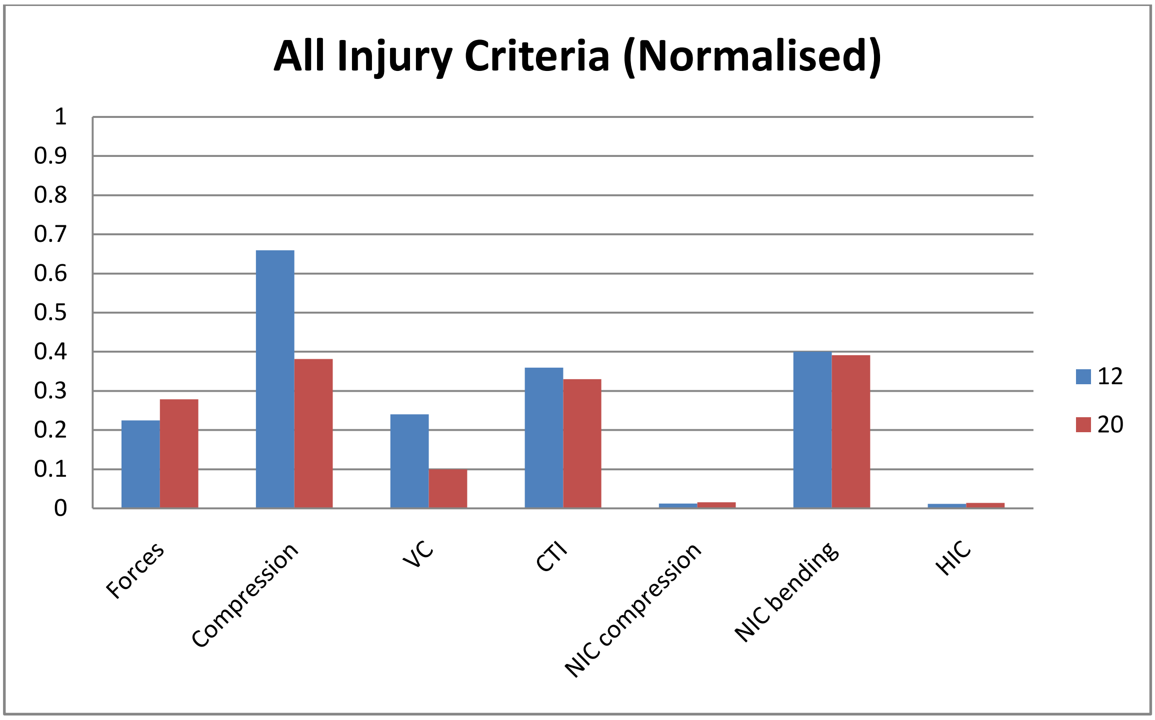

Figure 8: The relationship of fuse code and injury criteria

These results demonstrate a generally low potential for injury, with the following reservations:

- A single impact test was conducted on each fuse. Reliability testing is required.
- These tests are conducted at 30 km/h whereas much higher speed impact is possible. The next section conducts computer simulation to discover and quantify the risk of injury at these higher speeds.

4.2 Performance Comparison with Fixed Metal and Plastic Posts

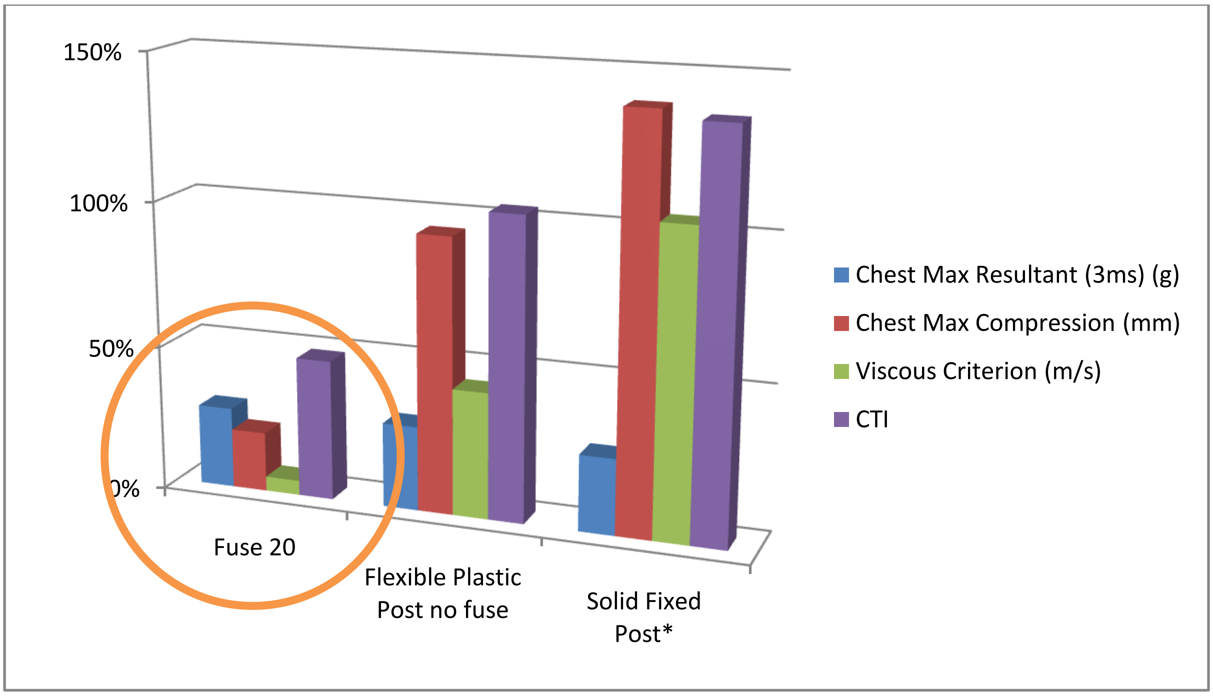

Figure 9: Bar chart showing the measured values as a percentage of the limit for a life threatening injury. The graphs show test results for the Barriers International fuse (at left) lower in comparison to a flexible plastic post without a fuse (middle) and a solid metal post[2] (right)

The tests indicate that the new Barriers International fuse has a capacity for preventing injury as it reduces the contact duration which leads to the following advantages:

- Forces cannot reach peak values which would otherwise be experienced.
- The chest compression is restricted as the force is switched off before too much compression can occur.
- The shock due to the impact is reduced as a low energy impulse is experienced.
- With both the force and the compression reduced the combined injury criteria is similarly reduced.
- The fuse reduces secondary injury such as whiplash. These injuries are prevented when the force causing the neck to rotate rapidly is eliminated.

[2] The data for a the solid metal post is from a MaDyMo simulation where no vest was worn and is included here as a guide.

4.3 Cadaver Testing and Human Tolerance to Forces

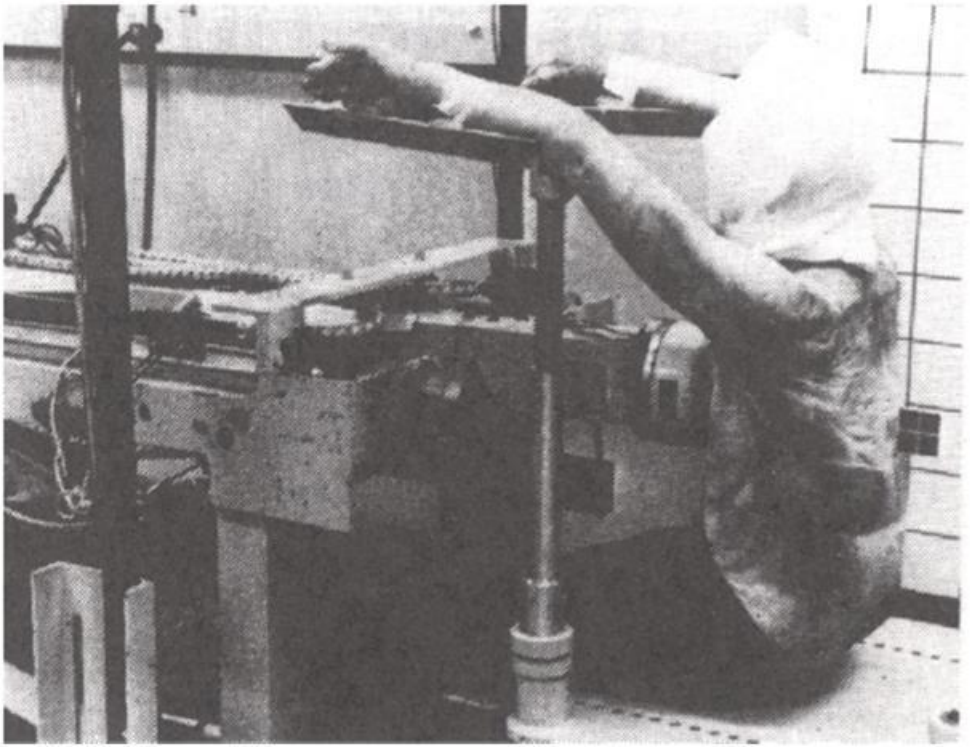

Figure 10: A reproduced figure depicting a cadaver in position prior to impact testing[3].

Figure 10 shows a cadaver in position for a chest impact test. In many countries including Australia, there are heavy restrictions on the conduct of this type of testing. Ethical approval needs to be granted before such tests are conducted and the scientists involved have to justify the value of the results in front of an ethics committee. They also have to prove that the source of the cadavers is legitimate.

The test involves preparing the cadaver by examining it for pre-existing injury or any condition that might bias the results. If any problems arise the cadaver is excluded. The height, weight and sex along with other parameters are recorded and only after being properly measured and passing all the pre-test criteria, the cadaver is placed in position, fitted out with sensors and impact tested.

[3] SAE paper 2004-01-0288, A Normalization Technique for Developing Corridors from Individual Subject Responses, David Lessley, Jeff Crandall, Greg Shaw and Richard Kent, University of Virginia, James Funk which is in term reprinted from Kroell et al. 1971

A post test medical examination or autopsy is then conducted to consider (for example) how many fractured ribs have resulted and to check for injury to any internal organs or other signs of injury.

Through cadaver testing, it has been possible to establish the physical thresholds and tolerances for injury over a number of subjects. Scientists such as Stapp and Messerer conducted trailblazing research in the biomechanics of injury to various body parts and more recently Prasad, Mertz, Viano and Nutzoltz have developed the injury criteria for vital organs such as the head and neck.

The injury criteria for the chest in particular are now explained in more detail.

At first, the injury criteria for the chest appear diverse, the reader is referred to a recent European funded project[4] for the review of Thoracic injury criteria for an excellent up-to-date overview of chest injury criteria and also to the earlier report on chest injury by Eppinger[5] which was prepared for NHTSA, both of which are quoted heavily in this section.

