Motorcycle helmets: Test and Assessment Protocol Prove Out

by V J M St Clair and M G McCarthy

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by V J M St Clair and M G McCarthy (TRL Limited)

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Executive summary

This project involved subjecting five UN ECE 22.05 approved motorcycle helmet models to a series of linear and oblique dynamic impact tests specified by the Department for Transport (DfT). The objective was to ensure that the test and assessment protocols proposed for the basis of a consumer information programme are robust and suitable for implementation. The protocols are based on the findings and recommendations made by the DfT project SO232/VF (Motorcyclists' Helmets and Visors - Test Methods and New Technologies) and a collaborative European project (European Co-operation in the Field of Scientific and Technical Research, Action 327), known as COST 327. TRL was commissioned to complete a series of linear and oblique impacts at 6m/s, 8.5m/s and 9.5m/s and to provide technical comment on their appropriateness and suitability for implementation.

The results of the test programme showed that the assessment methodology distinguished between the injury protection offered by five motorcycle helmets approved to UN ECE Regulation 22-05 in impacts up to 8.5m/s. There was a large range of performance between the helmets tested. Based on the revised assessment protocol it was estimated that up to 47 lives per year could be saved if all wearers used the best performing helmet model rather than the worst. However, it cannot be assumed that the helmets tested here are fully representative of the range of current helmet performance on the market. Three of the five helmet models were repeat tested and the protocols were shown to be repeatable for two helmet models. For one helmet model, a large difference was noted in the estimated number of fatalities between the repeat tests. This difference was equivalent to more than a quarter of the performance range (in terms of lives saved) for all the helmets tested; the reasons for this larger discrepancy could not definitively be attributed to the test and assessment protocols.

Impact tests on both sides of the each helmet at 8.5m/s were completed and the results of these indicate that the test methodology is generally repeatable, appropriate for purpose and provides consistent peak acceleration results. However, in a small number of cases, minor differences in the test helmet and test configuration were considered to be responsible for large variations in peak acceleration results. This was particularly evident when the helmet was close to its full energy absorbing capacity. Consequently, peak acceleration measurements at high speed alone may not be an appropriate measure of helmet performance. Instead an assessment of performance across the helmet performance range should be considered. Factors, such as the sensitivity to deviations from the target impact site and variations in impact energy may have influence the measured values. Excluding cases where the helmet may have exceeded the helmet's energy absorbing capacity, the results for the side site were close to 5% of the mean peak acceleration result.

Comparison of all other repeat linear impact tests (excluding side impacts) indicated that repeatability was very good. The maximum difference between equivalent tests, with both identical impact conditions and helmet model, was 39.4g, 21.7% of the mean peak acceleration result of 181.4g. This result was obtained from a test onto a kerb anvil at 8.5m/s onto the rear of the helmet. The conformity of production between similar helmets could not be verified, but fit and deterioration of the test helmet between tests was unlikely to be a major contributory factor to differences between identical tests. Since the third, fourth and fifth highest differences for 8.5m/s tests (10 to 20g) were onto kerb anvils, this suggests that the kerb anvil may be more prone to variation than the flat anvil. It was not possible to quantify this, but could be because the smaller contact area between anvil and helmet may exaggerate any deviation from the intended impact site.

A linear impact validity ratio was calculated for each impact which measured the lateral velocity change (x and y directions) compared with the longitudinal (z direction) over the duration of the impact. This ratio is sensitive to the period over which it is calculated and should be calculated from the initial point of impact with the anvil to the time at which the motion in the vertical direction has ended i.e. $T_{V=0}$ and where the displacement is at a maximum. During calibration tests with an MEP block, this ratio was calculated at a range of 1% to 9%. The maximum exceeded the 5% level stipulated by the FMVSS 218 standard for a monorail guide system. The stiffness of the twin-wire system may account for this difference as there may be reduced lateral support compared to the monorail system. The maximum validity ratio for all helmet tests was 17.5% (based on $T_{V=0}$) and an

average result of 7.8% was recorded. Consequently the validity ratio threshold for a twin wire configuration should be based on a higher level than FMVSS 218. Although in some cases, data may show signs of significant lateral motion or rotation this cannot necessarily be associated with an error in the test apparatus, carriage drop or helmet strike, but may reflect helmet/headform compatibility.

The kerb anvil was more likely to be associated with good validity ratios, with a slight bias towards poor levels on the flat anvil. Poor compatibility between the headform and helmet at the point of impact was a possible cause for increased levels of translational and rotational motion onto a flat anvil. The kerb anvil, however, appears to provide some stabilisation due to helmet rotation or deformation at the impact point; this may not apply to helmets with stiffer helmet shell materials.

For consecutive groups of tests with identical conditions (either before or after helmet evaluation), the maximum error between MEP tests used to calibrate the test equipment was less than 5g and below 2% of the average peak acceleration result. This demonstrates good repeatability in the instrumentation and test apparatus for consecutive tests. The least repeatable MEP test was made at a drop height of 0.4m (2.8m/s) onto the side of the headform. This demonstrates that test configuration and in particular impact energy and geometry (orientation) of the headform may influence MEP test results.

The coefficient of friction measurements using oblique anvil tests were very repeatable; the difference between repeat tests was within 5% when the impact sites were closely controlled and accurately struck. The measurement was influenced by site selection and in particular by raised profiles on the helmet surface, which tended to underestimate true coefficient values. Tests were more repeatable when fewer impacts were made on the same helmet.

UN ECE Regulation 22.05 requires that helmets do not exceed a peak acceleration of 275g. Test results at this level are indicative that the helmet is close to ‘bottoming out’ and little additional energy absorbing capacity is available. For eighty tests completed at 8.5m/s the peak acceleration was =275g in almost 1 in 3 cases (26 cases, 32.5%). Of fifteen tests completed at 9.5m/s (onto flat anvil only) the peak acceleration was =275g in two thirds (66.7%) of cases (excluding repeat tests onto the side impact sites). In 6 out of 11 helmet tests at 9.5m/s, the peak acceleration was 275g or more but achieved less than 275g during an equivalent test at 8.5m/s, indicating that the helmets were operating close to the limit of performance but still had the potential to offer protection above 8.5m/s.

For similar test conditions onto a flat anvil at 8.5m/s and 9.5ms, four impacts (out of 15) resulted in less than 275g for both tests. This shows that, in some helmet and test configurations, the helmet has potential to provide additional energy absorption and enhanced levels of safety above 9.5m/s. In order to assess the full protection offered by a helmet, it would be appropriate to continue testing at higher speeds until the peak acceleration exceeds 500g, a level which relates to a 100% risk of fatality in the assessment protocol.

The side test site accounted for almost 1 in 4 (22.7%) of impacts at 8.5m/s where the peak acceleration was =275g. This signifies that there may be reduced protection at the side of the helmet. At 8.5m/s, eight out of the ten highest peak accelerations were recorded for tests onto a kerb anvil. Although there may be some bias due to the high number of side impacts included in this dataset, this indicates that the kerb anvil may also be most likely to exceed the helmet’s design capacity.

The S0232/VF and revised (8.5m/s) assessment protocol relies on the back calculation of peak acceleration across a speed range using data from a higher speed test. Based on data from 30 impact tests, there was a statistically significant correlation ($P<0.05$) coefficient of $r=0.78$ ($r^2=0.61$) between 8.5m/s acceleration data predicted from 9.5m/s test results and actual peak acceleration measured in 8.5m/s tests. However, improved predictions were possible when tests onto the side which exceeded 400g were excluded. These tests were considered by the authors to be unreliable due to lack of repeatability on these sites for high speed tests. Based on a reduced set of 24 test samples, a statistically significant correlation ($P<0.05$) coefficient of $r=0.88$ ($r^2=0.77$) was noted and the relationship between actual and predicted acceleration was almost 1:1, with an offset of about 4g. It is estimated that the error of this method is close to 3% over this range, demonstrating that for impacts with consistent impact locations, the back calculation method is appropriate between 9.5m/s and 8.5m/s.

The prediction of 6.0m/s peak acceleration using 8.5m/s test data was less reliable than that between 9.5m/s and 8.5m/s. Despite correlations as high as $r^2=0.89$ for tests onto the rear impact site there was limited data, and other sites had less reliable estimations. Although the protocol does not require 6.0m/s data to be estimated in this way, the method was generally found to be unreliable for predicting low speed (6.0m/s) data from high speed (8.5m/s) data. Although this justifies the use of a low speed test in the test protocol, it also indicates that testing at additional test speeds between 6m/s and 8.5m/s would improve the accuracy of data across the speed range. An alternative approach, to increase the lower test speed from 6.0m/s to 7.0m/s could potentially improve the accuracy of the most critical assessment data in a cost effective manner.

It is the authors' opinion that, despite the associated reduction in absolute accuracy associated with the back calculation tool, the method supports the intended purpose of improving helmet performance, providing it is clearly stated that the performance of the helmet is assessed based on two test conditions, from which indicative performance at other speeds is estimated. It was not possible to fully evaluate the accuracy of the back calculation method as this would require tests at each of the speeds for which predictions of performance were made. However, the results indicate that the prediction method requires further research to understand the implications of potential deviations between predicted and actual helmet performance and to quantify these prior to the implementation of a consumer information scheme that incorporates performance assessment using predicted test values.

The modified assessment protocol has been used to estimate the number of fatalities for the range of helmets tested. The protocol uses similar principles to those proposed in SO232/VF and allows a comparative assessment of helmet performance up to the speed of 8.5m/s. The potential for helmets that perform well above 8.5m/s to be given a rating unrepresentative of the full level of protection offered by the helmet was not assessed here. However, the differences between current helmets above 8.5m/s is assumed to be small when compared to advanced helmet technology and will therefore influence only a relatively small number of casualties at this impact severity.

This test programme concluded with the following recommendations:

- At least three MEP impact calibration tests (to achieve approximately 300g) should be used to ensure that the repeatability of the test apparatus, including the data acquisition equipment, is within 2% of the average result for each test site. The frequency of these tests is dependent on the size of the test programme.
- There is potential for variation in assessed helmet performance due to variation in helmet/ headform fit; this is difficult to control objectively. In addition, some parameters have not been assessed here, e.g. influence of twin wire tension. The influence of such variables should ideally be minimised. It is recommended that wire tension should be as high as practically possible.
- The pre-conditioning requirements of an MEP should be established prior to use as a calibration tool. The use of an MEP may be particularly suitable for cross-laboratory calibration.
- In a full consumer assessment scheme, it is the authors' view that any removable features should remain on the helmet such that it is tested as it would be worn. Features that may exacerbate rotation or cause helmet instability should be avoided or eliminated by use of a validity ratio threshold. In this case, definition of the test site could be left to the discretion of the testing laboratory, with guidelines that the test site is as close to the UN ECE Regulation 22.05 site where possible. The test anvil should also meet the requirements of this standard to prevent inappropriate helmet loading.
- Each helmet should be tested up to its full capacity (>500g) in order to assess the entire range of protection offered by the helmet.
- The accuracy and reliability of the back calculation predictive method requires further research through testing at each of the speeds for which predictions are made. If this approach is not

appropriate, physical testing at each impact speed is required, if the assessment of performance is to be made across the impact speed range.

- The back calculation tool is subject to the accuracy of the test on which it is based and may be lower for a greater test and prediction speed differential. An acceptable separation should be determined through further testing if the assessment using calculated performance is appropriate.
- Oblique tests have been shown to be more repeatable when tests are completed on undamaged helmets. Damage should be minimised between repeat tests. A subjective evaluation on the appropriateness of continuing to perform additional tests on damaged helmets should also be made.

Abstract

Previous helmet impact research has indicated that current helmet performance, although beneficial, could be improved. TRL have demonstrated that improved helmet design has the potential to increase protection by more than 60% during both linear and oblique impacts and if all riders wore helmets with this level of safety performance, up to 100 lives a year could be saved in the UK (Mellor *et al.,* 2007). The S0232/VF project (Motorcyclists' Helmets and Visors - Test Methods and New Technologies) recommended a test protocol which specified a series of tests onto flat and kerb anvils at 6m/s and 9.5m/s in order to assess the performance of current helmets against the current state of the art of helmet design.

This project involved subjecting five UN ECE 22.05 approved motorcycle helmet models to a series of linear and oblique dynamic impact tests specified by the Department for Transport (DfT). The objective was to ensure that the test and assessment protocols proposed as the basis of a consumer information programme are robust and suitable to allow their implementation. The protocols are based on the findings and recommendations made by the DfT project SO232/VF (Motorcyclists' Helmets and Visors - Test Methods and New Technologies) and a collaborative European project (European Co-operation in the Field of Scientific and Technical Research, Action 327), known as COST 327. TRL was commissioned to complete a series of linear and oblique impacts at 6m/s, 8.5m/s and 9.5m/s and to provide technical comment on their appropriateness and suitability for implementation.

1 Introduction

1.1 Background

Each year more than 500 motorcycle riders or pillion passengers are killed on British roads, 7,000 are seriously injured and a further 20,000 suffer slight injuries. The total financial cost of these injuries is calculated to be approximately £1B (£478M fatal, £449M serious and £51M slight). Approximately 80% of the motorcyclists killed and 70% of those with serious injuries sustain head impacts and in more than half of these cases, the head injury was the most serious of those injuries sustained (Chinn *et al.*, 2001).

The COST 327 European research Action (COST 327) concluded that if helmets could be improved to improve impact energy absorption by 24%, some 20% of AIS 5-6 casualties could be reduced to AIS 3-4. As part of this research, new test methodologies and limit values were proposed, including performing linear impact tests at an increased speed of 8.5m/s compared with 7.5m/s prescribed in the UN ECE Regulation 22.05; an increase in impact energy of 28.4%.

Previous helmet research conducted by TRL developed a helmet with respect to the COST 327 proposals. The helmet offered improvements in impact performance of up to 60% during both linear and oblique impact. Based on an impact test assessment to 10.0m/s, it was concluded that if all riders wore helmets with this higher safety performance, up to an estimated 100 lives a year could be saved annually in the UK.

In response to the findings of this previous research, the SO232/VF project provided further research to improve helmet and visor test methods, evaluate new helmet concepts and to devise a consumer information scheme in order to facilitate improvements in helmet design and thereby encourage an improvement in the level of safety offered to motorcyclists (see Mellor *et al.,* 2007). Given the potential for reducing the number of motorcycle fatalities, the project considered various mechanisms to delivery safer helmets to the market. The project concluded that a consumer information scheme, based on tests at 6m/s and 9.5m/s would provide the most rapid delivery to the market of helmets offering improved head protection, and that this could be the first step towards improved regulations.

1.2 Project objective

The objective of this project was to ensure that the test and assessment protocols proposed for the basis of a consumer information programme are robust and suitable for implementation. This involved a series of linear impact tests, using the 'twin wire' guided test apparatus as detailed in BS6658 onto both flat and kerbstone anvils at 6m/s and 8.5m/s and oblique helmet impact tests to UN ECE Regulation 22.05 (Method A).

The aim of the testing was to determine whether the protocol provided results which can effectively distinguish between helmets and whether the proposed test methodology was appropriate. The testing was performed to establish the suitability of both the apparatus and protocols for their intended purpose and to provide technical comment on any potential improvements or limitations.

2 Methodology

2.1 Background

A selection of motorcycle helmets were tested at TRL's drop test facility according to the test procedure described below. The methodology and particular features of the test configuration are discussed below.

A series of calibration tests were also performed using a Modular Elastomer Polymer (MEP, see Section 2.6) block which allowed assessment of the variation contributed by the test apparatus and data acquisition equipment. Repeatability of the overall test (i.e. repeatability of the apparatus, acquisition equipment and helmet) was assessed by comparing the results from similar tests.

For both helmet and MEP tests, lateral acceleration of the headform was measured and compared with the longitudinal acceleration in order to make an assessment of the conditions of each drop test and the test 'validity'.

2.2 Helmets

The helmets tested were selected and supplied by the Department for Transport (DfT). The selection criteria were that they represented a range of helmet styles and retail price. In total, five helmet models, all approved to UN ECE Regulation 22.05 were tested. All helmets tested were size medium (570/580 mm). Each helmet was assigned a unique identification number during testing so that the results of each test on each helmet could be related to test data.

The helmets were new and unmodified. Prior to testing, helmet features which were judged to influence the linear impact performance were removed at the request of the DfT. This included large aerofoil wings fitted to the rear of two of the helmets (Helmets 2 and 5), raised stickers close to an impact site (Helmet 3) and asymmetric helmet features when testing on the side (thumb plate for Helmet 5). These features were removed to minimise possible sources of test variation which would affect the assessment of the test methodology.

In a full consumer assessment scheme, it is the authors' view that any removable features should remain on the helmet such that it is tested as it would be worn. Features that may exacerbate rotation or cause helmet instability should be avoided or eliminated by use of 'unacceptable-test' criteria such as a validity ratio threshold. In such cases, the selection of the test site could be left to the discretion of the testing laboratory with guidelines that the test site is worst case or as close to the proposed site as possible.

Figure 1 Example of helmet projection feature

2.3 Test apparatus

2.3.1 Test rig

The proposal to use a ‘twin wire’ guided impact test apparatus was based upon concerns raised that the free-motion method may allow dissipation of some linear impact energy through uncontrolled lateral and rotational motion (Mellor *et al.,* 2007). It is the opinion of the authors that certain helmet geometrical features on or close to the UN ECE 22.05 impact sites may induce and exacerbate this effect. The ‘twin wire’ guided test apparatus limits this uncontrolled motion and is believed by the authors to provide more accurate and repeatable results. A ‘twin wire’ guided test apparatus, as defined by BS6658 (1985) was used for linear impact tests. The headform used with this test rig is detailed below.

The guide wire tension and length was not specified but a measurement of lateral deflection was instead made for the fully tightened cables. The deflection was measured 1m above the lower cable anchorage. For each cable, a displacement of 70mm required a pull of around 80N and approximately 175N was required for a deflection of 120mm.

For oblique testing, it is essential to use a free-motion headform to allow post impact translational and rotational motion. For this reason a guide system was used based on the UN ECE Regulation 22.05 free motion headform test (Figure 2). To ensure the accuracy of the impact on the intended site, the apparatus was configured so that the helmet and headform were guided up to the point of impact. The helmet was held on the drop carriage using fabric tape. The tape used was strong in both tension and shear and was therefore cut to weaken and initiate tearing. It is the authors’ view that this fastening mechanism would have little influence on the resulting test data. The headform was held in place in the helmet solely by gravity, fit and the chinstrap fastening.

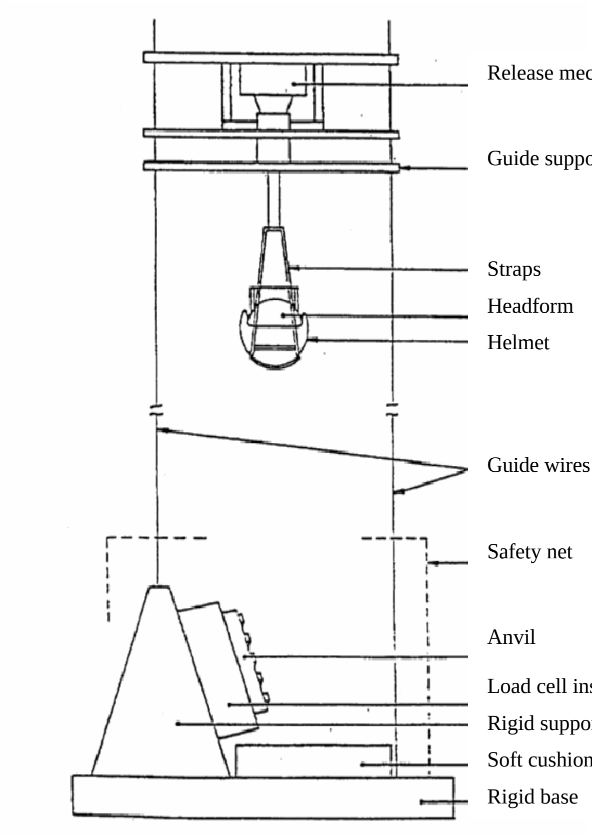


Figure 2. UN ECE Regulation 22.05 method A test apparatus

2.3.2 Headform

The headform used for all linear impact tests was a size J (570mm) conforming to the geometry defined in ISO DIS 6220:1983. The total mass of the headform and guide arm combination was 4.69kg and was within 1% of the stated mass of the size J (570mm) free motion headform, as used in UN ECE Regulation 22.05 (4.7kg). The mass of the headform alone was 3.00kg. This did not comply with the BS6658 requirements that the mass of the supporting assembly does not exceed 20% of the total mass of the drop assembly: in such a case the headform mass must be 3.525kg or greater. The remaining components comprising guide, ball arm, retaining bolts, and clamp rings had a cumulative mass of 1.39kg and represented 36% of the total mass.

For free-motion oblique tests, the headform used conformed to the requirements of UN ECE Regulation 22.05 and was 4.69kg. This particular free-motion headform has a chin, which is important for this testing as it allows the helmet to be correctly fastened on the head prior to oblique testing.

2.3.3 Instrumentation

For linear impact tests, a tri-axial accelerometer was fitted in the ball arm of the drop assembly to measure the acceleration on the headform in both the longitudinal and lateral directions. The three axes are mutually orthogonal with the Z-axis was vertical and aligned with the direction of free-fall travel prior to impact. The X and Y axes were in the horizontal plane with the X axis aligned with a plane passing between the two guide wires (see Figure 3a). The resultant tangential acceleration is the square root of the sum of the squares of the X and Y accelerometer data.

The accelerometer used was a piezo-resistive device and rated as 1500g full scale by the manufacturer. The full specification is given in Appendix C. Being an analogue device, the accuracy of the acceleration measurement was somewhat reliant on the data acquisition equipment although a maximum non-linearity of ±2% is quoted.

For oblique testing, no accelerometers were fitted to the test headform, but a load cell was fitted to the anvil plate to measure normal and tangential loads on the impact surface. The Kistler 9255B load cell used is detailed in Appendix C. The tri-axial load cell was configured to measure at least 10kN and 20kN, in the X and Z direction respectively. Data was captured at 100kHz for a minimum period of 20ms. The load cell is active in three directions but only two were used for the data analysis 1) the Z-axis acting normal to the anvil surface and 2) a positive tangential force was measured in the X-direction - parallel to the anvil face and in a direction 15º to the impact direction (see Figure 3b).

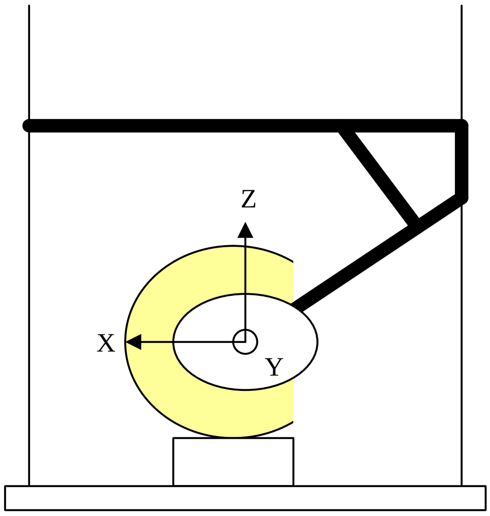


Figure 3(a) Configuration of linear impact test

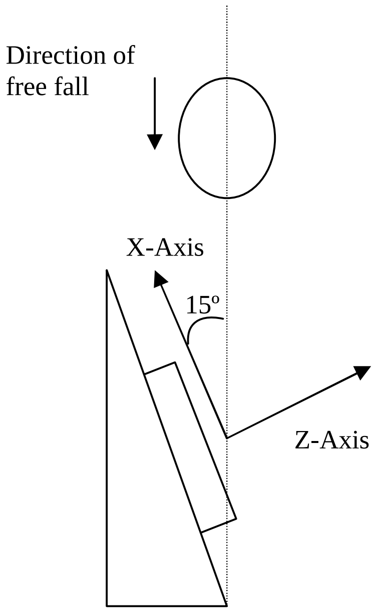


Figure 3(b) Configuration of oblique anvil test

For all testing, a speed measurement system consisting of a twin beam infra-red light gate with a vane fitted to the guide apparatus. This calculated the impact speed by measurement of the time taken for the guide arm to pass through the beams which are separated by 50mm. This measurement was made just prior to the point of impact and was used to ensure that a repeatable test speed was achieved.

2.3.4 Data acquisition equipment

The data acquisition equipment used for capturing transient impact test data was the Prosig P5650. The full specification of this product is provided in Appendix C (9 Channel LEMO spec). All tests were completed at a sampling rate of 100kHz which exceeds the 10kHz minimum sampling rate requirement stipulated by the instrumentation standards ISO6487 and BS6489 (CFC 1000) which are required by UN ECE Regulation 22.05 and BS6658 respectively. This higher frequency can enable the highest peak accelerations to be detected during very short transient events, especially when the helmet bottoms out and the duration may be very short. The data acquisition equipment has a resolution of 16bits and a quoted accuracy of ±0.1% at full scale. Based on the range of 600g for transverse and 1900g for normal measurements, this equates to a maximum error of ±1.9g.

2.4 Test set up

There were 191 tests completed as part of this study, comprising of 175 linear and 16 oblique impact tests (excluding MEP tests) as detailed below.

2.4.1 Linear impacts

Five test sites were selected for linear impact tests. These were defined in accordance with UN ECE Regulation 22.05. No helmet positioning indices were available for marking purposes, so the helmet was adjusted on the headform so that the vertical field (measured between the Regulation 22.05 reference plane and the upper edge of the visor aperture) was close to the stipulated 7º.

When testing on the side sites, it was found that the headform and helmet could not be rotated sufficiently to allow the UN ECE Regulation 22.05 test sites to be impacted. This was because the helmet shell contacting the guide arm apparatus. Although the helmet could be cut on the opposite side to fit around the guide arm (this is a method accepted by Snell test laboratories), the helmet was to be tested on both sides so this was not a practical solution. Instead, new impact sites were chosen slightly higher on the helmet, remaining on the central lateral plane and directly above the existing UN ECE Regulation 22.05 site. The distance above the UN ECE Regulation 22.05 was the minimum possible whilst ensuring the headform was still correctly fitted to the helmet. The increased height is given in Table 1.

For the crown site it was necessary to remove a small section of the chinguard to pass the guide arm and to leave the visor open. This is a practice known to be used by test laboratories such as Snell who use a guided test headform configuration. All fittings were refitted where possible, although in some cases such parts could only be weakly reattached with tape. The reduced mass of missing components may have had a slight affect on the energy that must be absorbed by the helmet, but this is negligible when compared to the kinetic energy of the headform that must also be absorbed.

During oblique tests, the headform was secured to the headform with the chinstrap tightened as much as possible. For linear tests this was not possible due to the absence of the headform chin. Instead, the helmet was positioned as close as possible to the position used for marking and secured to the guide arm using plastic zip ties around the chinstrap. These fastenings were not over-tightened so did not pre-compress the liner materials, except for the comfort padding. In most cases, the helmet was secured to ensure correct position of the helmet and to prevent voids between the helmet interior and headform in the vertical direction. This was merely to secure the helmet in position, rather than to stop or resist motion during the impact event.

Table 1 Position of the final side impact side relative to UN ECE Regulation 22.05 site

Helmet	Distance above UN ECE Regulation 22.05 test site on central transverse plane
1	22mm
2	26mm
3	19mm
4	22mm
5	22mm

For flat anvil tests, the anvil was of size 130mm in accordance with UN ECE Regulation 22.05. The size of this anvil is such that for some helmet and test site configurations, the impact site on this anvil was not necessarily the lowest point of the helmet. Hence, this impact may not be achievable in real life accident situations as the first contact would occur elsewhere on the helmet. The real-world performance of the helmet may therefore differ to that measured experimentally. A larger anvil would increase the likelihood that all features are impacted in a way representative of real life accidents. Conversely, a smaller anvil may allow features to be avoided that may have been positioned to give preferential test results. Such features can mask the real performance of the helmet by creating substantial lateral or rotational motions which are not measured during a regulatory test, but influence the peak linear acceleration measured.

It is recommended that the minimum anvil size be set as that prescribed by ECE Regulation 22.05. This anvil is believed to be greater than the area of interaction between the anvil and the helmet shell as it deforms during the impact duration. An anvil smaller in size could result in a penetrative action which would be unrepresentative of the loading intended using the proposed flat and kerb anvils.

For the front, rear and crown sites the kerb anvil was aligned such that it was at 45º to the central longitudinal plane and was running from the helmet front-left to rear-right. For side impact sites it was orientated at 45º to the central vertical axis and running front-bottom to rear-top. This configuration was selected to ensure that the influence between repeat tests was minimised. The configuration is illustrated by Figure 4 and is in accordance with ECE Regulation 22.05.

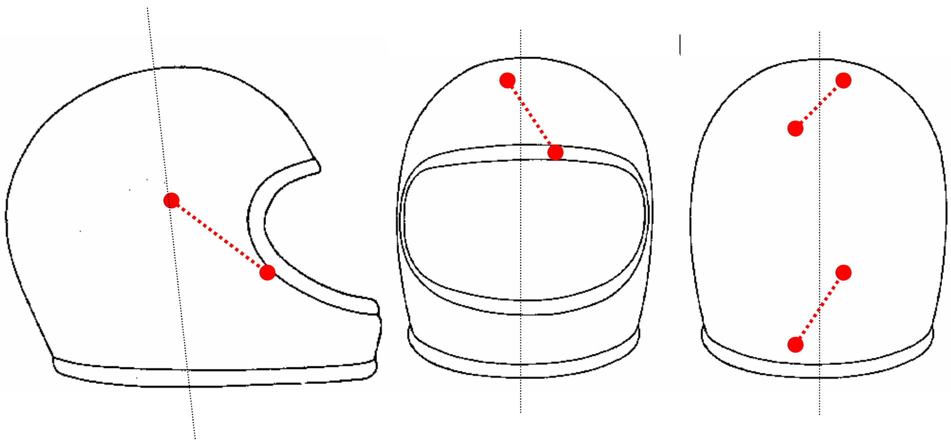


Figure 4 Orientation of the kerb anvil for linear impact tests

2.5 Test matrix

Table 2 shows the details of the tests carried out and provides information on the test speed, anvil type, impact site, and helmet number for each test.

Table 2. Test matrix for validation programme

Test Number	Test Type	Test Site	Helmet sample
1	6m/s Impact – Flat	Front	One
2	6m/s Impact – Flat	Side L	
3	6m/s Impact – Flat	Side R	
4	6m/s Impact – Flat	Crown	
5	6m/s Impact – Flat	Rear	
6	6m/s Impact – Kerbstone	Front	Two
7	6m/s Impact – Kerbstone	Side L	
8	6m/s Impact – Kerbstone	Side R	
9	6m/s Impact – Kerbstone	Crown	
10	6m/s Impact – Kerbstone	Rear	
11	8.5m/s Impact – Flat	Front	Three
12	8.5m/s Impact – Flat	Side L	
13	8.5m/s Impact – Flat	Side R	
14	8.5m/s Impact – Flat	Crown	
15	8.5m/s Impact – Flat	Rear	
16	8.5m/s Impact – Kerbstone	Front	Four
17	8.5m/s Impact – Kerbstone	Side L	
18	8.5m/s Impact – Kerbstone	Side R	
19	8.5m/s Impact – Kerbstone	Crown	
20	8.5m/s Impact – Kerbstone	Rear	
21	8.5m/s Surface Friction – Method A	Side L	Five
22	8.5m/s Surface Friction – Method A	Side R	

2.5.1 Linear Impacts

One hundred linear impacts (tests 1 to 20 in Table 2) were performed on five UN ECE Regulation 22.05 helmet models using TRL's 'twin wire' guided test rig. Furthermore, sixty repeat linear impacts (tests 1 to 20 in Table 2) for three of the five helmet models were repeated, thereby allowing some indication of the repeatability of the test method.

The test data collected through linear impact testing was to investigate the suitability of a proposed assessment protocol for a comparative assessment of current motorcycle helmets.

2.5.2 Test validity for linear impacts

The twin wire guided system was proposed because lateral movement is controlled during the impact test, thereby providing a more repeatable and controlled test method compared with free motion tests. However, the lateral motions of each impact test were quantified to assess the consistency of the impact.

For linear impacts, a tri-axial accelerometer was used, housed in the ball arm of the drop assembly. The alignment of the accelerometer was such that the Z axis was aligned to the vertical. This allowed lateral (horizontal) and longitudinal (vertical) acceleration to be captured during each impact and used to calculate a measure of how consistent each impact was in terms of the ratio between longitudinal and lateral velocity changes.

This was achieved by comparing the resultant change in velocity for the horizontal axes (X and Y) with the velocity change in the vertical axis (Z) for the impact event. The impact event start (T_{zero}) was considered to be the time at which acceleration in the z axis exceeded 2g. To define the end of the impact event, two separate calculations were made: the time at which peak acceleration occurred and the time at which peak displacement occurred, the latter also being the time at which the velocity of the head in the vertical (z) axis was zero. Given that the choice of time is somewhat arbitary, analysis was completed on the results calculated using $T_{v=0}$ only.

2.5.3 Oblique Impacts

Ten oblique impacts on five UN ECE Regulation 22.05 approved helmet models (tests 21 to 22 in Table 2) were conducted at 8.5m/s onto a 15º anvil, in accordance with UN ECE Regulation 22.05 Method A. The purpose of these tests was to measure the coefficient of friction between the helmet and abrasive paper. This parameter is used to characterise the helmet's potential for injurious rotational motions in real-life accidents within the proposed assessment protocol.

2.5.4 9.5 m/s Linear Impacts

In addition to the tests defined above, additional linear impact tests were performed at a higher test speed of 9.5m/s (see Table 3). It should be noted that a degree of damage was already present on these helmets as they had already been used for oblique impact testing. This data was intended to be used to validate the back calculation methodology and the capacity of the helmets to deal with high energy impacts.

Table 3 Test matrix for additional linear impact tests at 9.5m/s

Test Number	Test Type/Anvil	Impact Site	Helmet sample
23	9.5m/s Impact - Flat	Front	Fifth
24	9.5m/s Impact - Flat	Side L	
25	9.5m/s Impact – Flat	Side R	
26	9.5m/s Impact – Flat	Crown	
27	9.5m/s Impact – Flat	Rear	

These tests were conducted to provide additional information relating to the energy-absorbing capacity of the helmets at 9.5m/s which is the highest test speed recommended by SO232/VF. In addition, these tests provided an opportunity to assess the technical validity of deriving estimates of helmet performance at 8.5m/s by calculation from tests conducted at a higher 9.5m/s test speed. An assessment of test validity was also made for these tests and this is discussed in Section 4.

2.6 Tests onto a MEP

In order to assess the accuracy and repeatability of the test apparatus, calibration tests were carried out prior to, and following, helmet tests at each impact site. A total of 10 groups of calibration tests were completed, with at least three impact tests for each (two groups for each of five sites).

Each impact test was made onto a Modular Elastomer Programmer (MEP), as shown in Figure 5, which consists of a solid domed cylinder of homogenous rubber 6 inches in diameter and approximately 19mm minimum thickness (at the edge). This MEP is a Snell unit which was provided by HPE, Farnham. The use of a MEP provides a controlled impact surface and is specified by BS6658 prior to helmet testing to ensure that the instrumentation is within a ±15g tolerance for a typical 300g impact.

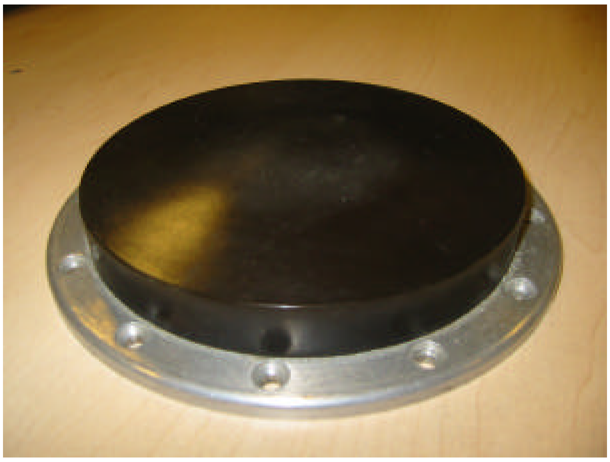


Figure 5 MEP used in testing

For this study, tests were completed at two drop heights 0.4m (2.8m/s) and 1.0m (4.3m/s) which produced peak accelerations in the region of 150g and 300g. These are typical of the levels expected for helmet tests at 6m/s and 8.5m/s respectively. The data was checked to ensure that the data was within ±15g tolerance required by BS6658. Additional tests were completed after the helmet tests to investigate whether there was any change in the test configuration or apparatus.

Each group of MEP tests were made at least three times in succession, using the headform in the orientation of the helmet test, e.g. front.

3 Results and Discussion

3.1 Test results

Test results are presented in the Appendices to this report. Appendix A contains a tabulated summary of the main test results. Appendix B provides the graphical results for the linear impacts together with the result from analysis using the 8.5m/s assessment protocol and the graphical results for the oblique impact tests. Appendix C contains the instrumentation specification, with Appendix D containing the test and assessment protocols proposed by Mellor *et al.* (2007).

3.2 Headform mass

Headform mass was within the tolerance of ± 1% of the 4.7kg target specified by UN ECE Regulation 22.05. The mass is critical for assessment of the helmet impact performance as it is directly proportional to the impact energy. A small change in impact energy can have a significant influence on the peak acceleration, particularly if the helmet is near to or exceeds its maximum energy absorbing capability.

Since mass was not varied within this project its influence could not be quantified; however, it is recommended that this close tolerance on mass should be included in the requirements for the test protocol. The mass distribution between the headform and guide arm components may also be important, but was not evaluated here. The location of the centre of mass is important and this may be influenced by the distribution of mass in the headform and guide arm apparatus.

3.3 Calibration tests onto a MEP

Sixty-four MEP tests were completed as part of this study. Generally, there were three tests before and after testing on each of five impact sites at each of two test speeds. The speeds were identified by a series of drop tests that produced peak accelerations of approximately 150g and 300g. This equated to drops of 0.4m and 1.0m for the MEP provided. Ten non-instrumented tests were made in rapid sequence onto the MEP to prime the MEP and test rig before use prior to each calibration run.

The results obtained at each impact site, show good repeatability of the tests with results within 15g of one another. Surprisingly the least repeatable test (3.5% variation) was that made at the low drop height of 0.4m (2.8m/s) onto the side. Further inspection of the data showed that this group also had a 1.6% variation of impact speed. Although there are too few tests to check for a correlation between these parameters, it is predictable that increased impact energy would result in increased head accelerations due to increasing MEP stiffness. However, there is good reason to believe that velocity may not entirely explain the variation in peak acceleration since the maximum difference in speed of 3.9% resulted in only a maximum 2.7% difference in acceleration for the front site at 2.8m/s. The geometry of the head is also likely to provide a significant effect.

