LEG PROTECTION FOR MOTORCYCLISTS

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1. Introduction

A number of earlier papers by Chinn and Macaulay (1), Chinn, Hopes and Macaulay (2) and Macaulay and Hunt (3) have discussed a research and development programme aimed at producing a specification for leg protectors to be fitted to motorcycles. This paper gives a short account of further developments in this programme which has now been divided into three main subject areas. These are:

i) The extension of the full scale crash programme to include all sizes of motorcycle and to cover more realistic test conditions.

ii) The development of more practical leg protectors using materials and manufacturing methods suitable for large scale production.

iii) The development of simple computer models to simulate the behaviour of motorcycles during full scale crash tests and real accidents.

These subject areas are discussed in turn.

2. Full Scale Crash Tests

2.1 Tests and Results.

Previous research which consisted of impacting motorcycles, many fitted with leg protection, into a barrier has indicated some of the essential properties of a leg protector. An attempt was made to test the validity of these by incorporating them into a fairing suitable for a B.M.W. type R.80 and then impacting several motorcycles, some fitted with this design of fairing into the side and front of a medium sized (Morris Marina) stationary saloon car.

Five motorcycles were crash tested, two into the side (one modified and one unmodified) and three into the front (two modified and one unmodified) of a car, all with the target face, at 30° to the direction of original travel. The dynamics of the two machines impacted into the side of the car were significantly affected by the horizontal cylinder heads of the B.M.W., and because of this the cylinder heads were removed for the subsequent tests and substituted by an equivalent mass placed in the crank case. One of the two modified machines impacted into the front of the car, was aimed at the corner to provide more information on the effect of leg protection.

The results are summarised in Table I and show the head velocity at critical points in the impact, i.e. the horizontal velocity at a vertical plane through the face of the target and the vertical velocity on impact with either the car roof or bonnet.

Unfortunately the modified motorcycle impacted nearer to the front of the vehicle than required, resulting in excessive interaction of the cylinder head with the wing aperture, thus rotation took place later in the impact than in the unmodified motorcycle test. However, both the vertical and horizontal head velocities are significantly lower with leg protection fitted. The potential leg injuries are also significantly lower.

The energy input into the leg of the dummy on the unmodified machine was 130J (100J upper, 30J lower leg) compared with only 38J (19J upper, 19J lower leg) for the machine fitted with leg protection.

The two similar impacts into the front of the car show that leg protection can cause a significant reduction in the estimated leg and head injuries. The movement of the dummy rider is small relative to the motorcycle, and the estimated reduction in injuries is brought about by the way in which the design of the leg protector controls the angular velocity of the machine, and greatly reduces the interaction between machine and target. This allowed the rider to stay with the motorcycle (Fig.1) and thus contact with the car was kept to a minimum. In contrast the rider of the unmodified machine was thrown off at impact, head first and subsequently head first into the ground. (see Fig.2).

The energy input into the dummy's leg was 58J for the unmodified machine and 55J for the machine with leg protection. The potential leg injuries were therefore similar and not severe, i.e. it is unlikely that the tibia or femur would have broken in either impact. This result is consistent with the trajectory of the dummy from the unmodified machine as the leg did not become trapped between the car and the motorcycle.

The rider of the machine impacted into the front corner of the car was thrown off the machine as in a 90° impact but the presence of the leg protection controlled the trajectory of the rider and the head velocities recorded were significantly lower than would have been expected with an unmodified machine, based on comparisons with previous tests.

2.2 Leg Protection Criteria.

Previous research (by T.R.R.L.) has indicated that a leg protector should consist of three basic regions as follows:

1. Main impact energy absorbing region.
2. Knee protection energy absorbing region.
3. Region to support 1 and 2 and to prevent interaction between them.

The performance intended for each region must be specified in detail for optimum benefit. Some of the criteria have yet to be determined precisely but the tests described in 2.1 have shown the importance of the criteria which must be applied to three aspects of region 1.

i) Shape
ii) Collapsed contour
iii) Position

Taken in order i) The external profile must be such that the first contact point is above "knee" height and that the profile presented to the target must be smooth and not likely to interact other than by friction. ii) The Collapsed contour should remain reasonably smooth throughout the impact, to avoid excessive interaction with the target. iii) The position of the main impact region should be placed so that the desired crush is achieved before any stiff component of the motorcycle contacts the target. Fig. 1 shows a motorcycle fitted with the fairing as used in the tests and Fig. 3 shows the crush in the main impact energy absorbing region.