4.4 The Abbreviated Injury Scale for Injuries to the Thorax

The abbreviated injury scale is the most widely used method for the categorisation of injuries in the medical field. It is useful for considering outcomes for treatment managing costs and hospital lists and is used here to categorise the severity of injuries on a threat to life scale. In the following table, a few examples of the types of injuries in each category are given:

[4] Review of the Thorax Injury Criteria, AP-SP51-0038B, by INRETS in France, Project no. FP6-PLT-506503 (APROSYS)

[5] **Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems – II, By Rolf Eppinger, Emily Sun, Faris Bandak, Mark Haffner, Nopporn Khaewpong, Matt Maltese,** National Highway Traffic Safety Administration, National Transportation Biomechanics Research Center (NTBRC) **Shashi Kuppa, Thuvan Nguyen, Erik Takhounts, Rabih Tannous, Anna Zhang** Conrad Technologies, Inc. **Roger Saul** National Highway Traffic Safety Administration Vehicle Research & Test Center (VRTC) **November 1999 (see also the supplement)**

AIS	Injury Severity	Skeletal injury	Soft tissue injury
1	Minor	1 rib fracture	Bruising of the bronchus
2	Moderate	2-3 rib fractures Sternum fracture	Partial thickness bronchus tear
3	Serious	4 or more rib fractures on one side 2-3 rib fractures with hemo/pneumothorax	Bruising of the lungs Minor heart bruising
4	Severe	flail chest 4 or more rib fractures on each side 4 or more rib fractures with hemo/pneumothorax	Lung laceration on both sides Minor laceration of the aorta Major heart bruising
5	Critical	Flail chest on both sides	Major aortic laceration Lung laceration with tension pneumothorax
6	Maximum - not normally survivable		Aortic laceration with haemorrhage not confined to mediastinum

Table 4: Examples of injuries of various AIS level from the APROSYS review of thoracic injury criteria

4.5 Chest Compression

Results of the cadaver tests include the amount of chest compression induced during the impact. The peak chest compression is plausibly linked with injury. Where the level of chest compression resulted in a life threatening injury during a cadaver impact test a 1 is awarded. Similarly, where a minor or moderate injury is suffered a 0 is awarded. **Figure 11** shows the collected results from a number of impact tests in the APROSYS report.

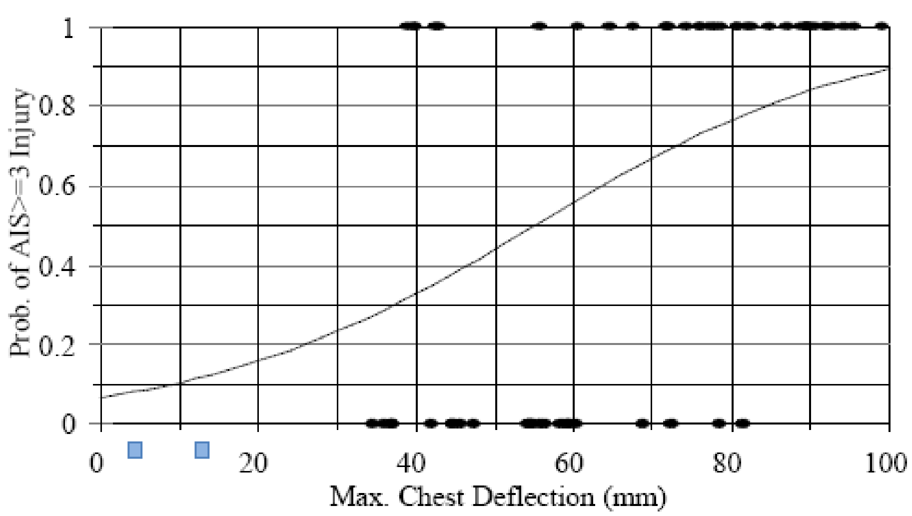

Figure 11: The correlation of chest injury with chest compression (APROSYS). The blue boxes show the results for the Barriers International tests on fuses 12 and 20.

Figure 11 indicates that the likelihood of AIS 3+ injury is 0.09 to 0.14 for the Barriers International tests.

However, it could be far less than that, as serious outcomes linked with life threatening injuries (AIS >=3) only began at approximately 37 mm of chest compression and this is far greater than the chest compression measures for the Barriers International System fuses 12 and 20. Further, the accepted injury threshold for the 5th percentile female is a chest compression of 41 mm and the figure touted for general chest impact tolerance by Eppinger is 53 mm. Figure 11 shows that an AIS >=3 (life threatening injury) can be suffered at a chest compression of 37 mm or greater, and that with a chest compression figures of 14.5 mm and 8.4 mm for the Barriers International fuses 12 and 20, there is little chance of inducing a serious chest injury.

The EuroNCAP limits for crash tests published in 2004 indicate that the higher limit is 50 mm where there is a 50% risk of AIS 3+ injury and a lower limit of 22 mm where there is a 5% chance of an AIS 3+ injury. The Barriers International fuses 12 and 20 will meet EuroNCAP standards.

Further, the chest results are three star, based on the fact that AIS3+ injuries are not reported at such low chest compression figures as those experienced by the Barriers International fuse.

4.6 Injury Due to Direct Force on the Chest

A commonly stated human tolerance level for severe chest injury (AIS ≥4) is a maximum linear acceleration in the centre of gravity of the upper thorax of 60 g which is sixty times the pull of gravity (see Eppinger in footnote 5).

The forces experienced by the dummy during the tests were relatively low.

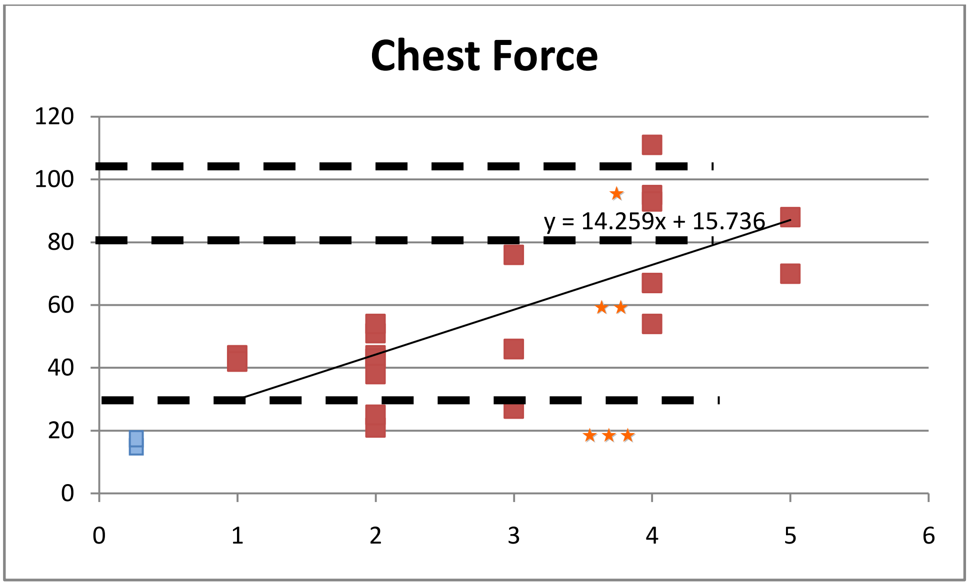

Figure 12: The effect of direct force on the chest and injury. The blue squares show the values measured in the Barriers International tests on fuses 12 and 20.

Figure 12 demonstrates that, based on the idea that force alone causes injury, the Barriers International fuses 12 and 20 are not likely to cause serious chest injury due to direct forces.

Based on the AIS injuries determined in the cadaver tests it is possible to apply the star rating system used in previous work by the author to this range of data. If chest force alone was considered, Barriers International fuses 12 and 20 would be determined to be three stars.

4.7 Viscous Injury (V.C.)

Viscous injury to the internal organs is an injury measure that was introduced to consider situations where a person is shot while wearing and bullet proof vest, where there is no penetration into the vest but the person still drops dead. Shock forces are translated into the thoracic cavity and can affect vital organs.

Viano conducted tests on rabbits under anaesthetics which were subject to blunt impacts of the chest. From these tests he proposed the concept of the viscous injury criterion and later used data from Kroell to parameterise the measure for humans[6].

[6] Lau I.V., Viano D.C. (1986). The Viscous Criterion – Bases and Applications of an Injury Severity Index for Soft Tissue. Proc. of the 13th Stapp Car Crash Conference.

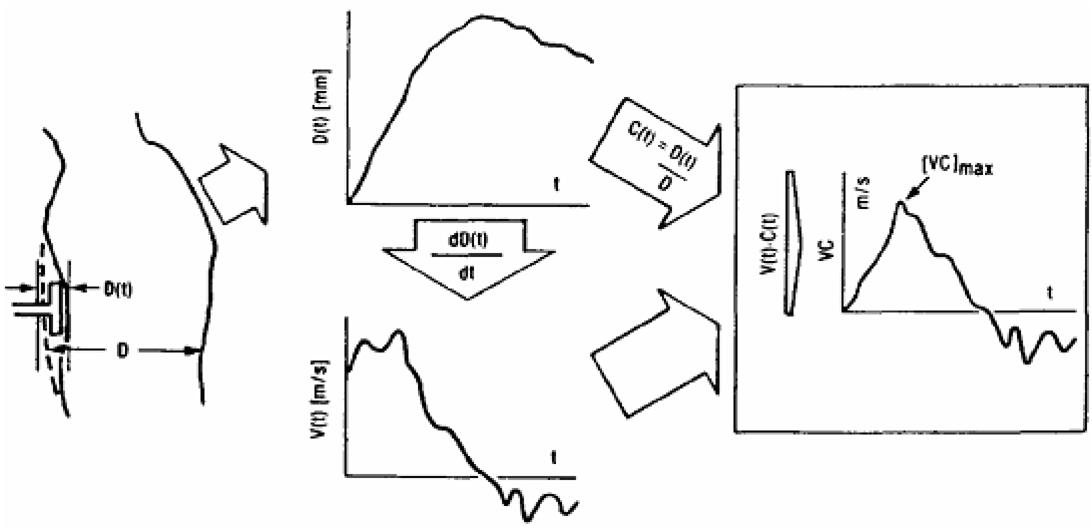

Figure 13: This excerpt from the APROSYS study, which is in turn from another author, indicates the calculation of V.C that includes the ratio of the chest compression to original chest width multiplied by the velocity of deformation as determined by the velocity of the sternum.

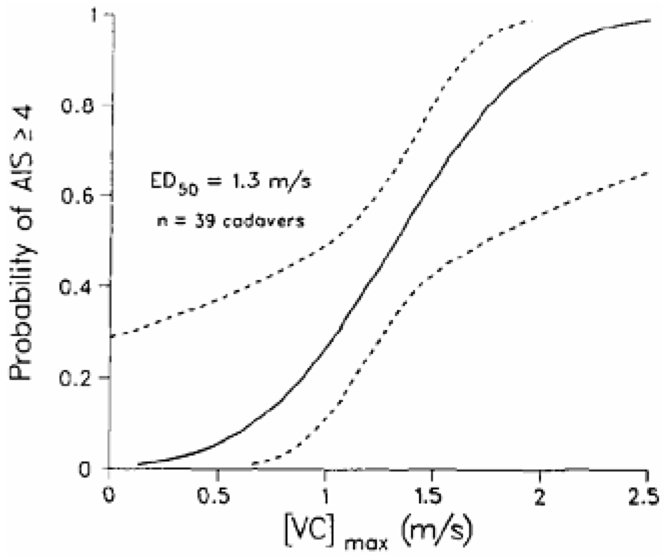

Figure 14: Reproduction of Figure 80 from the APROSYS study of thoracic injury criteria which indicates the 'at-risk' region for viscous injury.