Table 4 MEP test results summary

		4.3m/s				2.8m/s		
		Average peak acc	Max deviation from average			Average peak acc.	Max deviation from average	
		[g]	[g]	[%] of average		[g]	[g]	[%] of average
All tests	Front	293.1	7.0	2.4%		154.7	4.1	2.7%
	Side	323.1	9.3	2.9%		171.0	5.9	3.5%
	Crown	318.7	10.5	3.3%		166.0	0.4	0.2%
	Rear	303.5	1.6	0.5%		161.3	1.7	1.1%
Pre helmet tests	Front	295.4	4.8	1.6%		158.3	0.5	0.3%
	Side (R)	331.5	0.8	0.3%		174.3	0.3	0.2%
	Side (L)	320.3	1.4	0.4%		175.6	0.4	0.2%
	Crown	311.8	3.6	1.2%		166.0	0.4	0.2%
	Rear	304.2	0.3	0.1%		162.8	0.3	0.2%
Post-helmet test	Front	290.9	1.2	0.4%		151.2	1.1	0.8%
	Side (R)	320.4	1.4	0.4%		168.4	0.3	0.2%
	Side (L)	319.9	0.8	0.2%		165.7	0.6	0.4%
	Crown	325.6	1.7	0.5%		166.0	0.3	0.2%
	Rear	302.9	0.9	0.3%		159.9	0.2	0.1%

By subdividing test data into tests carried out before and after each group of helmet impact tests, the maximum variation in peak acceleration between tests reduces further. For example, the maximum deviation measured from the average result for each group of three tests with the same site and speed configuration (performed in sequence) was 4.8g and just 1.6% of the average result of 295.4g for the front site. The lowest was just 0.08% of the 304.2g for the rear test at 4.3m/s. The average for all tests was 0.4% of the average 238.6g result and marginally under 1.1g. This is very encouraging since as it demonstrates that for a very controlled and repeatable situation the test apparatus and instrumentation is accurate to almost 1g and less than 0.5% of the average result.

The influence of the head geometry (due to impact site) can be seen by comparison of all test data. For 4.3m/s tests, the peak acceleration ranges from 284.7g to 332.4g giving an enlarged maximum difference of 24.6g from the average 309.1g result. Similarly, at 2.8m/s (0.4m drop) a maximum deviation of 13.5g was recorded from the average 164.1g. In both cases, this equated to about 8% of the average result.

Since there was a large variation between pre and post helmet test groups,(see Table 4) this suggests that variations also exist in the test method and MEP. One such variation is test velocity, which has been discussed but may not fully explain all these differences. Since most test configuration variables were closely controlled between test groups, including headform mass, headform orientation, guide wire tension and alignment with the MEP, it seems likely that environmental factors may contribute to this. Temperature is one factor which may influence both the performance of the MEP and instrumentation and this should be considered for future test work.

3.4 Test validity

The test validity factor has been calculated using the formula below;

$$Validityratio = \frac{\sqrt{((\int_{Tzero}^{T1} a_x dt)^2 + (\int_{Tzero}^{T1} a_y dt)^2)}}{\int_{Tzero}^{T1} a_z dt}$$

where a_x = acceleration in lateral (x) direction
a_y = acceleration in lateral (y) direction
a_z = acceleration in normal (z) direction
Tzero = start of analysis period
T1 = end of analysis period

This parameter is used by the US Department of Transport (DOT) helmet test standard, FMVSS-218, where it is claimed that a monorail guide apparatus can limit the ratio to below 5%.

Due to the rapid changes in acceleration that can occur during an impact event, this ratio is sensitive to the period over which it is calculated. The selection of the start and end times is therefore important and should be as close to the start and end of the actual impact as possible. The authors recommend an event enclosed by T_{zero} (defined as the earliest time in the impact event at which acceleration is below 2g prior to reaching 10g) and $T_{v=0}$ where the velocity of the headform is zero and the maximum displacement is achieved (based on normal displacement calculated from accelerometer data). However, the selection of the start and end times is arbitrary and potentially these can, with the appropriate equipment, be defined by physical positions of the headform prior to and following impact.

Sixty-four MEP tests were completed as part of this study. These tests produced validity ratios between 0.6% and 9.2%, with average of 4.2%. The average is close to that of the FMVSS specification of 5% but the increased levels for some tests suggest that the twin–wire system is less stringent and prone to greater lateral motions that those for a monorail guide system. This is somewhat as expected due to the reduced lateral support which is provided by a twin wire guide wire system. However, in some cases the ratio is below 1% and this indicates either that there is scope for improvement or that the validity ratio is dependent on the test configuration.

Nine of the ten highest values were recorded for MEP tests completed onto the crown of the headform, despite this accounting for only 17% of all tests. This result clearly shows that the crown site is prone to higher validity ratios than for other sites. During helmet tests, higher validity ratios may be attributable to many factors, including;

- External helmet geometry (in particular protrusions) which can cause rotation of the helmet and headform.
- Poor fit or mismatch between the helmet and headform interface which can cause the headform to slide and translate inside the helmet.
- Anvil geometries that can encourage the helmet to slide and gain laterally velocity.
- The alignment between head centre of gravity and anvil can further encourage slippage on raised anvils such as kerb or hemispherical anvils.

Other factors which may affect the magnitude of the validity ratio include;

- Guide mechanism and design
- Tension in twin wire system
- Headform mass (although the mass was not varied in these tests)

Since, in the case of MEP tests, the helmet's influencing factors are removed and the impact test equipment is unchanged (e.g. mass and wire tension is unchanged), raised levels of the validity ratio can be attributed to the misalignment between the centre of gravity of the head and the impact anvil. This is probable since the headform is not flat and the orientation may cause the initial contact site to be misaligned with the headform's centre of gravity. Ideally, a guided headform should be designed to have as much mass as close to the centre of gravity as possible to reduce the potential for misalignment.

Validity ratios in excess of those measured during MEP tests do not necessarily indicate unacceptable helmet tests, but that some results may deviate more from the 'ideal' result than others. In reality, the ideal result may never actually be achieved as a pure linear test is unlikely for such complex and interactive headform and helmet geometries. A compromise must therefore be made and acceptance criteria should be defined such that there is an appropriate level of confidence in the result and that deviations, for whatever reason, do not have a significant effect on the performance assessment. The threshold would best be determined by repeat testing of controlled samples with a parametric sweep of a single influencing factor e.g. by increasing the lateral misalignment of the head centre of gravity and anvil until slipping is known to occur.

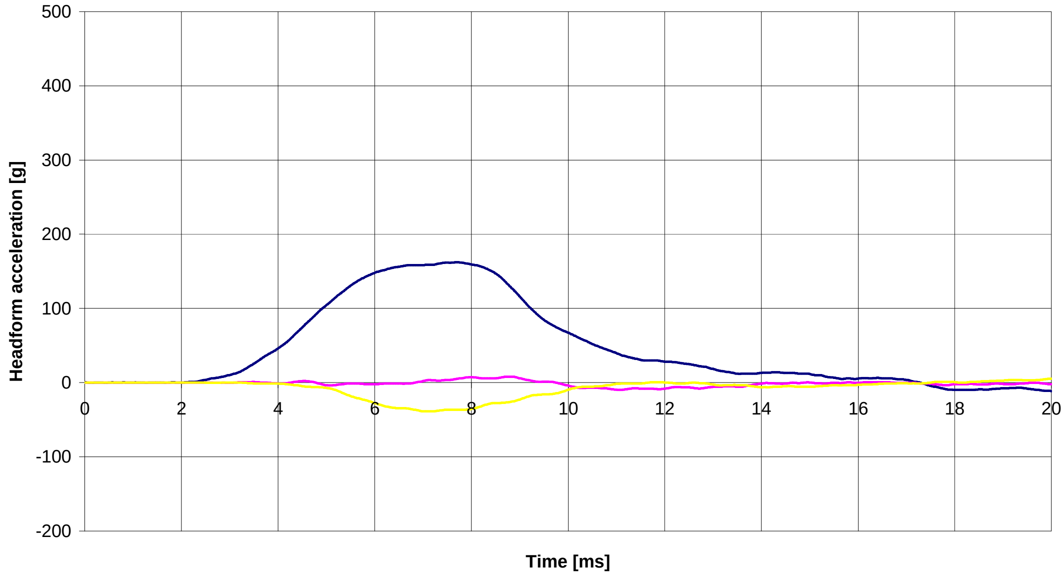
Test data for some 175 helmet impacts have been processed using two time intervals. Both starting from T_{zero} (as defined above) but with two end times; 1) $T_{v=0}$ which is the time at which helmet is stationary and 2) T_{peakg} at which the maximum acceleration of the headform during the impact event is reached. At T_{peakg} headform may still have normal and tangential velocity.

Based on this linear impact test data with variable speed, helmets and anvils, a maximum validity ratio of 17.5% was recorded when using $T_{v=0}$ and 19.8% for T_{peakg}. These differences are due to rapid changes in acceleration that occur after T_{peakg} which can influence the integral of acceleration (velocity) and subsequently the ratio between them. Since time $T_{v=0}$ is always greater than T_{peakg} it should provide a better estimate of the average validity ratio over the whole impact event. Indeed, it would be acceptable to calculate the ratio for all acquired impact data providing that no secondary impact events have occurred during the rebound phase. However, given the limitations of acquisition equipment and the accumulating errors associated with integration of acceleration data, it is recommends that the period should be kept as short as possible once the impact is complete. For this reason it is recommended that $T_{v=0}$ is used and this has been used for the remaining analysis.

In the instance where a ratio of 17.5% was recorded, the test was onto the side of helmet 4 onto a flat anvil (see Figure 6). Of the 10 highest ratios recorded (ranging from 17.5% to 13.8%), six were onto the same anvil using the same helmet and impact site combination. Four of these were made at the same 6m/s impact speed (the remaining two tests at 8.5m/s and 9.5m/s). Although the test setup and helmet appear generally repeatable this result indicates that there may be greater lateral motion of the headform for this helmet and anvil than for other configurations. It should however be noted that this particular helmet was repeat tested on this site/anvil (i.e. side/flat data are more frequent than other test configurations).

Linear impact test results

Project reference	S0614/V8	Impact anvil	Flat
Test reference	18lz34	Impact site	Side (L)
		Target impact speed [m/s]	6
Test helmet	4B		
Sample reference	4f	Peak |acceleration X| [g]	39
Helmet size	Medium	Peak |acceleration Y| [g]	10
Headform size	J	Peak |acceleration Z| [g]	162



B

Figure 6(a) Typical test results and validity ratio visualisation

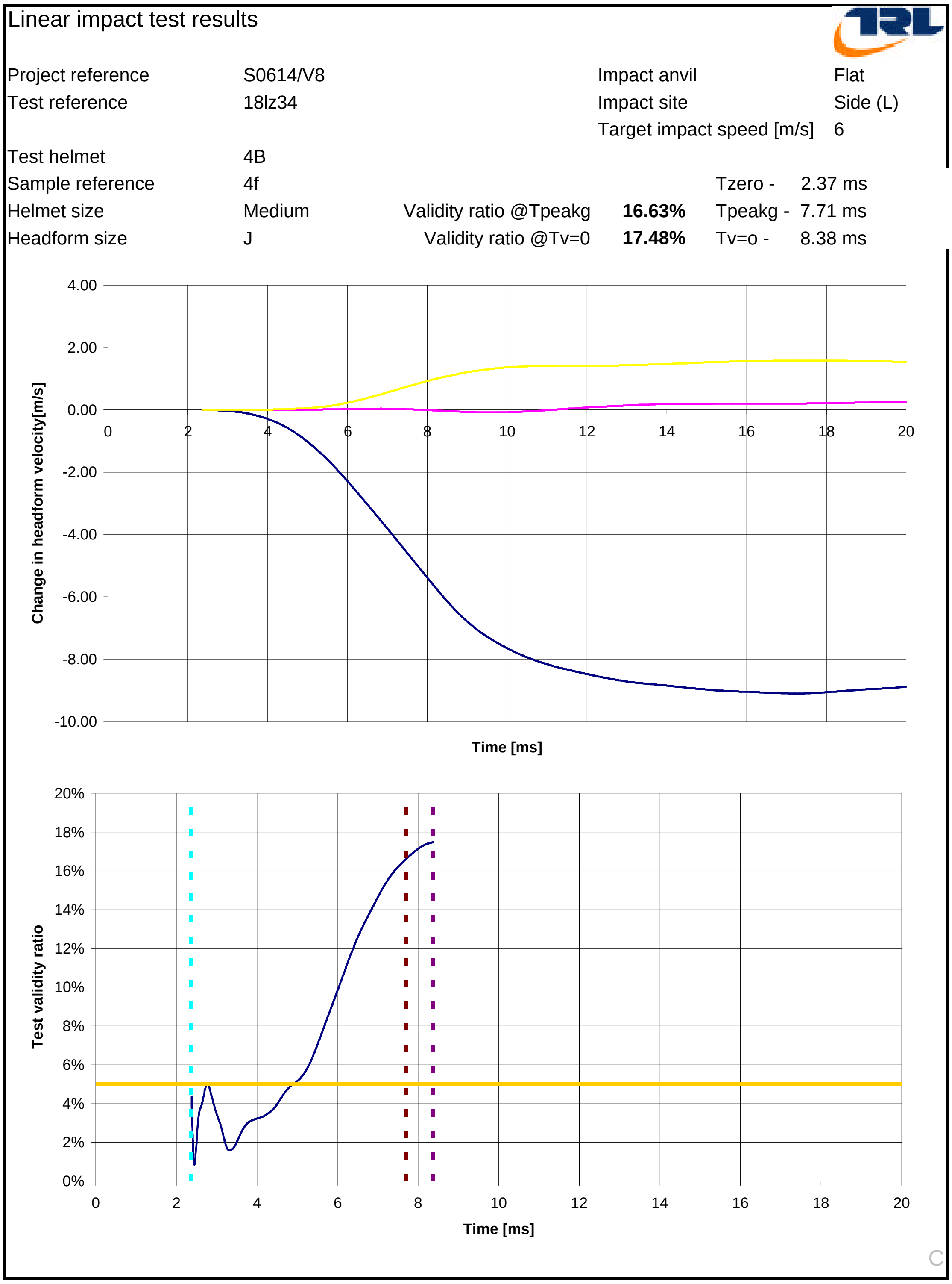


Figure 7(b) Typical test results and validity ratio visualisation

An inspection of helmet 4 (the helmet with the highest validity ratio) was completed to try to comprehend any factors that may influence the validity ratio. There were no unique external helmet features at this test site which would encourage rotation e.g. visor opening mechanism, and there were no markings to suggest high levels of slippage. Since these tests were completed on the flat anvil, which would be unlikely to encourage slippage, the influence of headform fit and geometry relative to both the helmet and anvil was assumed to be the likely cause of high validity ratios for this helmet. This is supported by incidental rise in both lateral and normal head acceleration for this test with peaks occurring at the same time. The geometry can encourage lateral motions as illustrated by Figure 7 below and this can be dependent on helmet design as well as size.

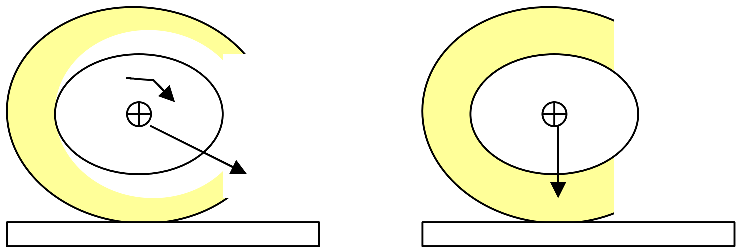


Figure 8 Illustration of impact motion possibilities for helmets of differing fit.

Surprisingly, the kerb anvil was least likely to be associated with increased levels of validity ratio. This was unexpected as raised anvils are thought to increase the risk of slippage. The kerb anvil accounted for only 31% of the 35 worst (top 20%) validity ratios compared with the 46% average for all tests (80 tests out of 175). This slight bias towards poor validity ratios for the flat anvil may suggest that a flat anvil may encourage greater translational motion and/or helmet/head rotation. This could be due to a poor compatibility between the curved helmet geometry and the flat surface, especially when the impact site (generally the lowest part on the helmet) does not align with the headform centre of gravity. The kerb anvil provides a much smaller contact area and ensures better alignment with the centre of gravity, but is also less likely to be affected by irregular geometry away from the impact site. Deflection of the outer shell due to the penetration effect of the kerb anvil may also provide some stabilising effect reducing the tendency for translation. This effect may not be so apparent on very stiff carbon fibre shells of which the highest performing helmets are expected to be constructed.

This project did not allow a sweep of parameters to fully quantify the ratio for “good” and “poor” test set ups, where both valid and unacceptable configurations were used. It is therefore not possible to define a validity ratio threshold by which all tests could be scrutinised. However, it is clear from the MEP tests completed, where the average result of 7.8% was recorded, that the FMVSS level of 5% is unlikely to appropriate for the twin wire test configuration used in this study. Indeed, a level in excess of the maximum recorded for MEP tests (9.2%), must be assumed to be valid for a helmeted headform tested with this equipment. An acceptable threshold level for validity ratio may be as high as the 17.5% recorded for all helmeted tests. This is because there was no evidence to suggest that any of the tests were poorly configured or that the helmet performed in an abnormal way with regard to rotation. A further larger scale experimental study would be necessary to define a threshold with greater certainty.

3.5 Comparison between identical tests

3.5.1 Linear impact tests

3.5.1.1 Side impact sites

Impact tests to the side of the helmet were completed on the left and right side. These tests were made in sequence on the helmet and any consequential damage between impacts was assumed to be limited. A comparison between the side left and right results is therefore feasible to investigate the combined variation of the helmet and test method. Two side impact tests were completed per helmet model on each of two anvils, at speeds of 6m/s and 8.5m/s, giving 40 tests in total. For three helmet models this sequence was repeated, giving a total of 64 tests for comparison.

Although the left and right impact sites are defined by the marking procedure and are essentially the same, there is a need to reposition the headform and helmet prior to testing on each side and consequently subtle difference in the test setup may exist. Such differences may affect the head's position and orientation relative to the anvil (particularly for the kerb anvil) and also the helmet position relative to the head.

The average absolute difference between left and right impact sites for all helmets and impact speeds was 32.6g (average peak acceleration was 254.8g). This was somewhat lower for 6.0m/s tests with an average of only 4.4g and a maximum difference of 11.6g from the 155.7g average result for these tests.

The maximum difference observed between left and right sites was 196.9g with peak acceleration results of 262.9g and 459.8g for tests at 8.5m/s onto a kerb anvil (Helmet 5A). A similar result was observed during flat anvil for side of the same helmet (262.0g versus 435.0g).

The high results are indicative that the helmet is close to its full energy absorbing capacity and consequently the peak acceleration measurement is very sensitivity to slight differences in impact energy. However, the kerb test with a peak acceleration of 459.8g had an impact energy that was only marginally higher (+1.6%) than that for the 262.9g test, and tests completed with an identical helmet model (helmet 5B) showed only a 34.5g difference between similar configurations of impact tests. In this case peak acceleration of 322.2g and 356.7g were recorded with a 2.3% difference in energy.

This suggests that other factors, such as the sensitivity of the helmet to deviations from the target impact site or helmet production inconsistency, may affect the result. This is supported by the fact that the greatest peak acceleration in these two tests was recorded with the lowest impact energy and that large differences in peak acceleration were only observed on two helmet models. Geometry is unlikely to have been a significant factor as the helmets were symmetrical (except helmet 5 where asymmetric features were removed).

A further pair of tests reiterates that the impact energy is not the only contributory factor since the largest difference between impact energy for equivalent 8.5m/s kerb tests was for helmet 2A, yet only a 15g difference in the peak acceleration results (251.5g versus 266.6g) was noted. This is equivalent to 5.8% of the average level recorded.

Excluding impacts where at least one helmet impact exceeded 300g and the difference between helmets was 145g or greater, the average difference between all left and right impacts was just 12.6g and equivalent to 5.4% of the average 234g peak acceleration result. The sensitivity of the protocols to these differences has not been considered here.

3.5.1.2 Other impact sites

Further to the comparison of left and right impact sites, it was possible to compare equivalent tests on other test sites for three of the helmet models (Helmet models 2, 3 and 5). Additional repeat tests were performed for these helmet models onto kerb and flat anvils, at both 6.0m/s and 8.5m/s impact speeds using an identical helmet model. Each helmet was tested in the same sequence of impact for each of five sites front, side (R), side (L), crown and rear. As the side impact sites have been assessed separately, only front, rear and crown have been included in the following analysis.

The average difference between all repeat linear impact tests (excluding side impacts) was 9.4g (11.8g for 8.5m/s and 7.1g for 6.0m/s impacts only) and equivalent to 5.2% of the average 181.4g peak acceleration result, indicating that in general the repeatability was very good. The maximum difference between equivalent tests (comparison between results for similar impact conditions and helmet models) was 39.4g which is 21.7% of the average 181.4g. This was well below the 196.9g recorded for side impact sites, but was similar to the 41.2g maximum recorded for side impact tests excluding those with a difference greater than 145g and at least one test above 300g. This indicates that similar repeatability can be expected for all impact sites providing helmets are not close to bottoming out. It was noted that in all tests (8.5m/s and 6.0m/s) none of the three helmets exceeded 300g on sites other than the side, indicating poor performance at this impact site.

The greatest difference recorded between the measured peak accelerations for equivalent tests (excluding side) of 39.4g was recorded for a kerb rear test at 8.5m/s. Here the difference in energy between these two tests was less than 1% and unlikely to have made a significant contribution to this result as the helmet was not close to the full capacity. Since the third, fourth and fifth highest differences for 8.5m/s tests (20.2g to 11.4g) were also onto kerb anvils, this suggests that this site may be particularly prone to set-up or helmet consistency issues. Another possible factor is that because this was the last test to be completed on each helmet, the helmet fit would have deteriorated due to residual liner compression at other impact sites. The degradation in fit was not assessed within this project.

The third highest difference for all tests (8.5m/s and 6.0m/s) was 36.1g, recorded for a kerb front test at 6.0m/s using helmet 5. This was more than 23% of the average result for the two helmet tests (155.9g), yet the energy difference for this low speed test was less than 0.1%. Since this was the first helmet impact, the helmet fit and deterioration was unlikely to be a major contributory factor. This again suggests that the kerb may create the greatest difference in helmet repeatability. This could be due to the smaller contact area between the anvil and helmet which may exaggerate any deviation from the intended impact site. Alternatively, there may be helmet production inconsistencies, but it is not possible to evaluate these issues further without completing sensitivity tests onto the kerb anvil using closely controlled samples.

Despite the possible tendency for kerb impacts to produce higher test results, the average difference for kerb and flat for 18 tests on each was similar at 11.2g and 7.7g respectively, equating to 6.7% and 3.9% of the average peak acceleration results for these test anvils (196.0g and 166.9g).

3.5.2 *Oblique impact tests*

Two oblique tests were completed on sites on opposite sides of the same helmet. The tests were consecutive and were the first two impacts completed on the test helmets. As far as possible helmets were cushioned post-impact to prevent excessive damage to the helmet.

The importance of impact site is highlighted by repeat tests which were carried out on helmet 2. These tests were considered necessary as lower than expected friction coefficient results were obtained for these tests (when compared to helmets of similar construction). Closer inspection of the helmets suggested that some helmet features including raised profiles on the helmet surface may have contributed to this by reducing the effective contact area. Friction may be affected by the area of interaction due to the mechanical abrading that occurs at the surface. For this reason tests on helmet 5, which had similar shell features, were also repeated.

The average friction coefficient recorded for the original tests using helmets 2 and 5 was 0.39 and 0.49 respectively. Including repeat tests a friction coefficient of 0.47 was obtained for helmet 2 and 0.49 for helmet 5. Importantly, a difference of more than 17% was recorded for helmet 2. This result indicates that test site may have a significant bearing on the friction coefficient recorded for the same helmet model. The correct selection of an appropriate test site is therefore an important consideration for test laboratories when completing helmet comparison studies.

Table 5 - Oblique impact test result summary

Helmet Ref	Site	Orientation	Velocity actual [m/s]	Anvil force		μ		Comment
				Normal [N]	Tangential [N]	Average rolling	Helmet Mean	
1	Side R	Chin up	8.51	3101	1677	0.51	0.52	
	Side L	Chin up	8.53	2993	1721	0.53		
2	Side L	Chin up	8.56	3639	1314	0.39	0.39	Raised shell detail
	Side R	Chin up	8.57	3251	1242	0.39		
2	Rear	Right side up	8.55	2152	1035	0.49	0.47	
	Rear	Left side up	8.57	2968	1491	0.46		
3	Side L	Chin up	8.57	3639	1899	0.56	0.56	
	Side R	Chin up	8.58	3777	2174	0.56		
4	Side L	Chin up	8.58	4041	2353	0.56	0.56	
	Side R	Chin up	8.58	4335	2518	0.57		
5	Side L	Chin up	8.57	3579	1878	0.49	0.49	Raised shell profile
	Side R	Chin up	8.59	3294	1629	0.49		
5	Side L	Chin up	8.57	3278	1569	0.49	0.49	
	Side R	Chin up	8.54	2917	1462	0.48		

Despite the apparent variation with impact site and helmet features, the difference in coefficient of friction between equivalent test pairs (original and repeat) was 0.02 (5%) or less. This measure includes the repeat pair of tests completed on helmets 2 and 5 which had sustained multiple impacts to investigate the friction variability with impact site. Excluding these tests, the maximum difference recorded was 0.01 equating to 2.5%. This suggests that the coefficient of friction parameter will provide a repeatable assessment of helmet performance providing similar impact sites and conditions are used and also that the helmet remains in good condition between tests. Given this close repeatability, the sensitivity of the final helmet assessment to this parameter has not been assessed here.

Tangential anvil forces provided less reliable measure of helmet performance, with the variation in peak force between comparable tests exceeding 35%. This makes the peak tangential force unsuitable parameter for direct comparison of helmet performance. The variation in tangential force was attributed to variation in normal force with which it was shown to have a good correlation (r^2 of 0.70 for 14 tests, see Figure 8). Indeed, the percentage increase in normal and tangential force between original and repeat tests was very similar and a correlation coefficient, r of 0.95 ($r^2 = 0.91$ for 7 pairs, see Figure 9) was observed between them. The variation in normal force may be attributed to changes in linear impact performance which may be due to either test setup, helmet consistency or deterioration between tests. Fortunately this does not affect the calculation of the friction which has been shown to be very repeatable.

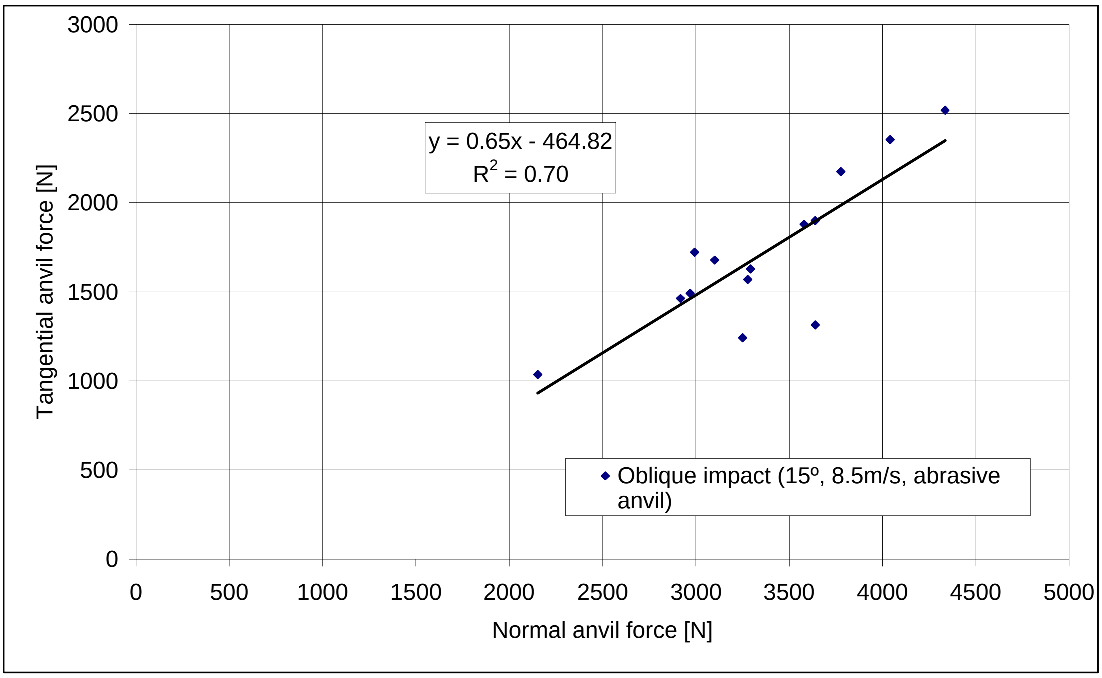


Figure 9 Relationship between tangential and normal anvil force for 8.5m/s oblique impacts

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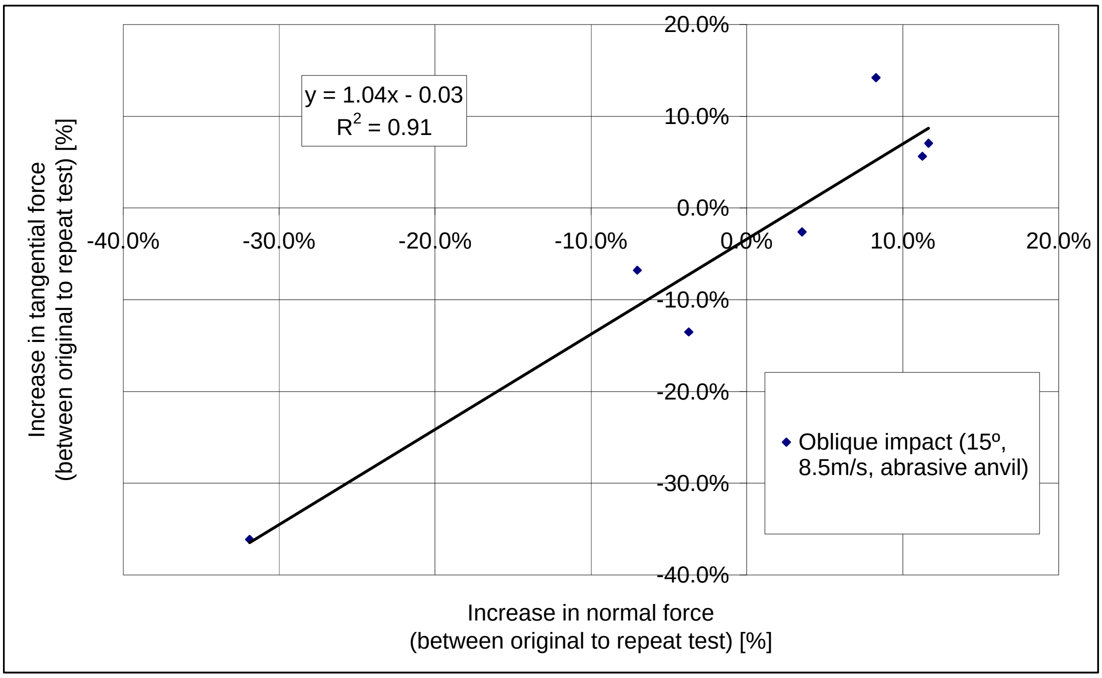

Figure 10 Relationship between change in tangential and normal anvil force for comparable (original and repeat) 8.5m/s oblique impacts

3.6 Capacity of helmets to absorb impact energy

There were fifteen impact tests completed at 9.5m/s onto a flat anvil (three helmet models and five impact sites). The conditions were identical to those for the 8.5m/s impacts and were performed on the same helmet models. In most cases these tests were completed immediately following the equivalent lower speed test.

Eighty tests were completed at 8.5m/s and the peak acceleration was =275g in almost 1 in 3 cases (26 cases, 32.5%) and the side impact site accounted for 23 (88%) of these. Accounting for repeat tests made onto a side impact site (40% of all 8.5m/s impact tests were onto this site), almost 1 in 4 (22.7%) impacts at 8.5m/s would be =275g and 79% of these would be side impacts. This suggests that there may be reduced protection provided at the side of the helmet when compared to the front, crown and rear sites.

Of the 26 helmets that had peak accelerations of less than 275g, 13 were onto the kerb anvil and 13 onto the flat. Significantly, eight of the ten highest peak accelerations were recorded for tests onto a kerb anvil. Although there may be some bias due to the high number of side impacts included in this dataset (the side may have especially poor performance onto this anvil), this indicates that the kerb anvil may be most likely to exceed the helmet's energy absorbing capacity.

Fifteen tests were completed at 9.5m/s onto the flat anvil. The peak acceleration was =275g in eleven cases (73.3%). Accounting for repeat tests onto the side impact sites, two thirds of impacts at 9.5m/s onto a flat anvil were =275g. Furthermore, 6 out of 11 impacts resulted in 275g or more at 9.5m/s but not at 8.5m/s. The remaining four impacts (out of 15) did not exceed 275g at either 8.5m/s or 9.5m/s. This shows a predictable tendency for helmets to bottom out at higher speed. Given the findings above, this tendency would also be greater for kerb anvil impacts.

For similar flat anvil test conditions, four impacts resulted in less than 275g for both tests at 8.5m/s and 9.5m/s. This shows that in some helmet and impact site combinations, the helmet's capacity has not been exceeded and there is potential to absorb further impact energy above 9.5m/s. This potential to absorb impact energy may provide enhanced levels of safety when compared to other helmets. Ideally this should be evaluated to provide an accurate assessment of the full protection available from the helmet. For this reason the addition of further tests at increasingly higher speeds to assess the full helmet capacity is recommended. The authors consider it would be appropriate to continue testing until the peak acceleration exceeds 500g, a level that the assessment protocol aligns with a 100% risk of fatality.

3.7 Assessment of the "back calculation" method

Within the SO232VF project (Motorcyclists' Helmets and Visors - Test Methods and New Technologies; Mellor *et al*., 2007), protocols were written that would enable the performance advantage of advanced helmets to be measured relative to current helmets, across a range of impact severities up to 9.5m/s. A revised protocol has been proposed allowing an assessment up to 8.5m/s.

The most accurate technical solution for assessment of helmet performance across an impact or injury severity range is to test the helmet onto each anvil at every test speed that is linked to an injury severity or casualty group. For the revised 8.5m/s protocol, this would require up to 13 impacts (0.5m/s intervals from 2.5m/s to 8.5m/s) onto each anvil and test site. However, Mellor *et al.,* (2007) proposed a two-speed test method to characterise helmet performance across the speed range. The justification for this approach is that a rigid anvil test is not necessarily fully representative of real life accidents. This is because, during accidents, the energy dissipated by the helmets is dependent on the loads imparted by the impacted surface and this surface may be deformable or moving, as opposed to rigid and stationary in the laboratory tests. Consequently a back-calculation method allowing the performance to be estimated across the accident severity range will provide a practical and cost effective solution.

The assessment protocol includes a back-calculation tool which allows the helmet performance to be characterised across a speed range. The tool predicts the peak linear acceleration that would be expected for tests at speeds below that of the actual test. The calculation determines the acceleration achieved at particular levels of energy absorption (which is associated with an impact speed and accident severity) and is therefore characteristic of the helmet's energy absorption rate. The energy absorption is a function of the acceleration and displacement during the impact event.

The back-calculation tool assumes that the performance of the helmets is not rate dependant, and that energy absorption is consistent for a given peak acceleration and impact type. Figure 11 depicts a series of three tests completed onto a flat anvil (front site) at 6.0m/s, 8.5m/s and 9.5m/s. The figure shows that the acceleration for a given displacement is similar for impacts at different speeds, but it is not identical and therefore indicates some rate dependency. Thus, the prediction of performance (in terms of peak acceleration at a particular test speed) cannot be 100% accurate. However, this tool could be effective at reducing the number of tests required to characterise helmet performance over a larger speed range and rewards helmets which offer good protection at both low and high impact severities. This effectiveness is discussed further in this section.

Within S0232/VF, advanced motorcycle helmets were assumed by TRL to have the capacity to absorb impact energy up to 9.5m/s, a performance beyond that expected for current motorcycle helmets. To accurately record helmet performance at lower test speeds, a further test speed of 6.0m/s was introduced. This speed corresponded with that recommended by Chinn *et al.,* 2001 (COST 327), where it was identified that the there may be compromise between high and low speed performance. Although the revised protocol evaluated here is based on a maximum 8.5m/s test speed, the assessment protocol still evaluates helmet performance across a range of test speeds and relies on the same prediction tool.

The 175 helmet tests completed within this study provide important information about the validity of the prediction techniques that are used to determine protection offered across the speed range and its appropriateness for use in an assessment protocol. A comparison of the actual peak accelerations measured at a given test speed have therefore been compared with those predicted using data from tests at higher test speeds.

