AN OVERALL EVALUATION OF UKDS MOTORCYCLIST LEG PROTECTORS BASED ON ISO 13232

Nicholas M. Rogers
International Motorcycle Manufacturers Association
Switzerland
John W. Zellner
Dynamic Research, Incorporated
United States
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ABSTRACT

The feasibility of devices intended to protect the legs of motorcyclists in impacts has been researched for three decades; this paper reviews the prior history and presents the latest results of an overall evaluation of a UK Draft Specification (UKDS) leg protector device, based on the standardized full scale test and simulation methods of ISO 13232. International Standard 13232 (1996) was developed and internationally approved for the purpose of providing common research methods for assessing the feasibility of protective devices which might be fitted to motorcycles and which are intended to reduce injuries to riders resulting from car impacts. A prototype UKDS device designed by the UK Transport Research Laboratory in 1990 was evaluated by means of 14 full scale crash tests with an instrumented MATD dummy; and 200 computer simulations representing 501 Los Angeles and Hannover accidents. The simulations were calibrated in detail against 32 instrumented laboratory tests and the 14 full scale tests. Results in terms of standardized injury analysis and risk/benefit analysis across the tests and simulated accident sample are presented, and conclusions and recommendations are discussed.

INTRODUCTION

Research on the feasibility of rider crash protection devices which might be fitted to motorcycles has occurred during the last 30 years in Great Britain, Japan, Germany and the United States. In general, this research has involved industry, government and private organizations; a variety of test methods, as reviewed by Rogers in Ref 1; and different rider protection strategies, for example those described by Sporner in Ref 2.

One example of such research during the 1980's was the leg protector work of the Transport and Road Research Laboratory (TRRL, now TRL) in the United Kingdom, culminating in 1987 in a proposed national and (later) international Draft Specification (UKDS, Ref 3) for motorcyclist leg protectors. Following publication of the UKDS, several leg protector designs intended to conform to it were evaluated in full scale tests by TRL, and by the motorcycle industry (Refs 4 to 6). One leg protector design was independently evaluated by TRL and by the industry, using different test methods (Ref 6); and this resulted in large differences in measurements and conclusions. Table 1 compares some of the different test methods used during this period of research.

In 1991, an International Leg Protector Seminar (Ref 7), and recommendation of experts in the crash protection field, led to the conclusion that an internationally accepted motorcyclist crash dummy and research methodology were the necessary next steps, before further objective and meaningful research could continue in the rider protection field.

In 1992, work on an International Standard on motorcycle crash research methodology was begun, and in 1996 this was finally approved as ISO 13232. The motorcycle industry then re-evaluated the UKDS leg protector device designed by TRL, this time using the ISO Standard, and this is the main topic of this paper.

This paper continues with a brief review of the history of leg protector research; the concurrent development of research methodologies, culminating in ISO 13232; application of the ISO 13232 to an overall evaluation of an example UKDS leg protector device; and the conclusions and recommendations reached regarding this type of device.

BACKGROUND

History of leg protector research

Since 1969, a number of industry and other organizations worldwide have studied a wide variety of motorcyclist leg protection devices with the aim of reducing injuries to riders during collisions.

A summary of leg protector research through 1990 is given by Rogers in Ref 1. This is described subsequently and summarized in Table 2.

Conventional crash bars - Early research in the late 1960s and early 1970s investigated commercially available accessory bars - generally loops of approximately 25 mm diameter steel tubes projecting to the side of the motorcycle. Bothwell, et al, (Ref 8) under contract to the US National Highway Traffic Safety Administration (NHTSA), found that these were too weak to protect legs during collisions and capsize situations.

Bothwell, et al (Ref 9) subsequently tested "revised heavy duty crash bars", constructed from 50 mm diameter tubes, which were able to endure 30 mi/h angled collisions. These retained leg space; however leg impacts to the bars were found to be potentially injurious.

Uto (Ref 10) of the Japan Automobile Manufacturers Association (JAMA) investigated "side protection devices", constructed of large diameter steel tubes with reinforcing braces. Using breakable dummy bones, it was found that: lower leg fractures could be reduced; however, upper leg fractures were changed from bending fractures to twisting fractures; and there was a greater tendency for the dummy to be ejected head first toward the opposing vehicle.

Livers (Ref 11) and Bartol, et al (Ref 12) under contract to the US NHTSA tested an "Experimental Safety Motorcycle Structure", similar in concept to the revised heavy duty crash bars and the side protection devices. It was found that upper and lower leg forces were reduced, but chest and head accelerations were generally greater, indicating an overall increase in potentially fatal injuries.

Modified reinforced leg protectors - Bothwell (Ref 13) next investigated a "reinforced leg shield fairing" which had thick knee pads covering the tubular structure. In an angled collision, the knee of the dummy impacted the knee pad, inducing a dummy somersaulting motion. This resulted in a large amount of dummy neck flexion, and lowered the head trajectory so that the head impacted the side of the opposing vehicle, again increasing the potential for fatal injury.