3. More Practical Leg Protectors.

The energy absorbed during an impact by the metal leg protectors used in earlier crash tests was about 10% of the total kinetic energy of the motorcycle and rider at 48 Km/h. (Chinn & Macaulay (1)). This is roughly the same as the energy in a medium sized motor car at 5 Km/h so that the energy absorbed is similar to that specified for testing energy absorbing car bumpers. It seemed reasonable from this to take the materials and manufacturing methods already in use for making such bumpers and to apply them to the manufacture of leg protectors for motorcycles.

The development of a leg protector for a medium sized motorcycle is discussed in Macaulay & Hunt (3). A number of protectors of this design were produced and tested on the T.R.R.L. indoor impact sled. The protector was struck by a flat rigid impactor. Four impact speeds were used and the mass of the impactor was varied so that its energy on impact was 2 kJ. The masses and impact speeds are listed in Table 2.

A typical graph of force and energy against displacement is shown in Fig. 4. There was no marked change in behaviour with temperature and there was no marked change in deflection with velocity but there was a systematic variation in the velocity with which the impactor rebounded. Rebound energy is plotted against impact velocity in Fig. 5.

4. Simple Computer Model

A very simple, two-dimensional computer model has been used to simulate a motorcycle crashing into a flat, rigid barrier at an angle to its direction of travel. This is shown in Fig. 6. The motorcycle is represented by a concentrated mass and moment of rotational inertia, two weightless arms fixed to this mass and two weightless deflecting elements, one at the end of each arm. One element represents the front wheel and associated structure and the other leg protector. The position of the leg protector is specified by length A measured from the mass along the longitudinal axis of the motorcycle and length B measured at right angles to this. The barrier angle and coefficient of friction can be varied.

The model has been used, so far, for qualitative assessment of the factors involved in an angled barrier impact. It behaves in broadly the same way as a motorcycle in an actual test and it gives useful insights but it is not intended to give accurate results at this stage. The results discussed are qualitative but approximate numerical values are included as a guide.

Both deflecting elements have been represented by linear springs with a small amount of linear, viscous damping. Recoil is restricted so that energy is not returned from the springs to the rest of the system. This type of element was chosen for simplicity but the model can deal with any appropriate load-deflection characteristics.

The range of useful combinations of A and B is limited as can be seen in Fig.7 In this the value of A is fixed whilst the value of B and the barrier angle are varied. There is a zone in which the leg protector deflects as intended bounded by zones in which it either does not touch the barrier or it overloads, bottoming out at the end of its available travel. Repeating the analysis for different values of A gives the range of useful locations for the leg protector and a similar analysis can be used to define the conditions under which the rider's leg is trapped. In line with normal motor car practice the barrier angle is measured from the perpendicular to the initial direction of travel so that a 60° barrier is at 30° to this initial direction.

Energy balances can be computed and compared with balances derived from test results. The results in Fig. 8 are for an impact speed of 48 Km/h and a barrier angle of 60°. The protector location is approximately that of the energy absorbing protectors used in the full scale impact tests, and the protector stiffness approximates to that of these protectors. The kinetic energy remaining in the forward motion of the motorcycle is selected to agree with the value derived from test results. The amount of friction between the leg protector and the barrier has a large effect but fairly large variations in the stiffness of the leg protector are much less important. It seems reasonable that friction should have a significant effect but it cannot be measured directly during an impact test so that the effect can only be studied by a combination of testing and computer modelling.

5. Discussion and Conclusion

There is some disagreement about the effectiveness of leg protectors in full scale crash tests. The case against is discussed by Tadokoro, Fukuda and Miyazaki (4). Our own experience does not agree with them but full scale crash testing of motorcycles is complicated and it is possible that the different test conditions are the cause.