Figure 14 shows that the force and extent of crushing is the greatest risk at low speed, but where the velocity of deformation becomes greater than 0.5 metres, the viscous injury criterion becomes more and more prominent. At speeds between 3 and 30 metres per second viscous injury is dominant, then blast injury takes over:

> *"Analyses of data from experiments on human cadavers show that a frontal impact which produces a VC value of 1.3 m/s has a 50% chance of causing severe thoracic injuries (AIS ≥=4). A value of 1 m/s may be used as a reference value for human*

tolerance in blunt frontal impact to the chest. Specific details may be found in the dummy hardware regulations and SAE J1727."[7]

The more stringent EuroNCAP performance limits for the Viscous Criterion (V.C.) are a higher limit of 0.5 m/s which has an associated risk of AIS4 of 5% and a higher limit of 1 m/s where the risk of AIS4 injury is 25%.

The VC values for fuse 12 and 20 were 0.12 m/s and 0.05 m/s respectively. These figures are not in the region where the jockey is 'at-risk' of AIS 3+ injury and are again identified as three star.

4.8 Combined Thoracic Injury (CTI)

The Combined Thoracic Index (CTI) is a measure of the injuries of the thorax. It is a combination of the maximum chest deflection (D_{max}) and the 3 ms clip maximum value of the resultant upper spine acceleration (A_{max}). The equation for the calculation of the CTI is:

$$CTI = D_{max}/D_{int} + A_{max}/D_{int}$$

Where A_{int} and D_{int} are constants that depend on the dummy.

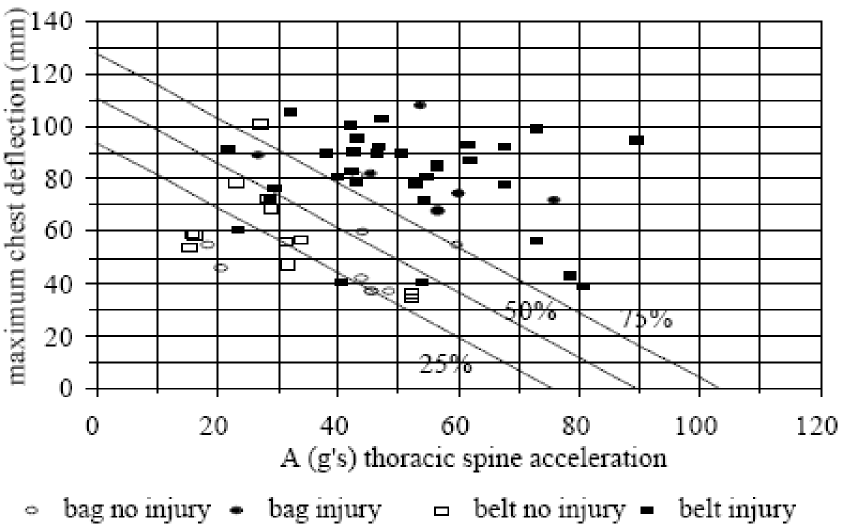

Figure 4-7. Lines of equal probability of AIS• 3 injury using the linear combination of maximum deflection and spinal acceleration (Model VII). The test data categorized into restraint condition and injury outcome is also presented on the graph.

Figure 15: The CTI injury criterion map.

[7] From the Madyo reference manual

The intercept values used in this study are 90 g for A_{max} and 84 mm for the chest deflection D_{max} as per the NHSTA proposed figures for the 5th Percentile Dummy[8].

The CTI results for the Barriers international fuses 12 and 20 were 0.36 and 0.32 respectively, which are not in a region considered to be 'at-risk' based on the CTI criterion.

4.9 Whiplash Injury

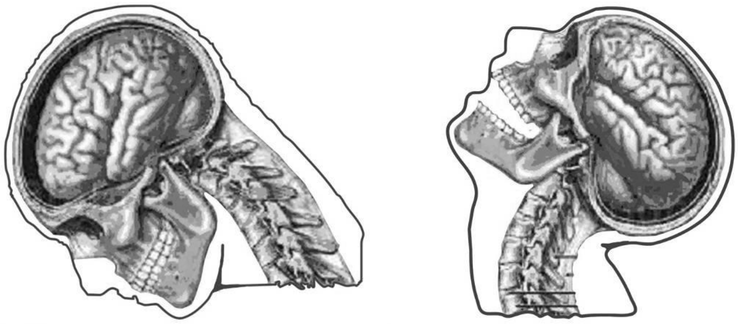

Figure 16: An anatomical drawing depicting a whiplash action

Whiplash injury can also occur due to chest impact that induces a violent nod of the head. For this reason the neck injury is also monitored in chest impact tests. Figure 16 shows this whiplash effect and also an associated closed head injury where the soft brain tissue has effectively sloshed around in the skull cavity, tearing at the connecting vessel between the brain and the meninges which surround the brain. While no contact at the head was noted, the Head injury criterion was nonetheless monitored for completeness.

Without significant contact on the chest, neck injury criteria values were well below that expected for the onset of cervical spinal (whiplash) injury.

4.10 Chest Contact Time and Injury

Through the overall testing experience, it has been noted that there is strong correlation with chest contact time and injury.

The chest contact time also significantly parses all data into two groups. Those with contact times in excess of 23 ms and those with contact times less than 23 milliseconds. The group with the shorter durations of chest contact show linear relationships between injury and contact time, but longer contact durations tend to be much longer. This delay is explained later using computer simulations.

[8] http://www.nhtsa.dot.gov/cars/rules/rulings/AAirBagSNPRM/PEA/pea-III.n.html

5 Computer Simulation Analysis and High Speed Prediction

To exemplify the usefulness of a fuse in the post, it is important to recall impact simulation tests conducted early in this testing program where the injury prevention capacity of the flexible plastic post was tested.

The findings were that while the flexible plastic tubes and structures will bend on impact and redirect the jockey where a glancing blow has occurred, if a direct impact has occurred they did not have the capacity to decelerate the jockey to rest safely. The jockey comes to rest, but has a measurable likelihood of suffering life threatening injury in the process.

5.1 Review of Fixed Post Impact

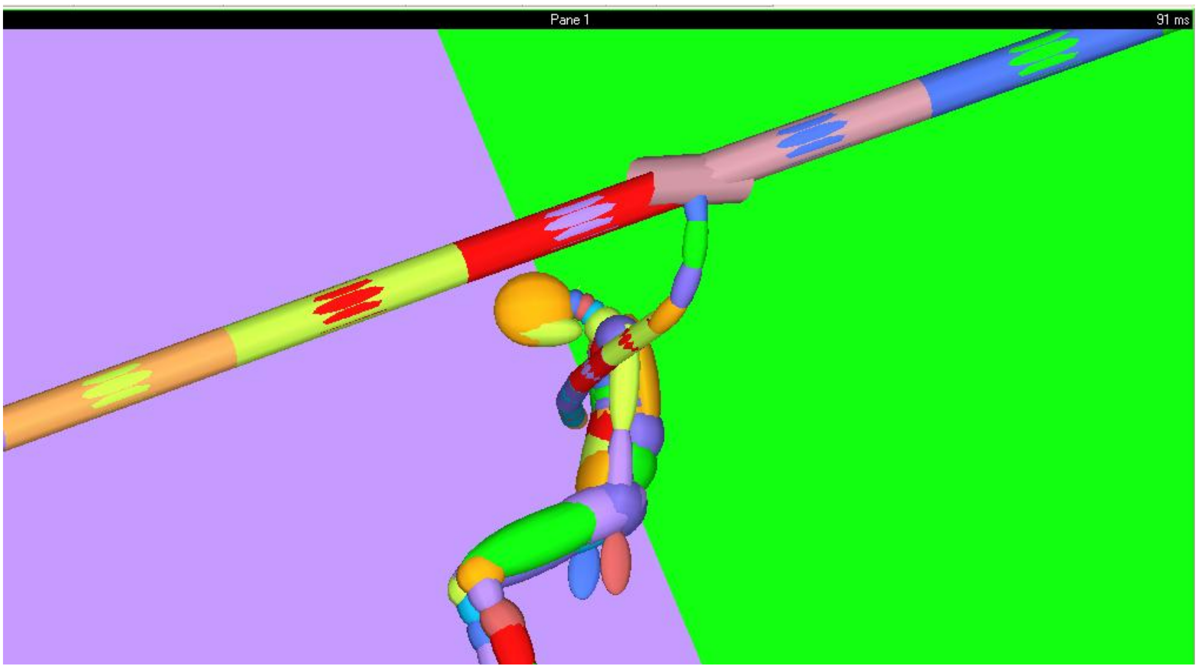

Figure 17: A 30 km/h impact with a fixed post without a fuse. The dummy chest is loaded the head nods causing bending moments at the neck.

Figure 17 is a screenshot from a simulation where the dummy was projected at the post at 30 km/h. Compared to a fixed metal post impact at the same speed, where the jockey is without a vest, the flexible nature of the post is such that in combination with a vest the potential for viscous chest injury (V.C.) is reduced. However, this appears to be a moot point when the simulation indicates that the hard structures are damaged and the likelihood of fracturing 6+ ribs is high. This level of thoracic injury leads to flail chest where the jockey cannot breathe. The relative contribution of the vest and the flexible plastic to preventing injury is not determinable from these tests.

Further, the 'clothes-line' affect (where the jockey is stopped at the chest) induces a nod of the head and neck which induces high tension and bending loads in the neck, otherwise referred to as whiplash injury.