Chinn, et al (Ref 14) of TRL investigated a "hard leg protector", which was apparently the same concept as Bothwell's "reinforced leg shield fairing" (RLSF). Although few details were presented, the test results indicated decreased yaw motion during angled collisions with fixed barriers, and maintenance of leg space, similar to the RLSF. However, forward pitching of the dummy torso and lowering of the dummy head were observed, as with the RLSF.

Energy Absorbing Leg Protectors - Bartol, et al (Ref 12) also investigated a "crash bar with energy absorbing bucket seat", which - although intended to reduce head accelerations - in fact did not reduce dummy injuries in a measurable way.

Chinn, et al (Ref 14), based on work in his doctoral dissertation, investigated a "soft leg protector", and reported that this reduced the dummy's forward head velocity.

Tadokoro, et al (Ref 15) of JAMA proposed and tested a "crushable leg protector" (CLP) intended 1) to reduce motorcycle impact acceleration and thereby to reduce the ejection tendency of the dummy; and 2) to maintain a minimum amount of leg space (since excessive leg space was considered a cause of ejection). Tests indicated that this device reduced leg fractures, but dummy ejection and the associated increased head velocities were not solved by the CLP.

Energy Absorbing Leg Retention Leg Protectors - A further leg protector concept described by Chinn, et al (Refs 16 and 17) resembled a 1980 UK patent of Bothwell involving: external and internal (knee) energy absorbing regions; a rigid structure supporting these regions, and a fairing enclosure. Although Bothwell no longer considered this concept valid, Chinn of TRL continued work on it, adding a "leg lateral retention element" and a "breakaway" mount intended to prevent leg trap.

The TRL published research on leg protectors differed from other research in the UK, US and Japan, in that at all stages, the evolving concept showed promise (eg, Refs 16, 17, 18), and the negative effects reported by other researchers were not observed. The motorcycle industry considers that the most likely reason for this is the test methodology used by TRL in its research, which is summarized later.

In 1986, in view of the major divergence in results between TRL and other researchers, the motorcycle industry proposed to the United Nations Expert Group for General Vehicle Safety Provisions (UN/ECE/TRANS/WP29/GRSG) that improvement of test methodologies was the next logical step for finding clearer answers to rider leg protection.

UK Draft Specification (UKDS)

In July, 1987, despite the continuing differences in research results, the United Kingdom Department of Transport unexpectedly published a national Draft Specification for motorcycle leg protectors for comment. The UKDS was based on the TRRL work and was proposed as a regulation applicable to all motorcycles and mopeds. The UKDS involved:

- A primary impact element;
- A rigid support element;
- A knee protector element;
- Leg lateral retention;
- Detachment of the rigid support at high impact energies (optional in the original draft; mandatory in the revised drafts);
- Smooth outer contour (during and after impact).

These elements had specific geometric and mechanical requirements to be verified by laboratory testing.

Industry response to UKDS - The motorcycle industry responded to the publication of the UKDS in several ways, including:

- Two commissioned reports from independent experts (Refs 19, 20), which discussed the limitations of the TRL methodology, including the crushable "honeycomb" dummy leg, which could not accurately predict leg fractures;
- Preliminary full scale tests of a UKDS prototype device (Ref 21), which found that the device resulted in lower leg fracture and increased upper leg damage in all three impact configurations examined; and other harmful effects, including increased rider ejection, torso pitch and head impact with the car and road;
- A meeting with the UK Parliamentary Under Secretary of State for Roads and Traffic in 1988, at which it was agreed that: the UK Department of Transport would not proceed without consulting the motorcycle industry; industry would accelerate refinement of its evaluation methodology with a view to a fuller evaluation of the UKDS in tests during 1989; and TRL and industry experts would hold technical meetings to discuss their differing results;
- A presentation and discussion at the United Nations UN/ECE/TRANS/WP29/GRSG in May 1988, at which the delegates agreed to postpone discussion of a Draft Recommendation (based on the UKDS), until industry had completed further research;
- A large, in-depth series of crash tests of UKDS leg protectors in 1989 by the industry (Ref 5). These tests were the most comprehensive to date in terms of: the types of motorcycles and cars used; the leg protector designs and UKDS categories; the type of impact configurations considered; and the use of state-of-the-art test methodologies, including a new motorcycle impact dummy and performance indices. Test results indicated that UKDS leg protection devices could increase both leg and head injuries, as well as overall injury severity;
- A series of detailed technical meetings and discussions between TRL , the UK Department of Transport and the motorcycle industry. This resulted in nine main points of technical agreement between TRL and the industry (Ref 22). It also resulted in an agreement for TRL and the industry to independently evaluate a TRL-built UKDS leg protector for a medium sized Kawasaki GPZ 500 (subsequently further described);
- An International Leg Protector Seminar (Ref 7) at Chantilly in 1991, for the purpose of clarifying the technical issues, resulted in the recommendation of experts in the crash protection field that an internationally accepted motorcyclist crash dummy and research methodology were necessary first steps, before further objective and meaningful research could be pursued.