Linear impact test results

Test reference 12lz02 / 13LZ08 / 13LZ24

Test speed [m/s]	Peak acceleration [g] at		
	6.0m/s	8.5m/s	9.5m/s
6.0	165.5	-	-
8.5	185.7	260.5	-
9.5	188.8	296.6	386.1

Impact anvil	Flat
Impact site	Front
Target impact speed [m/s]	6.0 / 8.5 /9.5
Test helmet	2A
Helmet size	Medium
Headform size	J

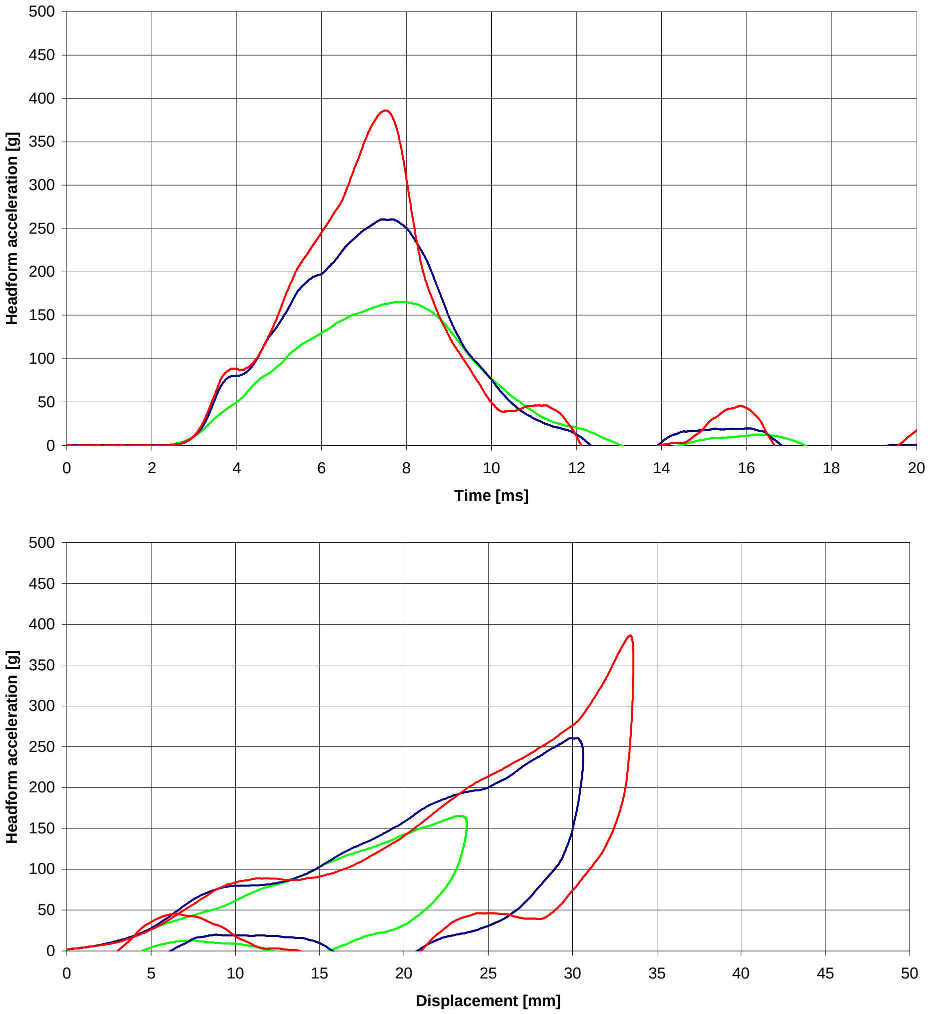

Figure 11 Illustration of acceleration – displacement curve for three helmet impact tests onto a flat anvil and differing speeds

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3.7.1 9.5m/s prediction of 8.5m/s data

Based on a total of thirty tests (fifteen at each test speed), Figure 12 shows that there was a statistically significant ($P<0.05$) correlation coefficient of $r=0.78$ ($r^2=0.61$) between peak accelerations predicted using 9.5m/s test data and those measured during tests at 8.5m/s. This relationship was tested by comparing predicted results at 8.5m/s from 9.5m/s tests, with actual test results at 8.5m/s. It is notable that at the highest acceleration levels there was a large discrepancy between the predicted and measured values with a 232g difference in one case. This is reflected by the gradient of curve being almost 1.4, where a good prediction tool would be close to unity (1.0). The relationship described by this data ($y = 0.5899x + 84.302$) shows that a potential error of almost 10g would be predicted based on a low severity (207g) impact. For a high severity impact, the error may be as great as 99g based on the worst case result (435g) recorded at 8.5m/s here.

However, closer inspection shows that the largest differences between the predicted and measured results are for impacts onto the helmet side at 8.5m/s (highlighted by round circles in Figure 12). This site has been shown to be sensitive to test setup and has the greatest spread in results for any site, particularly for high speed impacts where the helmet is close to its full energy absorbing capacity. At high speed, small changes in energy or accuracy of the target site can have large consequences to peak acceleration levels.

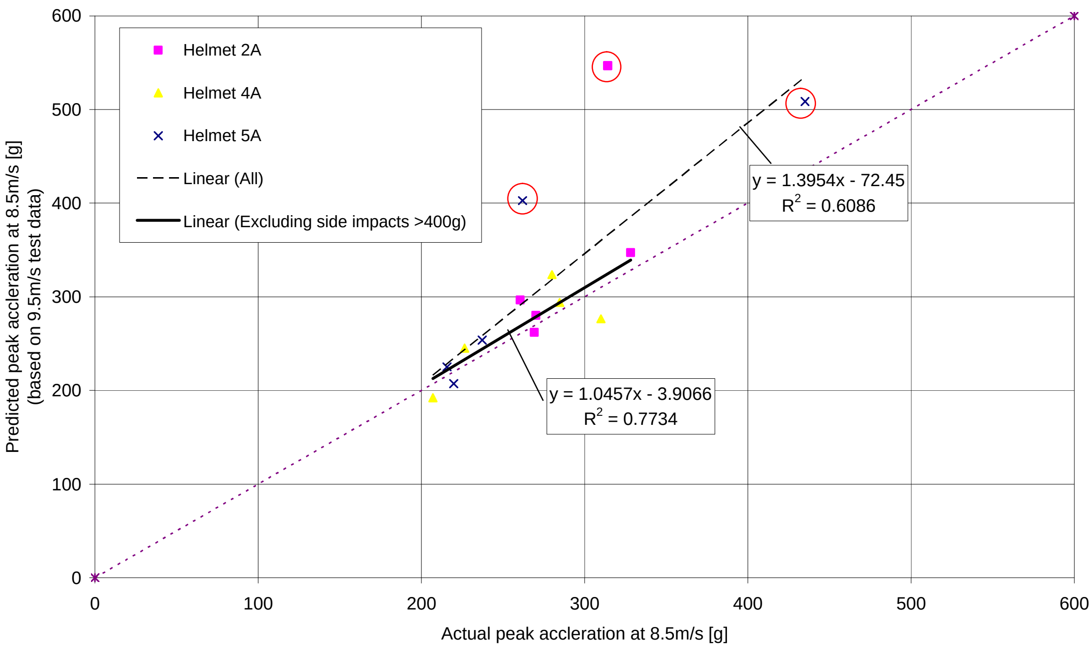

Figure 12 Comparison of predicted and measured peak acceleration for 8.5m/s helmet impacts

Given the potential for misleading data for tests completed at high speed onto the side impact site, a further analysis has been completed which excluded side impact test data where evidence of bottoming out was apparent, i.e. excluding tests where one or more result was above 400g. Based on the reduced set of 24 tests, (12 unique configurations) there is an improvement in the correlation coefficient of $r=0.88$ ($r^2 =0.77$). Importantly, the linearity factor, which relates the actual and predicted acceleration is close to 1.0 (1.05) and the offset, is less than 4g. This illustrates that the back-calculation method would provide good accuracy, with an average error of around 3.0% when predicting results at 8.5m/s using 9.5m/s test data (assumes a 250g result at 8.5m/s) providing the test site is accurately struck. Based on this revised relationship ($y = 1.0457x - 3.9066$), the error in the results for the range of accelerations recorded at 8.5m/s was less than 16g for a 435g impact and 5.6g at 207g. However, the difference in test speed between these two high speed tests is only 1.0m/s. It is not possible to comment whether this prediction tool could be applied accurately between 9.5m/s and 6.0m/s as proposed by SO232/VF. Estimation of 6.0m/s data from 8.5m/s test data is further examined in the next section.

Based on the comparison of 8.5m/s and 9.5m/s data, there is evidence to suggest that the back calculation is an accurate prediction tool for assessing performance for impacts 1m/s below the actual test speed. However, the prediction tool can only be accurate if the test on which it is based has a close tolerance on impact site and impact energy. The demonstrated accuracy of this tool was also reliant on the quality and consistency of the helmets in this study.

3.7.2 8.5m/s prediction of 6.0m/s data

Figure 13 shows the actual acceleration measured during a 6.0m/s test against that predicted using 8.5m/s test data. This demonstrates that for 80 test configurations conducted at 8.5m/s and 6.0m/s (160 impacts), the correlation between predicted and actual results at 6.0m/s is poor, with an r^2 of 0.4, considerably lower than that for the prediction of 8.5m/s data using 9.5m/s tests, discussed above. This suggests that as the difference between the actual test speed and the speed at which the prediction is made increases, the error in the back calculation also increases.

For the 80 samples considered here, two different anvils (kerb and flat) and five unique helmet models were used. This compares to the single anvil (flat) and three models for the previous analysis and may indicate that these parameters influence the accuracy of the back calculation. Further examination of this data indicates that better predictions are sometimes achieved when datasets are limited to the helmet, test site and anvil groups. This is summarised in Table 6 where the best correlations were observed for impacts onto the rear site ($r^2 = 0.89$, see Figure 13) and helmet 2 ($r^2 = 0.7$). However, for some groups no significant correlation was found (front site and helmet 5).

Although the assessment protocol only requires estimation of data at and between 6.5m/s and 8.0m/s and therefore the correlation expressed here is likely to be worst case, the lack of any discernible correlation for some anvil and site combinations suggests that the prediction tool may be unsuitable for accurately determining performance at these speeds. However, given that 8.5m/s data can be accurately predicted from 9.5m/s data for well controlled tests, the prediction tool may better estimate performance at 7.5m/s and 8.0m/s. Unfortunately, this could not be evaluated in this series of tests.

The poor correlations observed here justify the use of a lower test speed to improve accuracy and confidence in low-speed helmet performance.

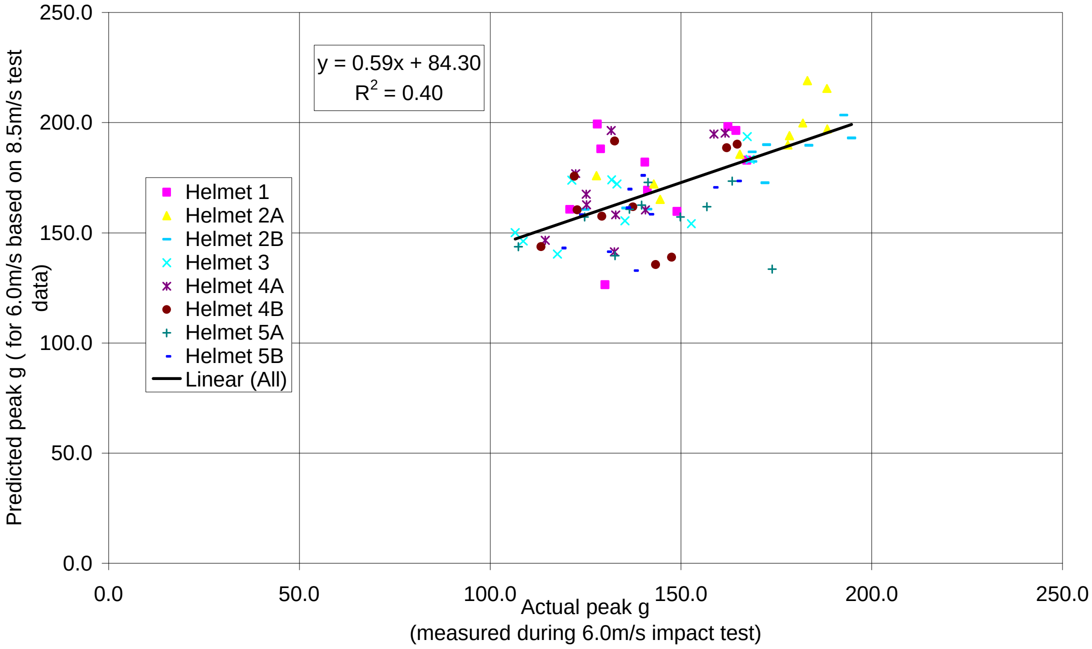

Figure 13 Comparison of predicted and measured peak acceleration for 6.0m/s helmet impacts

Table 6. Comparison of predicted and measured acceleration for 6m/s impacts

Dataset	**r^2**
Helmet 1	0.16
Helmet 2	0.70
Helmet 3	0.52
Helmet 4	0.21
Helmet 5	0.09
Front impact site	0.10
Side impact site	0.53
Crown impact site	0.27
Rear impact site	0.89
Kerb anvil	0.26
Flat anvil	0.36

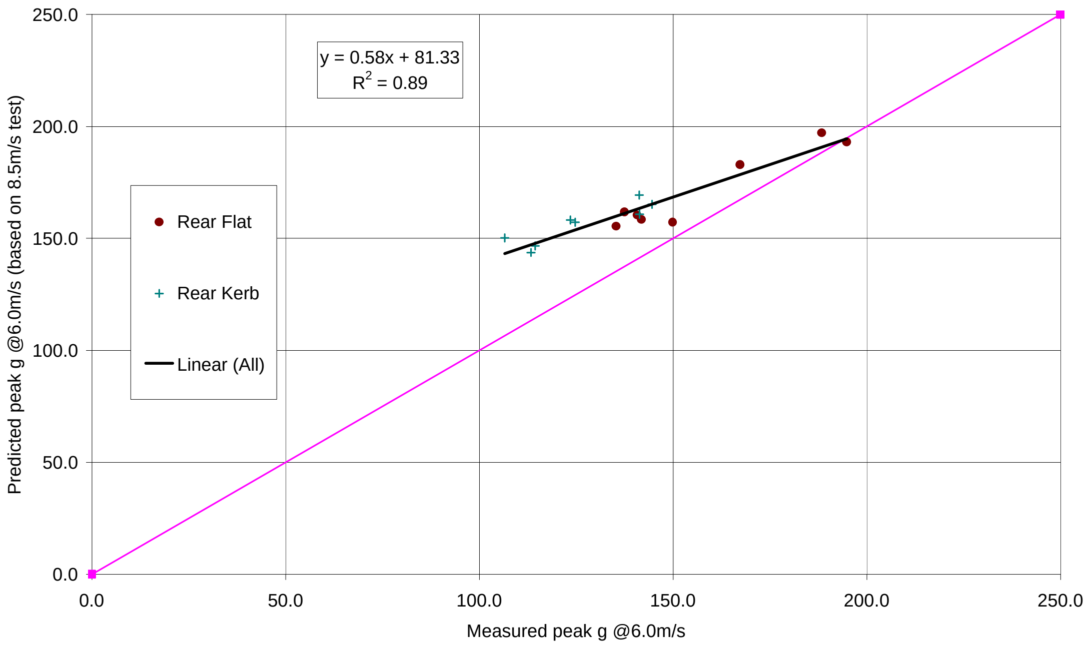

Figure 14. Comparison of predicted and measured acceleration for 6m/s impacts for rear impact site

3.7.3 General observations relating to back calculation method

This data suggests that, although the prediction tool may be sensitive to test configuration, the prediction tool is not generally reliable for accurate prediction of peak accelerations for low speed (6.0m/s) tests when using high speed test data (8.5m/s). Although the 9.5m/s versus 6.0m/s data comparison has not been completed here, a similar or worsening trend would be expected, as the difference between the test speeds increases. Although this analysis is based on a worst case situation (it is not required to predict 6.0m/s data points using 8.5m/s data in the protocol), this justifies the use of a low speed test to improve confidence and accuracy of data at this speed.

Given that predictions at 8.5m/s from 9.5m/s test data show that for small differences in speed the accuracy of the back-calculation improves, improved accuracy of the estimated helmet performance could be achieved by using a greater number of test speeds. An alternative measure to improve accurate prediction across the speed range would be to increase the low test speed from 6.0m/s to 7.0m/s so that the difference between speeds for actual and predicted data is reduced. This could be justified as most helmet tests at 6.0m/s (51 out of 80) did not exceed 150g; the level of acceleration which is associated with the onset of fatal head injuries. Test results below 150g do not contribute to the final rating when using the proposed helmet assessment protocol. However, helmets optimised for higher speed performance may tend to have higher peak accelerations at 6.0m/s and in excess of 150g which would be more critical to the helmet performance assessment.

It is the authors' opinion that, despite the associated reduction in absolute accuracy associated with the back calculation tool, the method supports the intended purpose of improving helmet performance, providing it is clearly stated that the performance of the helmet is assessed based on two test conditions, from which indicative performance at other speeds is estimated. It was not possible to fully evaluate the accuracy of the back calculation method as this would require tests at each of the speeds for which predictions of performance were made. However, the results indicate that the prediction method requires further research to understand the implications of potential deviations between predicted and actual helmet performance and to quantify these prior to the implementation of a consumer information scheme that incorporates a prediction of helmet performance.

The back calculation tool is less accurate for some helmet, site and anvil combinations due to an increased rate dependency that may be a consequence of the helmet features e.g. increased mass or ‘poor’ fit. Within this project it was not been possible to identify the factors most likely to introduce error in the back correlation estimates, or the consequence this may have to the overall assessment rating. Such an exercise would reveal whether the influence is significant and whether the rating of helmets would be unfair or compromised in some circumstances. Section 3.8 does however indicate that the final assessment in terms of estimated lives lost, varies within a helmet model by as much as 13 lives and this variation may be indicative of the maximum error that should be allowable due to back calculation inaccuracy.

3.8 Comparison of helmet performance using revised (8.5m/s) assessment protocol

The DfT project SO232/VF established test and assessment protocols that enable the performance of helmets to be compared using a theoretical measure of fatalities. This is based on UK accident statistics and is reliant on an understanding of both accident and injury mechanisms detailed by a large European study, COST 327 (Chinn *et al*., 2003). The test protocols were based on flat and kerb anvil linear impact tests with a maximum test speed of 9.5m/s. These tests were considered to be adequate to demonstrate the capacity of an improved safety prototype helmet developed in an earlier TRL study, S100L (Improved motorcycle helmet design). Since the tests completed in this study are not aligned with the 9.5m/s test proposed by Mellor *et al*., (2007), the test and assessment protocol from the SO232/VF (Motorcyclists’ Helmets and Visors - Test Methods and New Technologies) project could not therefore be applied to helmet test data obtained here. For this reason, the original assessment protocol was modified to allow an assessment of helmet at the chosen test speed of 8.5m/s. It is accepted that the modified protocol does not necessarily provide an assessment of the full range of protection offered by the helmet, but will allow an objective assessment of the helmet performance, based on impacts up to 8.5m/s.

The 8.5m/s test speed was incompatible with the original protocol proposed by SO232/VF, and a higher number of injury severity groups were therefore introduced. This change improves the sensitivity of the protocol to differences in helmet performance across the speed range. The principles of the original and modified protocol remain unchanged and data at 9.5m/s would be expected to give estimates of fatalities close to that achieved by using the 8.5m/s protocol. Subtle differences in the final scores would reflect the increased resolution with the modified protocol.

The modified protocol has been applied to the range of five helmet models tested here. Since three models were repeat tested these were treated as unique models within the protocol. The results are summarised in Table 7 below;

Table 7. Summary of helmet assessment to 6m/s and 8.5m/s test protocol

Helmet	Estimated fatalities†	Lives saved (Relative to helmet 2‡)	Ranking
1	116	47	1
2a	162	1	7
2b	163	0	8
3	120	43	2
4a	126	37	=4
4b	123	40	3
5a	126	37	=4
5b	139	24	6
Average / Range (helmet 2)	163 / ±0.5	0	n/a
Average / Range (helmet 4)	125 / ±1.5	38	n/a
Average /Range (helmet 5)	133 / ±6.5	30	n/a

† An assessment made using test and assessment protocols which characterise helmet performance up to 8.5m/s and relate the helmet performance to reported accident and injury mechanisms and UK motorcyclist casualty statistics. The numbers of fatalities assumes that the entire motorcyclist population will wear a helmet that performs in the same way as the test helmet.

‡ Lives saved is a measure of the estimated fatalities numbers relative to a baseline performance. In this case, the chosen baseline is the worst performing helmet tested (Helmet 2) and does not necessarily represent the actual saving compared to current motorcycle helmets.

Table 7 shows helmet performance quoted in terms of an estimated number of fatalities. This has been calculated using test and assessment protocols which characterise helmet performance up to 8.5m/s. The fatalities are those which are predicted if all helmets worn performed in the same way as the test helmet. The performance is based on peak acceleration measurements for linear impacts at 6.0m/s and 8.5m/s onto flat and kerb anvils and friction measurements for oblique abrasive impacts at 8.5m/s. This theoretical measure is based on UK accident statistics and accident and injury mechanisms detailed by a large European study, COST 327 (Chinn *et al.*, 2003). Based on these results it can be concluded that there is a spread of results equating to a potential life saving of up to 47 lives. However, it cannot be assumed that the helmets tested here are representative of the full range of all helmet performance on the market and this does not therefore represent actual life savings but an indication of potential benefits of one helmet model over another.

It is accepted that the analysis is based on a protocol which does not quantify helmet performance above 8.5m/s. SO232/VF indicates that above this speed there is potential for further life saving and this may theoretically exceed 47 lives. Further testing and analysis would be necessary to investigate whether this rating protocol would be misleading for helmets which offered performance above this speed. However, the differences are assumed to be small between UN ECE Regulation 22.05 helmets since the assumed number of casualties exposed to this speed is small and the helmet performance of current helmets is not expected to differ significantly when compared to advanced helmets such as those developed in the S100L project and Motorsports helmet technology.

Of those helmets which were retested, Helmet 2 had the lowest discrepancy between results of just ±0.5 lives (difference of 1 life) whereas Helmet 5 has a greater range of ±6.5 lives (a total difference of 13 lives). Helmet 4 had a range of ±1.5 lives (difference of 3 lives). This is indicative that helmet 2 and 3 are more repeatable than helmet 5, and this is supported by some evidence in this report. The results show that for these helmets tested, the maximum range of the predicted number of fatalities is ± 6.5 lives. This variation could be significant as it represented 28% (13 out of 47 lives) of the overall performance range, and has the potential to influence representative discrimination of helmet performance.

It should be noted that only one side impact test result was used for this analysis. The right-hand side was the first impact made and was therefore assumed to be the most reliable as there is less potential for coincidental damage during preceding test. A repeat test would not be required during a full evaluation with the proposed protocol.

4 Conclusions

The conclusions of this study can be summarised as follows:

- For consecutive tests with identical conditions, the maximum error between MEP tests used to calibrate the test equipment was less than 5g and below 2% of the average peak-acceleration result. This indicates good repeatability in the data acquisition equipment and test apparatus for consecutive tests. The least repeatable MEP test was made at a drop height of 0.4m (2.8m/s) onto the side of the headform. This demonstrates that test configuration and in particular impact energy and geometry (orientation) of the headform may influence MEP test results.
- Based on the helmets tested and the revised 8.5m/s assessment protocol, there was a large spread in the calculated helmet performance in terms of estimated fatalities. This equated to a potential life saving of up to 47 lives for the best performing helmet when compared with the worst. The assessment assumes that the entire motorcyclist population will use a helmet that performs in the same way as the test helmet. It cannot be assumed that the helmets tested here are representative of the full range of all helmet performance on the market and this life saving does not therefore represent actual life savings in the real world, but instead an indication of the possible benefits of one helmet over another. Some of the helmets underwent repeat tests and of these, Helmet 2 had the lowest variation between results of just ±0.5 lives (difference of 1 life) whereas Helmet 5 had a greater range of ±6.5 lives (a total difference of 13 lives). Helmet 4 had a range of ±1.5 lives (difference of 3 lives).
- It was generally concluded that the assessment methodology was repeatable. Specific reasons for the larger discrepancy for helmet 5 (±6.5 lives) could not be determined with certainty. This variation could be significant as it represented 28% of the overall performance range and has the potential to influence representative discrimination of helmet performance.
- The FMVSS 218 test validity ratio, which relates to normal and transverse headform motions during linear impact tests, ranged between 0.6% and 9.2% for all MEP impact tests. The maximum exceeds the 5% target set by the FMVSS 218 standard which uses a monorail guide system. The less rigid support of the twin-wire system compared to a monorail guide may account for this difference.
- The crown site was found to be responsible for nine of the highest ten validity ratios for MEP tests despite only accounting for 17% of the MEP tests completed. The headform geometry and consequential misalignment between the centre of gravity and the impact site would best explain this.
- The validity ratio is sensitive to the period over which it is calculated. The authors believe that the end time should represent the time at which the motion in the free-fall direction has ended i.e. $T_{v=0}$ and where the displacement is maximum.
- The maximum validity ratio for all helmet tests was 17.5% (based on $T_{v=0}$) and the average result was 7.8%. This exceeds a 5% target level of FMVSS 218 and, somewhat predictably, the levels recorded during MEP testing. The twin wire tension is again considered to a significant contributory factor.
- The kerb anvil was most likely to be associated with good validity ratios and there is a slight bias towards poor levels on the flat anvil. Poor compatibility between the headform and helmet was a possible cause for the increased levels of translational motion onto the flat anvil. The kerb anvil however appears to provide some stabilisation due to helmet compliance, but this may not be the case for very stiff helmet shells such as those made from carbon fibre composites.

- It is not possible to set a threshold for the validity ratio based on the test work completed here since there was no measure of poor or inappropriate test configuration which could be related to the validity ratio. Although in some cases, data may show signs of significant lateral motion or rotation this cannot necessarily be associated with an invalid test. Further and more detailed analysis of the test results or supplementary test work with additional high speed video or instrumentation may provide greater insight. In the absence of this data it seems appropriate that the validity ratio be set as 17.5%, the maximum recorded here.
- The average difference between repeat tests with the same helmet on the left and right impact sites was 32.6g (average peak acceleration of 254.8g). An average difference of only 4.4g was noted for 6.0m/s tests alone with the maximum 11.6g (155.7g average peak acceleration). The maximum difference observed between left and right sites was 196.9g with peak acceleration results of 262.9g and 459.8g for tests at 8.5m/s onto a kerb anvil (helmet 5A). This was an exceptional result and indicative that the differences may be exaggerated when the helmet is close to its full energy absorbing capacity. Factors such as the sensitivity of the helmet to deviations from the target impact sites, may influence the helmet performance. Excluding those anomalous impacts where a helmet may have bottomed out, the average difference between all left and right impacts was a respectable 12.6g and 5.4% of the 234g average peak acceleration This shows that the test can be very repeatable and close to 5%.
- The average difference between all repeat linear impact tests (excluding side impacts) was 9.4g (11.8g for 8.5m/s and 7.1g for 6.0m/s impacts only) indicating that in general the repeatability was very good. The maximum difference between equivalent tests with both similar impact conditions and helmet model was 39.4g for a kerb test at 8.5m/s onto the rear of the helmet. The conformity of production between similar helmets could not be verified but fit and deterioration of the test helmet between tests was unlikely to be a major contributory factor to differences between identical tests. Since the third, fourth and fifth highest differences for 8.5m/s tests (20.2g to 11.4g) were also onto kerb anvils; this suggests that the kerb anvil may be particularly prone to inconsistency of test set-up. A possible explanation is that the smaller contact area between the anvil and helmet may exaggerate any deviation from the intended impact site. It was not possible to quantify this further without sensitivity tests with known and closely controlled tolerances.
- The coefficient of friction measurement using oblique anvil tests was very repeatable and within 5% when the impact sites were closely controlled and accurately struck. The measurement was, however, influenced by site selection and in particular by raised profiles on the helmet surface, which tended to cause underestimation of the true coefficient values. Tests were more repeatable when there was no existing helmet damage. Tangential and normal forces were less reliable predictors, but were found to have a good correlation between one another.
- UN ECE Regulation 22.05 requires that helmets do not exceed a peak acceleration of 275g. Test results at this level are indicative that the helmet is close to ’bottoming out’ and little additional energy absorbing capacity is available. For eighty tests completed at 8.5m/s the peak acceleration was =275g in almost 1 in 3 cases (26 cases, 32.5%). Of fifteen tests completed at 9.5m/s (onto flat anvil only) the peak acceleration was =275g in two thirds (66.7%) of cases (excluding repeat tests onto the side impact sites). In 6 out of 11 impact tests at 9.5m/s, the peak acceleration was 275g or more but achieved less than 275g during an equivalent test at 8.5m/s. This confirms a predictable tendency for helmets to bottom out at higher speed.
- The side test site accounted for almost 1 in 4 (22.7%) of impacts at 8.5m/s where the peak acceleration was =275g. This signifies that there may be reduced protection at the side of the helmet.

- At 8.5m/s, eight out of the ten highest peak accelerations were recorded for tests onto a kerb anvil. Although there may be some bias due to the increased number of side impacts included in this dataset, this indicates that the kerb anvil may also be most likely to exceed the helmet's energy-absorbing capacity.
- For similar test conditions onto a flat anvil at 8.5m/s and 9.5m/s, four impacts (out of 15) resulted in less than 275g for both tests. This shows that, in some helmet and test configurations, the helmet has potential to provide additional energy absorption and enhanced levels of safety above 9.5m/s. To ensure compatibility with the assessment protocols it would be appropriate to continue testing at higher speeds until the peak acceleration exceeds 500g, a level which the assessment protocol aligns with a 100% risk of fatal injury.
- The SO232/VF and revised (8.5m/s) assessment protocol relies on the back calculation of peak acceleration across a speed range using data from a higher speed test. Based on data from 30 impact tests, a statistically significant ($P<0.05$) correlation of 0.78 ($r^2=0.61$) was observed between 8.5m/s acceleration data predicted from 9.5m/s test results and actual peak accelerations measured in 8.5m/s tests. However, improved predictions were possible when tests onto the side which exceeded 400g were excluded. These tests were thought to be unreliable due to lack of repeatability on this site for high speed tests. Based on a reduced set of 24 test samples, a statistically significant ($P<0.05$) correlation coefficient of $r=0.88$ was noted ($r^2=0.77$). Here, the relationship between actual and predicted acceleration was almost 1:1, with an offset of about 4g. It is estimated that the error of this method is close to 3% over this range.
- The prediction of 6.0m/s peak acceleration using 8.5m/s test data was less reliable than that between 9.5m/s and 8.5m/s. Although the protocol does not require estimation of 6.0m/s data in this way, the prediction tool is generally inaccurate when predicting data over a large speed range. Although this justifies the use of a low speed test in the test protocol, a higher number of specified test speeds would further improve the resolution and accuracy of test data across the speed range. Increasing the lower test speed from 6.0m/s to 7.0m/s could improve the accuracy of the most critical assessment data in a cost effective manner.
- It is the authors' opinion that, despite the associated reduction in absolute accuracy associated with the back calculation tool, the method supports the intended purpose of improving helmet performance, providing it is clearly stated that the performance of the helmet is assessed based on two test conditions, from which indicative performance at other speeds is estimated. It was not possible to fully evaluate the accuracy of the back calculation method as this would require tests at each of the speeds for which predictions of performance were made. However, the results indicate that the prediction method requires further research to understand the implications of potential deviations between predicted and actual helmet performance and to quantify these prior to the implementation of a consumer information scheme that incorporates performance assessment using predicted test values.
- The modified assessment protocol has been used to estimate the number of fatalities for the range of helmets tested. The protocol uses similar principles to those proposed in SO232/VF and allows a comparative assessment of helmet performance up to the speed of 8.5m/s. The potential for helmets that perform well above 8.5m/s to be given a rating unrepresentative of the full level of protection offered by the helmet was not assessed here. However, the differences between current helmets above 8.5m/s is assumed to be small when compared to advanced helmet technology and will therefore influence only a relatively small number of casualties at this impact severity.

5 Recommendations

- At least three MEP impact calibration tests (to achieve approximately 300g) should be used to ensure that the repeatability of the test apparatus, including the data acquisition equipment, is within 2% of the average result for each test site. The frequency of these tests is dependent on the size of the test programme.
- There is potential for variation in assessed helmet performance due to variation in helmet/ headform fit; this is difficult to control objectively. In addition, some parameters have not been assessed here, e.g. influence of twin wire tension. The influence of such variables should ideally be minimised, although it is recommended that wire tension should be as high as practically possible.
- The pre-conditioning requirements of an MEP should be established prior to use as a calibration tool. The use of an MEP may be particularly suitable for cross-laboratory calibration.
- In a full consumer assessment scheme, it is the authors' view that any removable features should remain on the helmet such that it is tested as it would be worn. Features that may exacerbate rotation or cause helmet instability should be avoided or eliminated by use of a validity ratio threshold. In this case, definition of the test site could be left to the discretion of the testing laboratory, with guidelines that the test site is as close to the UN ECE Regulation 22.05 site where possible. The test anvil should also meet the requirements of this standard to prevent inappropriate helmet loading.
- Each helmet should be tested up to its full capacity (>500g) in order to assess the entire range of protection offered by the helmet.
- The accuracy and reliability of the back calculation predictive method requires further research through testing at each of the speeds for which predictions are made. If this approach is not appropriate, physical testing at each impact speed may be required to provide an assessment of performance across an impact speed range.
- The back calculation tool is subject to the accuracy of the test on which it is based and may be lower for a greater test and prediction speed differential. An acceptable separation should be determined through further testing
- Oblique tests have been shown to be more repeatable when tests are completed on undamaged helmets. Damage should be minimised between repeat tests. A subjective evaluation on the appropriateness of continuing to perform additional tests on damaged helmets should also be made.

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Appendix A: Summary of test results

A1. GENERAL

Graphical results are presented in Appendix B.

A2. LINEAR TEST RESULTS

A2-1, Helmet 1 linear impact test summary

Test ref #	Part #	Site	Anvil	Velocity [m/s] (target)	Velocity [m/s] (actual)	Energy [J]	Peak acc. [g]	Displacement [mm]	HIC	Validity ratio $T_{V=0}$	Validity ratio T_{Peakg}
19lz07	1b	Crown	Flat	6.0	6.1	87	137.5	28.2	857.2	9.64%	9.86%
12lz01	1b	Front	Flat	6.0	6.0	85	149.0	26.2	807.9	6.24%	4.35%
20lz29	1b	Rear	Flat	6.0	6.0	85	167.3	25.1	1151.0	9.66%	9.52%
18lz07	1b	Side (L)	Flat	6.0	6.0	85	162.4	24.6	1025.8	9.68%	8.20%
15lz08	1b	Side (R)	Flat	6.0	6.0	86	164.5	24.3	1020.0	9.90%	6.56%
19lz08	1c	Crown	Kerb	6.0	6.1	88	120.9	30.0	730.5	8.63%	12.31%
12lz09	1c	Front	Kerb	6.0	6.1	87	130.2	28.6	768.2	8.49%	6.68%
20lz30	1c	Rear	Kerb	6.0	6.0	84	141.2	25.3	980.8	11.24%	11.75%
18lz08	1c	Side (L)	Kerb	6.0	6.1	86	140.6	26.2	825.7	10.36%	6.29%
15lz09	1c	Side (R)	Kerb	6.0	6.0	85	129.0	25.9	712.5	11.14%	6.75%
19lz11	1d	Crown	Flat	8.5	8.7	177	240.6	39.5	2496.7	9.21%	9.58%
13lz07	1d	Front	Flat	8.5	8.5	170	236.5	36.4	2086.4	5.25%	4.06%
20lz31	1d	Rear	Flat	8.5	8.5	170	249.0	33.8	2679.3	9.14%	8.48%
18lz09	1d	Side (L)	Flat	8.5	8.4	167	267.1	32.5	2757.1	10.68%	9.60%
15lz10	1d	Side (R)	Flat	8.5	8.5	169	250.5	32.1	2618.7	8.83%	7.69%
19lz10	1a	Crown	Kerb	8.5	8.8	183	189.4	46.1	1613.0	7.84%	13.56%
13lz15	1e	Front	Kerb	8.5	8.5	172	211.8	41.2	1799.9	3.40%	2.72%
20lz32	1e	Rear	Kerb	8.5	8.5	170	193.4	36.6	2056.1	13.61%	15.08%
18lz10	1e	Side (L)	Kerb	8.5	8.5	168	228.2	36.7	2132.0	11.05%	9.84%
15lz11	1e	Side (R)	Kerb	8.5	8.5	168	196.0	35.5	1856.8	7.42%	4.30%

A2-2, Helmet 2(A) linear impact test summary

Test ref #	Part #	Site	Anvil	Velocity		Energy	Peak acc.	Displacement	HIC	Validity ratio	
				[m/s] (target)	[m/s] (actual)	[J]	[g]	[mm]		$T_{V=0}$	T_{Peakg}
19lz21	2b	Crown	Flat	6.0	6.0	85	178.5	24.2	896.3	13.36%	13.88%
12lz02	2b	Front	Flat	6.0	6.1	86	165.5	23.7	1072.5	10.50%	8.67%
20lz16	2b	Rear	Flat	6.0	6.0	85	188.4	22.5	1360.9	10.66%	9.86%
18lz24	2b	Side (L)	Flat	6.0	5.9	83	182.0	22.5	1214.3	8.95%	7.39%
15lz12	2b	Side (R)	Flat	6.0	5.8	80	188.3	21.0	1271.0	9.66%	7.81%
19lz25	2c	Crown	Kerb	6.0	6.0	86	142.9	24.8	889.5	11.61%	19.77%
12lz10	2c	Front	Kerb	6.0	6.0	84	127.9	27.5	766.2	10.29%	8.21%
20lz18	2c	Rear	Kerb	6.0	6.0	85	144.6	23.4	913.8	9.55%	2.42%
18lz26	2c	Side (L)	Kerb	6.0	6.0	85	178.1	23.2	1124.6	5.73%	3.75%
15lz13	2c	Side (R)	Kerb	6.0	6.0	84	183.2	21.4	1260.4	3.64%	4.79%
19lz23	2d	Crown	Flat	8.5	8.6	172	269.1	32.0	2652.9	11.24%	12.14%
13lz08	2d	Front	Flat	8.5	8.5	169	260.5	30.6	2752.3	14.20%	12.25%
20lz20	2d	Rear	Flat	8.5	8.5	171	270.1	31.3	2956.6	9.99%	9.30%
18lz28	2d	Side (L)	Flat	8.5	8.5	169	314.1	27.4	3567.4	9.33%	8.61%
15lz14	2d	Side (R)	Flat	8.5	8.5	172	328.1	26.9	3651.9	7.46%	6.74%
19lz27	2e	Crown	Kerb	8.5	8.6	172	201.8	40.8	1434.1	10.40%	10.90%
13lz16	2e	Front	Kerb	8.5	8.5	170	254.8	33.3	2144.3	4.85%	3.81%
20lz22	2e	Rear	Kerb	8.5	8.5	171	201.1	35.5	1870.4	7.23%	8.38%
18lz30	2e	Side (L)	Kerb	8.5	8.5	168	266.6	30.5	2651.7	8.96%	8.86%
15lz15	2e	Side (R)	Kerb	8.5	8.6	173	251.5	29.0	2704.3	3.32%	3.89%
19lz33	2a	Crown	Flat	9.5	9.5	213	292.7	39.0	3772.4	11.83%	11.64%
13lz24	2a	Front	Flat	9.5	9.5	214	386.1	33.6	4603.7	6.28%	5.99%
20lz24	2a	Rear	Flat	9.5	9.5	214	307.4	33.5	3800.1	10.82%	8.76%
18lz32	2a	Side (L)	Flat	9.5	9.4	207	766.8	30.4	9551.5	7.09%	6.63%
15lz20	2a	Side (R)	Flat	9.5	9.5	214	508.3	29.3	5694.7	11.15%	10.96%