5.2 Fuse Timing

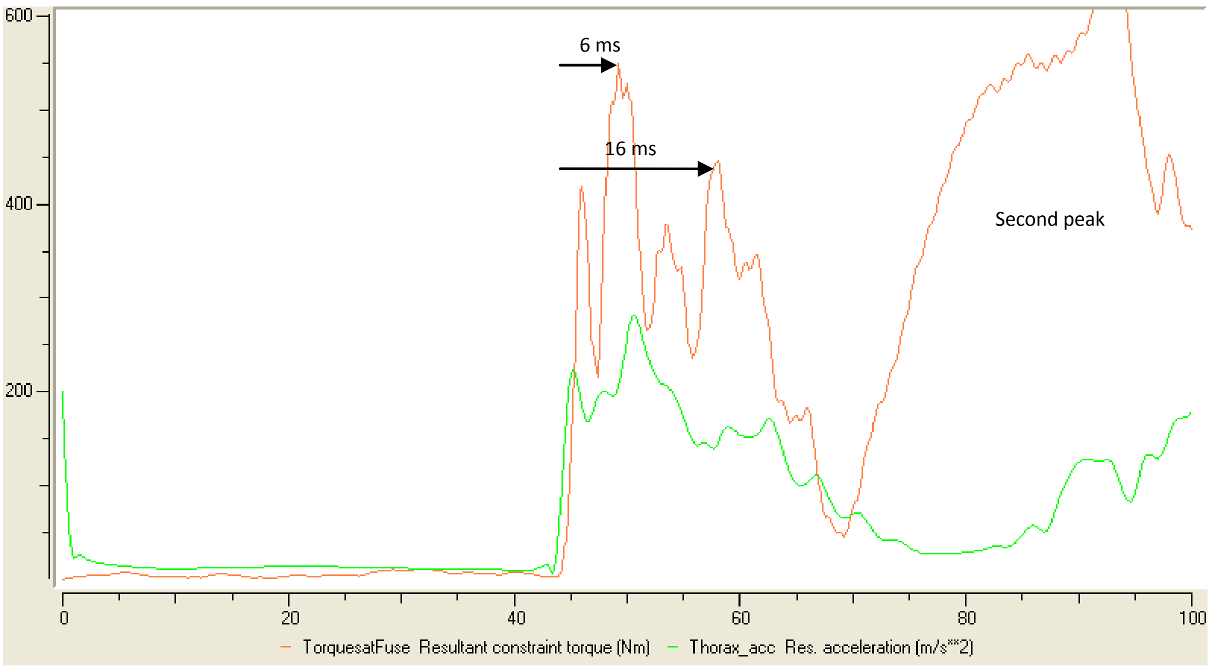

Figure 18: The acceleration experienced by the jockey overlaid with the associated torque at the fuse at each instant during the simulation.

Figure 18 indicates the torque or bending action at the post base (orange trace) and acceleration on the chest of the jockey (green trace) as the jockey hits a fixed post (no fuse) in a computer simulation at 30 km/h (as in **Figure 17**). The contact appears after a time of 44 milliseconds (0.044 seconds) has elapsed fom the start of the simulation. Forces and moments are at a low 24 milliseconds later where a second peak begins to emerge.

The initial peak is associated with a bounce of the post and a second round of loading on the post after the post has rebounded back onto the chest. This rebound may or may not be visible due to the compression of the chest, but the post bounces forward first. The loading decreases whether contact with the chest is lost or not and then the chest loading increases again in a second "hit".

The peak torque on the post of approximately 550 nm at ground level is achieved after 6 ms. The contact is known to be approximately 0.7 m from the ground and forces in excess of the body weight are known to be applied in a collision. The peak torque (~550 nm) correlates with approximately 1.5 times the body weight of 54 kg applied 0.7 m from the ground.

The fuse will ideally fire at 6 ms where some of the initial loading is avoided. The torque decreases dramatically after 16 ms. It is clear that in order to avoid the second loading peak, the fuse should fire before approximately 16 ms as the torque is dropping rapidly after that point and fuse fracture becomes increasingly unlikely.

If the fuse does not break early, it is a long time (in collision terms) before the second loading appears and the torque rises again to a similar level, at a approximately 44 ms after the initial contact, by which time the collision is over, at least as far as injury is concerned as any injury that might have been suffered would most likely have been suffered already.

5.3 Fuses Reduce Injury Potential at Increased Speed

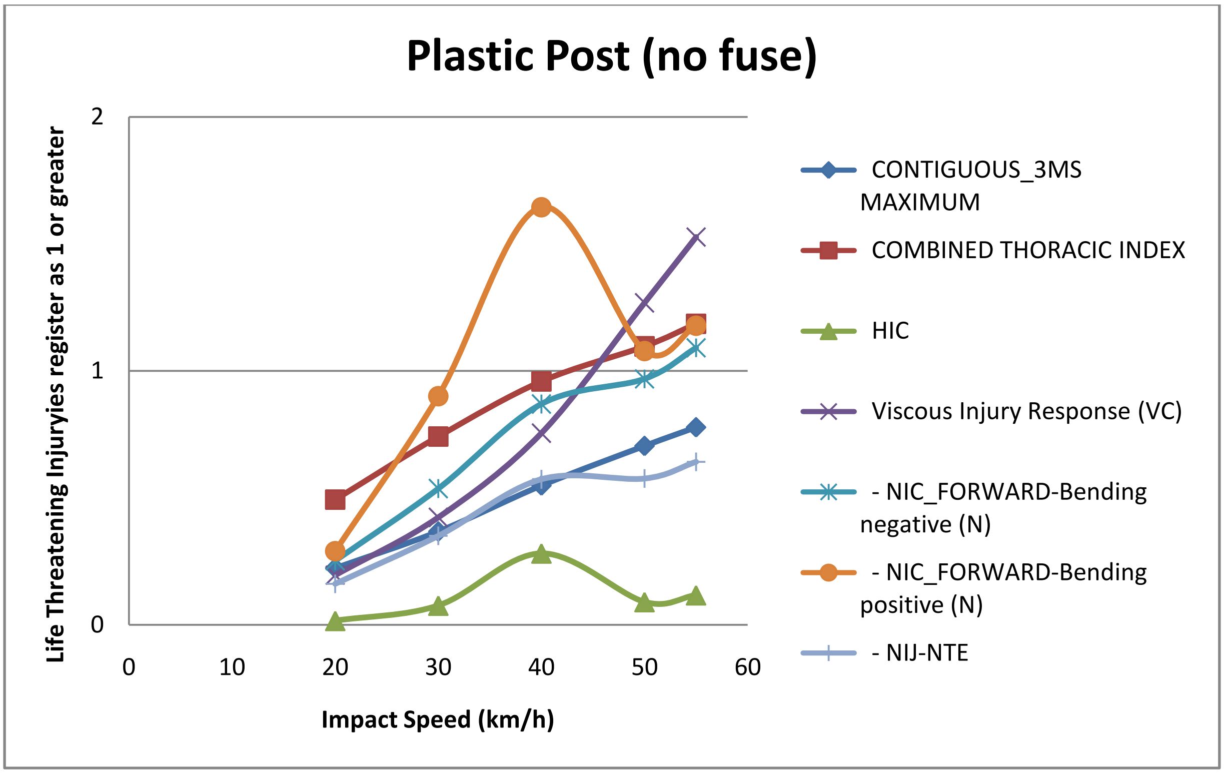

Figure 19: Injury potential without a fuse

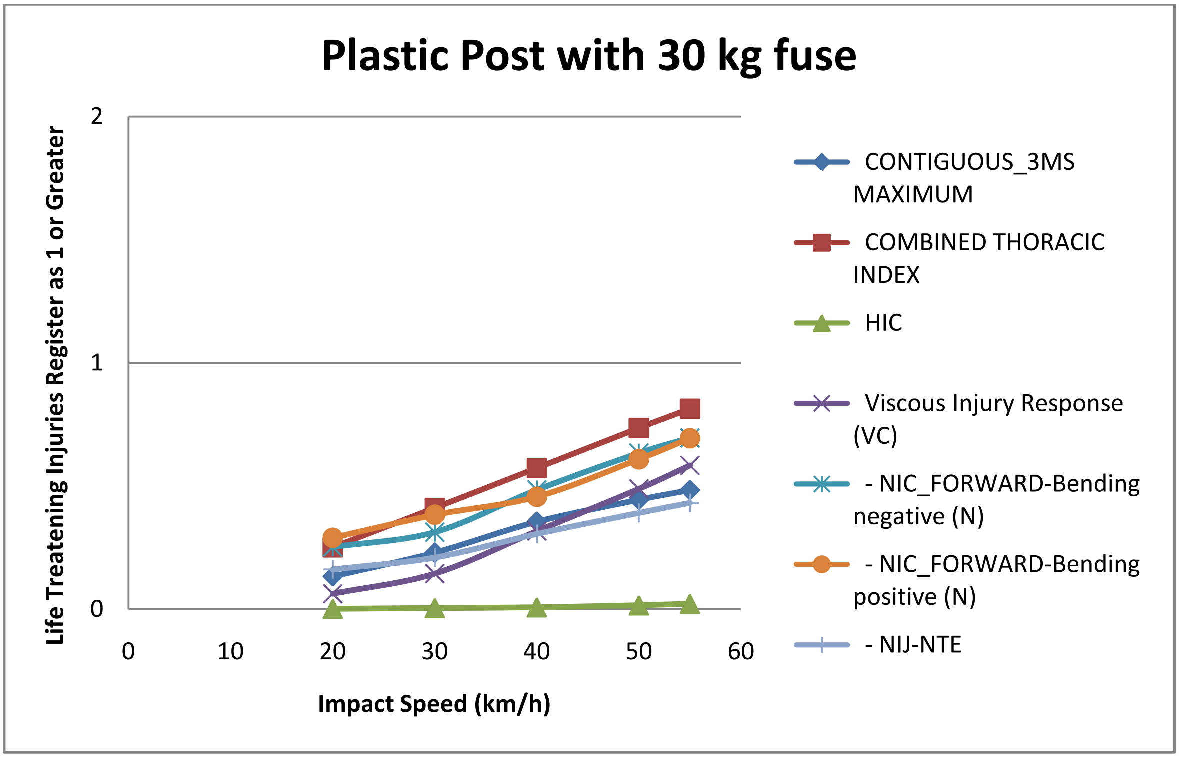

Figure 20: Injury Potential where a fuse has been added to the system. Note that compared to Figure 19, all injury potentials are reduced below injurious levels even as high as 55 km/h

Figure 19 shows injury measures from a post without a fuse and **Figure 20** is representative of a post with a fuse. The comparison of the figures show the advantages of including a fuse in the post and indicate that impacts at speeds higher than the 30 km/h impact tests conducted at Autoliv may not generate life threatening injuries where a fuse is added.

In each figure, a range of injury parameters for the head, neck and thorax are shown. The known (or accepted) threshold for the injury in these graphs is 1. Any values greater that 1 indicate that the level of risk is unacceptable. **Figure 19** indicates that the speed limit for impact on a plastic post is approximately 32 km/h. This limit is determined by that fact that life threatening spinal injuries are possible due to whiplash with a 32 km/h impact speed.

However, **Figure 20** shows the addition of a fuse (breaking load of 30kg) reduces this injury potential to acceptable levels and indicates that while the jockey may still break a leg or a rib, life threatening injuries are unlikely.

5.4 Rotation at the Rail

The connection between the post and the rail is of interest. The connection was setup in three different ways in a second series of computer simulations.

- Rotation around the axis of the post in the connector (as with the designed motion)
- Fixed and locked where no rotation is possible
- Free rotation about all axes (a universal joint like the shoulder)

Where rotation in one plane is possible, as in the designed motion, the fuse works admirably in terms of injury prevention. However, where the joint is locked, the fuse breaks as expected, but the jockey is stopped at the chest at high speed as the post cannot rotate out of the way.

Where a universal joint was in place the fuse did not break reliably as the tension is much reduced due to deflection of the post.

5.5 Head Injury Prevention

A fourth star is available for a HIC score of less than 1000 in a drop test. However, without padding on the rail it seems improbable that a HIC of less than 1000 would be achieved. There are cost limitations for the introduction of padding and there is parallel research being undertaken in developing the performance of jockey helmets.