There is a limited amount of information which can be derived from a short paper such as Tadukoro et al but there appear to be three main sources of possible disagreement.

i) Differences in leg protectors
ii) Differences in tests
iii) Differences in interpretation

Taken in order, i) The leg protectors described by Tadokoro et al have a very stiff supporting frame covered by a very soft energy absorbing layer which quickly bottoms out. Our protectors are more homogeneous with a stiffer energy absorbing region and a less stiff supporting frame. They also have a smoother collapsed contour which avoids the motorcycle interacting with the target vehicle other than by friction.

ii) The only tests which are directly comparable are those where a motorcycle runs into a moving motorcar at 45°, reported by Tadokoro et al, and those where a motorcycle runs into a stationary car at 60°, reported in the present paper. We shall be conducting tests with both vehicles moving to see if this produces significant differences.

iii) Results given by Tadokoro et al contain some anomalies. For instance the resultant velocity of the rider's head at 100 milliseconds is higher in their lower speed impacts than in their higher speed ones. This implies that further study of the dynamics of the impact is necessary. There are also conflicting interpretations of agreed data. For instance the dummy's hip rises further with a leg protector than without. Tadokoro et al conclude that this indicates that the rider is more likely to be ejected and injured. Our interpretation (Chinn & Macaulay (1)) is that, because forward movement at the knee is restricted, the leg straightens causing the hip to rise but that this does not increase the risk of ejection.

With the extensive programme discussed here it should be possible to understand more fully how such differences have arisen. Using a comprehensive series of full scale crash tests, component tests and computer simulations we are confident that we shall understand the processes involved in road accidents and that we shall achieve significant reductions in leg injuries without increasing the risk of other types of injury.

References.

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3. MACAULAY M A & HUNT L
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4. TADOKORO H, FUKUDA S & MIYAZAKI K
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TABLE I

TEST		INITIAL VELOCITY ms^{-1}	HORIZONTAL HEAD VELOCITY AT VERTICAL FACE ms^{-1}	VERTICAL HEAD VELOCITY INTO CAR ROOF OR BONNET ms^{-1}	AVERAGE ANGULAR VELOCITY OF MOTORCYCLE OVER 100 ms $rads^{-1}$
IMPACTS INTO SIDE OF CAR	UNMODIFIED	13.4	13.7, (+2.0%)	5.1	3.8
	WITH LEG PROTECTOR	13.4	12.4, (-7.5%)	3	0.6
IMPACTS INTO FRONT OF CAR	UNMODIFIED	13.8	14.5, (+5.1%)	6.6	4.6
	WITH LEG PROTECTOR	13.4	14.2, (+6%)	HEAD DID NOT HIT THE BONNET	1.8
	WITH LEG PROTECTOR (INTO CORNER)	14.0	11.5, (-17.8%)	1.1	0

TABLE II

Mass (kg)	Impact Speed (m/sec)
200	4.66
50	9
22	13.25
12.8	18

Three temperatures of the leg protector were used:
20°C -10°C and -20°C

Fig.1 Motorcycle fitted with leg protecting fairing. (During impact)

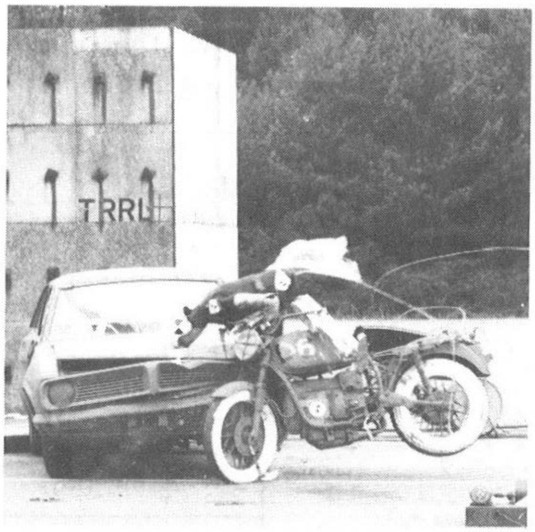

Fig.2 Unmodified motorcycle. (During impact)