A2-3, Helmet 2(B) linear impact test summary

Test ref #	Part #	Site	Anvil	Velocity		Energy	Peak acc.	Displacement	HIC	Validity ratio	
				[m/s] (target)	[m/s] (actual)	[J]	[g]	[mm]		$T_{V=0}$	T_{Peakg}
19lz22	2f	Crown	Flat	6.0	6.0	84	172.1	24.5	955.9	12.91%	13.51%
12lz03	2f	Front	Flat	6.0	6.0	85	168.9	22.9	1101.4	11.52%	9.88%
20lz17	2f	Rear	Flat	6.0	6.0	86	194.8	22.6	1453.0	9.47%	8.69%
18lz25	2f	Side (L)	Flat	6.0	6.0	86	184.4	22.8	1286.8	10.31%	10.11%
15lz16	2f	Side (R)	Flat	6.0	6.0	85	192.7	21.9	1240.3	9.40%	7.52%
19lz26	2g	Crown	Kerb	6.0	6.0	84	135.6	23.9	711.9	11.31%	17.57%
13lz01	2g	Front	Kerb	6.0	6.0	86	124.9	29.1	739.7	10.20%	7.27%
20lz19	2g	Rear	Kerb	6.0	6.0	86	141.3	24.2	886.0	6.19%	7.92%
18lz27	2g	Side (L)	Kerb	6.0	6.0	84	172.5	22.7	1052.3	3.91%	1.70%
15lz17	2g	Side (R)	Kerb	6.0	6.0	85	168.7	22.1	1083.1	6.00%	6.30%
19lz24	2h	Crown	Flat	8.5	8.6	173	260.2	34.9	2658.5	10.97%	11.26%
13lz09	2h	Front	Flat	8.5	8.5	170	269.6	31.3	2796.6	11.80%	10.35%
20lz21	2h	Rear	Flat	8.5	8.5	171	267.7	30.8	3091.9	11.97%	11.65%
18lz29	2h	Side (L)	Flat	8.5	8.5	168	296.0	28.5	3329.3	11.13%	10.02%
15lz18	2h	Side (R)	Flat	8.5	8.6	172	337.1	27.9	3600.3	7.89%	7.79%
19lz28	2i	Crown	Kerb	8.5	8.6	172	192.4	43.9	1484.0	12.38%	11.46%
13lz17	2i	Front	Kerb	8.5	8.6	172	236.3	35.1	2341.5	11.27%	10.76%
20lz23	2i	Rear	Kerb	8.5	8.6	172	240.5	38.7	2148.7	7.87%	8.31%
18lz31	2i	Side (L)	Kerb	8.5	8.5	168	361.3	30.7	3136.8	9.76%	8.36%
15lz19	2i	Side (R)	Kerb	8.5	8.5	170	394.7	30.3	3064.0	4.60%	3.73%

A2-4, Helmet 3 linear impact test summary

Test ref #	Part #	Site	Anvil	Velocity		Energy	Peak acc.	Displacement	HIC	Validity ratio	
				[m/s] (target)	[m/s] (actual)	[J]	[g]	[mm]		$T_{V=0}$	T_{Peakg}
19lz29	3b	Crown	Flat	6.0	6.0	85	121.4	31.7	628.2	11.22%	9.75%
12lz04	3b	Front	Flat	6.0	6.1	88	152.8	27.0	962.5	9.58%	7.87%
20lz25	3b	Rear	Flat	6.0	6.0	85	135.3	28.6	850.5	9.98%	9.75%
18lz20	3b	Side (L)	Flat	6.0	6.0	85	168.1	25.2	1071.9	12.37%	11.10%
15lz21	3b	Side (R)	Flat	6.0	6.1	86	167.4	26.1	1082.5	9.49%	8.34%
19lz30	3c	Crown	Kerb	6.0	6.0	86	108.7	34.2	525.4	14.33%	14.37%
13lz02	3c	Front	Kerb	6.0	6.0	86	117.7	29.6	698.1	6.68%	2.93%
20lz26	3c	Rear	Kerb	6.0	6.0	86	106.5	29.3	677.6	9.55%	7.13%
18lz21	3c	Side (L)	Kerb	6.0	6.0	85	133.2	28.5	754.6	8.49%	7.41%
15lz22	3c	Side (R)	Kerb	6.0	6.1	86	131.9	28.8	746.4	8.74%	7.26%
19lz31	3d	Crown	Flat	8.5	8.5	172	207.9	42.3	1945.3	10.53%	11.89%
13lz10	3d	Front	Flat	8.5	8.5	171	248.3	38.0	2258.4	9.83%	9.41%
20lz27	3d	Rear	Flat	8.5	8.6	172	211.7	37.0	1754.6	8.34%	7.38%
18lz22	3d	Side (L)	Flat	8.5	8.5	170	289.3	33.9	2821.9	9.89%	8.91%
15lz23	3d	Side (R)	Flat	8.5	8.5	169	281.4	32.8	2898.2	11.59%	11.45%
19lz32	3e	Crown	Kerb	8.5	8.5	172	154.7	49.5	1255.4	13.34%	9.83%
13lz18	3e	Front	Kerb	8.5	8.6	172	307.2	41.1	2428.2	4.18%	4.52%
20lz28	3e	Rear	Kerb	8.5	8.5	171	201.4	39.6	1756.6	6.82%	7.60%
18lz23	3e	Side (L)	Kerb	8.5	8.5	171	552.2	38.2	5420.2	8.81%	7.75%
15lz24	3e	Side (R)	Kerb	8.5	8.6	174	576.1	36.2	5898.9	7.40%	6.54%

A2-5, Helmet 4(A) linear impact test summary

Test ref #	Part #	Site	Anvil	Velocity		Energy	Peak acc.	Displacement	HIC	Validity ratio	
				[m/s] (target)	[m/s] (actual)	[J]	[g]	[mm]		$T_{V=0}$	T_{Peakg}
19lz12	4b	Crown	Flat	6.0	6.1	86	137.1	31.2	725.6	10.30%	10.61%
12lz05	4b	Front	Flat	6.0	6.1	86	132.9	28.5	834.8	11.23%	10.80%
20lz33	4b	Rear	Flat	6.0	6.0	85	140.7	26.6	817.3	10.58%	10.79%
18lz33	4b	Side (L)	Flat	6.0	5.9	83	158.7	24.8	1039.0	15.45%	15.03%
15lz25	4b	Side (R)	Flat	6.0	6.0	85	161.6	24.9	1062.8	16.53%	16.25%
19lz14	4c	Crown	Kerb	6.0	6.0	86	125.3	34.7	531.7	14.79%	1.40%
13lz03	4c	Front	Kerb	6.0	6.1	86	132.6	28.3	774.7	9.49%	8.73%
20lz35	4c	Rear	Kerb	6.0	6.0	85	114.5	29.6	678.2	8.76%	7.57%
18lz35	4c	Side (L)	Kerb	6.0	6.1	86	122.5	30.2	711.1	10.18%	11.03%
15lz27	4c	Side (R)	Kerb	6.0	6.1	86	125.2	29.7	745.9	11.97%	12.97%
19lz16	4d	Crown	Flat	8.5	8.6	172	209.2	39.5	2170.0	11.57%	13.26%
13lz11	4d	Front	Flat	8.5	8.5	171	284.6	38.0	2534.3	5.56%	6.16%
20lz37	4d	Rear	Flat	8.5	8.5	170	226.4	35.4	2183.6	9.76%	9.70%
18lz37	4d	Side (L)	Flat	8.5	8.6	172	280.0	34.1	2843.1	12.27%	11.34%
15lz29	4d	Side (R)	Flat	8.5	8.6	172	310.0	32.9	3094.2	10.22%	10.42%
19lz18	4e	Crown	Kerb	8.5	8.6	173	175.7	50.6	1461.1	9.90%	6.36%
13lz19	4e	Front	Kerb	8.5	8.6	173	280.7	42.2	2212.7	3.70%	3.58%
20lz39	4e	Rear	Kerb	8.5	8.5	170	179.6	39.8	1637.2	7.22%	8.01%
18lz39	4e	Side (L)	Kerb	8.5	8.5	171	573.9	36.7	5512.6	9.11%	8.19%
15lz31	4e	Side (R)	Kerb	8.5	8.5	169	424.2	37.1	3305.8	3.52%	3.80%
19lz20	4a	Crown	Flat	9.5	9.5	213	242.9	43.8	2765.0	8.05%	8.78%
13lz25	4a	Front	Flat	9.5	9.6	215	429.5	42.5	4335.9	5.13%	5.78%
20lz41	4a	Rear	Flat	9.5	9.5	210	265.2	40.7	2738.6	9.35%	7.12%
18lz41	4a	Side (L)	Flat	9.5	9.5	212	378.1	36.3	4167.1	7.40%	7.61%
15lz33	4a	Side (R)	Flat	9.5	9.5	213	288.6	35.6	3486.8	16.75%	16.64%

A2-6, Helmet 4(B) linear impact test summary

Test ref #	Part #	Site	Anvil	Velocity		Energy	Peak acc.	Displacement	HIC	Validity ratio	
				[m/s] (target)	[m/s] (actual)	[J]	[g]	[mm]		$T_{V=0}$	T_{Peakg}
19lz13	4f	Crown	Flat	6.0	6.1	86	136.3	31.5	713.1	11.32%	11.96%
12lz06	4f	Front	Flat	6.0	6.1	86	147.6	27.9	919.7	9.90%	7.94%
20lz34	4f	Rear	Flat	6.0	6.0	85	137.5	27.9	808.6	9.53%	9.58%
18lz34	4f	Side (L)	Flat	6.0	6.0	84	162.0	23.8	1089.1	17.48%	16.63%
15lz26	4f	Side (R)	Flat	6.0	6.0	86	164.8	25.0	1111.3	16.18%	15.91%
19lz15	4g	Crown	Kerb	6.0	6.0	86	129.3	35.5	540.1	10.08%	2.57%
13lz04	4g	Front	Kerb	6.0	6.1	87	143.4	24.2	900.9	9.22%	9.56%
20lz36	4g	Rear	Kerb	6.0	6.0	84	113.3	29.4	694.6	10.07%	9.37%
18lz36	4g	Side (L)	Kerb	6.0	6.0	86	122.1	29.4	744.4	10.61%	11.27%
15lz28	4g	Side (R)	Kerb	6.0	6.0	85	122.9	28.2	732.5	9.18%	9.06%
19lz17	4h	Crown	Flat	8.5	8.6	172	196.9	39.3	2104.7	11.60%	12.88%
13lz12	4h	Front	Flat	8.5	8.5	169	248.2	39.6	2203.0	6.85%	7.11%
20lz38	4h	Rear	Flat	8.5	8.5	171	233.9	36.4	2260.4	8.00%	7.45%
18lz38	4h	Side (L)	Flat	8.5	8.5	171	271.2	33.7	2777.4	13.91%	13.24%
15lz30	4h	Side (R)	Flat	8.5	8.5	171	286.2	32.8	2877.2	11.24%	11.36%
19lz19	4i	Crown	Kerb	8.5	8.5	172	164.6	50.3	1320.9	9.58%	10.08%
13lz20	4i	Front	Kerb	8.5	8.5	171	269.3	42.9	2124.2	5.20%	4.60%
20lz40	4i	Rear	Kerb	8.5	8.5	170	199.8	41.7	1732.6	6.35%	5.38%
18lz40	4i	Side (L)	Kerb	8.5	8.5	171	583.7	39.4	6191.4	7.67%	6.92%
15lz32	4i	Side (R)	Kerb	8.5	8.5	170	566.1	35.3	5155.3	4.57%	4.42%

A2-7, Helmet 5(A) linear impact test summary

Test ref #	Part #	Site	Anvil	Velocity		Energy	Peak acc.	Displacement	HIC	Validity ratio	
				[m/s] (target)	[m/s] (actual)	[J]	[g]	[mm]		$T_{V=0}$	T_{Peakg}
19lz34	5b	Crown	Flat	6.0	6.0	85	139.7	26.3	812.8	6.44%	6.45%
12lz07	5b	Front	Flat	6.0	6.1	87	132.7	29.0	831.6	10.75%	9.94%
20lz07	5b	Rear	Flat	6.0	6.0	86	149.9	25.7	998.8	6.65%	6.65%
18lz11	5b	Side (L)	Flat	6.0	6.0	84	156.8	23.7	1012.9	10.36%	8.86%
15lz34	5b	Side (R)	Flat	6.0	6.1	87	163.5	23.9	1063.5	9.79%	8.59%
19lz36	5c	Crown	Kerb	6.0	6.0	85	107.4	34.0	538.4	9.30%	6.36%
13lz05	5c	Front	Kerb	6.0	6.0	86	173.9	23.3	1121.5	12.45%	11.54%
20lz09	5c	Rear	Kerb	6.0	6.0	84	124.7	27.8	753.0	7.77%	5.40%
18lz13	5c	Side (L)	Kerb	6.0	6.0	85	136.6	25.7	889.6	5.48%	3.46%
15lz36	5i	Side (R)	Kerb	6.0	6.1	86	141.4	24.6	927.9	6.12%	5.99%
19lz38	5d	Crown	Flat	8.5	8.5	172	219.7	37.3	2085.5	4.74%	5.05%
13lz13	5d	Front	Flat	8.5	8.5	171	237.2	38.6	2206.8	4.54%	3.25%
20lz11	5d	Rear	Flat	8.5	8.5	172	215.7	35.8	2169.1	6.74%	6.87%
18lz17	5d	Side (L)	Flat	8.5	8.5	170	262.0	33.0	2575.9	12.13%	11.56%
15lz40	5d	Side (R)	Flat	8.5	8.5	170	435.0	30.5	3695.4	6.64%	6.40%
19lz40	5e	Crown	Kerb	8.5	8.5	170	159.8	44.6	1495.5	5.17%	2.60%
13lz21	5e	Front	Kerb	8.5	8.6	172	196.9	40.9	1621.3	10.37%	7.77%
20lz13	5e	Rear	Kerb	8.5	8.6	172	165.1	41.1	1648.3	8.29%	8.43%
18lz15	5e	Side (L)	Kerb	8.5	8.5	169	262.9	34.9	2217.7	12.08%	11.34%
15lz39	5e	Side (R)	Kerb	8.5	8.6	172	459.8	32.2	4398.6	4.64%	3.15%
19lz42	5a	Crown	Flat	9.5	9.5	214	262.5	39.1	3102.3	5.01%	5.53%
13lz23	5a	Front	Flat	9.5	9.4	208	306.5	42.5	3383.4	4.55%	2.89%
20lz15	5a	Rear	Flat	9.5	9.6	215	257.9	40.0	3009.2	5.29%	5.68%
18lz19	5a	Side (L)	Flat	9.5	9.4	209	579.6	34.2	6325.4	9.22%	9.08%
15lz42	5a	Side (R)	Flat	9.5	9.5	211	649.7	32.3	8134.0	3.82%	4.03%

A2-8, Helmet 5(B) linear impact test summary

Test ref #	Part #	Site	Anvil	Velocity		Energy	Peak acc.	Displacement	HIC	Validity ratio	
				[m/s] (target)	[m/s] (actual)	[J]	[g]	[mm]		$T_{V=0}$	T_{Peakg}
19lz35	5f	Crown	Flat	6.0	6.1	87	136.7	28.2	722.9	5.78%	5.83%
12lz08	5f	Front	Flat	6.0	6.0	85	130.8	27.7	823.4	11.63%	10.70%
20lz08	5f	Rear	Flat	6.0	6.0	85	141.8	28.3	933.0	7.20%	6.02%
18lz12	5f	Side (L)	Flat	6.0	6.1	87	158.7	24.2	1054.7	11.67%	10.07%
15lz35	5f	Side (R)	Flat	6.0	6.0	86	164.8	23.9	1064.9	10.68%	9.41%
19lz37	5g	Crown	Kerb	6.0	6.0	85	118.9	29.6	582.4	7.49%	4.99%
13lz06	5g	Front	Kerb	6.0	6.0	86	137.8	27.1	765.3	7.63%	5.23%
20lz10	5g	Rear	Kerb	6.0	6.0	85	123.5	28.2	756.8	8.35%	5.64%
18lz14	5g	Side (L)	Kerb	6.0	6.0	84	135.8	25.1	885.2	6.04%	4.30%
15lz37	5g	Side (R)	Kerb	6.0	6.0	86	139.7	24.7	906.4	5.78%	5.74%
19lz39	5h	Crown	Flat	8.5	8.5	171	222.7	35.8	2230.8	3.62%	3.87%
13lz14	5h	Front	Flat	8.5	8.5	170	239.9	37.8	2269.8	5.04%	4.23%
20lz12	5h	Rear	Flat	8.5	8.5	170	205.7	35.6	2115.9	5.91%	6.29%
18lz18	5i	Side (L)	Flat	8.5	8.5	170	282.7	31.8	2740.9	12.81%	12.14%
15lz41	5h	Side (R)	Flat	8.5	8.5	171	455.6	30.4	4229.6	5.33%	5.38%
19lz41	5i	Crown	Kerb	8.5	8.5	169	155.9	44.3	1477.4	5.42%	3.32%
13lz22	5i	Front	Kerb	8.5	8.5	171	202.3	41.3	1791.8	5.60%	2.80%
20lz14	5i	Rear	Kerb	8.5	8.5	172	168.3	40.0	1692.8	5.51%	4.52%
18lz16	5h	Side (L)	Kerb	8.5	8.6	172	322.2	34.4	2548.5	11.09%	9.78%
15lz38	5c	Side (R)	Kerb	8.5	8.5	168	356.7	32.2	2895.1	8.86%	8.17%

A3. OBLIQUE TEST RESULTS

Helmet	Site	Impact Anvil	Test No.	Velocity	Normal force	Tangential force	μ		
							based on peak anvil forces	peak where normal force >0.7 of peak force	average where normal force >0.7 of peak force
				[m/s]	[N]	[N]			
1a	Side R	15º, 80Grit	g01lz	8.51	3101	1677	0.54	0.57	0.51
1a	Side L	15º, 80Grit	h01lz	8.53	2993	1721	0.58	0.66	0.53
2a	Side L	15º, 80Grit	a08lz	8.56	3639	1314	0.36	0.49	0.39
2a	Side R	15º, 80Grit	b08lz	8.57	3251	1242	0.38	0.45	0.39
3a	Side L	15º, 80Grit	d08lz	8.57	3639	1899	0.52	0.61	0.56
3a	Side R	15º, 80Grit	e08lz	8.58	3777	2174	0.58	0.58	0.56
4a	Side L	15º, 80Grit	f08lz	8.58	4041	2353	0.58	0.59	0.56
4a	Side R	15º, 80Grit	h08lz	8.58	4335	2518	0.58	0.58	0.57
5a	Side L	15º, 80Grit	i08lz	8.57	3579	1878	0.52	0.53	0.49
5a	Side R	15º, 80Grit	j08lz	8.59	3294	1629	0.49	0.53	0.49
2a	Side L	15º, 80Grit	k08lz	8.57	2363	1144	0.48	0.55	0.43
2a	Rear	15º, 80Grit	a11lz	8.56	3043	1674	0.55	0.58	0.54
2a	Rear	15º, 80Grit	b11lz	8.55	2152	1035	0.48	0.56	0.49
2a	Rear	15º, 80Grit	c11lz	8.57	2968	1491	0.50	0.53	0.46
5a	Side L	15º, 80Grit	d11lz	8.57	3278	1569	0.48	0.56	0.49
5a	Side R	15º, 80Grit	e11lz	8.54	2917	1462	0.50	0.52	0.48

A4. MEP TEST RESULTS

Test ref #	Site	Velocity [m/s] (target)	Velocity [m/s] (actual)	Energy [J]	Peak acc. [g]	Validity ratio $T_{V=0}$	Validity ratio T_{Peakg}
Calibration 1	Front	4.3	4.3	43.8	300.1	2.47%	1.61%
Calibration 2	Front	4.3	4.3	43.9	293.1	3.32%	2.24%
Calibration 3	Front	4.3	4.3	44.1	292.9	3.75%	2.68%
Calibration 4	Front	4.3	4.3	44.0	291.7	3.26%	2.23%
Calibration 5	Front	4.3	4.3	44.3	291.2	2.94%	1.87%
Calibration 6	Front	4.3	4.3	44.4	289.7	1.74%	0.79%
Calibration 7	Front	3.3	3.3	26.1	200.8	4.21%	3.05%
Calibration 8	Front	3.1	3.1	22.7	182.7	4.45%	3.25%
Calibration 9	Front	2.8	2.8	18.4	157.9	4.96%	3.74%
Calibration 10	Front	2.8	2.8	18.6	158.1	5.32%	4.06%
Calibration 11	Front	2.8	2.8	18.6	158.8	4.28%	3.12%
13lz26	Front	2.8	2.7	16.6	152.4	3.74%	2.85%
13lz27	Front	2.8	2.7	16.5	150.6	3.53%	2.66%
13lz28	Front	2.8	2.6	16.1	150.7	3.02%	2.38%
13lz29	Front	2.8	2.8	18.6	164.0	2.54%	1.94%
13lz30	Front	2.8	2.8	18.8	164.5	2.40%	1.89%
13lz31	Front	2.8	2.8	18.1	162.4	3.85%	2.91%
13lz32	Front	4.3	4.3	43.9	288.1	2.91%	2.17%
13lz33	Front	4.3	4.3	43.7	284.5	1.62%	1.61%
13lz34	Front	4.3	4.3	43.3	289.7	4.11%	3.38%
15lz01	Side (R)	2.8	2.7	17.5	174.3	1.92%	1.64%
15lz02	Side (R)	2.8	2.8	17.8	174.6	1.98%	1.95%
15lz03	Side (R)	2.8	2.7	16.8	175.8	2.64%	1.91%
15lz04	Side (R)	2.8	2.7	17.5	173.9	1.76%	1.03%
15lz05	Side (R)	4.3	4.3	44.3	331.1	2.42%	1.91%
15lz06	Side (R)	4.3	4.4	45.0	331.1	1.39%	1.65%
15lz07	Side (R)	4.3	4.4	44.8	332.4	1.60%	1.90%
15lz43	Side (R)	2.8	2.7	16.9	168.8	1.87%	0.73%
15lz44	Side (R)	2.8	2.7	16.8	168.3	1.43%	0.48%
15lz45	Side (R)	2.8	2.7	16.9	168.2	1.47%	0.64%
15lz46	Side (R)	4.3	4.3	44.1	319.1	0.62%	0.69%
15lz47	Side (R)	4.3	4.3	43.4	321.6	3.72%	2.64%
15lz48	Side (R)	4.3	4.3	44.1	320.6	1.08%	0.07%
18lz01	Side (L)	2.8	2.7	17.6	175.9	5.31%	5.10%
18lz02	Side (L)	2.8	2.8	17.8	175.2	4.98%	4.75%
18lz03	Side (L)	2.8	2.8	17.8	175.8	5.09%	4.98%
18lz04	Side (L)	4.3	4.3	43.5	321.8	5.52%	5.51%
18lz05	Side (L)	4.3	4.3	43.6	320.2	4.75%	4.51%
18lz06	Side (L)	4.3	4.3	43.6	319.0	4.76%	4.17%
18lz42	Side (L)	2.8	2.7	16.7	165.1	3.82%	3.72%
18lz43	Side (L)	2.8	2.7	16.8	166.1	4.10%	3.94%
18lz44	Side (L)	2.8	2.7	16.8	165.9	4.60%	4.51%
18lz45	Side (L)	4.3	4.3	44.4	319.1	4.72%	4.53%

Test ref #	Site	Velocity [m/s]		Energy	Peak acc.	Validity ratio	
		(target)	(actual)	[J]	[g]	$T_{V=0}$	T_{Peakg}
18lz46	Side (L)	4.3	4.4	44.6	319.9	4.95%	4.89%
18lz47	Side (L)	4.3	4.3	44.4	320.7	4.67%	4.46%
19lz01	Crown	2.8	2.7	17.6	165.6	7.17%	6.63%
19lz02	Crown	2.8	2.8	17.8	166.0	6.48%	5.87%
19lz03	Crown	2.8	2.7	17.8	166.4	5.99%	5.38%
19lz04	Crown	4.3	4.3	43.3	314.3	6.91%	6.16%
19lz05	Crown	4.3	4.3	43.7	308.2	9.22%	8.47%
19lz06	Crown	4.3	4.3	43.6	313.0	7.68%	6.90%
19lz43	Crown	2.8	2.7	17.5	165.8	6.17%	5.34%
19lz44	Crown	2.8	2.7	17.7	166.2	5.43%	4.55%
19lz45	Crown	2.8	2.7	17.8	166.2	5.66%	4.76%
19lz46	Crown	4.3	4.4	45.7	324.5	7.27%	6.30%
19lz47	Crown	4.3	4.4	45.6	325.0	6.87%	5.92%
19lz48	Crown	4.3	4.4	45.7	327.4	5.32%	4.52%
20lz01	Rear	2.8	2.8	18.8	162.5	5.69%	4.54%
20lz02	Rear	2.8	2.8	18.8	162.8	5.37%	4.08%
20lz03	Rear	2.8	2.8	18.9	163.1	5.35%	4.13%
20lz04	Rear	4.3	4.4	45.1	304.4	5.85%	4.42%
20lz05	Rear	4.3	4.4	45.6	303.9	3.80%	3.03%
20lz06	Rear	4.3	4.4	45.4	304.3	4.30%	3.38%
20lz42	Rear	2.8	2.7	17.3	160.0	5.54%	4.38%
20lz43	Rear	2.8	2.7	17.1	159.8	5.32%	4.33%
20lz44	Rear	2.8	2.7	17.1	160.0	5.01%	4.12%
20lz45	Rear	4.3	4.4	44.5	303.3	5.28%	4.38%
20lz46	Rear	4.3	4.3	44.2	303.4	4.67%	3.70%
20lz47	Rear	4.3	4.3	44.2	302.0	4.51%	4.15%

Appendix B: Test results

B.1 ASSESSMENT PROTOCOL RESULTS AND GRAPHICAL LINEAR IMPACT RESULTS

The overall rating is an estimate of the number of UK Fatal casualties if all riders were wearing a helmet of this type. This rating has been calculated using the revised assessment protocols which assess helmet performance up to 8.5m/s.

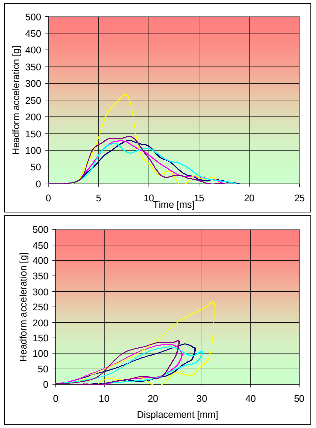
Note – not all helmets were tested at 9.5m/s.

Helmet	**1**
Season	**2006**
Manufacturer	
Model	
Size	**J**
Weight	
Approval	**Reg22.05**

OVERALL RATINGS (FATAL)

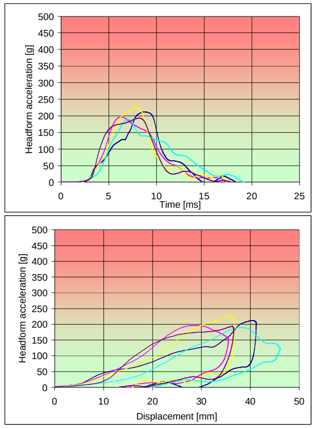
116	Fatal

KERB ANVIL @ 6.0m/s



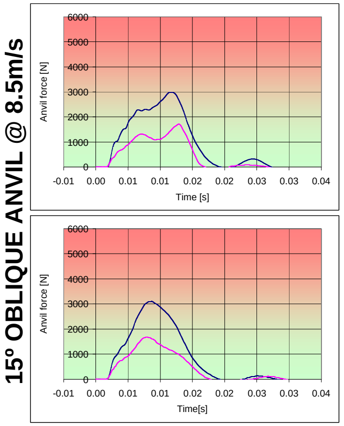
	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	12lz09	130	29	768	8.5%	6.7%
Side R	15lz09	129	26	712	11.1%	6.7%
Side L	18lz09	141	26	826	10.4%	6.3%
Crown	19lz08	121	30	730	8.6%	12.3%
Rear	20lz30	141	25	981	11.2%	11.7%
Side average	n/a	135	n/a	769	n/a	n/a

KERB ANVIL @ 8.5m/s



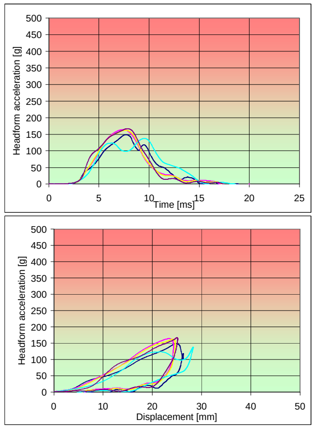
	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz15	212	41	1800	3.4%	2.7%
Side R	15lz11	196	35	1857	7.4%	4.3%
Side L	18lz10	228	37	2132	11.1%	9.8%
Crown	19lz10	189	46	1613	7.8%	13.6%
Rear	20lz32	193	37	2056	13.6%	15.1%
Side average	n/a	212	n/a	1,994	n/a	n/a

15° OBLIQUE ANVIL @ 8.5m/s



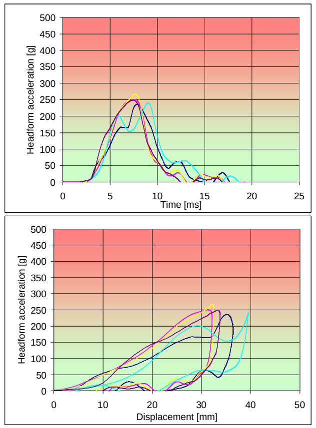
	Filename	µ
Side R	h01lz	0.53
Side L	g01lz	0.51

FLAT ANVIL @6.0m/s



	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	12lz01	149	26	808	6.2%	4.3%
Side R	15lz08	164	24	1020	9.9%	6.6%
Side L	18lz07	162	25	1026	9.7%	8.2%
Crown	19lz07	138	28	857	9.6%	9.9%
Rear	20lz29	167	25	1151	9.7%	9.5%
Side average	n/a	163	n/a	1,023	n/a	n/a

FLAT ANVIL @8.5m/s



	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz07	236	36	2086	5.2%	4.1%
Side R	15lz10	251	32	2619	8.8%	7.7%
Side L	18lz09	267	33	2757	10.7%	9.6%
Crown	19lz11	241	39	2497	9.2%	9.6%
Rear	20lz31	249	34	2679	9.1%	8.5%
Side average	n/a	258.8	n/a	2,688	n/a	n/a

FLAT ANVIL @9.5m/s

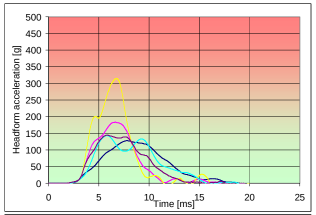
	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	0	0	0	0	0.0%	0.0%
Side R	0	0	0	0	0.0%	0.0%
Side L	0	0	0	0	0.0%	0.0%
Crown	0	0	0	0	0.0%	0.0%
Rear	0	0	0	0	0.0%	0.0%
Side average	n/a	0.0	n/a	0	n/a	n/a

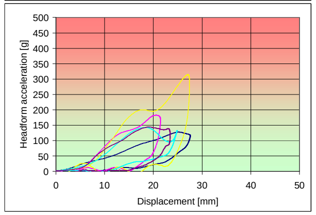
Helmet	**2**
Season	**2006**
Manufacturer	
Model	
Size	**J**
Weight	
Approval	**Reg22.05**

OVERALL RATINGS (FATAL)

162 Fatal

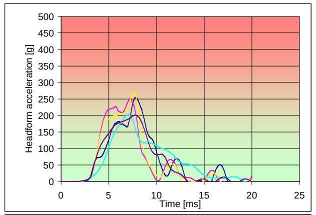
KERB ANVIL @ 6.0m/s

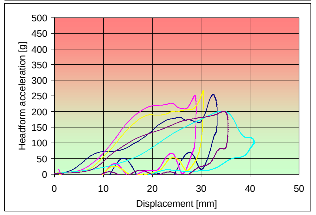




	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	12lz10	128	28	766	10.3%	8.2%
Side R	15lz13	183	21	1260	3.6%	4.8%
Side L	18lz28	178	23	1125	5.7%	3.7%
Crown	19lz25	143	25	890	11.6%	19.8%
Rear	20lz18	145	23	914	9.6%	2.4%
Side average	n/a	181	n/a	1,193	n/a	n/a

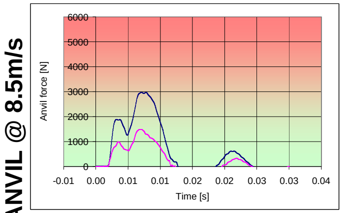
KERB ANVIL @ 8.5m/s

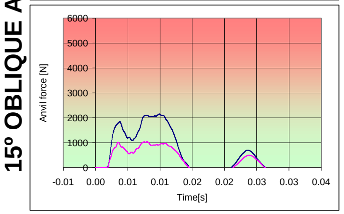




	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz16	255	33	2144	4.8%	3.8%
Side R	15lz15	252	29	2704	3.3%	3.9%
Side L	18lz30	267	30	2652	9.0%	8.9%
Crown	19lz27	202	41	1434	10.4%	10.9%
Rear	20lz22	201	35	1870	7.2%	8.4%
Side average	n/a	259	n/a	2,678	n/a	n/a

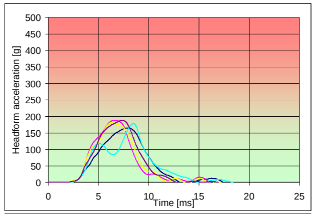
15º OBLIQUE ANVIL @ 8.5m/s

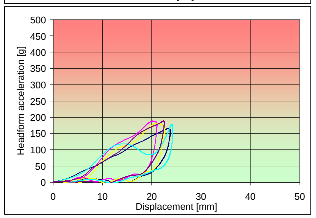




	Filename	µ
Side R	c11lz	0.46
Side L	b11lz	0.49

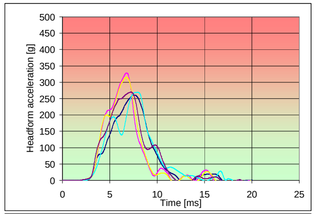
FLAT ANVIL @6.0m/s

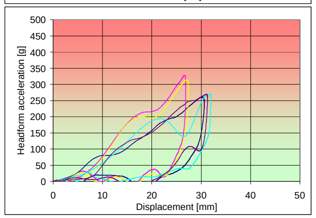




	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	12lz02	165	24	1072	10.5%	8.7%
Side R	15lz12	188	21	1271	9.7%	7.8%
Side L	18lz24	182	23	1214	8.9%	7.4%
Crown	19lz21	179	24	896	13.4%	13.9%
Rear	20lz16	188	22	1361	10.7%	9.9%
Side average	n/a	185	n/a	1,243	n/a	n/a

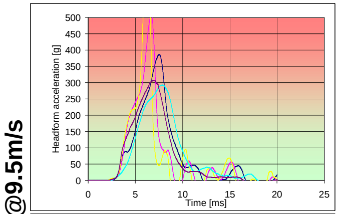
FLAT ANVIL @8.5m/s

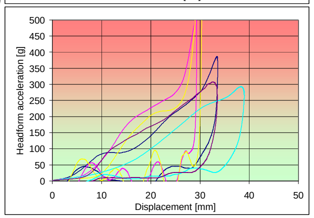




	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz08	261	31	2752	14.2%	12.2%
Side R	15lz14	328	27	3652	7.5%	6.7%
Side L	18lz28	314	27	3567	9.3%	8.6%
Crown	19lz23	269	32	2653	11.2%	12.1%
Rear	20lz20	270	31	2957	10.0%	9.3%
Side average	n/a	321.1	n/a	3,610	n/a	n/a

FLAT ANVIL @9.5m/s





	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz24	386	34	4604	6.3%	6.0%
Side R	15lz20	508	29	5695	11.1%	11.0%
Side L	18lz32	767	30	9551	7.1%	6.6%
Crown	19lz33	293	39	3772	11.8%	11.6%
Rear	20lz24	307	34	3800	10.8%	8.8%
Side average	n/a	637.5	n/a	7,623	n/a	n/a

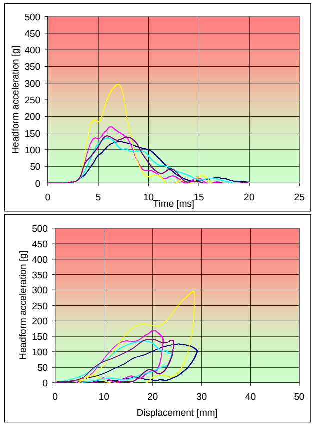
Helmet 2
Season 2006

Manufacturer
Model
Size J
Weight
Approval Reg22.05

OVERALL RATINGS (FATAL)

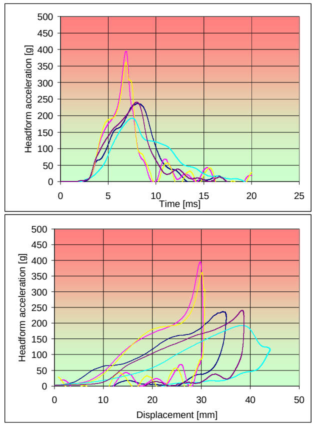
163 Fatal

KERB ANVIL @ 6.0m/s



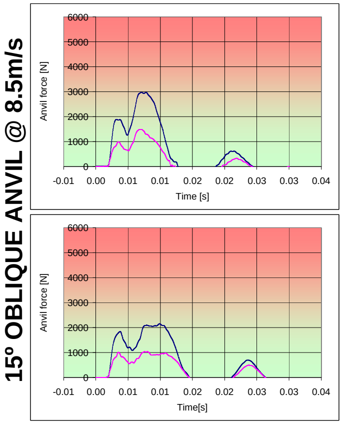
	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz01	125	29	740	10.2%	7.3%
Side R	15lz17	169	22	1083	6.0%	6.3%
Side L	18lz29	173	23	1052	3.9%	1.7%
Crown	19lz26	136	24	712	11.3%	17.6%
Rear	20lz19	141	24	886	6.2%	7.9%
Side average	n/a	171	n/a	1,068	n/a	n/a

KERB ANVIL @ 8.5m/s



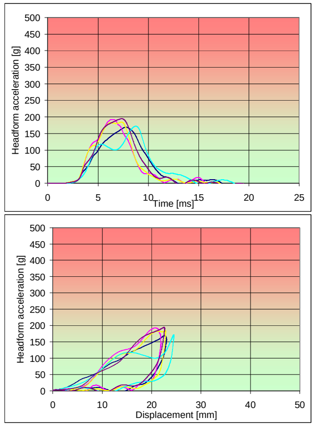
	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz17	236	35	2342	11.3%	10.8%
Side R	15lz19	395	30	3064	4.6%	3.7%
Side L	18lz31	361	31	3137	9.8%	8.4%
Crown	19lz28	192	44	1484	12.4%	11.5%
Rear	20lz23	240	39	2149	7.9%	8.3%
Side average	n/a	378	n/a	3,100	n/a	n/a

15° OBLIQUE ANVIL @ 8.5m/s



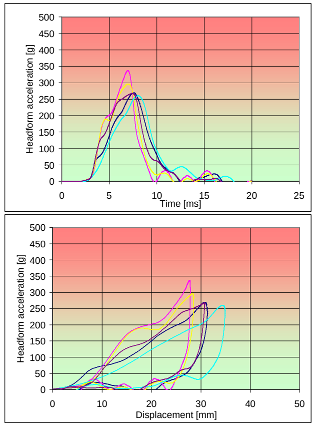
	Filename	µ
Side R	c11lz	0.46
Side L	b11lz	0.49

FLAT ANVIL @6.0m/s



	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	12lz03	169	23	1101	11.5%	9.9%
Side R	15lz16	193	22	1240	9.4%	7.5%
Side L	18lz25	184	23	1287	10.3%	10.1%
Crown	19lz22	172	24	956	12.9%	13.5%
Rear	20lz17	195	23	1453	9.5%	8.7%
Side average	n/a	189	n/a	1,264	n/a	n/a