It might be that this new helmet obviates the need for substantial padding, or at least reduces the level of padding required. Given the impending research results for helmets, to recommend the installation of padding would be premature.

A high fidelity computer model of a helmet is required to do useful computer simulated predictions for the Head Injury Criterion. Whereas the computer models of the crash test dummy is backed up with extensive validation research, a similarly widely respected standard helmet model is not available. The development of such a helmet model is currently a subject of research and without a suitable model predictions are not worthwhile.

Testing with current helmets is also possible, but this may become obsolete with the imminent arrival of a new design.

In conjunction with a newly developed helmet this system may well have a five star performance. Physical testing with a head form will determine the final star rating.

6 The Correlation of Speed Loss and Injury

The idea that injury potential is correlated with the speed of impact finds a lot of support in the literature. The following articles and references are included to illustrate this point.

VicRoads fact sheet on Speeding

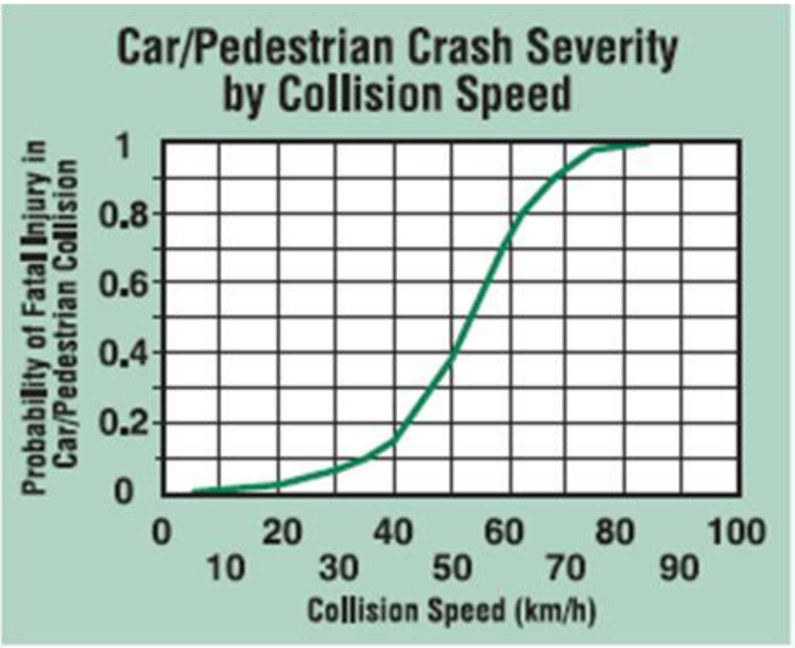

Figure 21: Vic roads advice from Fact Sheet 4: Speeding

Figure 21 shows the established correlation of impact speed and risk of fatality (AIS 6) for pedestrians.

The figure indicates that the likelihood of injury increases with impact speed. At 56 to 60 km/h (thoroughbred gallop speed) the chance of fatality is approximately 50 to 70 %. This chance of death is too high. For example, where the jockey is brought completely to rest in an impact with an immovable surface at 54 to 60 km/h they have a 50 to 70% chance of fatality.

The tests are conducted at 30 km/h where there is an inherent 7% risk of fatal injury. The 30 km/h test speed is convenient for the measurements. However, there is a rapid increase in risk with speed.

John Lambert Report

The following is an extract from a report by John Lambert[9] related to motorcyclist injuries where pedestrian injury statistics are utilised. It is included here as there are similarities between using pedestrian data for motorcyclists and using pedestrian data for Jockeys.

> *"The greatest cause of injury to motorcyclists is impact with their motorcycle in a crash situation or impacts with other vehicles or fixed objects either while still on the bikes of after they have separated from their bike. There are no studies into speed of impact versus risk of injury for motorcyclists. However there are a number of studies into pedestrian trauma outcomes versus speed of impact by cars. Whilst these are not representative of impacts with other fixed objects they do provide guidance into what outcomes impact speeds may have on motorcyclists.*
>
> *The outcomes of available studies on pedestrian impact speeds are shown in the graph below. Note that studies 2 and 3 relate to fatalities while study 4 relates to injury.*

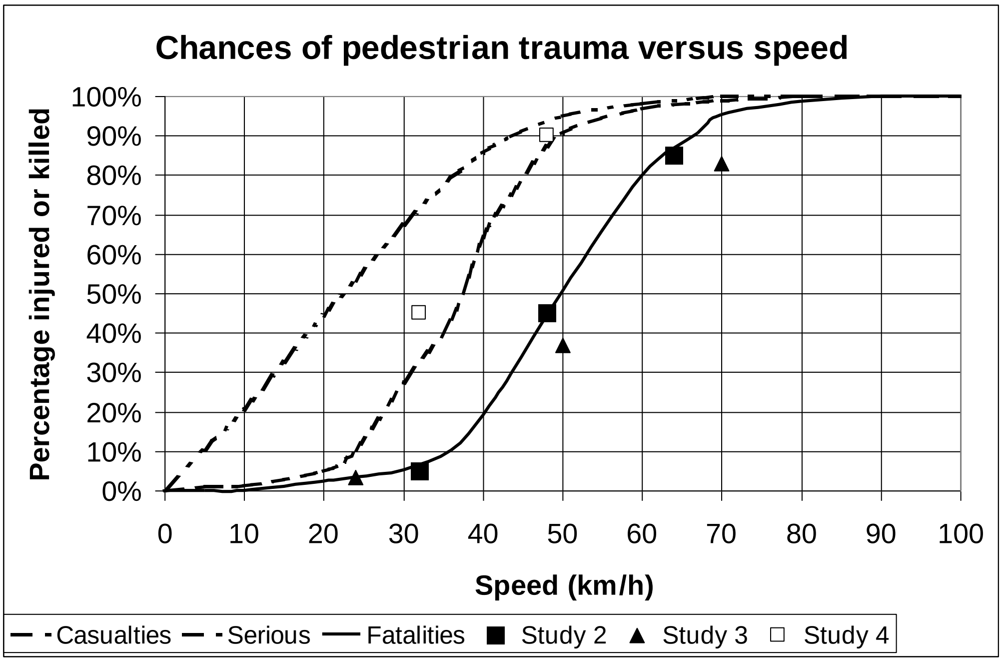

Figure 22: The correlation of impact speed with injury risks

[9] MOTORCYCLE SAFETY – AN OXYMORON?, JOHN LAMBERT, MIEAust, CPENG 180 785, B.Eng (Agric), ARMIT (Mech). John Lambert and Associates Pty Ltd

6.1 Correlation of this Data with the Star Rating

One safety star is awarded if the speed change experienced by the jockey is approximately 30 km/h or less where the chance of fatality is approximately 6%. This correlates with Figure 22 where the risk of fatality is reduced to a low level and the chance of serious injury is markedly reduced.

A two star safety rating is awarded at 18 km/h where the chance of fatality becomes approximately 1% or immeasurably small. This correlates with Figure 22 in that it is at this point that the data on serious fatality begins to taper out.

A similar graph can be drawn for serious and moderate injury. Three stars are awarded where the speed change experienced by the jockey is less than 8 km/h at which point the chance of serious and severe injury is reduced to low levels. This is backed up by every test; systems found to be three star in the video based measurements (**Section 3**) were also found to be three star by the Crash test dummy injury ratings (**Section 4**).

7 Conclusions

Based on the available evidence and calculations performed, it is the author's considered opinion that:

Fuses 12 and 20 can be recommended subject to

i. Reliability testing of these fuses (nine dynamic impacts)

ii. Testing of the whole running rail system for serviceability for thoroughbred loading

Dr Andrew Short

B.A., M.Sc., BMED, D.Phil (Orthopaedic Engineering)

Appendix A – Crash Test Dummy Parameters

The following are included to specify the parameters of the anthropometric test device (ATD) used in the tests at Autoliv. The 5^{th} percentile (female) Hybrid III dummy was used.

Test Results for the 12 and 20 Fuses

Test Code	BI -3025		BI -3026	
Fuse code	12		20	
	Barrier Impact, Mid position / System 12 fuse		Barrier Impact, Mid position / System 20 fuse	
Impact speed	8.4		8.4	
Pulse regulation	30.	15.4	30.3	15.2
Head	Max	Time	Max	Time
Head Max Resultant (g)	16.		20.1	76
Head Max Resultant (3ms) (g)	15.1		17.3	75-78
HIC36/HP36	8		10	70-82
HIC15/HPC15	8		10	70-82
Chest				
Chest Max Resultant (3ms) (g)	13.5		16.7	74-77
Chest Max Compression (mm)	-14.5		-8.4	78
Viscous Criterion (m/s)	0.12		0.05	74
Neck				
Upper Neck Force +Fx (kN)	0.04		0.05	145
Upper Neck Force -Fx (kN)	-0.3		-0.36	79
Upper Neck Moment +Mocy (Nm)	22.8		22.3	94
Upper Neck Moment -Mocy (Nm)	-16		-18.3	78

Revised Injury Tolerances for Dummies[10]

Table ES.3: Deflection and Acceleration Intercepts for Modified CTI

Dummy Type	Large Male §	Mid-Sized Male	Small Female	6 Year Old Child	3 Year Old Child	1 Year Old Infant
Chest Deflection Intercept for CTI (Dint)	114 mm (4.5 in)	103 mm (4.0 in)	84 mm (3.3 in)	64 mm (2.5 in)	57 mm (2.2 in)	50 mm (2.0 in)
Chest Acceleration Intercept for CTI (Aint)	83	90	90	90	74	57

§ The Large Male (95th percentile Hybrid III) is not currently proposed for inclusion in the SNPRM, but the performance limits are listed here for completeness.

Table ES.4: Performance Limits for Chest Deflection and Chest Acceleration Evaluated Independently

Dummy Type	Large Male §	Mid-Sized Male	Small Female	6 Year Old Child	3 Year Old Child	1 Year Old Infant
Chest Deflection Limit for Thoracic Injury (Dc)	70 mm (2.8 in)	63 mm (2.5 in)	52 mm (2.0 in)	40 mm (1.6 in)	34 mm (1.4 in)	30 mm** (1.2 in)
Chest Acceleration Limit for Thoracic Injury Criteria (Ac)	55	60	60*	60	55	50

§ The Large Male (95th percentile Hybrid III) is not currently proposed for inclusion in the SNPRM, but the performance limits are listed here for completeness.

* Although geometric scaling alone would predict higher Ac values for females, it is believed that lower bone mineral density would offset this effect. Therefore, the acceleration tolerance values for small females are kept the same as for mid-sized males.

