A New Oblique Impact Test for Motorcycle Helmets

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Introduction

Otte *et al*. [1] found that oblique impacts are more common than radial (normal) impacts in motorcycle crashes, and that the mean angle, between the helmet direction and the horizontal axis, was 28 degrees. Such oblique impacts can cause high rotational head accelerations, which in turn can produce Diffuse Axonal Injury (DAI). Current helmet standards [2,3] only measure headform linear acceleration in direct impacts. There are oblique impact tests to check that helmet projections do not cause excessive tangential forces, but these tests do not measure the headform angular acceleration. The aims were to develop an oblique impact test, and to compare the responses of conventional and novel helmets.

The Oblique Impact Test

A free falling headform impacts a horizontally moving steel plate (Figure 1) moved by a pneumatic cylinder of 1 m stroke. There is no neck or torso, since a realistically flexible neck would not impede the headform accelerations. A rough road surface was simulated by grade 80 SiC grit grinding paper, bonded to the steel plate, which slides on flat PTFE bearings. Alternatively, to simulate a fractured windscreen, a 25 mm thick layer of 20 kg m^{-3} density extruded polystyrene foam was used as a crushable surface.

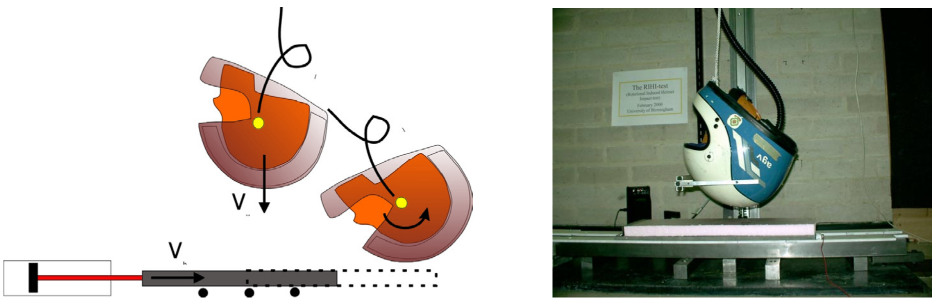

Figure 1. Left: helmet 123 and laboratory XYZ axes. V_h is the plate horizontal velocity and V_v the helmet vertical velocity. Right: test position A illustrated with a full face helmet.

The hollow aluminium headform, with a PVC plastisol skin (Ogle Ltd), has at its centre of gravity a triaxial linear accelerometer and a single axis angular rate sensor, aligned with the helmet rotation axis. The tests were filmed with digital cameras, taking 1000 frames per second.

Helmet modification

The open-face helmets (Fig. 2) had an ABS thermoplastic shell and expanded Polystyrene liners of density 40 kg/m^3. The helmets differed at the interface between the shell and the liner (Table 1).

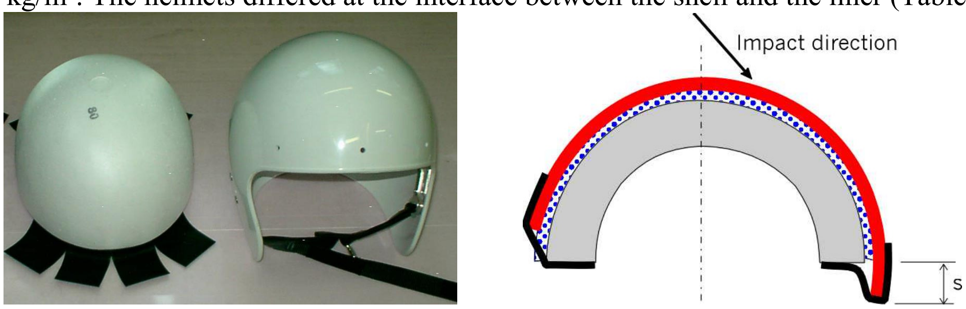

Figure 2. Left: liner with rubber strips and shell. Right: An oblique force causes shear deflection *S*.

Table 1 Helmet construction:

Abbreviation	Layer between shell and liner	at front and rear edge of shell/liner
BONDED	Unibond adhesive	None
FREE	Air	Rubber strip
MIPS	Low friction layer	Rubber strip

In the FREE and MIPS helmets, the shell and liner are joined by rubber strips at the bottom edge (figure 2), bonded to the shell exterior, and to the EPS liner edge. The MIPS helmets have a low friction Teflon film between the shell and the liner. In an oblique impact, the layer allows the shell to rotate relative to the liner (Fig 2). The helmet liner, which had no comfort foam inside, was an interference fit to the headform.

Table 2. Impact sites and directions for the oblique tests. The horizontal and vertical speed was in all tests 5 m/s

Test	Figure	Impact site	Tangential force direction relative to helmet
A	1	Crown	Rearwards
C	3	Midway from crown to side	Rearwards
D	5	Crown	Lateral

Figure 3.Test C with a foam covered steel plate. Left: view almost along the X axis, 11ms after impact, Right: view along the Y axis, 5ms after impact. The black arrow shows the plate velocity.