FLAT ANVIL @8.5m/s



	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz09	270	31	2797	11.8%	10.4%
Side R	15lz18	337	28	3600	7.9%	7.8%
Side L	18lz29	296	29	3329	11.1%	10.0%
Crown	19lz24	260	35	2658	11.0%	11.3%
Rear	20lz21	268	31	3092	12.0%	11.6%
Side average	n/a	316.5	n/a	3,465	n/a	n/a

FLAT ANVIL @9.5m/s

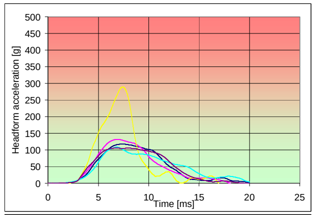
	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	0	0	0	0	0.0%	0.0%
Side R	0	0	0	0	0.0%	0.0%
Side L	0	0	0	0	0.0%	0.0%
Crown	0	0	0	0	0.0%	0.0%
Rear	0	0	0	0	0.0%	0.0%
Side average	n/a	0.0	n/a	0	n/a	n/a

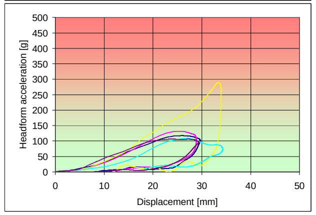
Helmet	**3**
Season	**2006**
Manufacturer	
Model	
Size	**J**
Weight	
Approval	**Reg22.05**

OVERALL RATINGS (FATAL)

120	Fatal

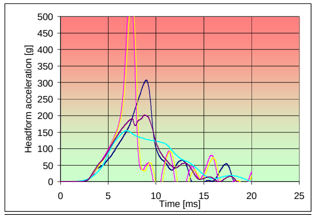
KERB ANVIL @ 6.0m/s

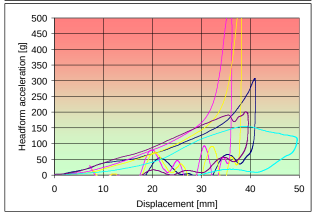




	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz02	118	30	698	6.7%	2.9%
Side R	15lz22	132	29	746	8.7%	7.3%
Side L	18lz22	133	28	755	8.5%	7.4%
Crown	19lz30	109	34	525	14.3%	14.4%
Rear	20lz26	107	29	678	9.6%	7.1%
Side average	n/a	133	n/a	750	n/a	n/a

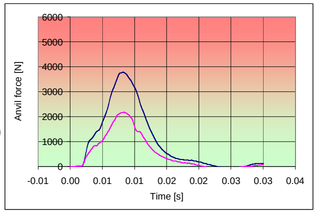
KERB ANVIL @ 8.5m/s

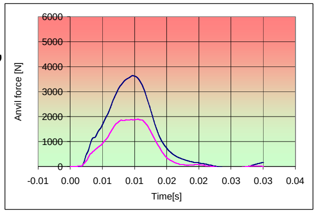




	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz18	307	41	2428	4.2%	4.5%
Side R	15lz24	576	36	5899	7.4%	6.5%
Side L	18lz23	552	38	5420	8.8%	7.8%
Crown	19lz32	155	49	1255	13.3%	9.8%
Rear	20lz28	201	40	1757	6.8%	7.6%
Side average	n/a	564	n/a	5,660	n/a	n/a

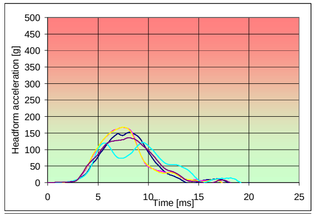
15° OBLIQUE ANVIL @ 8.5m/s

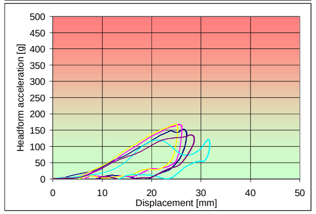




	Filename	µ
Side R	e08lz	0.56
Side L	d08lz	0.56

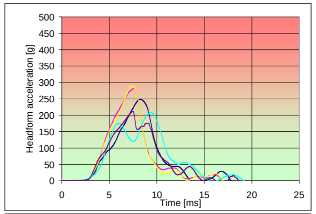
FLAT ANVIL @6.0m/s

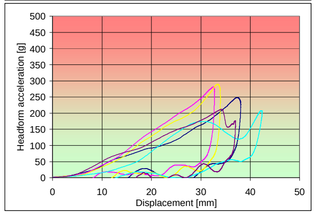




	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	12lz04	153	27	963	9.6%	7.9%
Side R	15lz21	167	26	1083	9.5%	8.3%
Side L	18lz20	168	25	1072	12.4%	11.1%
Crown	19lz29	121	32	628	11.2%	9.8%
Rear	20lz25	135	29	851	10.0%	9.8%
Side average	n/a	168	n/a	1,077	n/a	n/a

FLAT ANVIL @8.5m/s





	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz10	248	38	2258	9.8%	9.4%
Side R	15lz23	281	33	2898	11.6%	11.5%
Side L	18lz22	289	34	2822	9.9%	8.9%
Crown	19lz31	208	42	1945	10.5%	11.9%
Rear	20lz27	212	37	1755	8.3%	7.4%
Side average	n/a	285.3	n/a	2,860	n/a	n/a

FLAT ANVIL @9.5m/s

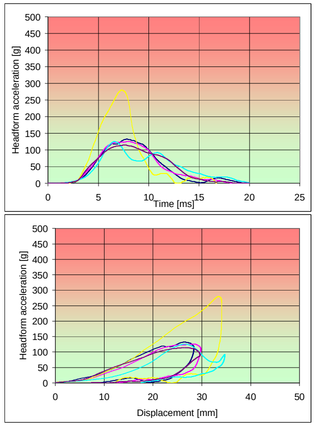
	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	0	0	0	0	0.0%	0.0%
Side R	0	0	0	0	0.0%	0.0%
Side L	0	0	0	0	0.0%	0.0%
Crown	0	0	0	0	0.0%	0.0%
Rear	0	0	0	0	0.0%	0.0%
Side average	n/a	0.0	n/a	0	n/a	n/a

Helmet	**4**	
Season	**2006**	
Manufacturer		
Model		
Size	**J**	
Weight		
Approval	**Reg22.05**	

OVERALL RATINGS (FATAL)

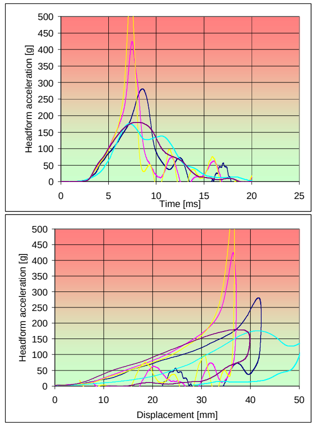
126	Fatal

KERB ANVIL @ 6.0m/s



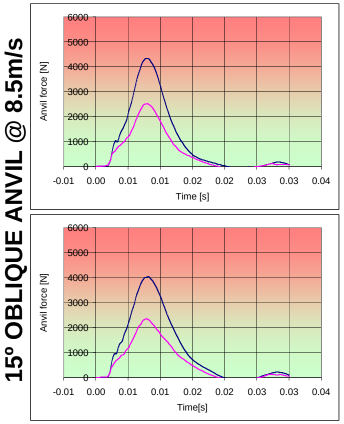
	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz03	133	28	775	9.5%	8.7%
Side R	15lz27	125	30	746	12.0%	13.0%
Side L	18lz37	122	30	711	10.2%	11.0%
Crown	19lz14	125	35	532	14.8%	1.4%
Rear	20lz35	114	30	678	8.8%	7.6%
Side average	n/a	124	n/a	729	n/a	n/a

KERB ANVIL @ 8.5m/s



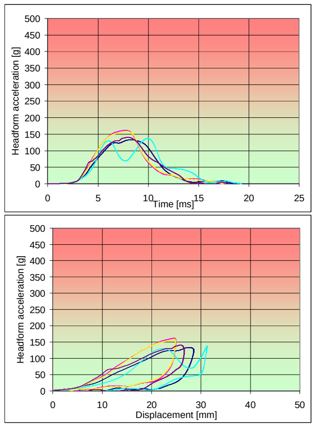
	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz19	281	42	2213	3.7%	3.6%
Side R	15lz31	424	37	3306	3.5%	3.8%
Side L	18lz39	574	37	5513	9.1%	8.2%
Crown	19lz18	176	51	1461	9.9%	6.4%
Rear	20lz39	180	40	1637	7.2%	8.0%
Side average	n/a	499	n/a	4,409	n/a	n/a

15° OBLIQUE ANVIL @ 8.5m/s



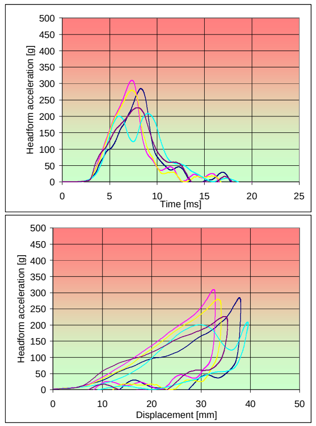
	Filename	μ
Side R	h08lz	0.57
Side L	f08lz	0.56

FLAT ANVIL @6.0m/s



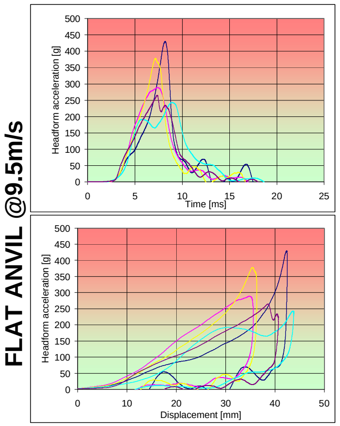
	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	12lz05	133	29	835	11.2%	10.8%
Side R	15lz25	162	25	1063	16.5%	16.2%
Side L	18lz33	159	25	1039	15.5%	15.0%
Crown	19lz12	137	31	726	10.3%	10.6%
Rear	20lz33	141	27	817	10.6%	10.8%
Side average	n/a	160	n/a	1,051	n/a	n/a

FLAT ANVIL @8.5m/s



	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz11	285	38	2534	5.6%	6.2%
Side R	15lz29	310	33	3094	10.2%	10.4%
Side L	18lz37	280	34	2843	12.3%	11.3%
Crown	19lz16	209	39	2170	11.6%	13.3%
Rear	20lz37	226	35	2184	9.8%	9.7%
Side average	n/a	295.0	n/a	2,969	n/a	n/a

FLAT ANVIL @9.5m/s



	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz25	429	42	4336	5.1%	5.8%
Side R	15lz33	289	36	3487	16.7%	16.6%
Side L	18lz41	378	36	4167	7.4%	7.6%
Crown	19lz20	243	44	2765	8.0%	8.8%
Rear	20lz41	265	41	2739	9.3%	7.1%
Side average	n/a	333.4	n/a	3,827	n/a	n/a

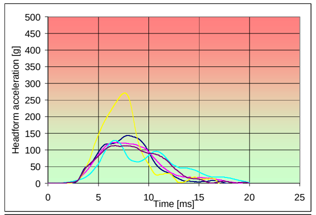
Helmet 4
Season 2006

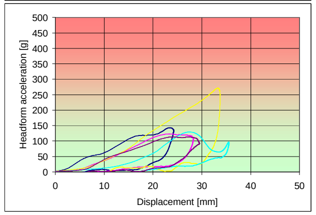
Manufacturer
Model
Size J
Weight
Approval Reg22.05

OVERALL RATINGS (FATAL)

123 Fatal

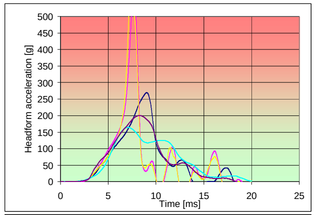
KERB ANVIL @ 6.0m/s

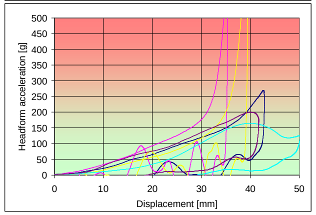




	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz04	143	24	901	9.2%	9.6%
Side R	15lz28	123	28	732	9.2%	9.1%
Side L	18lz38	122	29	744	10.6%	11.3%
Crown	19lz15	129	35	540	10.1%	2.6%
Rear	20lz36	113	29	695	10.1%	9.4%
Side average	n/a	122	n/a	738	n/a	n/a

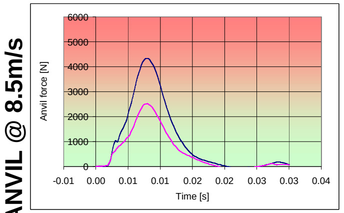
KERB ANVIL @ 8.5m/s

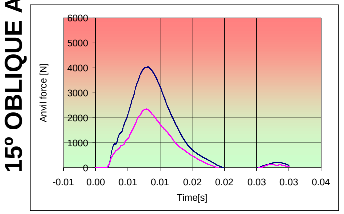




	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz20	269	43	2124	5.2%	4.6%
Side R	15lz32	566	35	5155	4.6%	4.4%
Side L	18lz40	584	39	6191	7.7%	6.9%
Crown	19lz19	165	50	1321	9.6%	10.1%
Rear	20lz40	200	42	1733	6.3%	5.4%
Side average	n/a	575	n/a	5,673	n/a	n/a

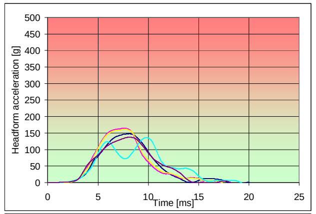
15° OBLIQUE ANVIL @ 8.5m/s

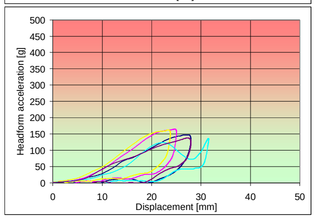




	Filename	µ
Side R	h08lz	0.57
Side L	f08lz	0.56

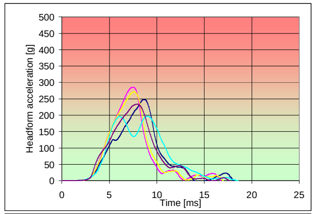
FLAT ANVIL @6.0m/s

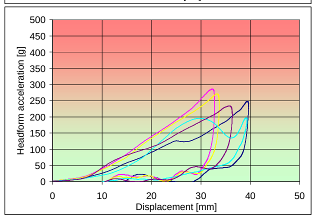




	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	12lz06	148	28	920	9.9%	7.9%
Side R	15lz26	165	25	1111	16.2%	15.9%
Side L	18lz34	162	24	1089	17.5%	16.6%
Crown	19lz13	136	31	713	11.3%	12.0%
Rear	20lz34	137	28	809	9.5%	9.6%
Side average	n/a	163	n/a	1,100	n/a	n/a

FLAT ANVIL @8.5m/s





	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz12	248	40	2203	6.8%	7.1%
Side R	15lz30	286	33	2877	11.2%	11.4%
Side L	18lz38	271	34	2777	13.9%	13.2%
Crown	19lz17	197	39	2105	11.6%	12.9%
Rear	20lz38	234	36	2260	8.0%	7.4%
Side average	n/a	278.7	n/a	2,827	n/a	n/a

FLAT ANVIL @9.5m/s

	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	0	0	0	0	0.0%	0.0%
Side R	0	0	0	0	0.0%	0.0%
Side L	0	0	0	0	0.0%	0.0%
Crown	0	0	0	0	0.0%	0.0%
Rear	0	0	0	0	0.0%	0.0%
Side average	n/a	0.0	n/a	0	n/a	n/a

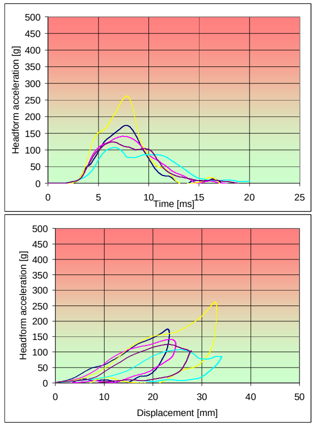
Helmet 5
Season 2006

Manufacturer
Model
Size J
Weight
Approval Reg22.05

OVERALL RATINGS (FATAL)

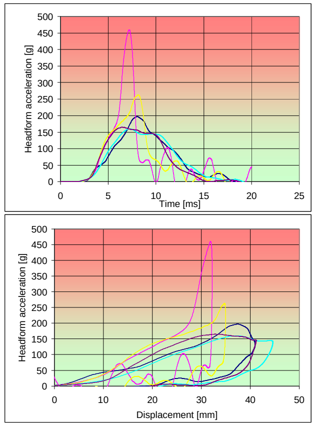
126 Fatal

KERB ANVIL @ 6.0m/s



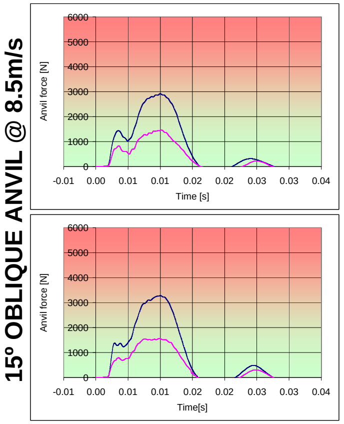
	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz05	174	23	1121	12.4%	11.5%
Side R	15lz36	141	25	928	6.1%	6.0%
Side L	18lz17	137	26	890	5.5%	3.5%
Crown	19lz36	107	34	538	9.3%	6.4%
Rear	20lz09	125	28	753	7.8%	5.4%
Side average	n/a	139	n/a	909	n/a	n/a

KERB ANVIL @ 8.5m/s



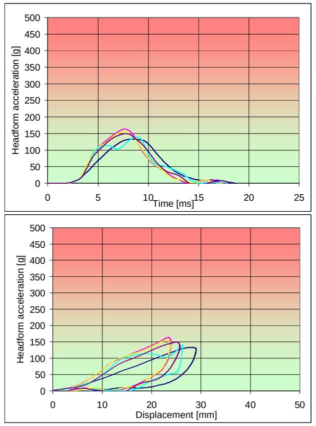
	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz21	197	41	1621	10.4%	7.8%
Side R	15lz39	460	32	4399	4.6%	3.2%
Side L	18lz15	263	35	2218	12.1%	11.3%
Crown	19lz40	160	45	1496	5.2%	2.6%
Rear	20lz13	165	41	1648	8.3%	8.4%
Side average	n/a	361	n/a	3,308	n/a	n/a

15º OBLIQUE ANVIL @ 8.5m/s



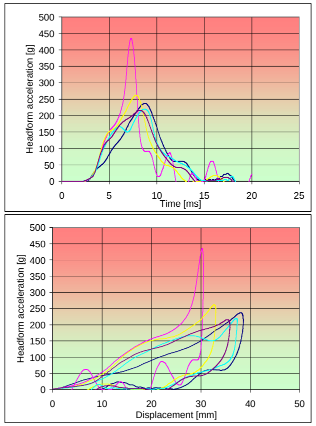
	Filename	µ
Side R	e11lz	0.48
Side L	d11lz	0.49

FLAT ANVIL @6.0m/s



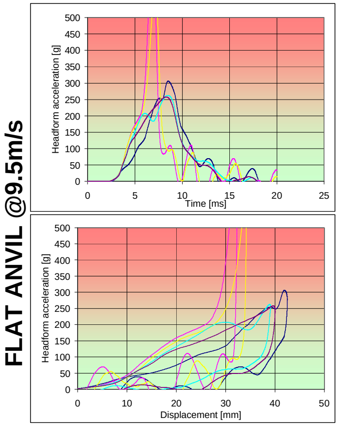
	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	12lz07	133	29	832	10.7%	9.9%
Side R	15lz34	163	24	1064	9.8%	8.6%
Side L	18lz11	157	24	1013	10.4%	8.9%
Crown	19lz34	140	26	813	6.4%	6.5%
Rear	20lz07	150	26	999	6.6%	6.6%
Side average	n/a	160	n/a	1,038	n/a	n/a

FLAT ANVIL @8.5m/s



	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz13	237	39	2207	4.5%	3.3%
Side R	15lz40	435	31	3695	6.6%	6.4%
Side L	18lz17	262	33	2576	12.1%	11.6%
Crown	19lz38	220	37	2085	4.7%	5.1%
Rear	20lz11	216	36	2169	6.7%	6.9%
Side average	n/a	348.5	n/a	3,136	n/a	n/a

FLAT ANVIL @9.5m/s



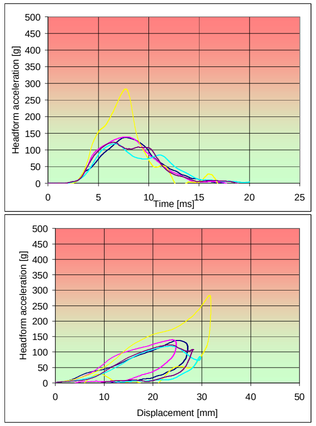
	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz23	306	42	3383	4.6%	2.9%
Side R	15lz42	650	32	8134	3.8%	4.0%
Side L	18lz19	580	34	6325	9.2%	9.1%
Crown	19lz42	263	39	3102	5.0%	5.5%
Rear	20lz15	258	40	3009	5.3%	5.7%
Side average	n/a	614.6	n/a	7,230	n/a	n/a

Helmet	**5**
Season	**2006**
Manufacturer	
Model	
Size	**J**
Weight	
Approval	**Reg22.05**

OVERALL RATINGS (FATAL)

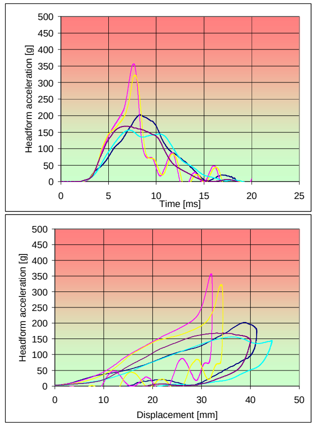
139	Fatal

KERB ANVIL @ 6.0m/s



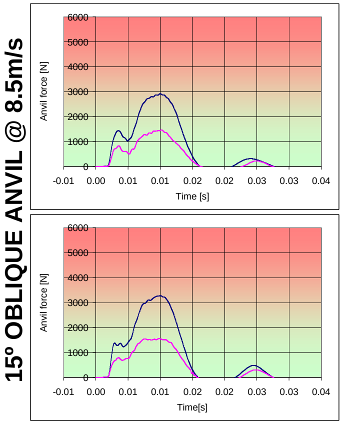
	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz06	138	27	765	7.6%	5.2%
Side R	15lz37	140	25	906	5.8%	5.7%
Side L	18lz18	136	25	885	6.0%	4.3%
Crown	19lz37	119	30	582	7.5%	5.0%
Rear	20lz10	124	28	757	8.3%	5.6%
Side average	n/a	138	n/a	896	n/a	n/a

KERB ANVIL @ 8.5m/s



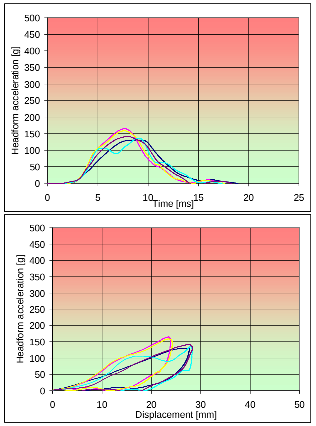
	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz22	202	41	1792	5.6%	2.8%
Side R	15lz38	357	32	2895	8.9%	8.2%
Side L	18lz16	322	34	2548	11.1%	9.8%
Crown	19lz41	156	44	1477	5.4%	3.3%
Rear	20lz14	168	40	1693	5.5%	4.5%
Side average	n/a	339	n/a	2,722	n/a	n/a

15° OBLIQUE ANVIL @ 8.5m/s



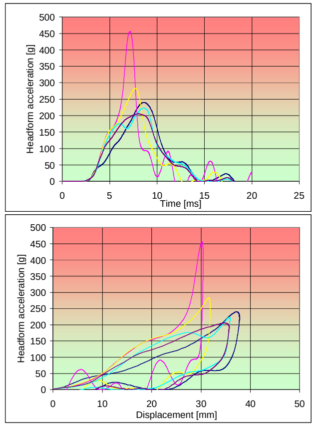
	Filename	µ
Side R	e11lz	0.48
Side L	d11lz	0.49

FLAT ANVIL @6.0m/s



	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	12lz08	131	28	823	11.6%	10.7%
Side R	15lz35	165	24	1065	10.7%	9.4%
Side L	18lz12	159	24	1055	11.7%	10.1%
Crown	19lz35	137	28	723	5.8%	5.8%
Rear	20lz08	142	28	933	7.2%	6.0%
Side average	n/a	162	n/a	1,060	n/a	n/a

FLAT ANVIL @8.5m/s



	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	13lz14	240	38	2270	5.0%	4.2%
Side R	15lz41	456	30	4230	5.3%	5.4%
Side L	18lz18	283	32	2741	12.8%	12.1%
Crown	19lz39	223	36	2231	3.6%	3.9%
Rear	20lz12	206	36	2116	5.9%	6.3%
Side average	n/a	369.2	n/a	3,485	n/a	n/a

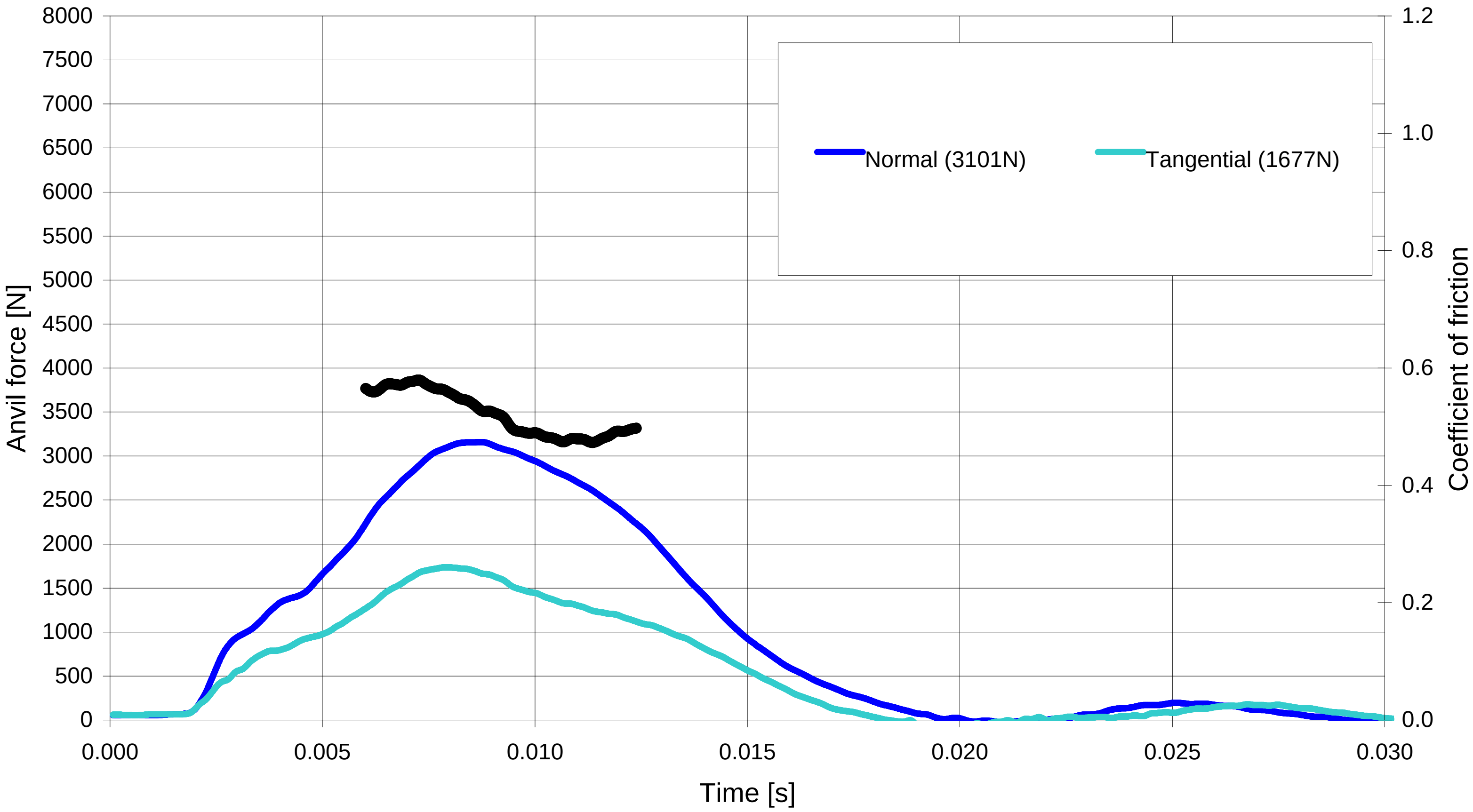
FLAT ANVIL @9.5m/s

	Filename	Peak acc [g]	Max disp [mm]	HIC	Validity (Tv=0)	Validity (Tpeakg)
Front	0	0	0	0	0.0%	0.0%
Side R	0	0	0	0	0.0%	0.0%
Side L	0	0	0	0	0.0%	0.0%
Crown	0	0	0	0	0.0%	0.0%
Rear	0	0	0	0	0.0%	0.0%
Side average	n/a	0.0	n/a	0	n/a	n/a

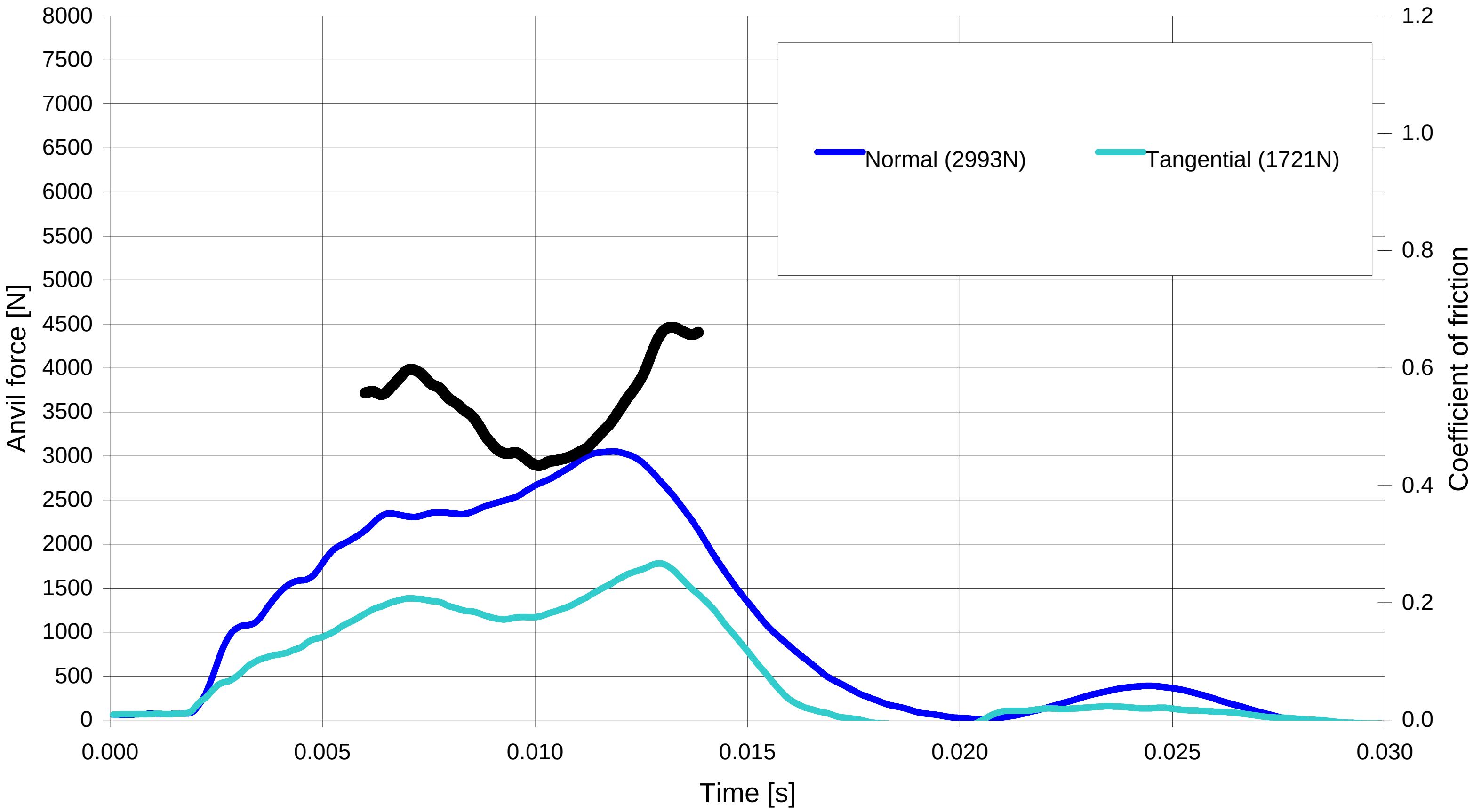
B.2 OBLIQUE IMPACT RESULTS

The following graphs show the normal and tangential forces for the oblique impacts completed within this project. The black line illustrates the coefficient of friction calculated by dividing instantaneous tangential force by normal force for a duration over which the normal force is 70% of the peak normal force.