** The CRABI 12 month old dummy is currently not capable of measuring chest deflection.

[10] Available from http://www-nrd.nhtsa.dot.gov/pdf/nrd-11/airbags/rev_criteria.pdf Table II-4

Post Tests: Chest Impact Testing at Autoliv, Campbellfield [17/7/2008]

Component	Body Segment	Criteria	Small Female	Mid-size Male	Large Male
Head	Head	HIC	**1113, 15ms**	1000, 15ms	957, 15ms
Head /Neck	Neck	Flexion Bending Moment (Nm)	**104**	190	258
		Extension Bending Moment (NM)	**31**	57	78
		Axial Tensile Loading vs. Time Duration (N)	**2201 max. Fig.4A2**	3300 max.	4052 max.
		Axial Compressive loading vs. Time Duration (N)	**2668 max. Fig. 4A3**	4000 max.	4912 max.
		Fore/Aft Shear Force vs. Time Duration (N)	**2068 max. Fig. 4A4**	3100 max. Fig. 4A4	3807 max. Fig. 4A4
Chest	Thoracic Organs	Resultant Chest Spine Acceleration (Gs)	**73, 3ms**	60, 3ms	54, 3ms
	Thoracic Organs	Compressive Deflection Due to Shoulder Belt	**41mm**	50mm	55 mm
	Thoracic Organs	Compresssive Deflection Due to Air Bag & Steering Wheel Hub	**55 mm**	65 mm	72 mm
	Viscous Criterion	1	**1**	1	1
Femur	Patella, Femur, Pelvis	Axial Compressive, Femur Load vs. Time, Duration (N)	**6186 max.,**	9070 max.,	11537 max.,
Knee	PCL	Tibia to Femur, Translation	**12 mm**	15 mm	17 mm
Knee Clevis	Tibial Plateau	Med/lat. Clevis Comp. Loading (N)	**2552**	4000	4920
Femur		Comp. Loading (N)	**5104**	8000	9840 N
Tibia		Tibia Index, TI =M/Mc, where Mc = Critical	**1**	1	1
			115	225	307
		Bending Moment, and Pc = Critical Comp.	**22.9**	35.9	44.2
Ankle	Ankle	compressive Loading (N)		4000 inferred	

The Vest

The Jockey Association of Victoria was asked to provide a jockey safety vest and a helmet for the tests. The following figure show the vest used. The vest incorporated a 17 mm layer of padding at the point of impact on the chest.

Figure 23: The vest worn in impact tests

Figure 24: A close up of the padding from the vest

The vest is not described in great detail here as it is not the focus of the testing. It was donned by the dummy so that the outcomes are representative of a racetrack experience for a jockey and not a car occupant who will be unlikely to be wearing any personal protective equipment.

Appendix B – Measurements from High Speed Video

The following series of video stills depict the full range of salient events measured during the impact sequence.

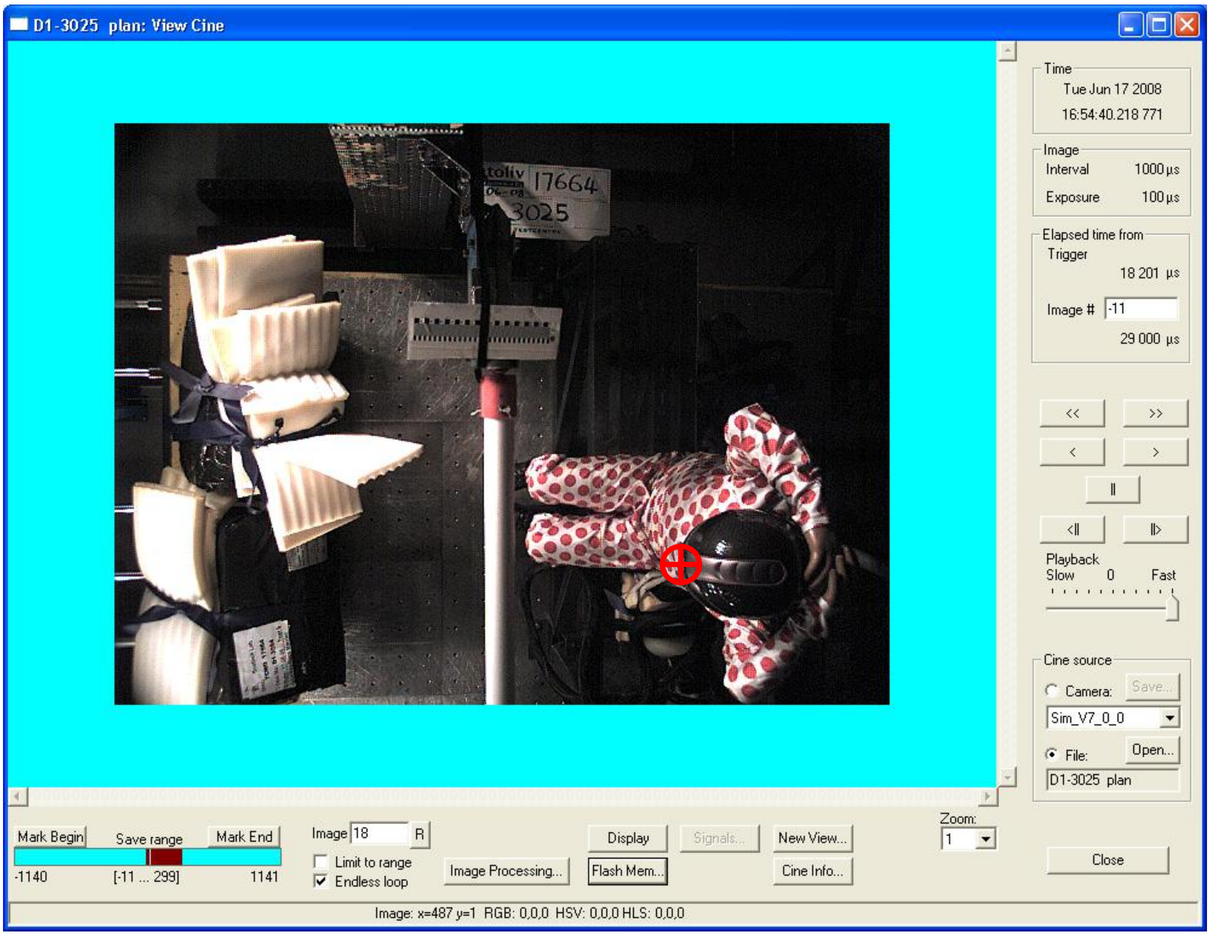

Figure 25: The approach to the post. In this figure, the measured location of the front of the helmet is shown.

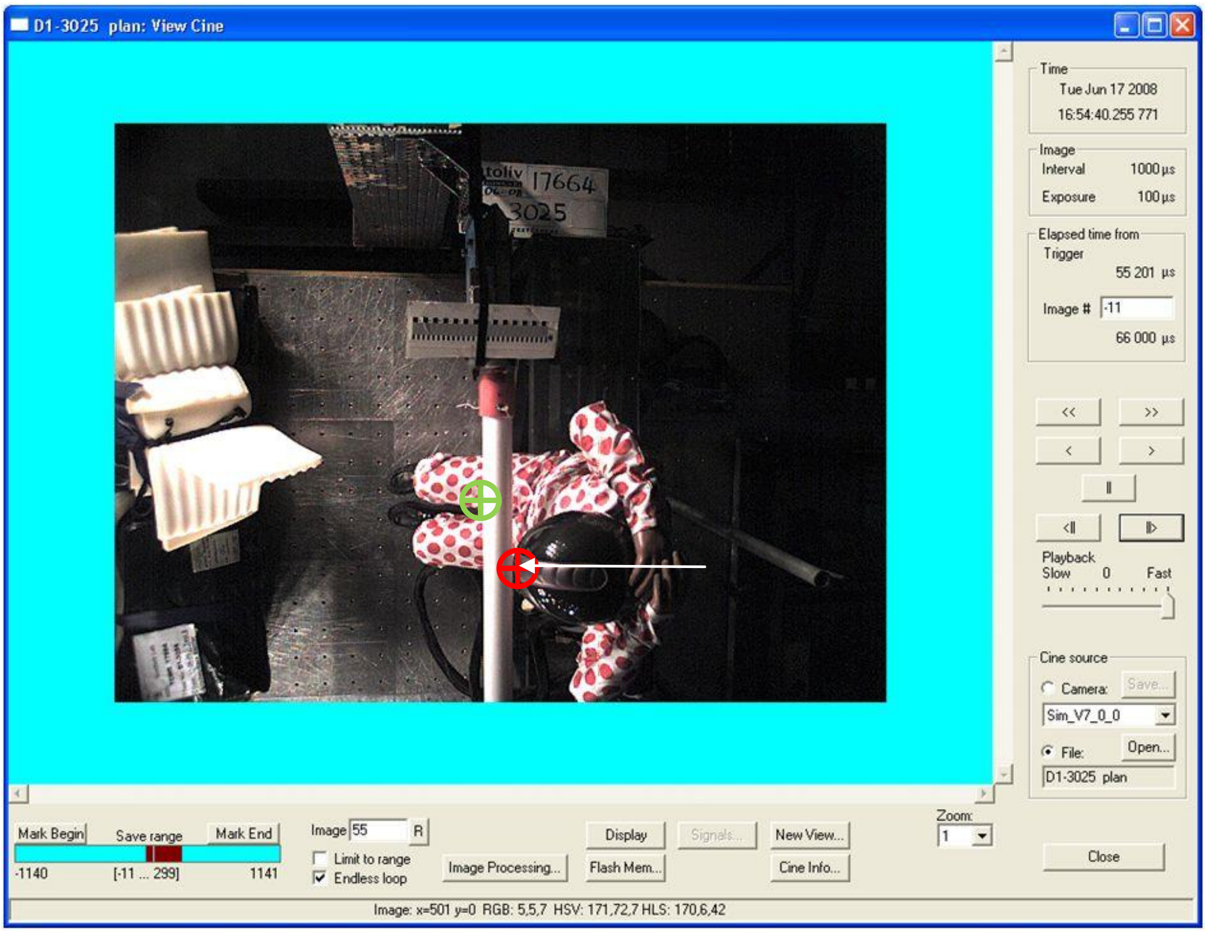

Figure 26: A second instant during the approach. The time elapsed and distance travelled by the forward edge of the dummies helmet (white arrow) since the still in the previous figure, is used as the marker for incident speed. This still is also used to measure the initial position of the left edge of the post (in the photograph) so that the deflection of the post can be measured at the instant which the fuse breaks.