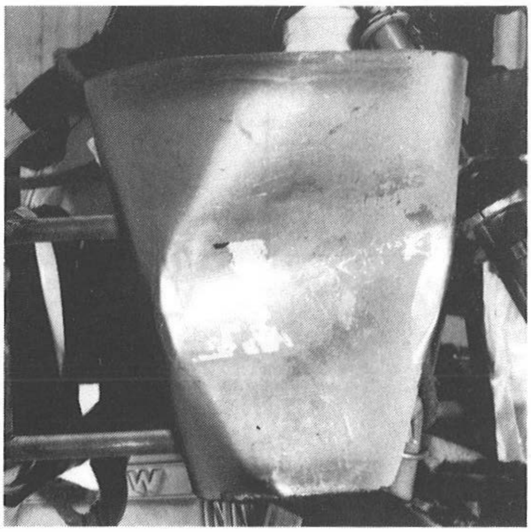

Fig.3 Crush in main impact energy absorbing region. (Outer fairing removed)

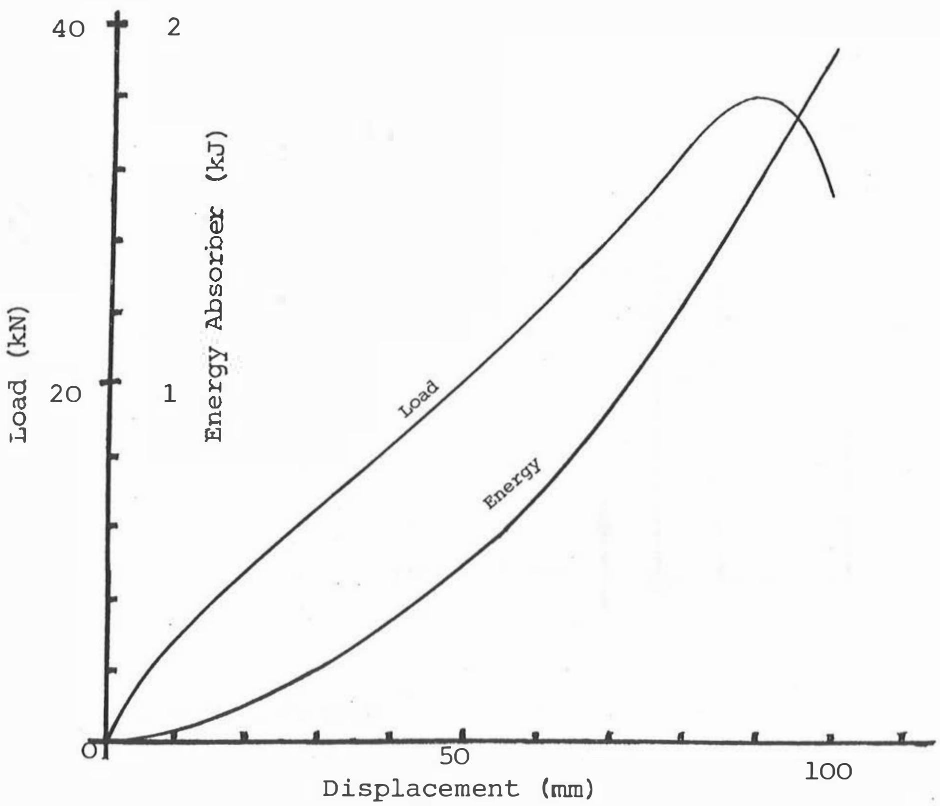

Fig. 4 Protector Characteristics for 48 km/h Impact by 22 kg mass.