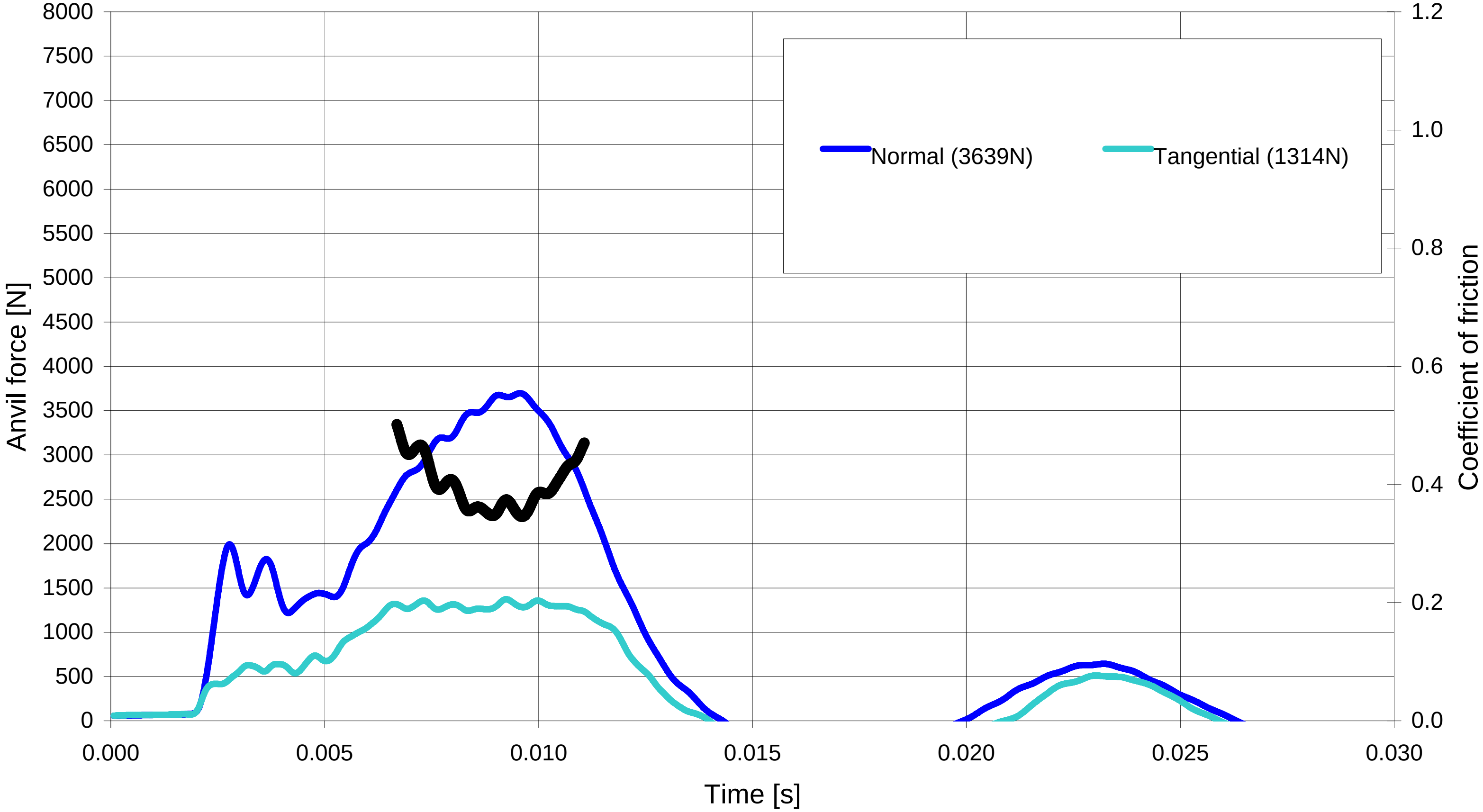
1a helmet [Side R] equiped with a Reg22 headform onto 15º Oblique at 8.5m/s (g01lz)



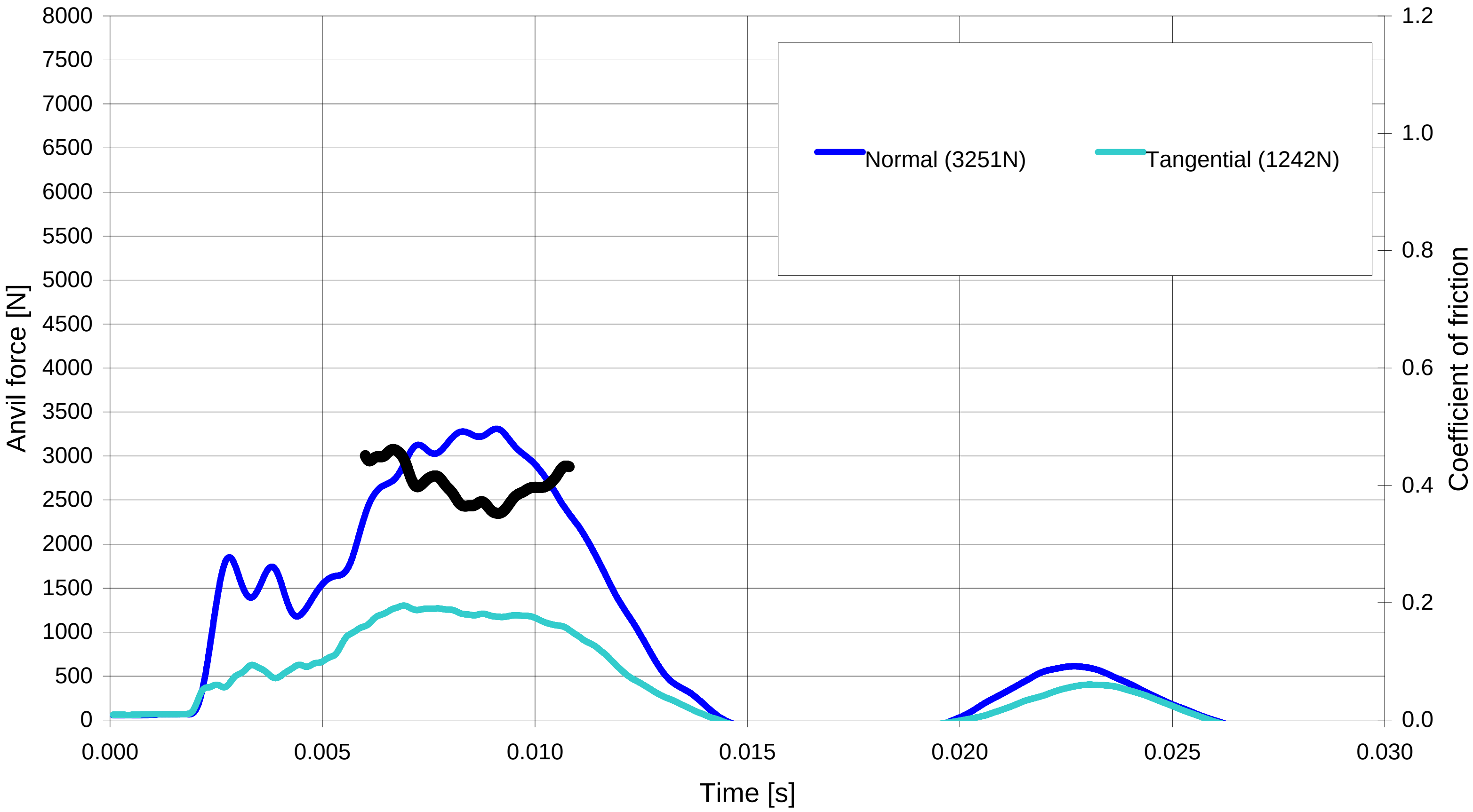
1a helmet [Side L] equiped with a Reg22 headform onto 15º Oblique at 8.5m/s (h01lz)



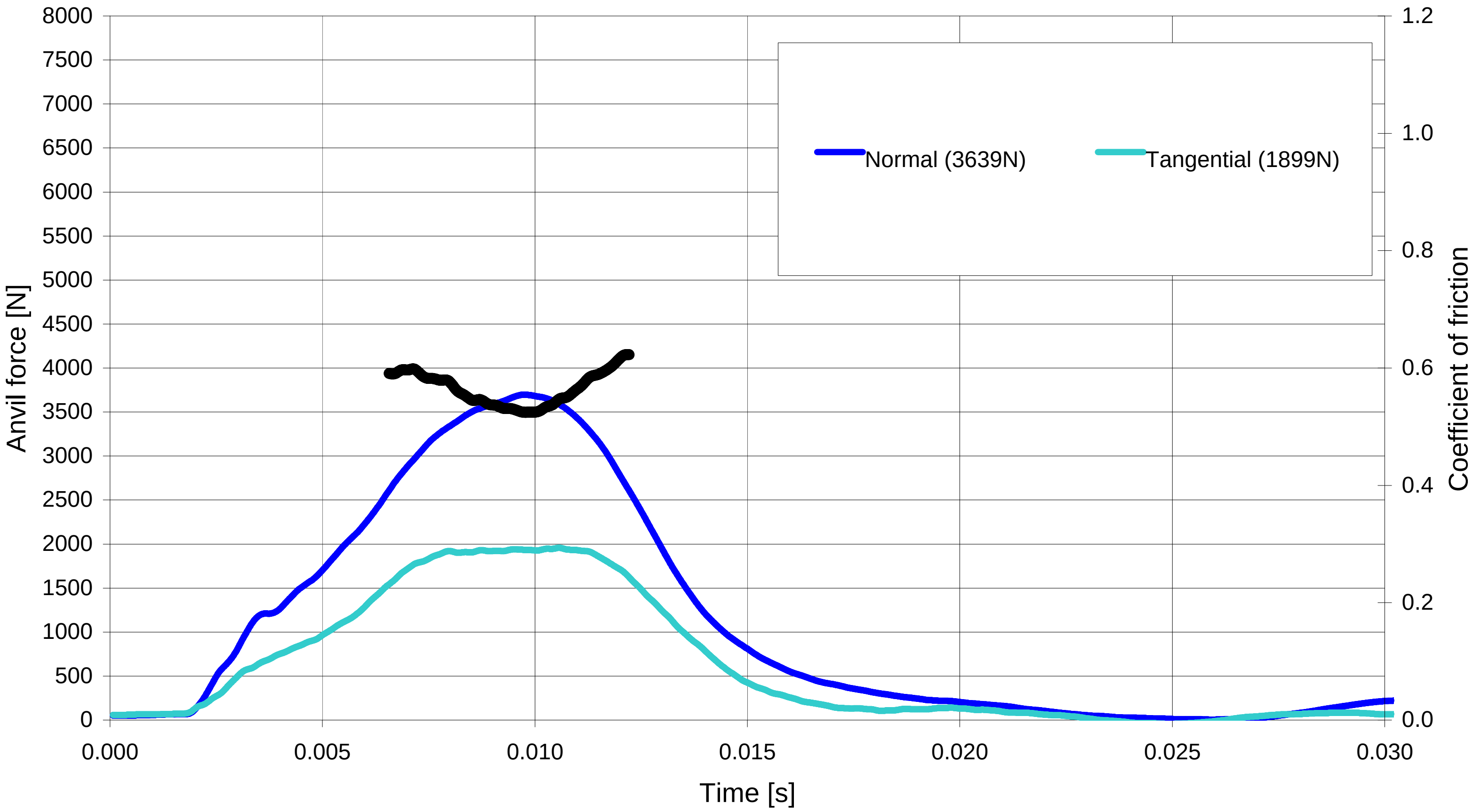
2a helmet [Side L] equiped with a Reg22 headform onto 15º Oblique at 8.5m/s (a08lz)



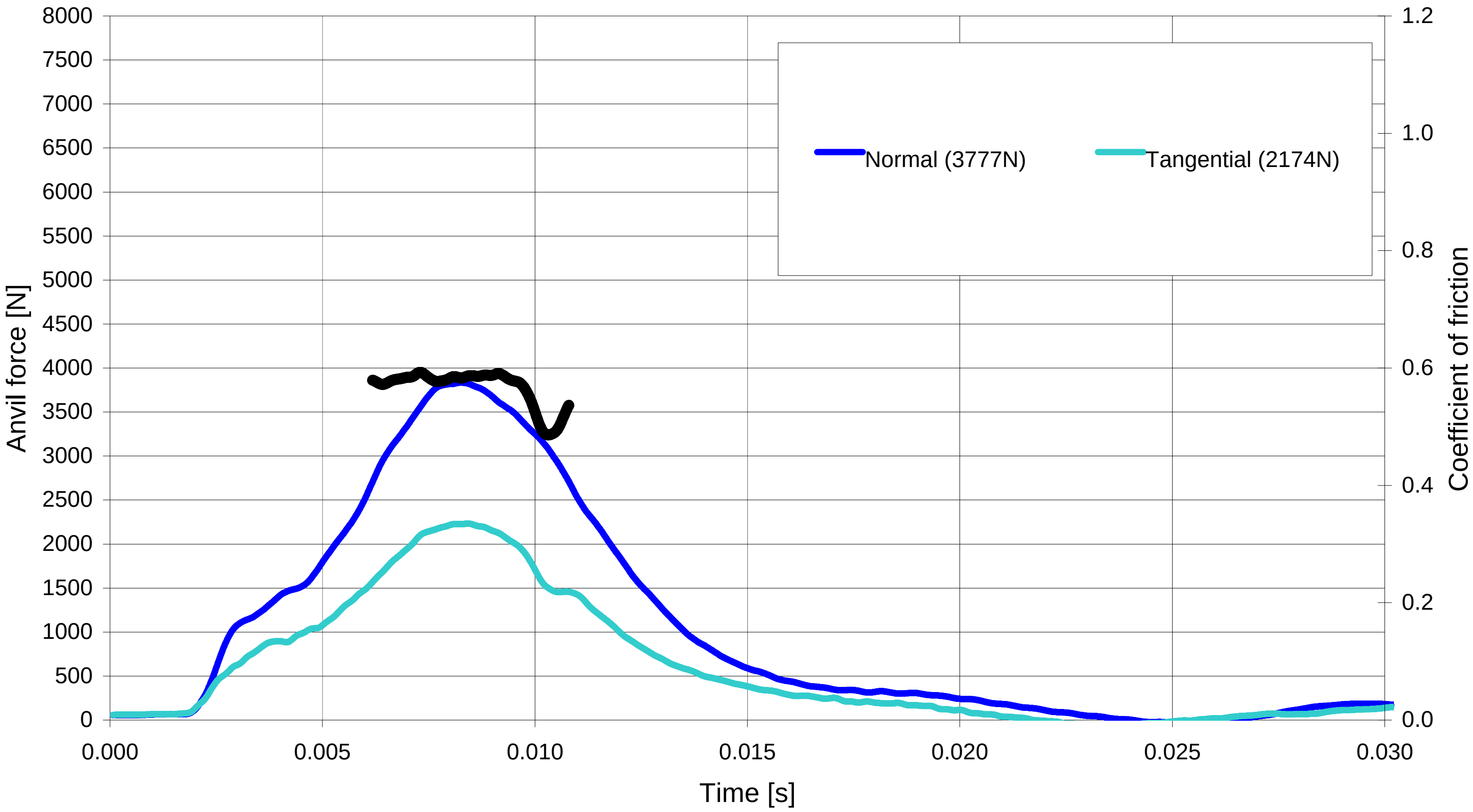
2a helmet [Side R] equiped with a Reg22 headform onto 15º Oblique at 8.5m/s (b08lz)



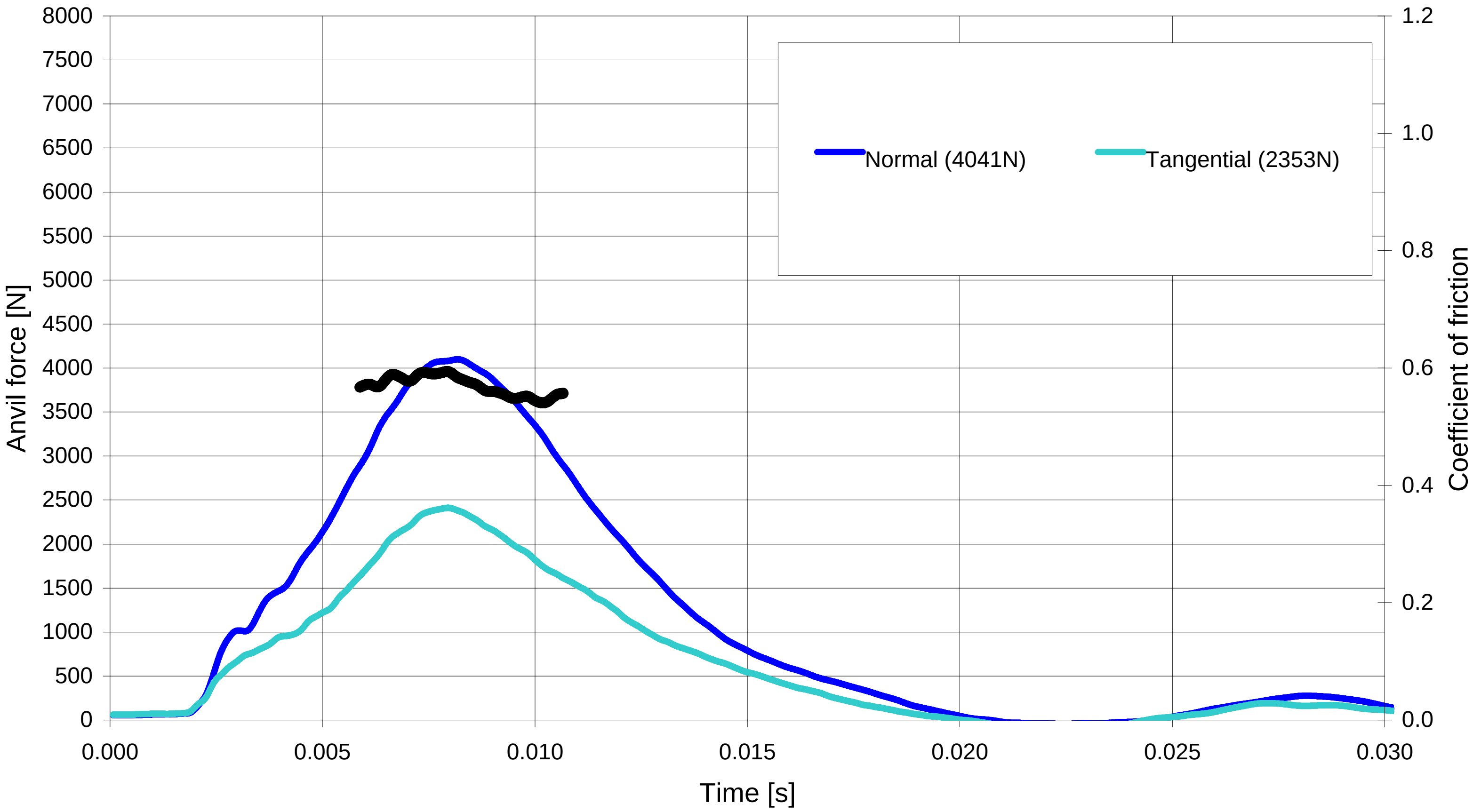
3a helmet [Side L] equiped with a Reg22 headform onto 15º Oblique at 8.5m/s (d08lz)



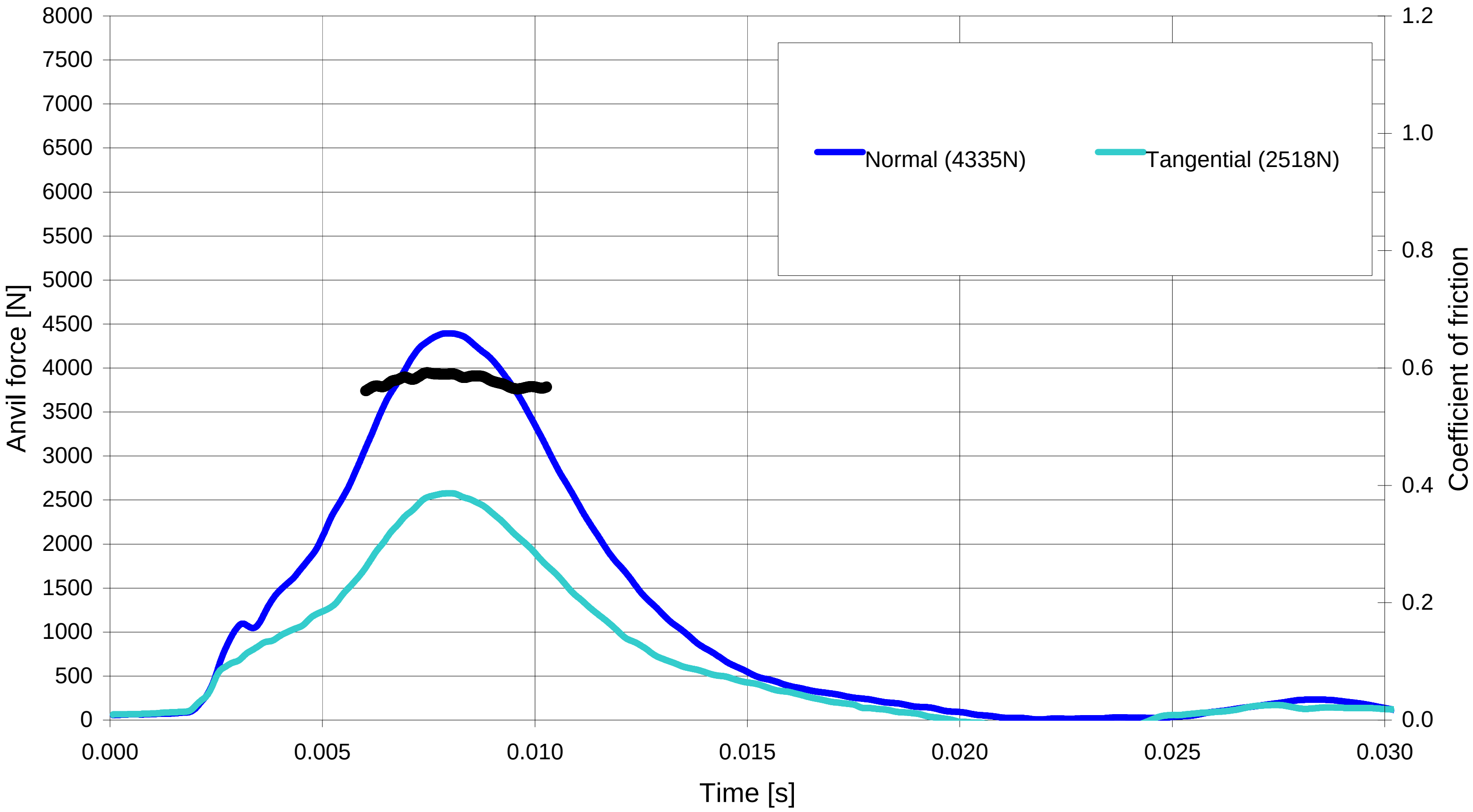
3a helmet [Side R] equiped with a Reg22 headform onto 15º Oblique at 8.5m/s (e08lz)



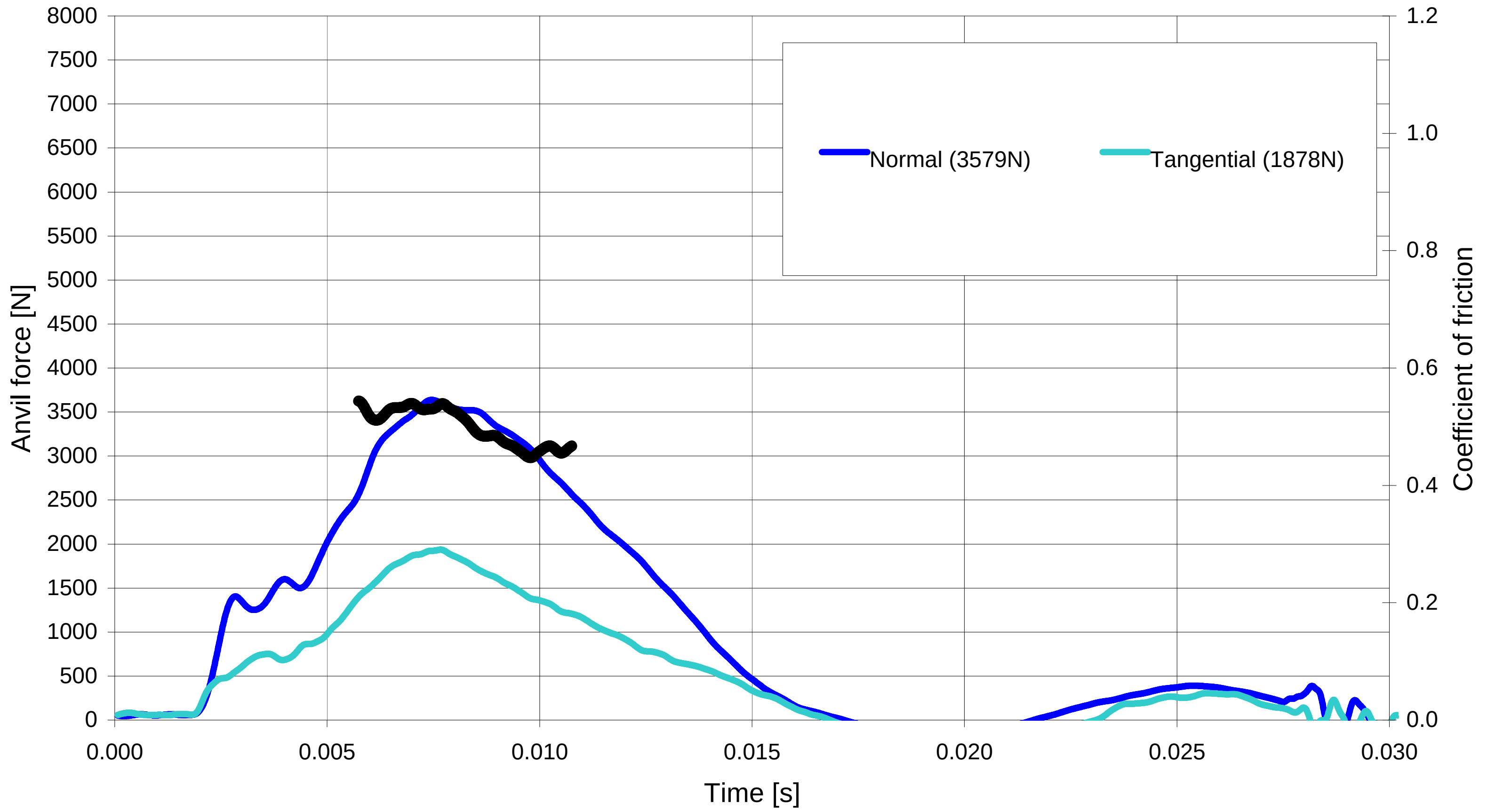
4a helmet [Side L] equiped with a Reg22 headform onto 15º Oblique at 8.5m/s (f08lz)



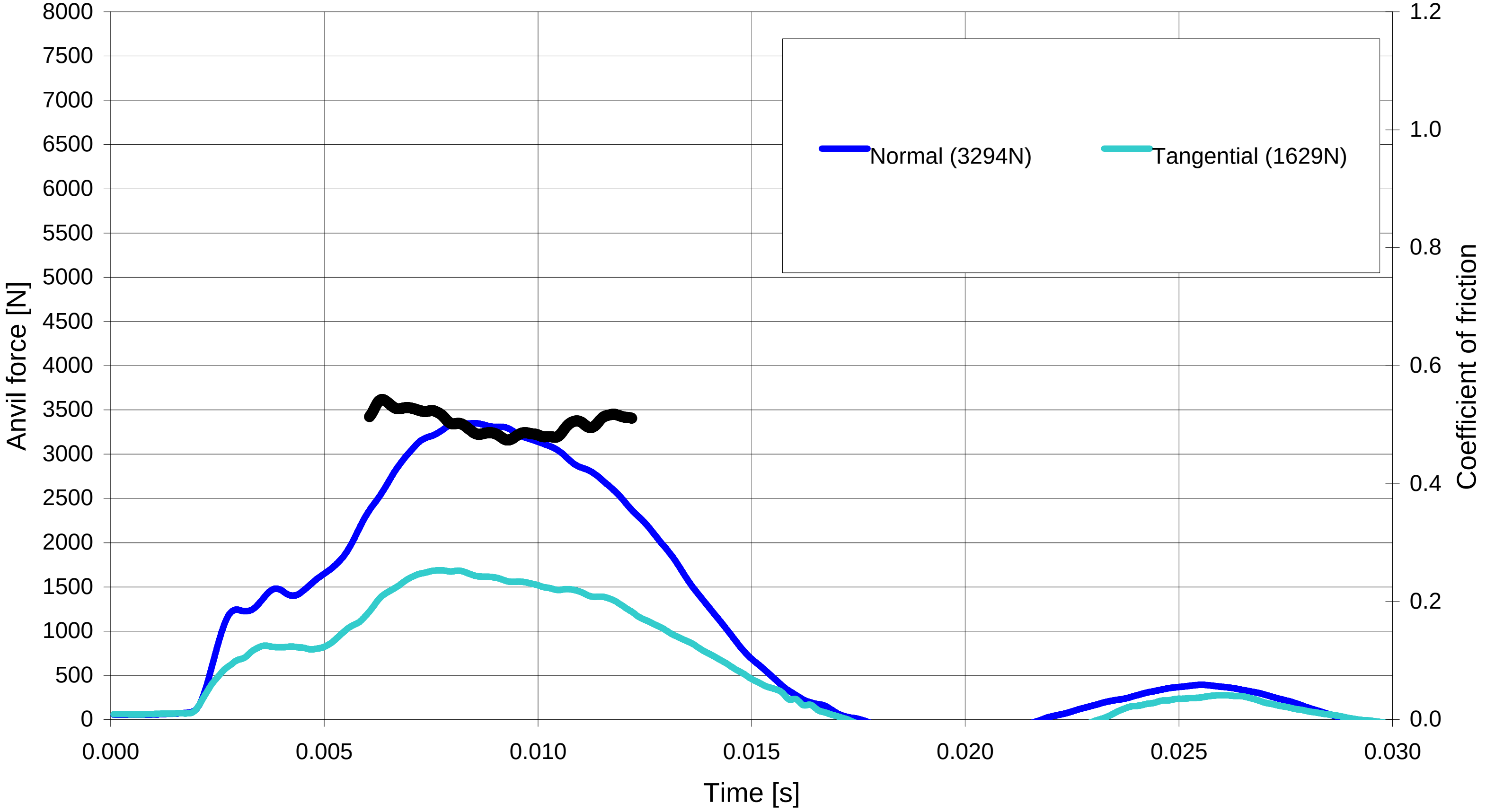
4a helmet [Side R] equiped with a Reg22 headform onto 15º Oblique at 8.5m/s (h08lz)



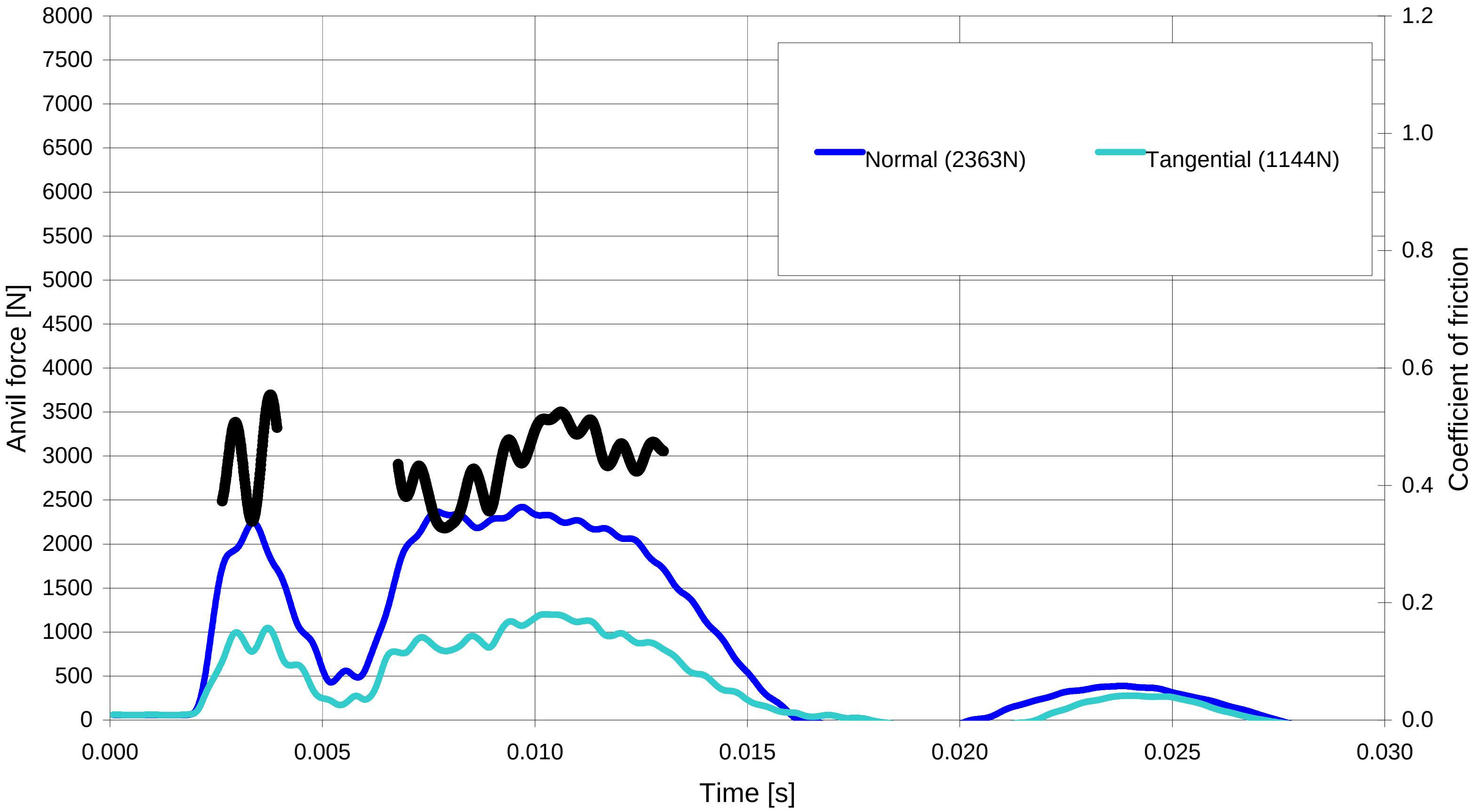
5a helmet [Side L] equiped with a Reg22 headform onto 15º Oblique at 8.5m/s (i08lz)



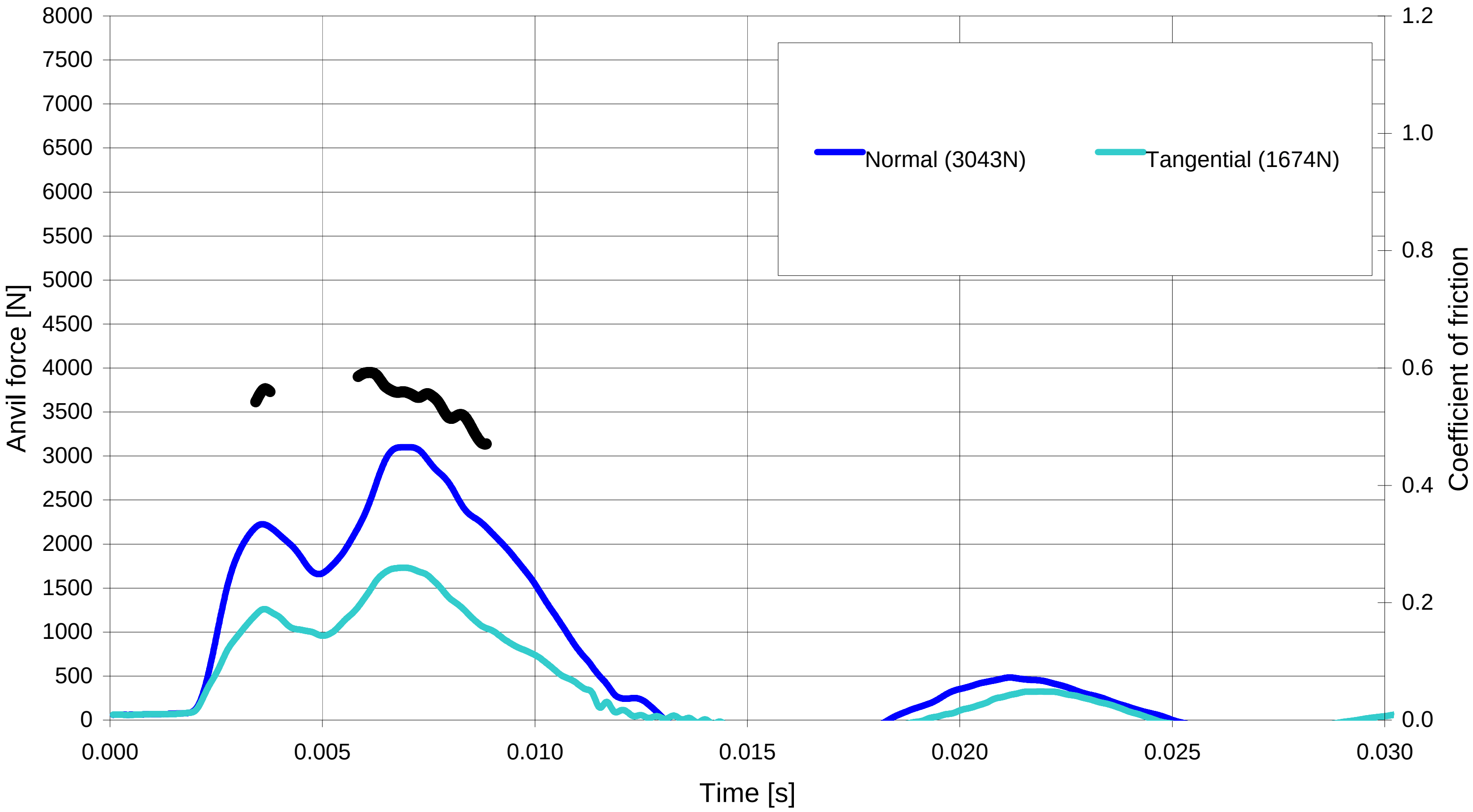
5a helmet [Side R] equiped with a Reg22 headform onto 15º Oblique at 8.5m/s (j08lz)



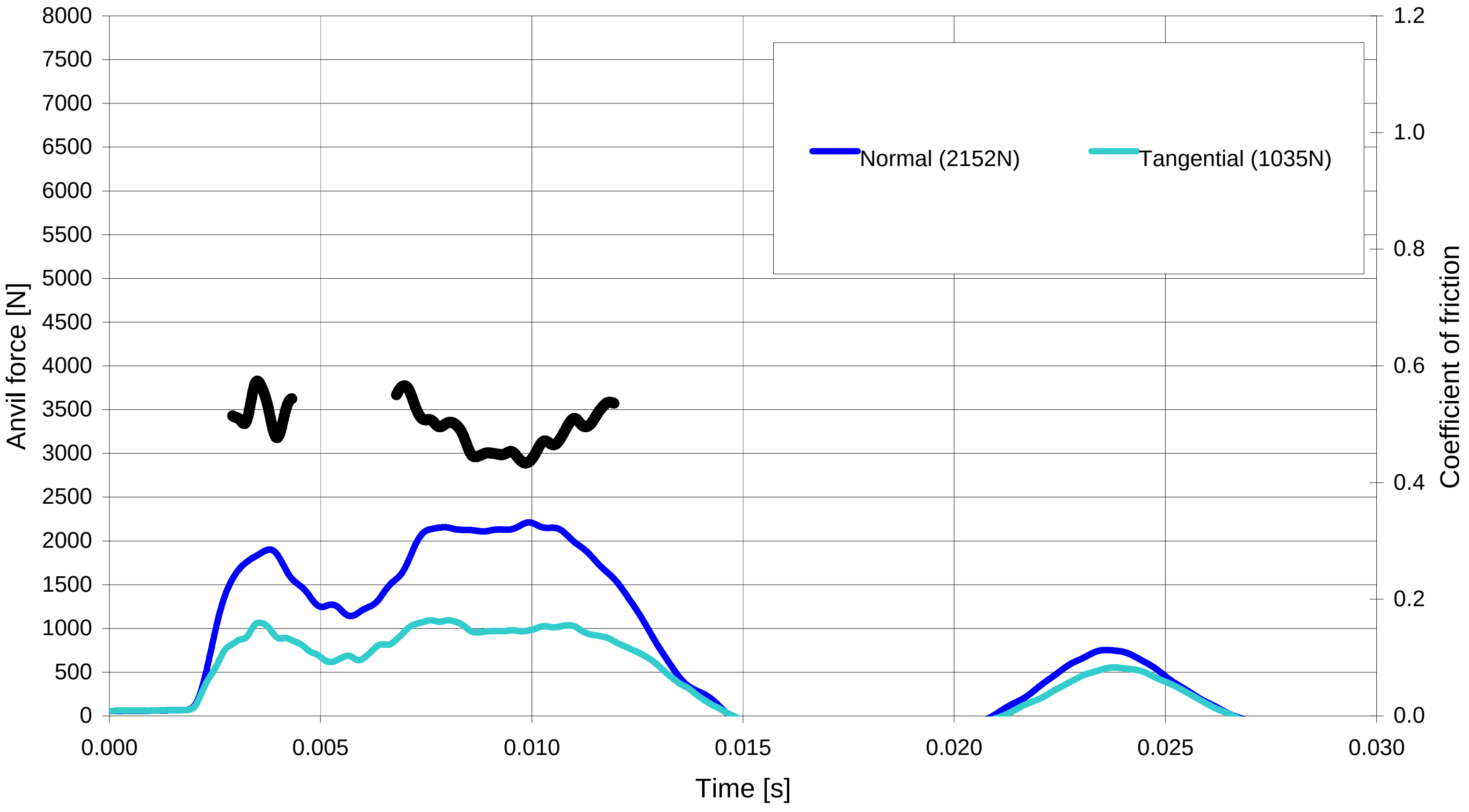
2b helmet [Side L] equiped with a Reg22 headform onto 15º Oblique at 8.5m/s (k08lz)



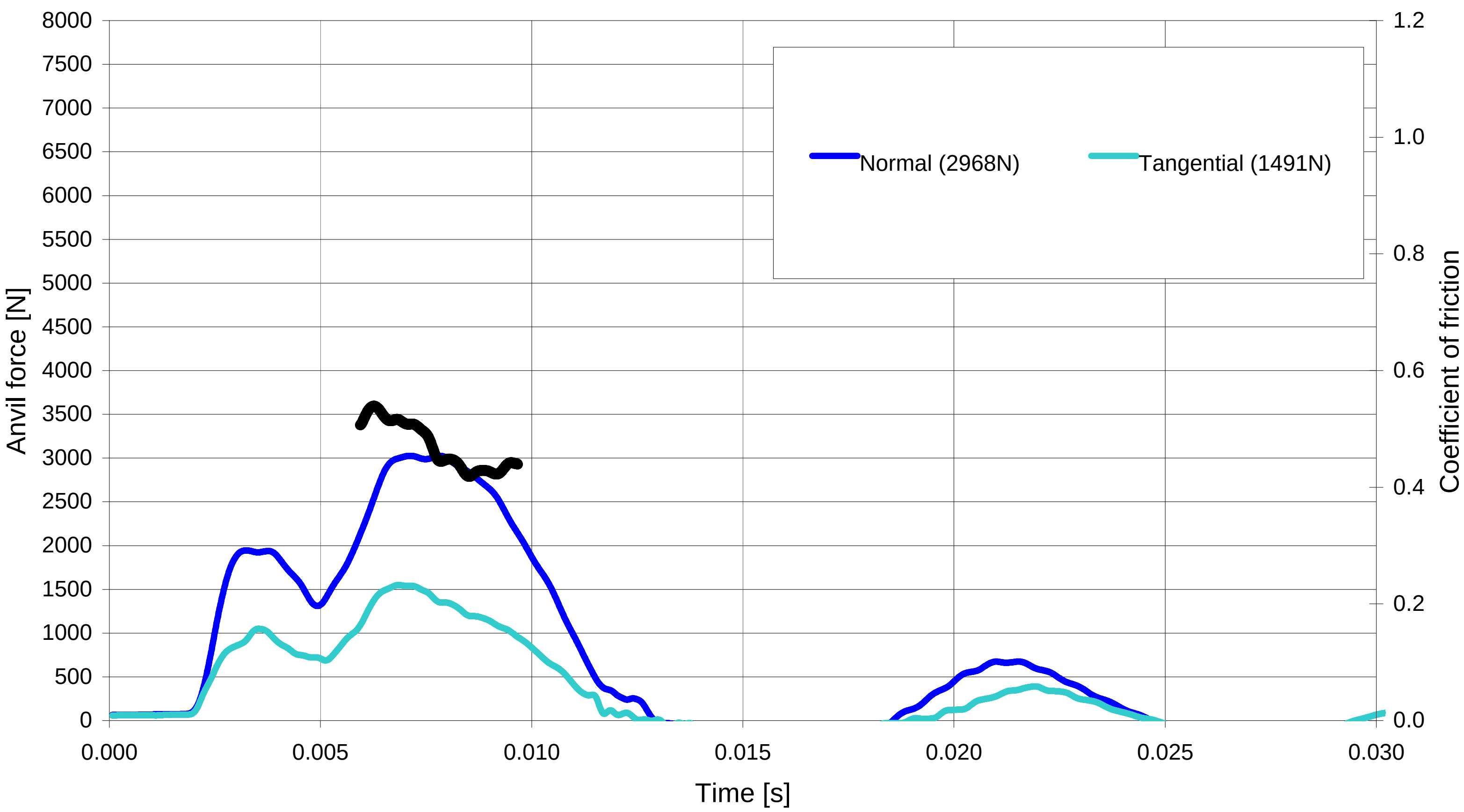
2a helmet [Rear] equiped with a Reg22 headform onto 15º Oblique at 8.5m/s (a11lz)