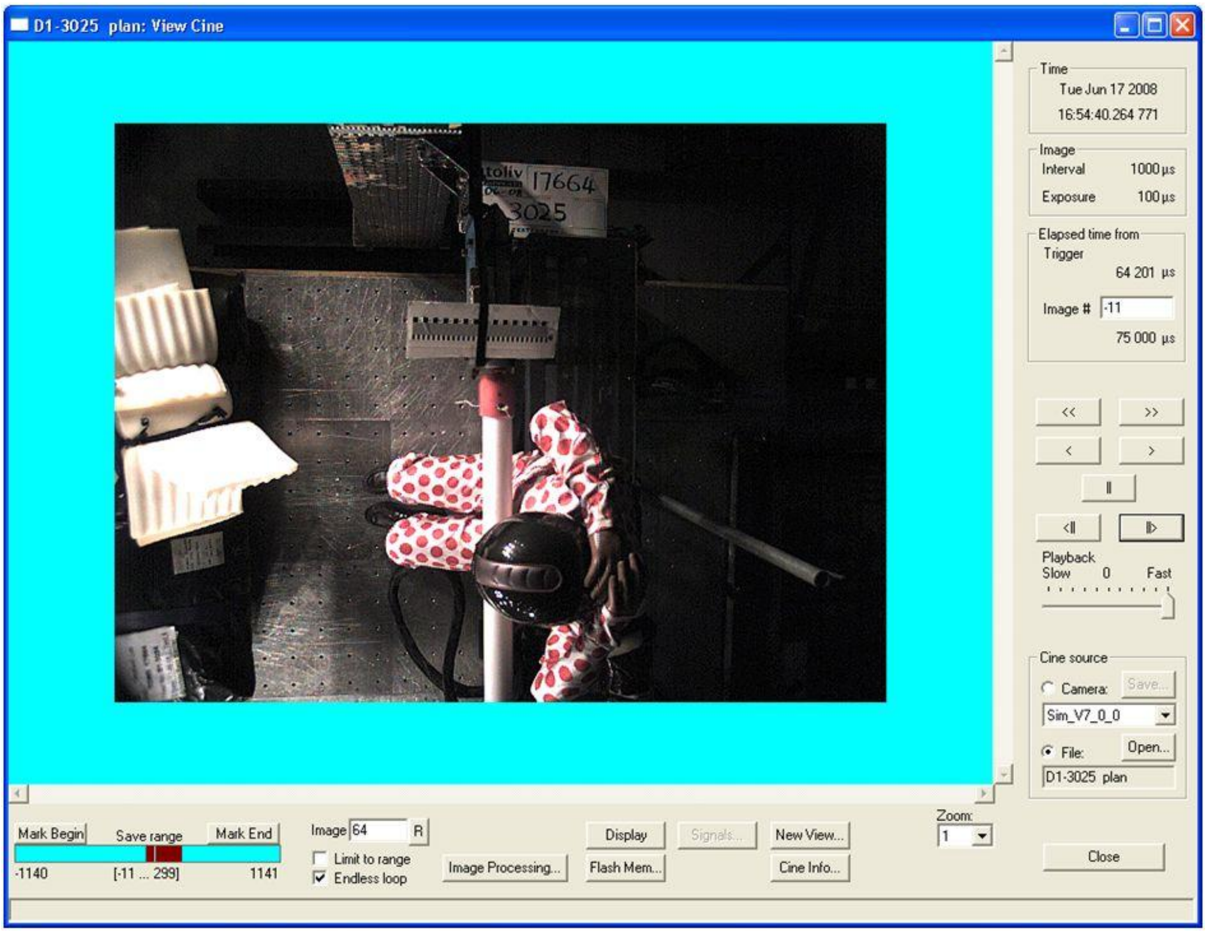

Figure 27: Contact. The chest of the jockey is determined to be in contact with the post.

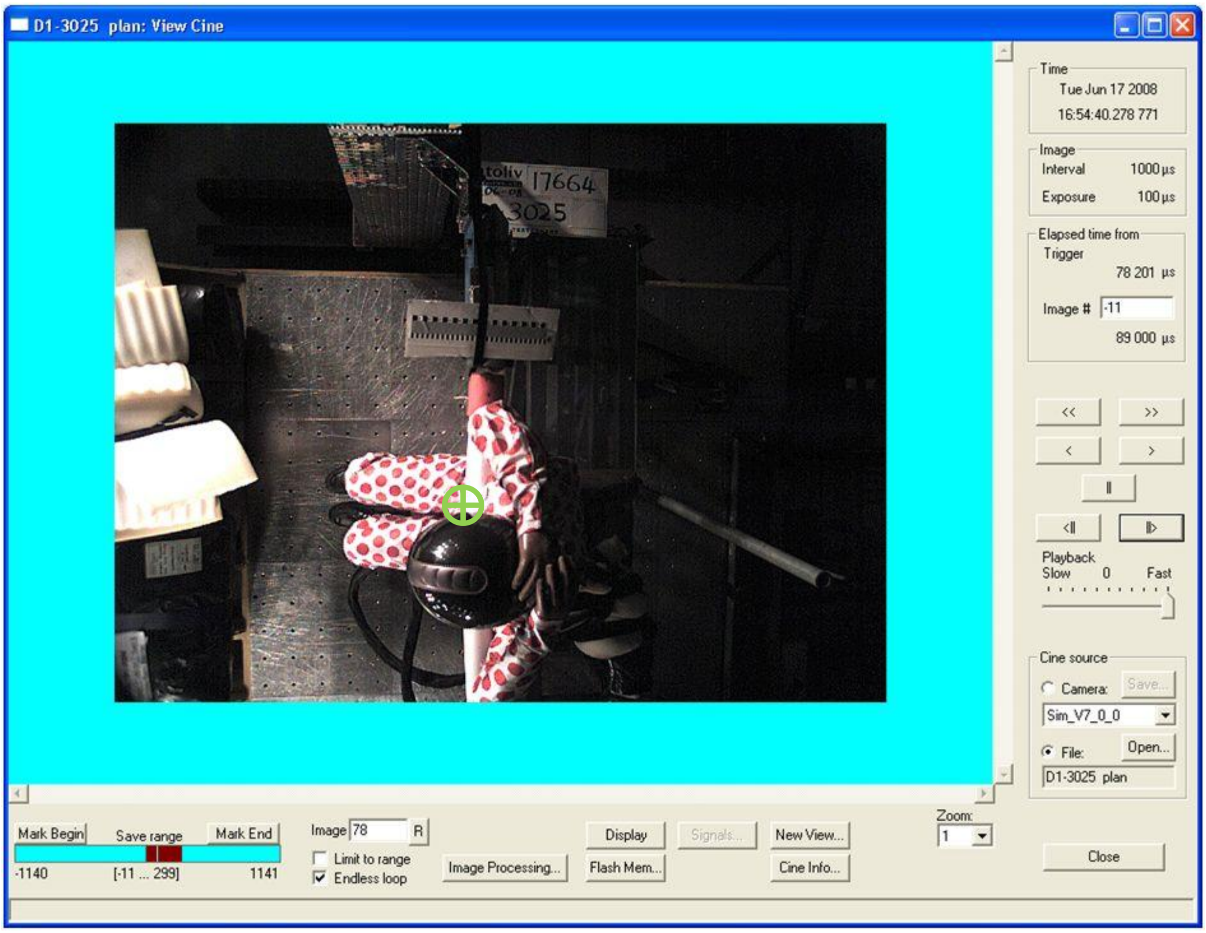

Figure 28: The fuse has broken. This is also determined to be the instant at which the post is at its maximum bend. The green marker position in this shot is compared to the green marker in Figure 26 to measure the deflection of the post.

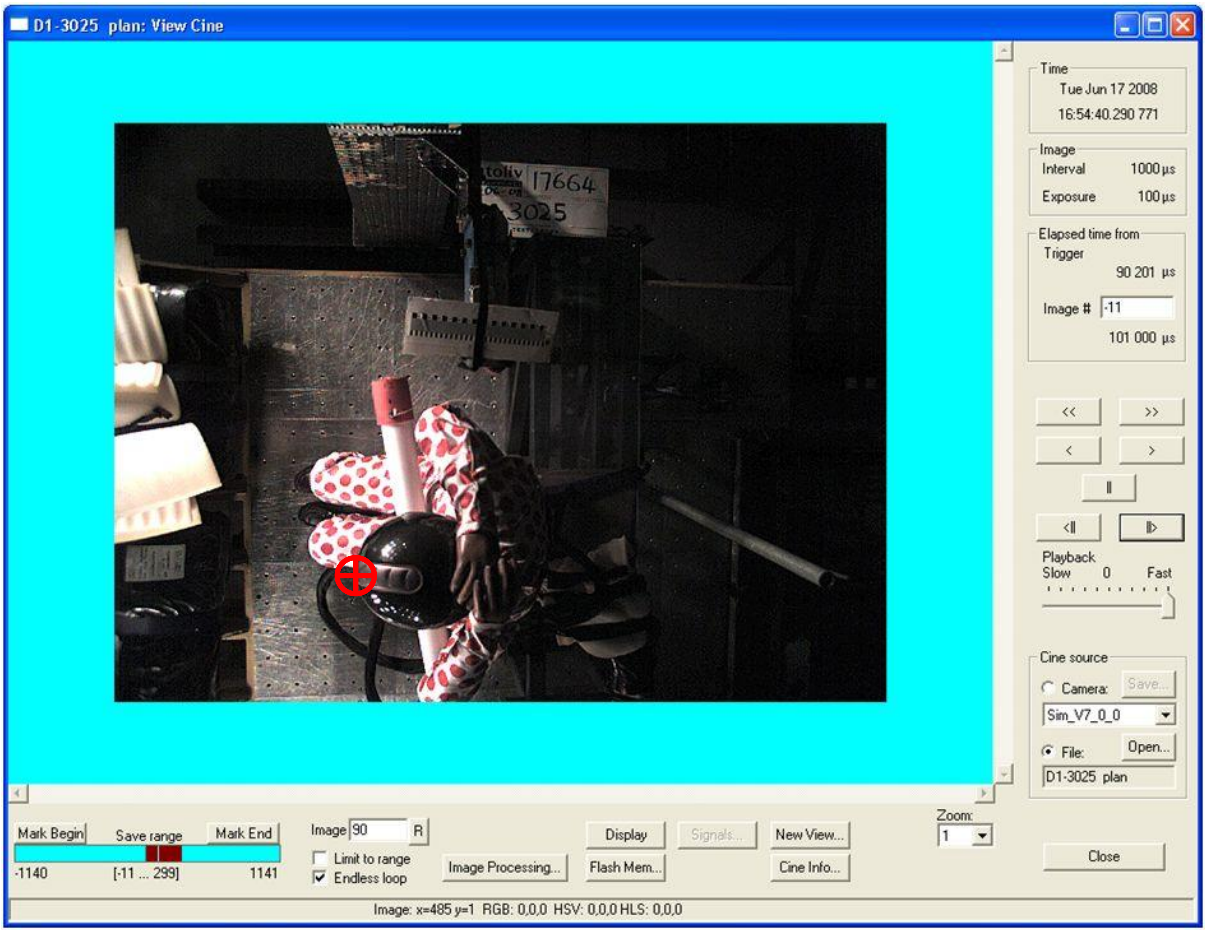

Figure 29: This instant is when the contact with the chest is released. Due to the bend in the post and the release of the bend, the contact with the chest is released some time after the fuse breaks. The position of the front of the helmet in this frame is also the first point used in the exit speed determination.