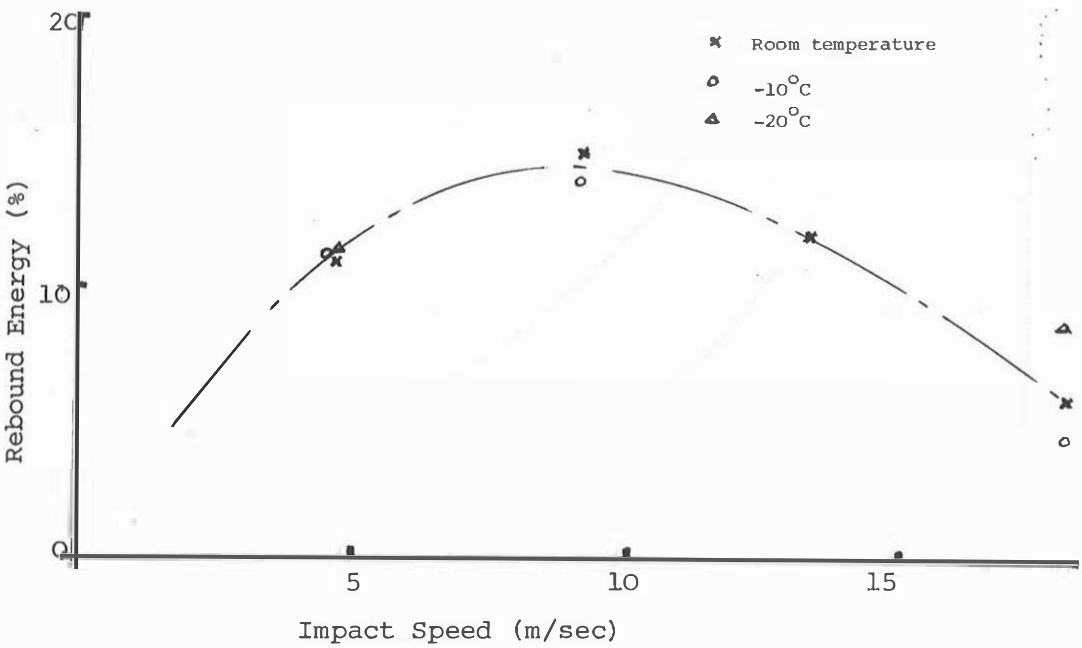

Fig. 5 Variation in Rebound Energy with Impact Velocity.

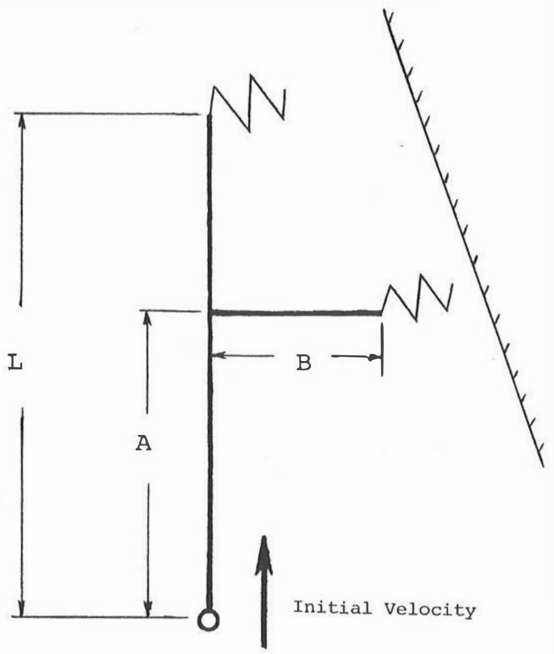

Fig. 6   Two-Dimensional Computer Model.