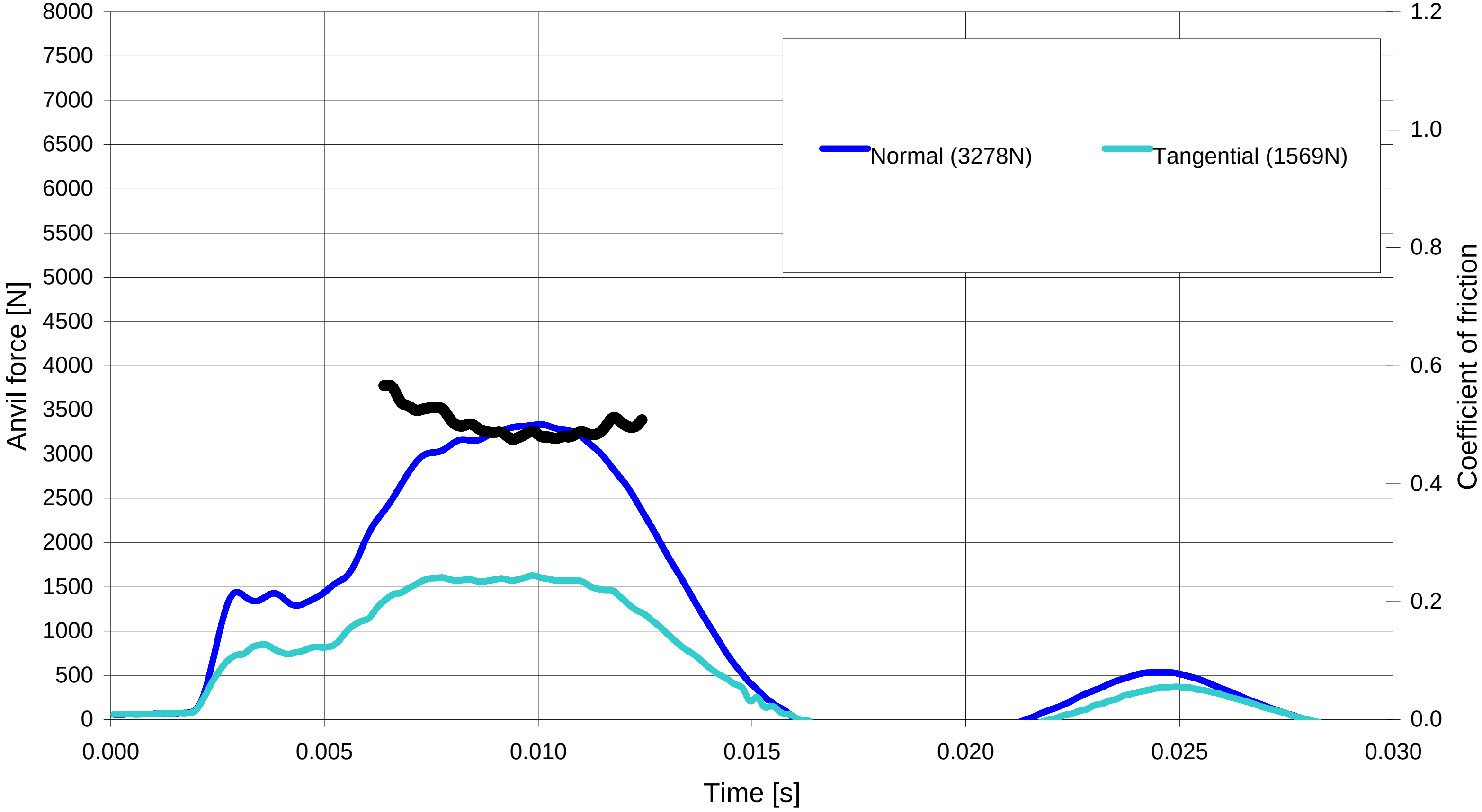
2a helmet [Side L] equiped with a Reg22 headform onto 15º Oblique at 8.5m/s (b11lz)



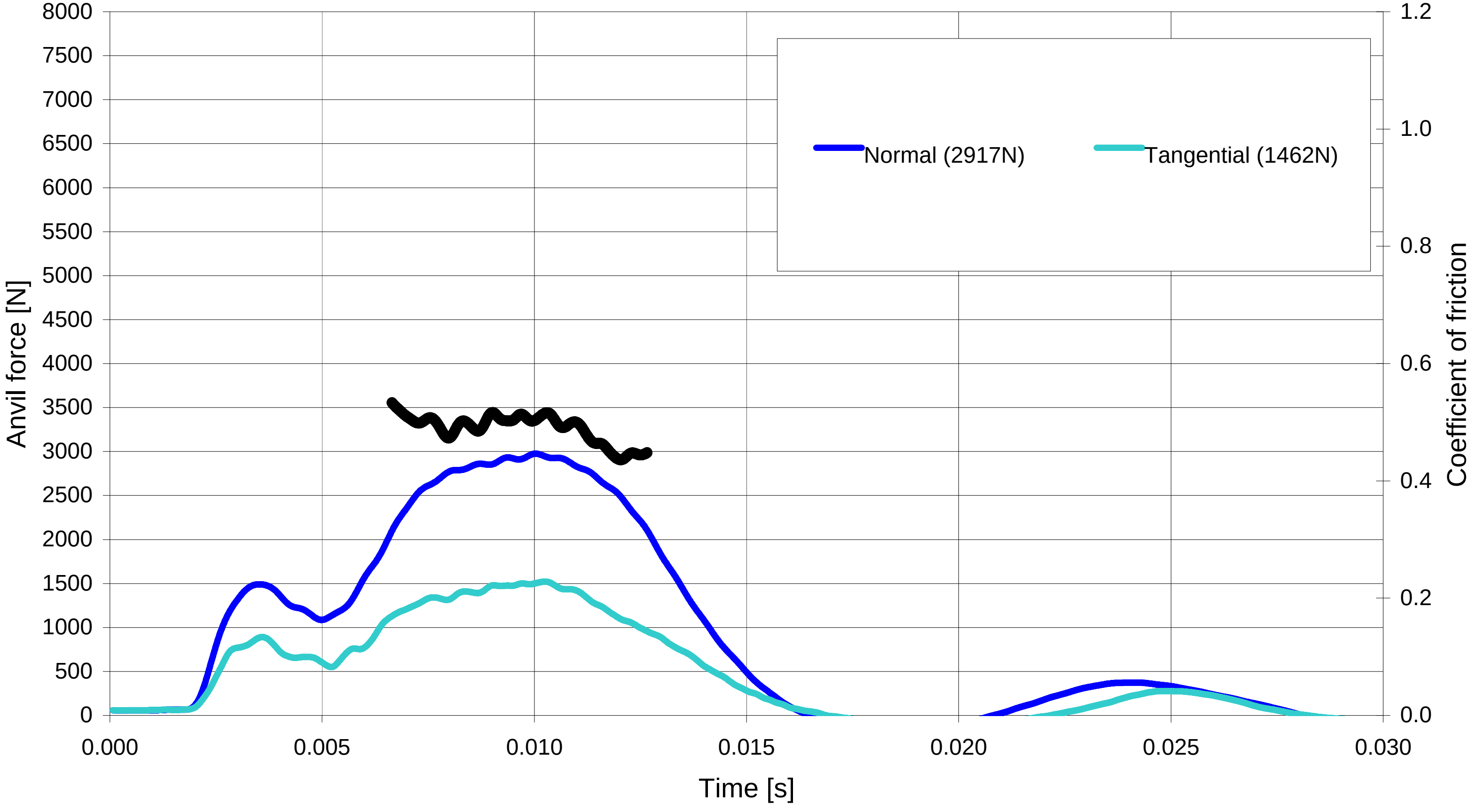
2a helmet [Rear] equiped with a Reg22 headform onto 15º Oblique at 8.5m/s (c11lz)



5a helmet [Side L] equiped with a Reg22 headform onto 15º Oblique at 8.5m/s (d11lz)



5a helmet [Side R] equiped with a Reg22 headform onto 15º Oblique at 8.5m/s (e11lz)



Appendix C: Instrumentation specifications

C.1 ACCELEROMETER SPECIFICATION

Piezoresistive Accelerometer

ENDEVCO MODEL 7267A

Actual size

Model 7267A

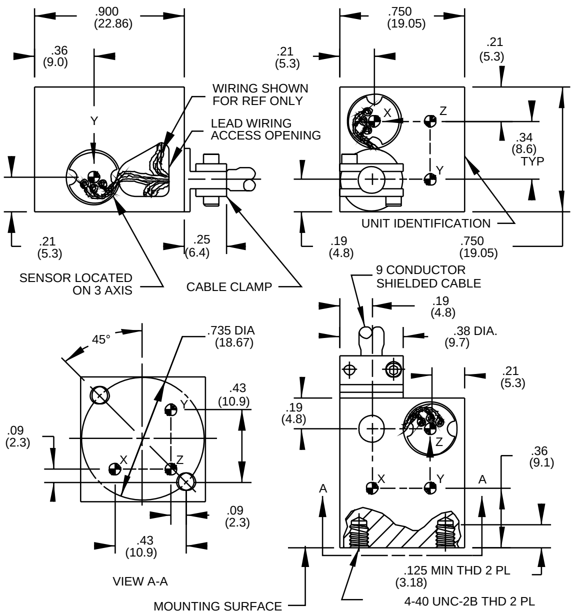
- Triaxial Accelerometer
- DC Response
- 1500 g Full Scale
- Replaceable Sensors
- Undamped

DESCRIPTION

The ENDEVCO® Model 7267A is a replaceable-element triaxial accelerometer designed to measure acceleration in three mutually-perpendicular axes. Although designed for installation in anthropomorphic test dummies used in automotive crash studies, it has application wherever triaxial accelerometers are used for steady state or long duration pulse measurements. The Model 7267A uses ENDEVCO's PIEZITE® piezoresistive elements in half-bridge configuration and meets SAEJ211 specifications for anthropomorphic dummy instrumentation.

The three sensors are mutually perpendicular and are positioned so that theoretical lines drawn through the centers of the seismic masses intersect at a single point.

Each sensor is replaceable. It is held in place by a single screw for easy installation or removal by the user. Solder pins are provided for electrical connection of an easily replaced nine-conductor cable. Both side and top cable entry holes are provided. Accessories include a 10 ft. (3.05 m) cable and a mounting base. Sensors, housing and cable clamp are available as replacement components.



ENDEVCO Model 136 Three-Channel System, Model 4430A or OASIS 2000 Computer-Controlled System are recommended as signal conditioner and power supply.

SPECIFICATIONS

PERFORMANCE CHARACTERISTICS: All values are typical at 75°F (+24°C), 100 Hz and 10 Vdc excitation unless otherwise specified. Calibration data, traceable to the National Institute of Standards (NIST), is supplied.

	Units	7267A
RANGE	g pk	±1500
SENSITIVITY (at 100 Hz)	mV/g Typ	0.15
	(Min)	(0.10)
AMPLITUDE RESPONSE [1] [2]		
±5% (X and Y Axis)	Hz	0 to 1200
±5% (Z Axis)	Hz	0 to 2000
±1dB (X and Y Axis)	Hz	0 to 1600
±1dB (Z Axis)	Hz	0 to 2700
MOUNTED RESONANCE FREQUENCY [1]	Hz Typ	14 000
	(Min)	(10 000)
DAMPING RATIO		0.005
NON-LINEARITY AND HYSTERESIS (% of reading, to full range)	% Max	±2

ENDEVCO
MODEL
7267A

Piezoresistive Accelerometer

SPECIFICATIONS—continued

PERFORMANCE CHARACTERISTICS—continued	Units	7267A
TRANSVERSE SENSITIVITY [3]	% Max	3
ZERO MEASURAND OUTPUT	mV Max	±25
THERMAL ZERO SHIFT [4]		
From -10°F to +150°F (-23°C to +66°C)	mV Max	±15
THERMAL SENSITIVITY SHIFT		
At -10°F and +150°F (-23°C and +66°C)	% Typ	± 3
WARM-UP TIME	Minutes Max	2

ELECTRICAL	
EXCITATION [5] [6]	10.0 Vdc, 15 Vdc maximum
INPUT RESISTANCE [5] [7]	1000 ohms
INSULATION RESISTANCE	100 megohms minimum at 100 Vdc; pin to case

PHYSICAL	
CASE, MATERIAL	Stainless Steel
ELECTRICAL, CONNECTIONS [8]	Integral cable, nine conductor No. 32 AWG, Teflon® insulated leads, braided shield, silicone rubber jacket
IDENTIFICATION	Manufacturer's logo, model number and serial number
MOUNTING/TORQUE	Holes for two 4-40 mounting screws/6 lbf-in (0.7 Nm)
WEIGHT	50 grams

ENVIRONMENTAL	
ACCELERATION LIMITS (in any direction)	
Static	4000 g
Sinusoidal Vibration	1000 g pk below 2000 Hz
Shock (half-sine pulse) [1]	4000 g, 500 µsec or longer
TEMPERATURE	
Operating	-10°F to +150°F (-23°C to +66°C)
Storage	-100°F to +300°F (-73°C to +149°C)
HUMIDITY	Unaffected. Individual sensors are hermetically sealed.
ALTITUDE	Unaffected

CALIBRATION DATA SUPPLIED (X, Y and Z axes)	
SENSITIVITY (at 100 Hz and 10 g pk)	mV/g
FREQUENCY RESPONSE	100-2000 Hz, Z axis, 100-1200 Hz, X & Y axis
ZERO MEASURAND OUTPUT	mV
MAXIMUM TRANSVERSE SENSITIVITY	% of sensitivity
INPUT RESISTANCE	Ohms

ACCESSORIES

23699 CABLE, 10 FT. (3.0 M). CABLE IS FACTORY-INSTALLED THROUGH TOP ENTRY. SIDE ENTRY ON SPECIAL ORDER.
23700 CABLE CLAMP
23898 MOUNTING BASE

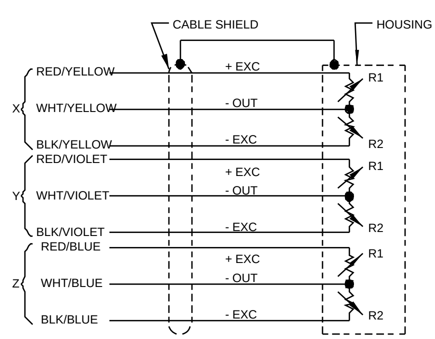
OPTIONAL ACCESSORIES

23937 HOUSING
24236 SENSOR (INCLUDES INSTALLATION HARDWARE KIT
24356)
2974M1 TRIAXIAL CALIBRATION FIXTURE X-Y AXIS
2974M2 TRIAXIAL CALIBRATION FIXTURE Z AXIS ONLY

NOTES

1. In shock measurements, minimum pulse duration for half sine or triangular pulses should exceed 0.25 milliseconds to avoid excessive high frequency ringing.
2. Mounting is in the Z axis. It is normal for accelerometers with multi-axes to have reduced frequency response performance in the axes perpendicular to the mounting.
3. Transverse sensitivity is factory adjusted to be less than 3% before shipment. Replacement sensors must be measured and adjusted to ensure comparable performance.
4. Thermal Zero Shift millivolts specified are at -10°F/+150°F (-23°C/+66°C), reference 75°F (24°C).
5. Rated excitation is 10.0 Vdc. The strain gage elements have a positive temperature coefficient of resistance of approximately 0.5% per °F. Power supply current regulation capability should be carefully considered when operating at low temperature extremes.
6. Other excitation voltages may be used to 15.0 Vdc. Specify at time of order to obtain a more accurate calibration.
7. Half-bridge input resistance measured across the excitation leads. It does not include external bridge completion resistance. Measured at approximately 1 Vdc. Bridge resistance increases with applied voltage due to heat dissipation in the strain gage elements.
8. Three pin solder terminations on each of three recessed surfaces. Cable entry holes for either side or top cable entry.
9. Maintain high levels of precision and accuracy using Endevco's factory calibration services. Call Endevco's inside sales force at 800-982-6732 for recommended intervals, pricing and turn-around time for these services as well as for quotations on our standard products.

NOTE: Tighter specifications available on special order.



SCHEMATIC

ENDEVCO CORPORATION, 30700 RANCHO VIEJO ROAD, SAN JUAN CAPISTRANO, CA 92675 USA (800) 982-6732 (949) 493-8181 fax (949) 661-7231
www.endevco.com Email:applications@endevco.com
1100

C.2 LOAD CELL SPECIFICATION

Force – FMD

KISTLER

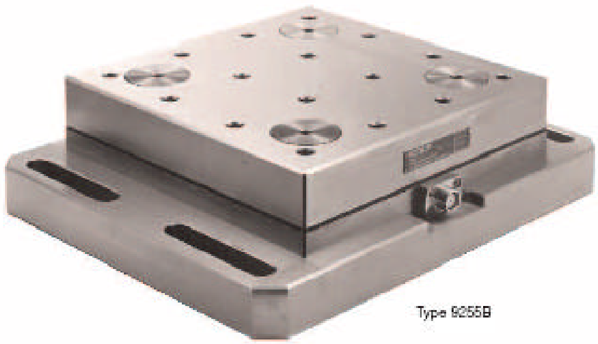
3-Komponenten-Dynamometer F_x, F_y, F_z
Dynamomètre à 3 composantes F_x, F_y, F_z
3-Component Dynamometer F_x, F_y, F_z

9255B

Quarzkristall-Dreikomponenten-Dynamometer zum Messen der drei orthogonalen Komponenten einer Kraft. Das Dynamometer besitzt eine grosse Steifheit und demzufolge eine hohe Eigenfrequenz. Das grosse Auflösungsvermögen ermöglicht das Messen von kleinsten dynamischen Änderungen grosser Kräfte.

Dynamomètre à cristal de quartz à trois composantes pour mesurer des trois composantes orthogonales d'une force. Le dynamomètre possède une grande rigidité et par conséquent une fréquence propre élevée. Sa très haute résolution permet de mesurer les moindres variations de larges forces.

Quartz three-component dynamometer for measuring the three orthogonal components of a force. The dynamometer has a great rigidity and consequently a high natural frequency. Its high resolution enables the smallest dynamic changes in large forces to be measured.



Type 9255B

Technische Daten	Données techniques	Technical Data			
Bereich	Gamme	Range	F_x, F_y F_z	kN kN	–20 ... 20 *) –10 ... 40 *)
Kalibrierter Teilbereich	Gamme partielle étalonnée	Calibrated partial range	F_x, F_y F_z	kN kN	0 ... 2 0 ... 4
Überlast	Surcharge	Overload	F_x, F_y F_z	kN kN	–24/24 –12/48
Ansprechschwelle	Seuil de réponse	Threshold		N	<0,01
Empfindlichkeit	Sensibilité	Sensitivity	F_x, F_y F_z	pC/N pC/N	≈–8 ≈–3,7
Linearität, alle Bereiche	Linéarité, toutes les gammes	Linearity, all ranges		% FSO	≤±1
Hysterese, alle Bereiche	Hystérésis, toutes les gammes	Hysteresis, all ranges		% FSO	≤0,5
Übersprechen	Cross talk	Cross talk		%	≤±2
Steifheit	Rigidité	Rigidity	c_x, c_y c_z	kN/µm kN/µm	>2 >3
Eigenfrequenz	Fréquence propre	Natural frequency	f_o (x, y, z)	kHz	≈3
Eigenfrequenz (montiert an Flanschen)	Fréquence propre (installé sur brides)	Natural frequency (mounted on flanges)	f_o (x, y) f_o (z)	kHz kHz	≈1,7 ≈2
Eigenfrequenz (montiert an Flanschen u. durch Deckplatte)	Fréquence propre (installé sur brides et à travers la plaque supérieure)	Natural frequency (mounted on flanges and through top plate)	f_o (x, y) f_o (z)	kHz kHz	≈2 ≈3,3
Betriebstemperaturbereich	Gamme de température d'utilisation	Operating temperature range		°C	0 ... 70
Temperaturkoeffizient der Empfindlichkeit	Coefficient de température de la sensibilité	Temperature coefficient of sensitivity		%/°C	–0,02
Kapazität (pro Kanal)	Capacité (de canal)	Capacitance (of channel)		pF	≈500
Isolationswiderstand (20 °C)	Résistance d'isolement (20 °C)	Insulation resistance (20 °C)		Ω	$>10^{13}$
Masseisolation	Isolé à la masse	Ground insulation		Ω	$>10^{8}$
Schutzart	Classe de protection	Protection class		–	IP 67 **)
Gewicht	Poids	Weight		kg	52

*) Kraftangriff innerhalb und max. 100 mm oberhalb der Deckfläche.
**) Mit Anschlusskabel Typen 1687B5, 1689B5

*) Point d'application de la force au-dedans et max. 100 mm au-dessus de la plaque supérieure.
**) Avec câble de connexion types 1687B5, 1689B5

*) Application of force inside and max. 100 mm above top plate area.
**) With connecting cable Types 1687B5, 1689B5

1 N (Newton) = 1 kg · m · s⁻² = 0,1019... kp = 0,2248... lbf; 1 inch = 25,4 mm; 1 kg = 2,2046... lb; 1 Nm = 0,73756... lbft

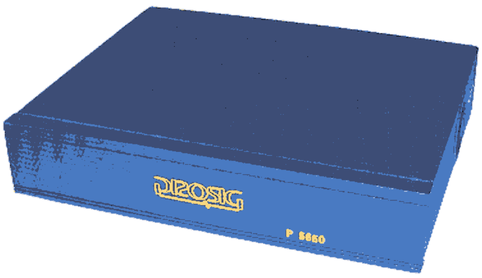
000-148m-02.91 (DB06.9255Bm)

C.3 DATA ACQUISITION INSTRUMENTATION

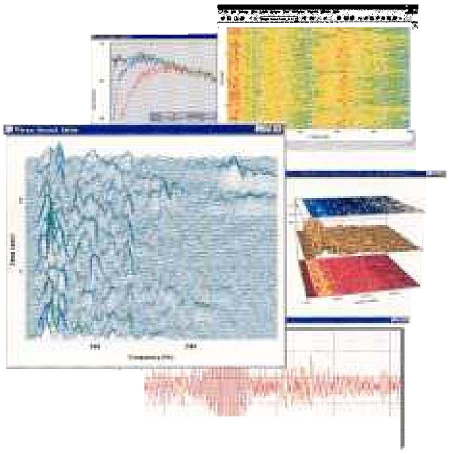
P5650

Product Refinement * NVH Sound Quality * Vehicle Dynamics
Chassis Refinement * Rotating Machinery Analysis * Steering
Transmission & Powertrain * Structural Animation * Signal Processing

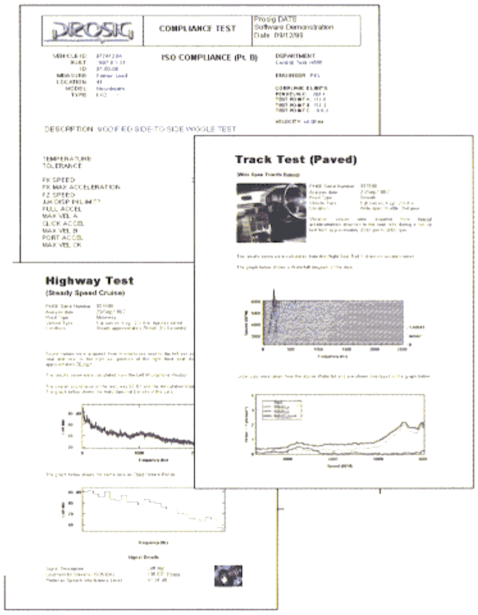
Capture



Analyze



Report



Product development has a constant pressure from markets demanding **new products**, **higher specifications** and **emphasis on cost**. The Prosig solution is a system that is **accurate**, **cost effective**, **expandable**, **simple to use** and **easy to transport**.

h a r d w a r e

The P5650 is a compact, 8-channel unit with industry standard BNC or Lemo connectors. The tough casing makes it ideal for mobile use and units can be stacked to expand the system up to 64 channels.

Internally there is comprehensive signal conditioning for voltage, ICP and optional strain gauge inputs with programmable amplifiers, anti-alias filters and transducer power all controlled by the DATS software.

Accurate high speed parallel 16-bit sampling from 250 samples/sec to 100000 samples/sec covers all requirements. Multi-band support enables synchronous measurement of low frequency vibration and high frequency acoustics and strain.

With a 12V DC power supply and only transducers to connect the integrated electronics of the P5650 guarantee high quality results every time.

s o f t w a r e

DATS software is fully integrated with the P5650 hardware and is available for Windows *95, 98, Me, 2000 and XP*. It includes acquisition, analysis and display of data acquired using the P5650.

Standard processing procedures allow signal manipulation, analysis and display. Signal and system analysis can be performed in the time and frequency domain.

Extensive interactive graphical tools and analysis automation provide an objective measurement system. This can be used by technical or non-technical personnel alike. Easily repeatable test results can be quickly compared with previous data.

The data processing is supported by extensive Q.A. tracking through data history recording, and the use of the integrated Project Manager.

specification

Software

Standard Functions

Graphical Functions
Display as:
- Data vs. time / frequency
- Data vs. data
- Real & imaginary
- Modulus & phase
- Modulus vs. phase (polar plot)
- Real vs. imaginary
- Numeric table
- 3D Isometric
- 3D Histogram
- Contour plot
- Waterfall plot
- Intensity (color) map

Line Styles
- Solid, dashed or dotted
- Line thickness
- Symbols
- Bars
- Steps
- Histogram

Set scales with:
- Graphical zoom (using mouse)
- Scroll bars
- Numeric value

Liner / logarithmic / time X Axes
Linear / logarithmic / dB Y Axes
Configure axis markings and annotation
Overlay graphs
Add text labels
Add legend
Select grid styles
- Axes
- Box
- Full grid

Set colors for
- Axes
- Annotation
- Curves
- Labels
- Grid and window fills

Autoscale

Data Acquisition Functions
Ready to use - no programming required
Spreadsheet style set-up
Set-up saved with data
Oscilloscope display (time & frequency)
Multi-channel (bar chart) display
Integrated signal calibration tools
Automatic gain ranging
Multi-channel runtime graphics for time, FFT and over-range
Automatic increment of filenames

Signal Generation
Sinewave
Damped sinewave
Swept sinewave
Modulated sinewave
Pulsed sinewave
Gaussian random
Rectangular random
Narrow band random
Square wave
Swept square wave
Triangle wave
Saw tooth
Exponential

Signal Import
ASCII
Binary
CSV
DASYLab
DIA / DIAdem
IOtech WaveView
nCode DAC
Racal Storeplex
RPC II/III
SDF
Universal file (UFF)
WAV

Signal Export
ASCII
Microsoft Excel
RPC-III
SDF
Universal File (UFF)
WAV

Cursor Functions
Data readout of real, imaginary, modulus and phase
Define "workzone" for analysis
Scale
Zoom
Pan

Arithmetic Operations
Data with data
Data with constant
Rectangular complex data with data
Rectangular complex data with constant
Polar complex data with data
Polar complex data with constant

Calculus
Differentiate
Integrate

Curve Fitting
Least squares polynomial
Smooth
Spline fit

Filtering
Alpha Beta
Bessel
Butterworth
Chebyshev
Notch
RC Filter

Frequency Analysis
Auto (Power) spectrum
Cepstrum
Coherence spectrum
Cross spectrum
dB Weighting
Weighting (A,B,C,D)
FFT (Forward & reverse)
Hopping FFT
Omega arithmetic
Third octave bands
RMS over frequency band
Autoregressive filter
Coefficients
Envelope (complex demodulation)
Envelope (Fourier)
Instantaneous frequency
Min. phase spectrum
Maximum entropy spectral estimate
Winograd transform
Zoom FFT & spectra

Maths Functions
Absolute
Arc tangent
Antilog
Cos
Cosh
Exponential
Log e
Log 10
Sin
Sinh
Square root
Tanh

Time Domain Analysis
ADC simulation
Auto/Cross correlation
Convolution in the time domain
Normalise
Threshold
Time reverse
Cosine taper function
Statistics
Signal decimation
Trend analysis
Bias removal
Trend removal
Probability analysis
Joint probability density function
Probability density function
Signal generation

Statistical Counting
Level counting
Mean crossing peak count
Modified Lambie range count
Net peak count
Peak and trough count
Rainflow counting

Optional Add-On Functions

Rotating Machinery
Waterfall analysis
Waterfall averaging
Order tracking

NVH
dB weighting
Sound quality
1/nth octave
Weighting (A, B, C & D)

Structural Animation
3D Surfaces and frames
Visualization of orders and spectra
Replay of operational deflections
Animated displays
Graphical overlays
Multiple sub-structures
Frequency sweeps
Point and drag rotation
Zoom and translation control
Animated Node labeling
Freeze-frame mode
Multiple view angles

Hammer Impact
FFT (Instantaneous & averaged)
Coherence
Transfer function (H1 & H2)
Signal quality checks

Audio Replay
Play DATS signal
Play WAV file
Repeat play with blend/smooth
Live cursor tracking

S.E.A.T.
ISO & EEC Limits
EM Spectrum

Biomechanics
Calculate resultant (x, y, z)
CFC60,180,600 & 1000 filter
Chest Severity Index
Deflection of dummy ribs
Exceedance duration
FIR100 filter
Head Injury Criterion
Bias removal
Thoracic Trauma Index
Viscus Criterion
Vibration quality measures
Building vibration assessment weighting
Human vibration
Motion sickness dose value (MSDV)
Vibration dose value (VDV)
Estimated dose value (eVDV)
Maximum transient vibration value (MTVV)
Root mean quad (RMQ) measure

Fatigue Analysis
Critical location analysis
Weld classification
SN fatigue curve generation
SN curve fatigue prediction

Hardware

System

Analogue Inputs	8 channels per unit
Expansion	Up to 64 channels using multiple units
Sampling rate	Up to 100k samples/sec per channel
Internal storage capacity	32 million samples
Split rate sampling	Two different sampling rates can run concurrently in separate channels
Programmability	All features under software control
Resolution	16 bit
Overall accuracy	± 0.10% full scale at gain < 1000
Non-linearity	Less than 1LSB
Sensitivity	(gain=1000) ±0.3μV(gain=1) ±0.3mV
Input voltage range	± 10V
Input impedance	10Mohm
Analogue over voltage protection	70V p-p
Communications	USB

Signal Conditioning

Signal inputs	Direct voltage ICP
Gain	1 to 8000
Anti-alias filter	Butterworth low pass, 48 dB / octave (160dB / decade)
Autozero	Signal autozero and amplifier autozero
DC offset control	± 5V in 1024 steps
ADC	16 bit ADC per channel

Environmental

Shock and Vibration	Suitable for mobile use (10g)
Operating temperature	0^oC to $+40^oC$ (32^oF to $+104^oF$)
Humidity	80% RH, non-condensing
Weight	3kg (6.6lbs)

General

Consumption	26W per 8 channel unit
Supply voltage	Choice of 10-17V DC (e.g. vehicle battery) or AC mains (adapter supplied)
Connectors	BNC
Dimensions	60 (H) x 300 (W) x 240(D) mm 2.4"(H) x 11.8"(W) x 9.4"(D)

P5650 Lemo Option

Transducer excitation	10V in 128 steps
Signal inputs	Direct voltage ICP Powered transducer (0-10V) Sensed excitation Powered triaxial transducer Strain gauge Quarter, half and full bridge option Internal bridge completion for 120ohm, 350ohm & 1000ohm bridges Internal & external shunt calibration

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Appendix D: Protocols

i) S0232/VF Test protocols

ii) S0232/VF Assessment protocols

TRL Limited
2005

TEST PROCEDURES FOR THE ASSESSMENT OF

MOTORCYCLE HELMET SAFETY PERFORMANCE

Final Draft. Issue 1.2

9 March 2006

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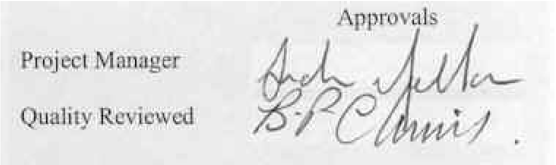
TRL Limited

TEST PROCEDURES FOR THE ASSESSMENT OF MOTORCYCLE HELMET SAFETY PERFORMANCE

A N Mellor

Prepared for: Project Record: S0232VF



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CONTENTS

FOREWORD

These test procedures are based on the test specification that was agreed during the workshop on future helmets and visors held in London on 21st November 2003. The test procedures take account of the recommendations reported by the European Co-operation in the Field of Scientific and Technical Research (COST 327) during 2001, together with the performance of an advanced helmet developed by TRL on behalf of the UK Department Transport within project S100L and the FIA 8860-2004 helmet specification.

The new test procedures will permit objective evaluation and comparison of the protection provided by a wide selection of motorcycle helmet models. The results may be published to provide consumers and end-users with an independent and objective assessment of the safety performance. Furthermore, it is intended that the new procedures will encourage significant improvements to the protection afforded by future helmet designs.

1. SCOPE

This document defines the test procedures for assessment of motorcycle helmet safety performance. The assessment protocols are presented in the document “Assessment Protocol for the Assessment of Motorcycle Helmet Safety Performance”.

The aim of the test procedures are to provide appropriate methodologies for the assessment of all Motorcycle helmet designs that are currently available in Europe. The procedures also aim to be appropriate for assessing advanced designs such as low friction and sliding membrane helmets.

2. MHAP TEST SCHEDULE

2.1 General

Each helmet model and size will be subjected to fifteen (15) tests as described below. The test results will be processed to determine a performance rating for each helmet model and size.

2.2 Helmet Sizes

Five sizes of each helmet model shall be tested, with the exception of surface friction and projection strength. These shall be size A (500mm), size E (540mm), size J (570mm), size M (600mm) and size O (620mm). Four helmet samples will be required in each size. Thus a total of twenty helmets are required for each helmet model.

2.3 Procurement of Test Samples

The helmets must be procured from an outlet or store which is chosen to ensure that the manufacture cannot influence the selection of test samples.

3. HELMET RECEIPT PROCESS

The helmet receipt process shall include the following tasks for each helmet model and size.

- digital photograph
- mass
- recording of all available manufacturer's data on test sample labels (serial number, batch number, date of manufacture, certification levels)
- tagging of helmet samples (both overtly and covertly) with a unique identification number

4. TEST PROCEDURES

Linear impact tests shall be conducted in accordance with the impact procedures of ECE Regulation 22-05, section 7, with the following selections or modifications.

- A twin-wire guided headform system fitted with a uni-axial accelerometer shall be used
- The equipment shall enable the measurement linear acceleration in accordance with SAE J211 CFC1000.
- The total mass of the headforms including the carriage shall conform to ECE Regulation 22-5 as follows. The mass of the carriage must not be greater than 1.5kg for all headform sizes.

Size A 500mm 3.1± 0.05kg
Size E 540mm 4.1± 0.05kg
Size J 570mm 4.7± 0.05kg
Size M 600mm 5.6± 0.05kg
Size O 620mm 6.1± 0.05kg

- The geometry of the headforms shall conform to BS6489 (EN960 or ISO DIS 6220) extending down at least to line H-H.
- The tolerance on impact velocity shall be +2% -0%.
- All impacts shall be located within Ø10mm of the test site defined by ECE R22-05.