RESULTS

Figure 4 shows the headform angular and linear acceleration as function of time for test A. The MIPS-

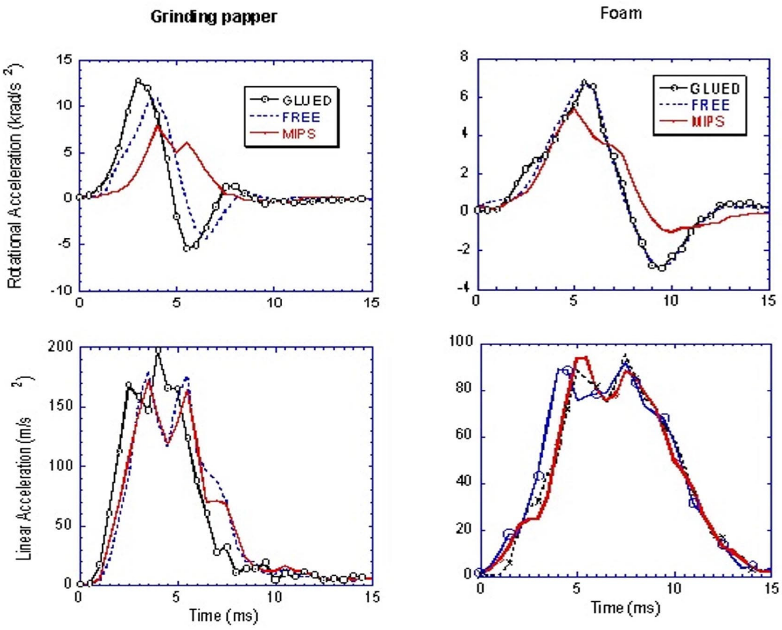

Figure 4. Test A. Rotational (upper) and linear (lower) accelerations vs time (ms) for the 3 types of helmet impacting rough rigid (left) and foam surfaces (right), at $V_h = V_V = 5$ m/s.

helmet reduces the peak angular acceleration by 28% and 39% respectively, compared with the FREE and the BONDED helmets, for impacts on the rough rigid surface. For a foam surface, the reduction was 20% compared with the FREE and BONDED helmets. In test C and D the rotational acceleration was reduced by 47% and 42%, respectively, comparing the BONDED and the MIPS helmets. The tests with the rough rigid surface give higher angular and linear acceleration peaks than those with foam surface. However, the angular velocity changes seemed to be independent of the impact surface, indicating that helmet sliding on the plate changed to rolling before the end of contact. In Figure 5 frame 1, the helmet hits the plate; in 2 it indents the foam, and in 3 it rotates.

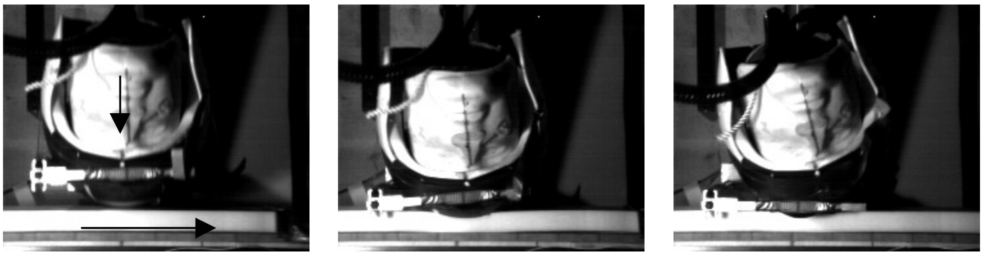

Figure 5. Test D on a foam surface. The time interval between the frames is 9 ms.

DISCUSSION

Measured headform angular accelerations were up to 15 krad/s^2 and angular velocity changes up to 36 rad/s. These compare with values of 10 krad/s^2 and 100 rad/s, proposed [4] as injury thresholds for DAI. For similar velocity oblique impacts, the peak angular acceleration was greater with the foam surface than with the rough rigid surface. The rotational acceleration trace for the bonded helmet (Fig. 4) has a similar shape to that for tangential force vs time traces for BS6658 oblique impact tests. The acceleration becomes negative in the later parts of the trace, due [5] to a rotational oscillation of the helmet shell on the deformable EPS foam. In real life, there is sliding at the comfort foam/hair/scalp interface, so reverse angular accelerations of the head are unlikely. Further research will concentrate on impact sites away from the crown, given the low frequency of crown impacts.

CONCLUSION

The oblique testing method for motorcycle helmets simulates typical falls to the road surface. It produces greater helmet deformation than the *oblique impact* tests in BS 6658 and Regulation 22/05, which are only intended to test helmet projections. The test rig will aid research on helmets that minimise rotational trauma. However, to force a change in helmet design, such a test would need to be adopted in European standards, with a strict criterion for headform acceleration limits. The MIPS helmet reduces the peak headform angular acceleration, independent of the initial position of the helmet in the test.

ACKNOWLEDGEMENT

We are grateful to Helmets Ltd of Stranraer, Scotland for assisting with the supply of helmets, and to the instrument loan scheme of EPSRC for the high speed camera. We also wish to thank the Länsförsäkringar Corporation Research Found and NUTEK (National board for Industrial and Technical Development), for financial support.

REFERENCES

1. D Otte, B Chinn, et al. Contribution to Final Report COST 327, University of Hannover. 1999.
2. United Nations, Economic commission for Europe, Regulation 22, Protective helmets for drivers and passengers of motorcycles and mopeds, Geneva, amendment 05, 1999.
3. British Standards Institution. Protective helmets for vehicle users, BS 6658, London, 1985.
4. S S Margulies and L E Thibault, J. Biomechanics, 1992, **25** 917-923.
5. N J Mills & A Gilchrist. Int. J. Crashworthiness, 1997, **2**, 7-23.