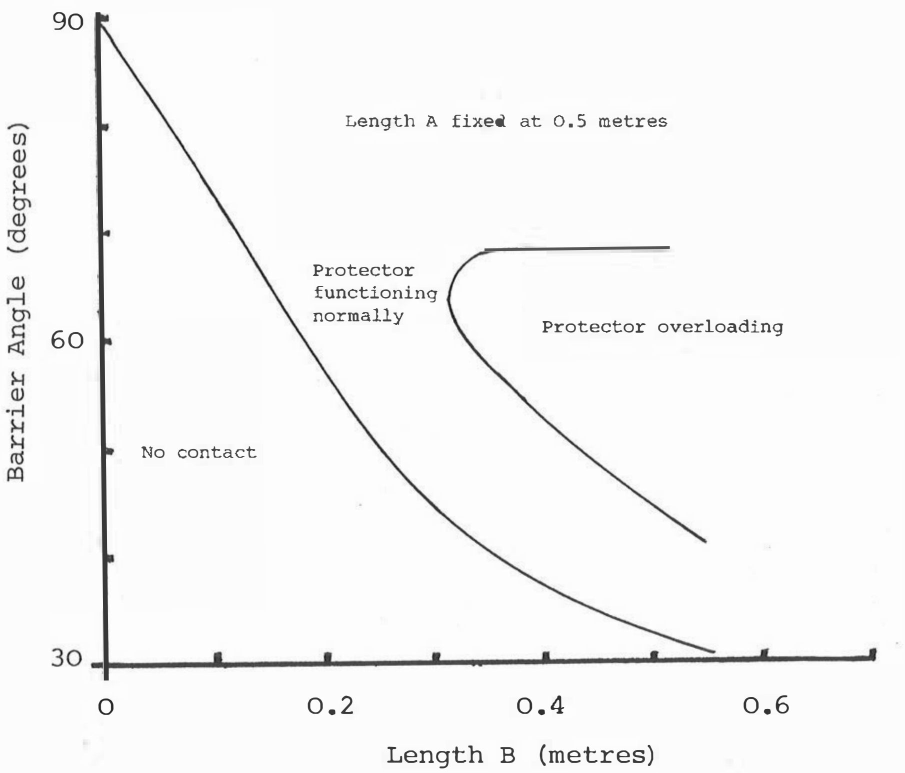

Fig. 7 Typical Curves of Useful Protector Locations

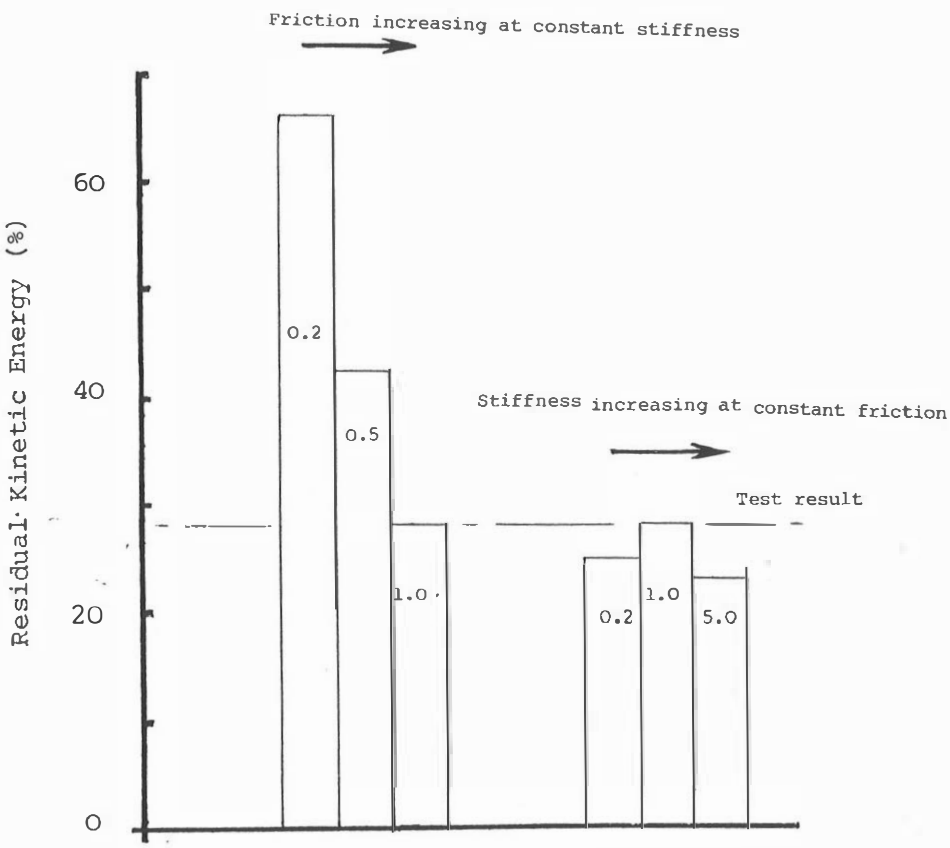

Fig. 8 Effect of Friction and Stiffness of Leg Protector on Residual Kinetic Energy in Forward Motion.