4.1 Linear Impact Test – Low Speed
Flat Anvil - Front

- The helmet and headform will impact the flat anvil as specified by ECE Regulation 22-05
- The impact site shall be the front, point B, as defined by ECE Regulation 22-05.
- The impact velocity shall be 6.0m/s in accordance with COST 327

4.2 Linear Impact Test – Low Speed
Flat Anvil - Side

- The helmet and headform will impact the flat anvil as specified by ECE Regulation 22-05
- The impact site shall be the left temporal region, point X, as defined by ECE Regulation 22-05
- The impact velocity shall be 6.0m/s in accordance with COST 327

4.3 Linear Impact Test – Low Speed
Flat Anvil – Crown

- The helmet and headform will impact the flat anvil as specified by ECE Regulation 22-05
- The impact site shall be the crown region, point P, as defined by ECE Regulation 22-05
- The impact velocity shall be 6.0m/s in accordance with COST 327

4.4 Linear Impact Test – Low Speed
Flat Anvil - Rear

- The helmet and headform will impact the flat anvil as specified by ECE Regulation 22-05
- The impact site shall be the rear, point R, as defined by ECE Regulation 22-05
- The impact velocity shall be 6.0m/s in accordance with COST 327

4.5 Linear Impact Test – High Speed
Kerbstone Anvil - Front

- The helmet and headform will impact the kerbstone anvil as specified by ECE Regulation 22-05
- The impact site shall be the front, point B, as defined by ECE Regulation 22-05
- The impact velocity shall be 9.5m/s in accordance with FIA 8860-2004

4.6 Linear Impact Test – High Speed
Kerbstone Anvil - Side

- The helmet and headform will impact the kerbstone anvil as specified by ECE Regulation 22-05
- The impact site shall be the left temporal region, point X, as defined by ECE Regulation 22-05
- The impact velocity shall be 9.5m/s in accordance with FIA 8860-2004

4.7 Linear Impact Test – High Speed
Kerbstone Anvil - Crown

- The helmet and headform will impact the kerbstone anvil as specified by ECE Regulation 22-05
- The impact site shall be the crown region, point P, as defined by ECE Regulation 22-05
- The impact velocity shall be 9.5m/s in accordance with FIA 8860-2004

4.8 Linear Impact Test – High Speed
Kerbstone Anvil - Rear

- The helmet and headform will impact the kerbstone anvil as specified by ECE Regulation 22-05
- The impact site shall be the rear, point R, as defined by ECE Regulation 22-05
- The impact velocity shall be 9.5m/s in accordance with FIA 8860-2004

4.9 Linear Impact Test – High Speed
Flat Anvil - Front

- The helmet and headform will impact the flat anvil as specified by ECE Regulation 22-05
- The impact site shall be the front, point B, as defined by ECE Regulation 22-05
- The impact velocity shall be 9.5m/s in accordance with FIA 8860-2004

4.10 Linear Impact Test – High Speed
Flat Anvil - Side

- The helmet and headform will impact the flat anvil as specified by ECE Regulation 22-05
- The impact site shall be the left temporal region, point X, as defined by ECE Regulation 22-05
- The impact velocity shall be 9.5m/s in accordance with FIA 8860-2004

4.11 Linear Impact Test – High Speed
Flat Anvil - Crown

- The helmet and headform will impact the flat anvil as specified by ECE Regulation 22-05
- The impact site shall be the crown region, point P, as defined by ECE Regulation 22-05
- The impact velocity shall be 9.5m/s in accordance with FIA 8860-2004

4.12 Linear Impact Test – High Speed
Flat Anvil - Rear

- The helmet and headform will impact the flat anvil as specified by ECE Regulation 22-05
- The impact site shall be the rear, point R, as defined by ECE Regulation 22-05
- The impact velocity shall be 9.5m/s in accordance with FIA 8860-2004

4.13 Surface Friction Test
'Guided' Method A – Left Side
The surface friction test shall be conducted in accordance with the procedures of ECE Regulation 22-05 (section 7.4.1), with the following selections or modifications. The test will be conducted with helmet sizes appropriate for the size J headform only and the results will be applicable to all helmet sizes.

- The helmet shall be guided onto the impact anvil and released immediately before impact
- The impact site shall be the left side of the helmet within the test area defined by ECE Regulation 22-05
- The impact direction shall be such that the helmet is moving backwards immediately before the impact
- The equipment shall enable the measurement of both normal and tangential forces at the impact surface in accordance with SAE J211 CFC1000.

4.14 Surface Friction Test
'Guided' Method A – Right Side
The surface friction test shall be conducted in accordance with the procedures of ECE Regulation 22-05 (section 7.4.1), with the following selections or modifications. The test will be conducted with helmet sizes appropriate for the size J headform only and the results will be applicable to all helmet sizes.

- The helmet shall be guided onto the impact anvil and released immediately before impact
- The impact site shall be the right side of the helmet within the test area defined by ECE Regulation 22-05
- The impact direction shall be such that the helmet is moving forward immediately before the impact

- The equipment shall enable the measurement of both normal and tangential forces at the impact surface in accordance with SAE J211 CFC1000.

4.15 Projection Strength Test – For Motor Sport Applications Only

'Guided' Method A

The projection strength test shall be conducted in accordance with the procedures of ECE Regulation 22-05 (section 7.4.1) Method A, with the following selections or modifications. The test will be conducted with helmet sizes appropriate for the size J headform only and the results will be applicable to all helmet sizes.

- The helmet shall be guided onto the impact anvil and released immediately before impact
- As many tests as necessary shall be conducted in order to evaluate ALL notable features such as visor fittings, screws, press studs, steps in the shell surface.
- The impact direction shall be such that the helmet is moving forwards immediately before the impact if this is appropriate. If this direction is not appropriate, any appropriate direction may be chosen.

Table 1. Summary of test specification and recommended test sequence

Test number	Test sequence	Test type	Helmet number	Test site
4.1	1	6m/s Impact – Flat	1	Front
4.2	2	6m/s Impact – Flat	1	Side L
4.3	3	6m/s Impact – Flat	1	Crown
4.4	4	6m/s Impact – Flat	1	Rear
4.5	5	9.5m/s Impact – Kerbstone	2	Front
4.6	6	9.5m/s Impact – Kerbstone	2	Side L
4.7	7	9.5m/s Impact – Kerbstone	2	Crown
4.8	8	9.5m/s Impact – Kerbstone	2	Rear
4.9	9	9.5m/s Impact – Flat	3	Front
4.10	10	9.5m/s Impact – Flat	3	Side L
4.11	11	9.5m/s Impact – Flat	3	Crown
4.12	12	9.5m/s Impact – Flat	3	Rear
4.13	13	Surface friction	4	Left
4.14	14	Surface friction	4	Right
4.15	15+	Projection Strength	4	All features

5. RESULTS

5.1 The results for each helmet model and size will be presented in a colour A4 sheet, to include the following information:

1. Pre-test photograph of the helmet
2. Make, model, type, size (mm), mass (g), approval standards and approval country
3. Image (photograph of drawing) of the test apparatus
4. acceleration history (g,ms) for each of tests 1 to 12 showing peak g and HIC
5. acceleration vs displacement (g, mm) for each of tests 1 to 12
6. Force history, normal and tangential, (N,ms) for each of tests 13 to 14 showing peak normal and tangential force
7. * Force history, normal and tangential, (N,ms) for all tests in series 15 showing peak normal and tangential force

* Motor Sport applications only

5.2 The ASC data for each test, filtered at CFC1000, will be required for the analysis prescribed by the document “Assessment Protocol for the Assessment of Motorcycle Helmet Safety Performance”.

APPENDIX A. TEST EQUIPMENT

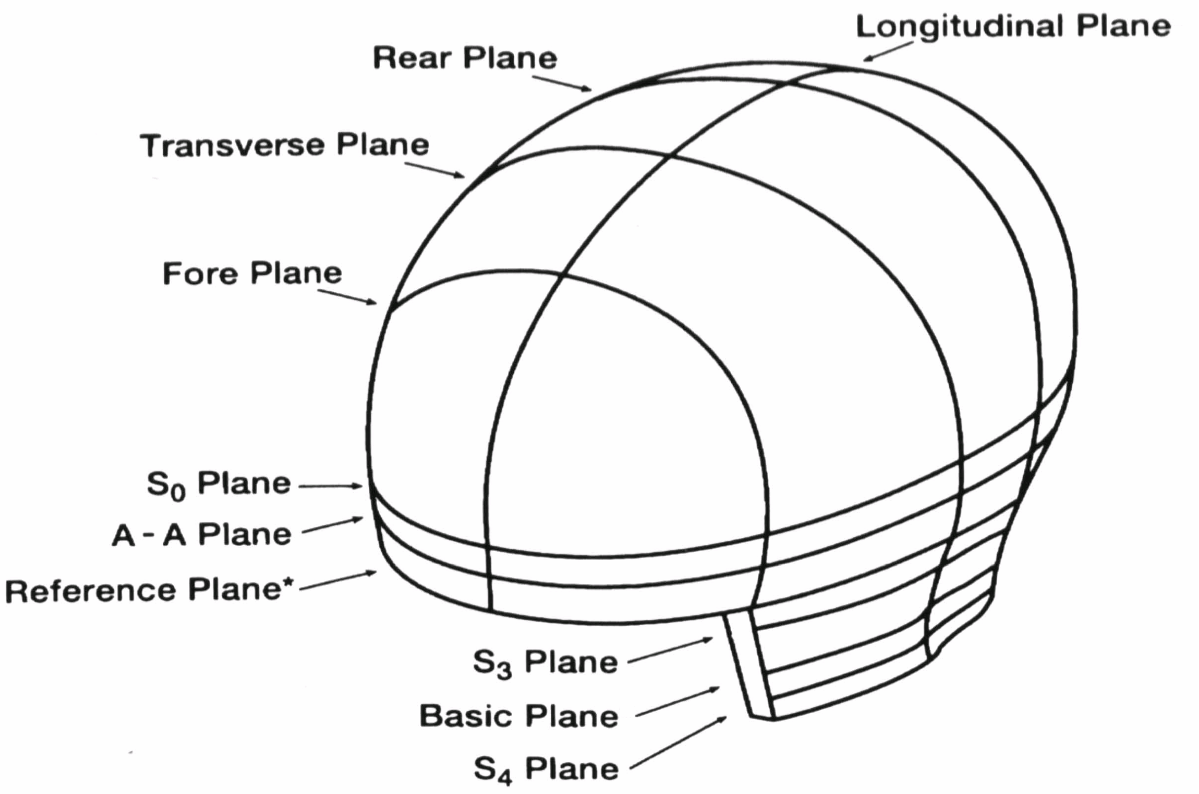

Figure A1. ISO DIS 6220 test headform

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ASSESSMENT PROTOCOL FOR

MOTORCYCLE HELMET SAFETY PERFORMANCE

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ASSESSMENT PROTOCOL FOR

MOTORCYCLE HELMET SAFETY PERFORMANCE

A N Mellor

Prepared for: **Project Record: S0232VF**

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CONTENTS

FOREWORD

The test procedures which accompany this assessment protocol are based on the test specification that was agreed during the workshop on future helmets and visors held in London on 21st November 2003. The procedures take account of the recommendations reported by the European Co-operation in the Field of Scientific and Technical Research (COST 327) during 2001, together with the performance of an advanced helmet developed by TRL on behalf of the UK Department for Transport within project S100L/VF and the FIA 8860-2004 helmet specification.

The new test procedures and assessment protocol will permit objective evaluation and comparison of the protection provided by a wide selection of motorcycle helmet models. The results may be published to provide consumers and end-users with an independent and objective assessment of the safety performance. Furthermore, it is intended that the new procedures will encourage significant improvements to the protection afforded by future helmet designs.

A safe helmet must provide good protection during both high severity and low severity impacts. The risk of injury increases rapidly with impact severity, but the exposure reduces significantly, and the vast majority of head impacts cause slight or moderate rather than serious or fatal injuries. Thus, whilst striving to improve protection during severe accidents, great care must be taken not to worsen the situation during the less severe accidents. Although the risk of injury during less severe accidents may be low, due to the large exposure, even a small risk could result in many numbers of riders being seriously or fatality injured.

For the purpose of this assessment, the injury risk function is based on COST 327 data but takes account of other relevant published data. The exposure data is based on RAGB 2001 which corresponds closely to the time of the COST 327 action.

This protocol enables the performance of a helmet to be determined with respect to a broad range of accident conditions and severities, and the Final Assessment corresponds to the number of fatalities that may occur, each year, on UK roads, if all riders and pillion passengers wore such helmets.

1. SCOPE

This document defines the assessment protocol for determining the performance ratings of helmets that have been subjected to tests as defined by the "TEST PROCEDURES FOR THE ASSESSMENT OF MOTORCYCLE HELMET SAFETY PERFORMANCE". The protocol has been developed by the Transport Research Laboratory on behalf of the United Kingdom Department for Transport.

2. MHAP TEST SCHEDULE

2.1 General

Each helmet model and size will be subjected to fourteen (14) tests as described in the Test Procedures for Assessment of Motorcycle Helmet Safety Performance. The test results will be processed to determine a performance rating for each helmet model and size.

2.3 Procurement of Test Samples

The helmets must be procured from an outlet or store which is chosen to ensure that the manufacture cannot influence the selection of test samples.

3. ASSESSMENT

3.1 General

Each helmet model and size will be subjected to fourteen (14) tests including linear impacts at 6m/s, linear impacts at 9.5m/s and surface friction tests. The test results will be assessed, as detailed in section 4, to determine a performance rating for each given test. The overall assessment rating for each helmet model and size will be calculated as detailed in section 5.

3.2 Helmet Sizes

[Three] sizes of each helmet model (Small-540mm, Medium-570mm and Large-600mm) shall be evaluated in all of the tests with the exception of the Surface Friction tests which shall be conducted on size Medium-570mm only and the results shall be applicable to all sizes.

4. ASSESSMENT PROTOCOL

4.1 Test Results

In accordance with the Test Specification, the following tests will be conducted on each helmet model.

Table 1. Test Matrix

Test number	Test type	Test site
1	6m/s Impact – Flat	Front
2	6m/s Impact – Flat	Side L
3	6m/s Impact – Flat	Crown
4	6m/s Impact – Flat	Rear
5	9.5m/s Impact – Kerbstone	Front
6	9.5m/s Impact – Kerbstone	Side L
7	9.5m/s Impact – Kerbstone	Crown
8	9.5m/s Impact – Kerbstone	Rear
9	9.5m/s Impact – Flat	Front
10	9.5m/s Impact – Flat	Side L
11	9.5m/s Impact – Flat	Crown
12	9.5m/s Impact – Flat	Rear
13	Surface friction	Left
14	Surface friction	Right

4.2 Peak acceleration as function of impact velocity

For each linear impact test (tests 1 to 12), the acceleration history data shall be processed, by integration, with respect to displacement rather than time, to generate the peak acceleration (g) as a continual function of velocity (m/s) from 0m/s to the actual impact velocity. These results shall be presented in graphical form - an example is presented in Figure 1 and a flow chart demonstrating the methodology is provided in Figure 2.

4.3 Peak acceleration for each accident severity (Linear Impact)
Module 1 defines six accident severities in terms an equivalent test speed. The equivalent test speed represents the normal impact velocity during a laboratory test onto a rigid anvil.

With reference to 4.2, for each helmet site (front, side, crown and rear) and each impact anvil (flat and kerb), the maximum acceleration shall be determined for each accident severity as follows:

Note: for equivalent test speeds of 9.5m/s, the actual results from the 9.5m/s tests shall be used.

Table 2. Impact Anvil - Flat

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Flat anvil equivalent test speed [m/s]	3.2	5.0	6.6	7.9	8.8	9.5
Maximum acceleration – front (g)	F1	F2	F3	F4	F5	F6
Maximum acceleration – side (g)	F7	F8	F9	F10	F11	F12
Maximum acceleration – crown (g)	F13	F14	F15	F16	F17	F18
Maximum acceleration – rear (g)	F19	F20	F21	F22	F23	F24

Table 3. Impact Anvil - Kerb

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Kerb anvil equivalent test speed [m/s]	3.7	5.4	6.8	8.3	9.0	9.5
Maximum acceleration – front (g)	K1	K2	K3	K4	K5	K6
Maximum acceleration – side (g)	K7	K8	K9	K10	K11	K12
Maximum acceleration – crown (g)	K13	K14	K15	K16	K17	K18
Maximum acceleration – rear (g)	K19	K20	K21	K22	K23	K24

Table 4. Impact Anvil – Flat (data from linear impacts to be used for oblique assessment)

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Flat anvil equivalent test speed [m/s]	2.7	4.0	5.2	7.0	8.1	9.5
Maximum acceleration – front (g)	A1	A2	A3	A4	A5	A6
Maximum acceleration – side (g)	A7	A8	A9	A10	A11	A12
Maximum acceleration – crown (g)	A13	A14	A15	A16	A17	A18
Maximum acceleration – rear (g)	A19	A20	A21	A22	A23	A24

4.4 Helmet coefficient of friction during oblique impact
The results from the surface friction tests 13 and 14 shall be processed to determine the effective coefficient of friction, for each test, as follows:

(i) The peak normal force shall be determined F_normal_max

(ii) The coefficient of friction (ie the tangential force divided by the normal force) shall be calculated for all values where the normal force exceeds 0.7* F_normal_max.

(iii) The average value of the coefficient of friction shall be calculated for the cumulative period during which the normal force exceeds 0.7* F_normal_max.

The two results will be referred to as COF1 and COF2.
The average of these two results $COF_{average} = (COF1+COF2)/2$

4.5 Peak acceleration for each accident severity (Oblique Impact)

The peak resultant linear acceleration for each accident severity, during oblique impacts, shall be calculated as follows, thus giving the results in table 5. A_N represents the normal component of the impact acceleration.

$O_N = A_N x \sqrt{}(1+COF_{average}\hat{}2)$
For all values of N from 1 to 24.

ie:
$O1 = A1 \times \sqrt{}(1+COF_{average}\hat{}2)$
$O2 = A2 \times \sqrt{}(1+COF_{average}\hat{}2)$
$O3 = A3 \times \sqrt{}(1+COF_{average}\hat{}2)$ … etc

Table 5. Impact Anvil – Oblique

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Maximum acceleration – front (g)	O1	O2	O3	O4	O5	O6
Maximum acceleration – side (g)	O7	O8	O9	O10	O11	O12
Maximum acceleration – crown (g)	O13	O14	O15	O16	O17	O18
Maximum acceleration – rear (g)	O19	O20	O21	O22	O23	O24

4.6 Injury risk for each accident severity (Linear and Oblique Impact)

Module 2 defines the risk of head injury with respect to head linear acceleration. The risk of injury shall be calculated for each result F1 to F24, K1 to K24 and O1 to O24 as follows, thus giving the results in tables 6, 7 and 8.

R_F_N = risk associated with acceleration F_N with reference to Module 2
For all values of N from 1 to 24

R_K_N = risk associated with acceleration K_N with reference to Module 2
For all values of N from 1 to 24

R_O_N = risk associated with acceleration O_N with reference to Module 2
For all values of N from 1 to 24

Table 6. Injury Risk – Linear impact, Flat Anvil

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Injury risk – front %	R_F1	R_F2	R_F3	R_F4	R_F5	R_F6
Injury risk – side %	R_F7	R_F8	R_F9	R_F10	R_F11	R_F12
Injury risk – crown %	R_F13	R_F14	R_F15	R_F16	R_F17	R_F18
Injury risk – rear %	R_F19	R_F20	R_F21	R_F22	R_F23	R_F24

Table 7. Injury Risk – Linear impact, Kerb Anvil

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**

Injury risk – front %	R_K1	R_K2	R_K3	R_K4	R_K5	R_K6
Injury risk – side %	R_K7	R_K8	R_K9	R_K10	R_K11	R_K12
Injury risk – crown %	R_K13	R_K14	R_K15	R_K16	R_K17	R_K18
Injury risk – rear %	R_K19	R_K20	R_K21	R_K22	R_K23	R_K24

Table 8. Injury Risk – Oblique Impact, Flat anvil

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Injury risk – front %	R_O1	R_O2	R_O3	R_O4	R_O5	R_O6
Injury risk – side %	R_O7	R_O8	R_O9	R_O10	R_O11	R_O12
Injury risk – crown %	R_O13	R_O14	R_O15	R_O16	R_O17	R_O18
Injury risk – rear %	R_O19	R_O20	R_O21	R_O22	R_O23	R_O24

4.7 Injury number for each accident severity (Linear and Oblique Impact)

Module 3 defines the exposure for each accident severity. The injury number shall be determined by multiplying the injury risk values by the exposure values as follows, thus giving the results in tables 9, 10 and 11.

$N\_F_{N} = R\_F_{N}$ x exposure
For all values of N from 1 to 24

$N\_K_{N} = N\_K_{N}$ x exposure
For all values of N from 1 to 24

$N\_O_{N} = R\_O_{N}$ x exposure
For all values of N from 1 to 24

Where exposure =	4089	for N = 1,7,13,19
	2193	for N = 2,8,14,20
	452	for N = 3,9,15,21
	493	for N = 4,10,16,22
	492	for N = 5,11,17, 23
	21	for N = 6,12,18,24

Table 9. Injury Number – Linear impact, Flat Anvil

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Injury number – front %	N_F1	N_F2	N_F3	N_F4	N_F5	N_F6
Injury number – side %	N_F7	N_F8	N_F9	N_F10	N_F11	N_F12
Injury number – crown %	N_F13	N_F14	N_F15	N_F16	N_F17	N_F18
Injury number – rear %	N_F19	N_F20	N_F21	N_F22	N_F23	N_F24

Table 10. Injury Number – Linear Impact, Kerb Anvil

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Injury number – front %	N_K1	N_K2	N_K3	N_K4	N_K5	N_K6
Injury number – side %	N_K7	N_K8	N_K9	N_K10	N_K11	N_K12
Injury number – crown %	N_K13	N_K14	N_K15	N_K16	N_K17	N_K18
Injury number – rear %	N_K19	N_K20	N_K21	N_K22	N_K23	N_K24

Table 11. Injury Number – Oblique Impact, Flat anvil

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Injury number – front %	N_O1	N_O2	N_O3	N_O4	N_O5	N_O6
Injury number – side %	N_O7	N_O8	N_O9	N_O10	N_O11	N_O12
Injury number – crown %	N_O13	N_O14	N_O15	N_O16	N_O17	N_O18
Injury number – rear %	N_O19	N_O20	N_O21	N_O22	N_O23	N_O24

4.8 Weighting for impact site

Module 4 defines the distribution of impacts with regard to helmet location. The weighted average injury number shall be calculated as follows, thus giving the results in tables 12, 13 and 14.

N_F(1) = 0.236 x N_F1 + 0.532 x N_F7 + 0.022 x N_F13 + 0.21 x N_F19
N_F(2) = 0.236 x N_F1 + 0.532 x N_F8 + 0.022 x N_F14 + 0.21 x N_F20
N_F(3) = 0.236 x N_F3 + 0.532 x N_F9+ 0.022 x N_F15 + 0.21 x N_F21
N_F(4) = 0.236 x N_F4 + 0.532 x N_F10 + 0.022 x N_F16 + 0.21 x N_F22
N_F(5) = 0.236 x N_F5 + 0.532 x N_F11 + 0.022 x N_F17 + 0.21 x N_F23
N_F(6) = 0.236 x N_F6 + 0.532 x N_F12 + 0.022 x N_F18 + 0.21 x N_F24

N_K(1) = 0.236 x N_K1 + 0.532 x N_K7 + 0.022 x N_K13 + 0.21 x N_K19
N_K(2) = 0.236 x N_K1 + 0.532 x N_K8 + 0.022 x N_K14 + 0.21 x N_K20
N_K(3) = 0.236 x N_K3 + 0.532 x N_K9+ 0.022 x N_K15 + 0.21 x N_K21
N_K(4) = 0.236 x N_K4 + 0.532 x N_K10 + 0.022 x N_K16 + 0.21 x N_K22
N_K(5) = 0.236 x N_K5 + 0.532 x N_K11 + 0.022 x N_K17 + 0.21 x N_K23
N_K(6) = 0.236 x N_K6 + 0.532 x N_K12 + 0.022 x N_K18 + 0.21 x N_K24

N_O(1) = 0.236 x N_O1 + 0.532 x N_O7 + 0.022 x N_O13 + 0.21 x N_O19
N_O(2) = 0.236 x N_O1 + 0.532 x N_O8 + 0.022 x N_O14 + 0.21 x N_O20
N_O(3) = 0.236 x N_O3 + 0.532 x N_O9+ 0.022 x N_O15 + 0.21 x N_O21
N_O(4) = 0.236 x N_O4 + 0.532 x N_O10 + 0.022 x N_O16 + 0.21 x N_O22
N_O(5) = 0.236 x N_O5 + 0.532 x N_O11 + 0.022 x N_O17 + 0.21 x N_O23
N_O(6) = 0.236 x N_O6 + 0.532 x N_O12 + 0.022 x N_O18 + 0.21 x N_O24

Table 12. Injury Number – Flat Anvil

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Injury number – weighted average	N_F(1)	N_F(2)	N_F(3)	N_F(4)	N_F(5)	N_F(6)

Table 13. Injury Number – Kerb Anvil

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Injury number – weighted average	N_K(1)	N_K(2)	N_K(3)	N_K(4)	N_K(5)	N_K(6)

Table 14. Injury Number – Oblique Impact

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Injury number – weighted average	N_O(1)	N_O(2)	N_O(3)	N_O(4)	N_O(5)	N_O(6)

4.9 Weighting for impact surface

Module 5 defines the distribution of impacts with regard to impact surface. The final injury numbers shall be calculated for each accident severity as follows, thus giving the results in table 15.

N(x) = 0.384 x N_F(x) + 0.016 x N_K(x) + 0.60 x N_O(x)
For all values of x from 1 to 6

Table 15. Injury Number – Final

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Injury number – weighted average	N(1)	N(2)	N(3)	N(4)	N(5)	N(6)

4.10 Final Assessment

The Final Assessment for each helmet model and size shall be calculated by summing the six injury number scores as follows.

Final Assessment = N(1) + N(2) + N(3) + N(4) + N(5) + N(6)

5. PERFORMANCE RATING

The Final Assessment corresponds to the number of fatalities that may occur, each year, on UK roads, if all riders and pillion passengers wore such helmets. The results for a size medium R22-05 helmet may be considered to be baseline, thus, lower values represent lives that may be saved and higher values represent lives that may be lost.

The Final Assessment may be simplified, for instance, by using a 5 star Performance Rating as for Euro-NCAP, in which case the transfer function from the Final Assessment to the Performance Rating may be chosen to appropriately represent the range of protection provided by the helmets within the Consumer Testing Programme. This will be further discussed during the next phase of the CIS programme.

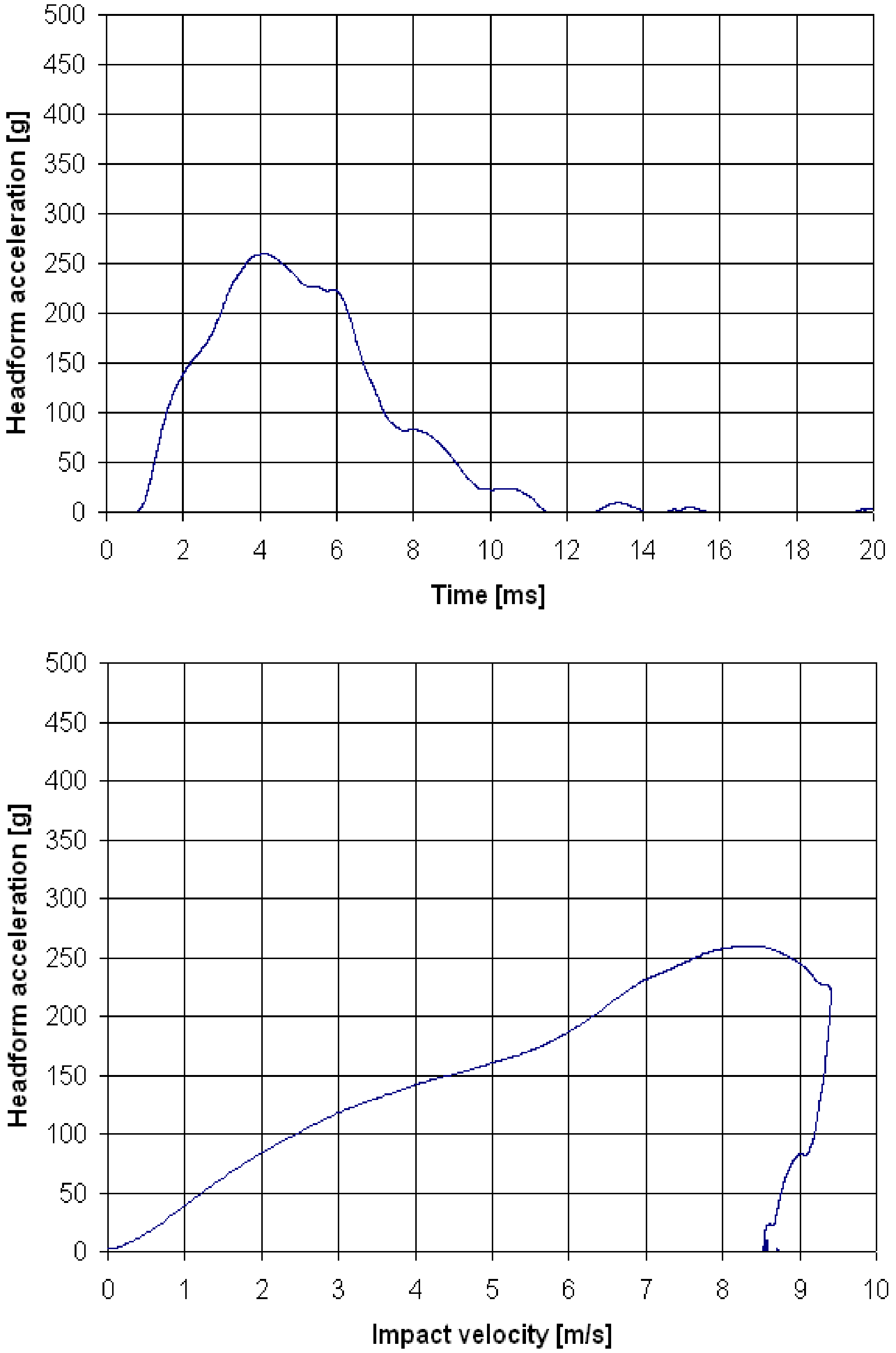

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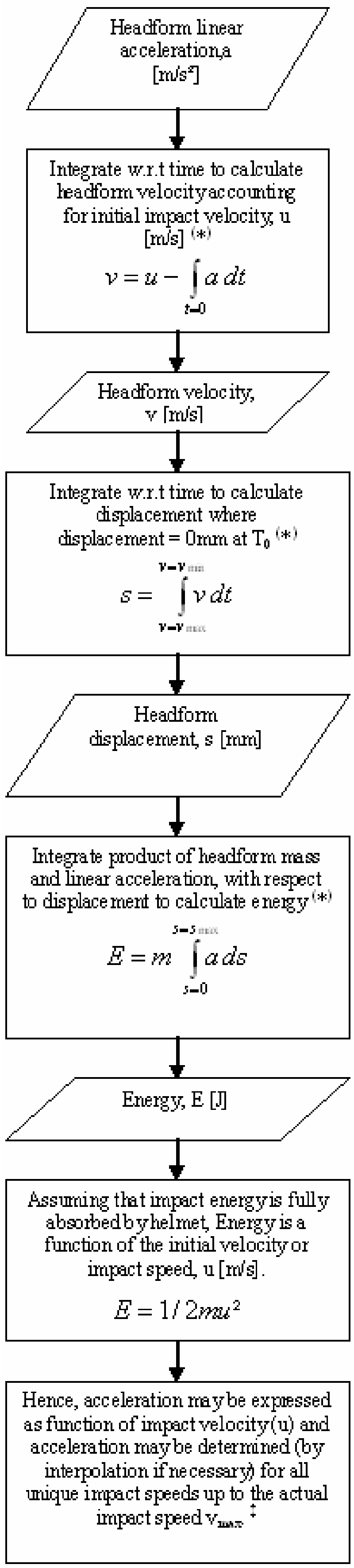
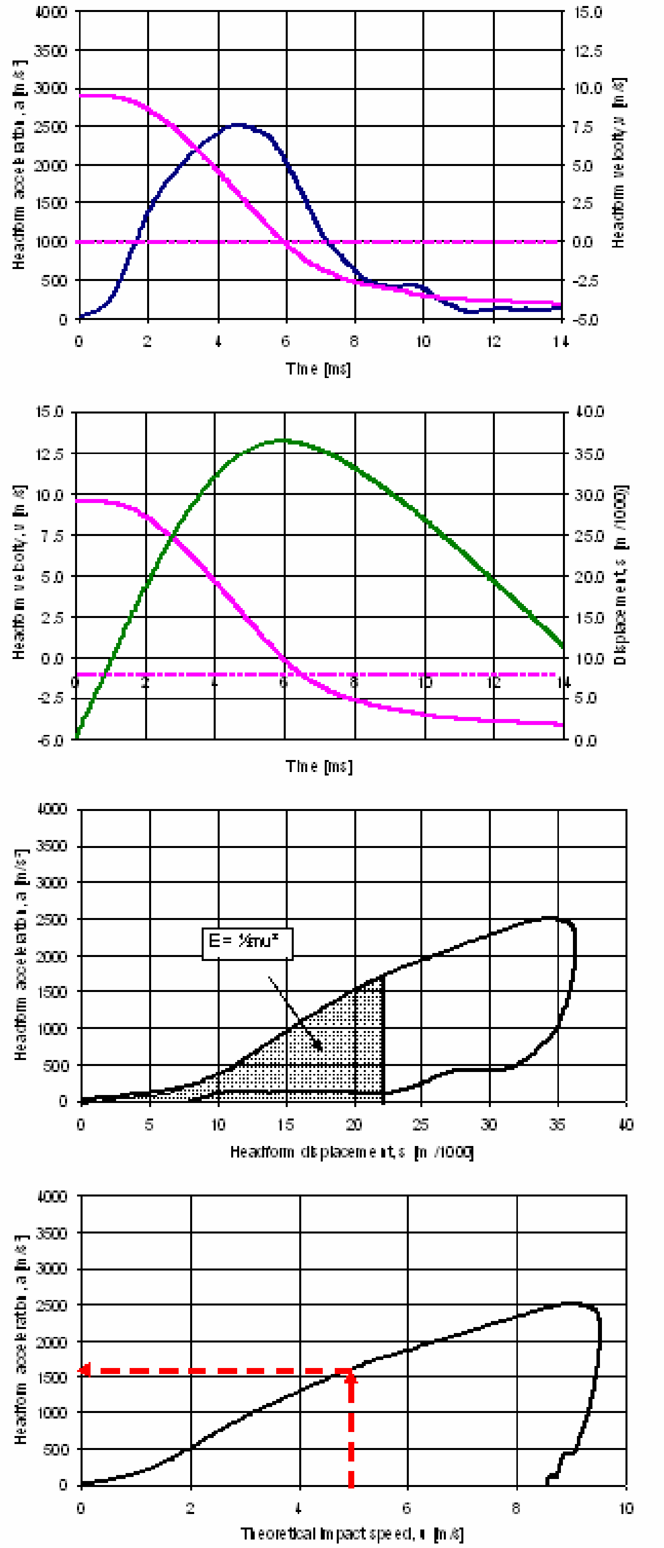
Figure 1 Graphical results showing

(i) acceleration history

(ii) acceleration vs impact velocity





(*) Numerical integration can be performed using the composite trapezoidal rule approximation method. An interval of 1/f should be used for instrumentation data of a minimum sampling frequency f.

‡ Differences will exist between the acceleration calculated at theoretical impact speeds and those measured in actual tests with the same speed.

Figure 2. Flow chart for integration calculation

MODULE 1. EQUIVALENT TEST SPEED

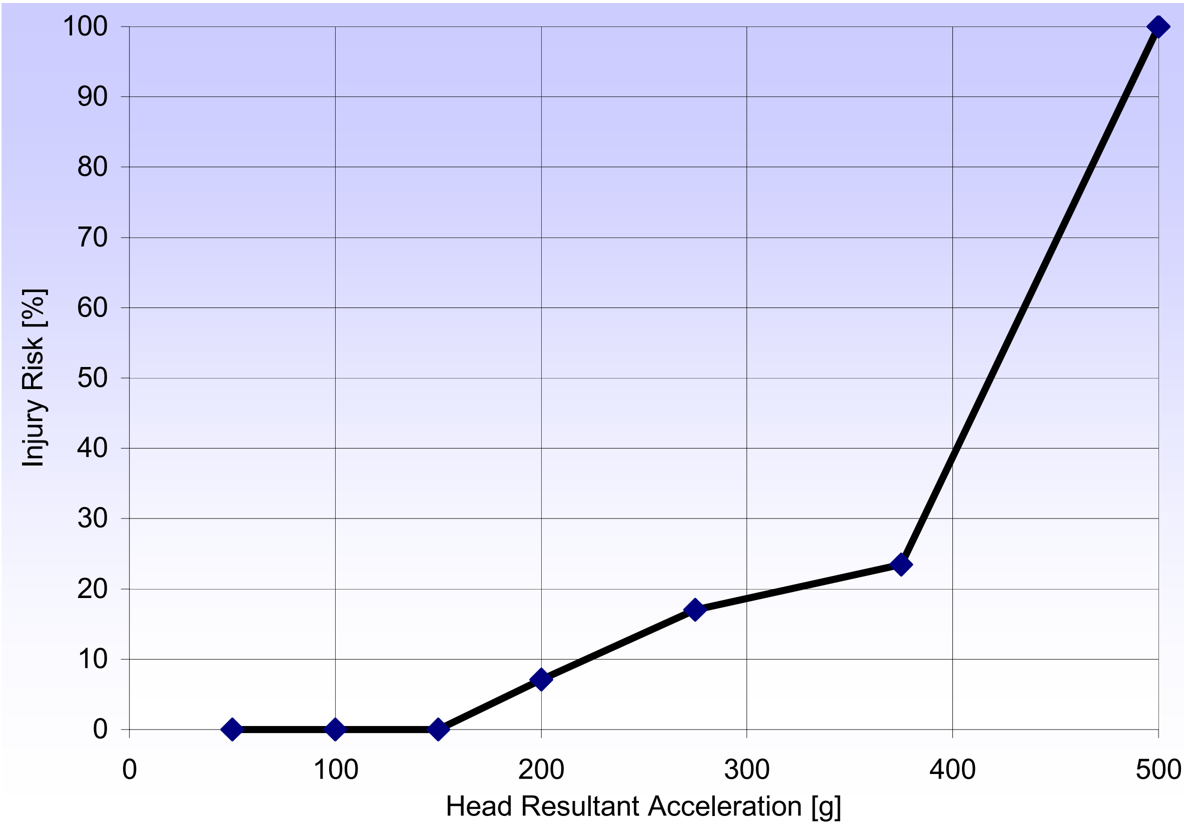
The equivalent test speed is the laboratory test speed that is equivalent to the average impact conditions for each accident severity.

Accident Severity	**1**	**2**	**3**	**4**	**5**	**6**
Flat anvil equivalent test speed[1] [m/s]	3.2	5.0	6.6	7.9	8.8	9.5
Kerb anvil equivalent test speed[1] [m/s]	3.7	5.4	6.8	8.3	9.0	9.5
Flat anvil equivalent test speed[2][m/s]	2.7	4.0	5.2	7.0	8.1	9.5

[1] data used for assessment of linear impact

[2] data used for assessment of oblique impacts

MODULE 2. HEAD INJURY RISK CURVE



Shadow AIS	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Headform acceleration [g]	50	100	150	200	275	375	500
Injury risk [%]	0.0	0.0	0.0	7.1	17.0	23.5	100

Note. The data assumes a linear response between each reference acceleration value.

For example. The risk at, say, _225_ g = 7.1 + (_225_-200)/(275-200)*(17.0-7.1) = 10.4%

MODULE 3. ACCIDENT EXPOSURE

United Kingdom accident cases where the rider or pillion passenger (PP) suffered a head impact, where the head injury was the most severe of all injuries sustained, and an improved helmet may be beneficial.

Accident Severity	1	2	3	4	5	6
Number riders and pillion passengers	4089	2193	452	493	492	21

MODULE 4. DISTRIBUTION OF IMPACTS BY LOCATION ON HELMET

The distribution of impacts by location on helmet.

Impact Site	Distribution [%]
Front	23.6
Side	53.2
Crown	2.2
Rear	21
Total	100

MODULE 5. DISTRIBUTION OF IMPACTS BY SURFACE TYPE

The distribution of accidents by impact surface.

Impact Surface	Distribution [%]
Flat anvil	38.4
Kerb anvil	1.6
Oblique impact	60.0
Total	100