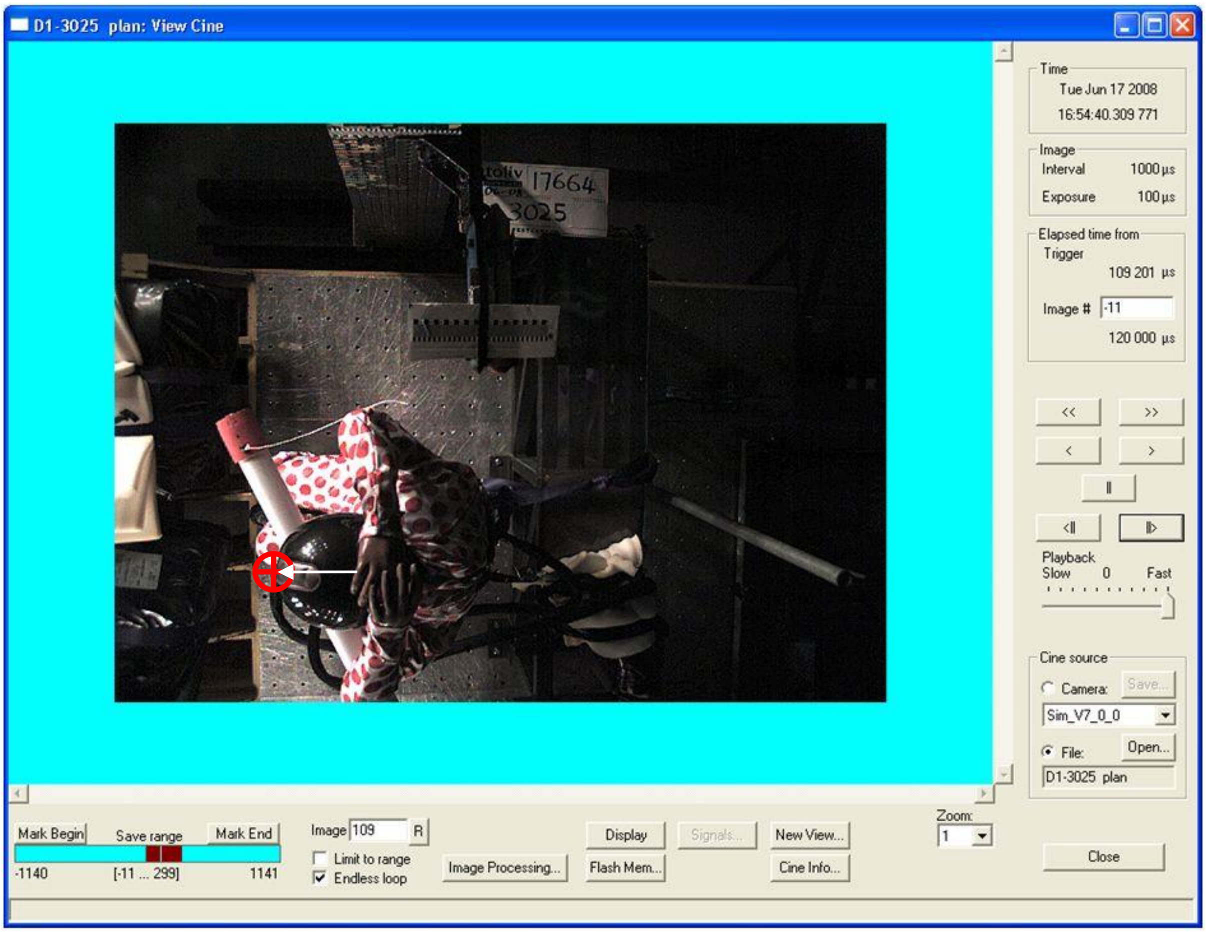

Figure 30: A second point used for the determination of exit speed. The ratio of the incident and exit pixel speeds is the same as the ratio of the exit speed to the already known impact speed. So the exit speed can be deduced. In the helmet measurement, the nod of the head is neglected as it is considered to occur during the chest loading which is short. Further, the interest is in finding out whether the exit speed is less than 7 km/h different from the incident speed. Where this is the case there will be little deflection of the neck.

		BI-3025	BI-3026
Fuse		12	20
Contact durations (ms)	Fuse loading	10	14
	Chest contact	21	26
	contact		73
Post bend	Pre- Impact	305	304
	At break	296	287
		9	17
	Deflection (m)	0.02	0.04
Speed	helmet	helmet	helmet
Entry	ms	50	49
	ms	62	59
	pixels	349	371
	pixels	304	334
	Distance traveled	0.1095	0.09
	time elapsed (ms)	-12	-10
	Pixel Speed	9.13	9.009
Exit	ms	87	99
	ms	110	109
	pixels	209	184
	pixels	129	152
	distance traveled	0.194783	0.077913
	Time elapsed	-23	-10
	Speed	8.468809	7.791304
known entry speed		30	30
exit speed		27.82609	25.94595
Speed lost		2.17	4.05
Star rating		***	***

Table 5: Results from video based measurements

Appendix C – Future Safety Items – Neck Brace and Airbag Jacket

Figure 31 shows a neck brace addition (at right in yellow) to a normal full face helmet (left). Neck braces are already being used by Formula One drivers. It prevents excessive deflection of the neck and consequent spinal injury. Similar devices have been found to work well for downhill skiers, who are as similar in vulnerability as a jockey.

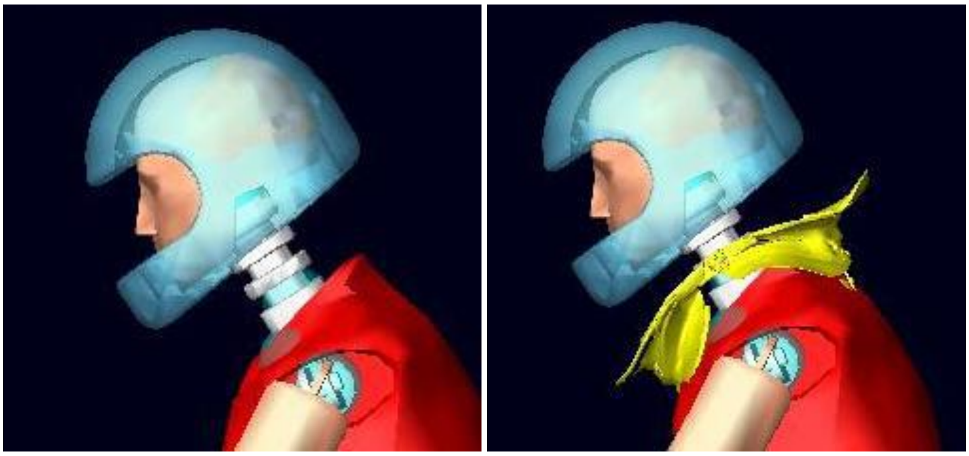

Figure 31: A new neck brace design presented at a European Motorcyclist safety conference[11]

Another recent innovation which is already available in Australia is an airbag jacket (**Figure 32**) which inflates when a cord attached between the saddle and the jacket becomes taught due to the fact that the jockey has left the saddle. These two items are included here to motivate the idea that the synergy of addressing a number of safety issues for jockeys at the same time can have an interaction and make the environment much safer than the sum of the individual safety value of each part in isolation.

Figure 32: An airbag design that is operated by a lanyard that is attached to the saddle.

[11] **Innovation in the developing of BMW Motorrad Riders Equipment to reduce the risk of injuries shown at the Neck-Brace System,** Geisinger, Diehl-Thiele, Kreitmeier, Bachmann, Leatt, Proceedings of the 6th International, Motorcycle Conference 2006

Appendix D –Frequently Asked Questions

1. How does this testing further the understanding of jockey injury and how do these tests compare to previously conducted tests?

    - This testing round provides more detailed information on post impact and measures actual injury criteria rather than using markers for injury. It also links with impact testing standards for seatbelts.
    - It also validates the previously used markers for injury such as loss of speed.

2. Why are tests conducted in the lab and then the same tests conducted on the turf?

    - It was determined that each testing round would not solve all the questions about the operation of running rails. The testing is separated into lab tests and turf tests, each of which has advantages and disadvantages. The combination of both testing types answers most of the questions.
    - The advantages of lab testing are:
        1. The data presented is detailed such as high speed colour video
        2. Detailed injury data is collected from a dummy that meets internationally recognised standards for testing
    - The disadvantages of lab testing are :
        1. Due to risk to the instrumentation the speed limit for testing is 30 km/h
        2. The posts are not fixed into curated track turf, and due to space restrictions an extended section of running rail could not be installed
        3. Cameras are high specification, but at the time, it was not possible to zoom in to see the post impact event in more close detail
        4. There is little time available for making design decisions during testing

- The advantages of working on the track are:

    i. the environment is authentic

    ii. a full length of extended rail can be evaluated

    iii. impacts can be conducted at any realisable speed as a ballast dummy is used which is readily replaceable

    iv. the materials are tested to a greater extent at higher speeds consistent with the more potentially injurious falls

- Disadvantages of working at the track are:

    i. The track is not a suitable environment for the operation of expensive and moisture sensitive equipment.

    ii. Specific equipment setup is required or the use of portable equipment

3. Fixation of the post:

- The posts were secured by using a number of metal clamp fixation methods

- This was decided due to the variety of fixation methods which would have required a number of different soil samples one of which would have required a 500 litre soil sample to be properly accommodated

- The size of the samples required would involve significant transportation costs and other details about handling, hygiene and method of disposal or replacement at the track was unclear. Further, the facility is not used to or capable of managing large soil samples.

- There was also uncertainty that a suitable sample of track turf could be harvested without upsetting the profile, maintained in condition and be serviceable in terms of fixing the posts.

- There was assumed difficulty in maintaining the soil in a horizontal position, without including methods to keep the soil in place that would counter the realism of a turf sample.

4. Fixation of the rail

- Previous testing has identified that the extent of movement of the top rail in an impact is limited.
- While the top rail can be moved where a body weight force is applied along the direction of the top rail, there is quite an amount of extended weight (inertia) involved in the top rail and with the resistance of all the connected posts, it is difficult to see how a properly operating fuse would end up loading the rail to the extent that it might move.
- For the purposes of focusing the tests on the posts, the top rail was bolted to a metal plate at one end or restricted in its forward movement with a metal restricting plate.
- Gross rotation of the rail was also restricted by clamping

Appendix E – Case Study of Roadside Fuses

It is important to consider previous implementations of the fuse idea in the built environment. **Figure 33** shows a post which has been fused by drilling a hole near the base. In theory, the fuse weakens the post or at least encourages breaking at a particular point. In this case, it is designed make the post frangible to cars that come into collision with it. In this way the car occupants are exposed to a lower potential for injury.

However, the strength of the post may be unaffected by this hole. In the Figure, it does not appear to have fired correctly. It seems to have broken away at the base and not at the fuse hole. So the fuse hole has not controlled or affected the break at all. This means that the post was not effectively weakened.

Figure 33: A fused post which has obviously broken at the base instead of at the fused location identified by the drilled hole.

In fairness, there may be an area of rot or a natural knotted weakness in the wood at the base that caused the break as that point, but these factors should be considered in the engineering design phase. It appears that this post was not crash tested properly and there are a number of examples evident at the site.

In contrast, the running rail fuses in this report have been properly and extensively crash tested and will be expected to operate properly.