Development of Research Methodology

A wide range of test and evaluation methodologies have been used in the field of motorcyclist leg protection research, and, for example, Sakamoto (Ref 23) reviews the history of leg injury measurement methods. These included:

- Leg acceleration measurement;

- Leg lateral load measurement;

- Frangible (ie, breakable) surrogate leg bones;

- Leg "lateral impact energy" estimation, via crushable aluminum honeycomb material;

- Combinations of load measurement and frangible leg bones.

In addition, various crash dummies had been used in such research, as described by Zellner, et al (Ref 24), including:

- An early anthropomorphic manikin;

- Alderson CG-50 dummy and parachutist dummies;

- 50th percentile male anthropomorphic dummy;

- Modified Ito 3DGM-AM50-70 standing dummy;

- OPAT 50th percentile male manikin;

- Hybrid III/ Hybrid III combined standing dummies;

- A motorcyclist MATD-1 dummy (Ref 25).

In general, these dummies had different geometric, mass, stiffness and damping characteristics and corresponding impact responses; different levels of biofidelity; as well as different means for evaluating leg and other injuries. As a result, the same test done with different dummies would fundamentally produce different results.

A similar large diversity existed with regard to:

- Electronic and photo optic measurements;

- Injury indices;

- Full scale impact test procedures including the impact configurations used;

- Test documentation procedures.

Development of ISO 13232 - Recognizing the need for common tests and evaluation methods, the United Nations Expert Group for General Vehicle Safety Provisions (UN/ECE/TRANS/WP29/GRSG) decided in March 1992, at the suggestion of the International Motorcycle Manufacturers Association (IMMA) and in view of the Chantilly seminar recommendations, to ask the International Organization for Standardization (ISO), to establish a common research methodology for motorcycle crash testing.

GRSG's parent committee, UN Working Party 29, approved the plan but asked that the standard be completed before the end of 1995, which meant that a complete draft would be needed by Spring 1994.

In September 1992, the motorcycle subcommittee of ISO (ISO/TC22/SC22) established a new working group, WG22, to deal with "motorcycle research impact test procedures".

Six working group meetings were held between November 1992 and April 1994 involving some 25 experts and observers from the United Kingdom, Germany, France, the Netherlands, Belgium, Italy, the United States of America, Japan, Canada, and China, with input from both the motorcycle industry worldwide and technical experts in the crash research field (Ref 26). As official originator of the proposed ISO standard, IMMA provided to WG22 an initial working draft (WD), based on methods developed and used by the motorcycle industry in preceding years. In the process of preparing more detailed and complete drafts, WG22 based its work on the use of existing technology, consensus procedures, and data indicating method feasibility. The Standard was therefore a codification of methods which, for the most part, were available and in use. In addition, throughout the drafting process, liaison was maintained with the corresponding ISO car subcommittees.

In Summer 1994, a committee draft (CD) was balloted and approved within SC22. This was followed by balloting of a Draft International Standard (DIS); and final approval of the DIS by the ISO National Member Bodies in March 1996. ISO 13232 was finally approved and published in December 1996.

Review of ISO 13232 provisions - ISO 13232 consists of 8 interacting and mutually dependent parts:

- Part 1: Definitions
- Part 2: Definition of impact conditions in relation to accident data
- Part 3: Motorcyclist dummy
- Part 4: Measurements
- Part 5: Injury indices and risk/benefit analysis
- Part 6: Full scale impact test procedures

- Part 7: Computer simulation procedures
- Part 8: Test and simulation documentation

Application of these 8 parts enables:

- Quantitative measurement of the effect of the device on injury indices, for each body region, and summed across all body regions;

- A full scale test evaluation of the effects of a proposed device, based on seven pairs of full scale impact tests (ie, each pair comprising a motorcycle with and without the device fitted); and

- An overall evaluation of the predicted effects of the proposed device, across a sample of the accident population, based on a calibrated computer simulation, and 200 pairs of simulated impacts (with and without the device fitted).

A more detailed description of the provisions and rationale is given in Ref 26, and of the ISO motorcyclist dummy in Ref 24. In addition, specific rationale for the provisions is included in the Standard (Ref 32).

SUMMARY OF LATEST TESTS AND SIMULATIONS DONE

Beginning in 1994, IMMA conducted an overall evaluation of a UKDS leg protector prototype, in accordance with the test and analysis methods of ISO 13232 (based initially on the CD version and then subsequent versions). These tests and results are described in further detail in Ref 27. This involved the following test aspects:

UKDS leg protector - Photographs of the UKDS leg protector as designed and fitted to the test motorcycle by TRL are given in Figs 1 and 2. Table 3 describes the leg protector, and laboratory test data for it are described in Ref 6.

Motorcycle - The test motorcycle (MC) was a Kawasaki GPZ 500 with specifications given in Table 4.

Opposing Vehicle - The opposing vehicle was a production Toyota Corolla 4 door saloon, Japan domestic model, model year 1988 to 1990, inclusive, as specified in ISO 13232-6. Specifications are summarized in Table 5. Photographs of the opposing vehicle are given in Figs 3 and 4.

Impact configurations - The impact configurations (IC's) for the full scale tests were the seven IC's required by ISO 13232 for a full scale test evaluation of a proposed device, and illustrated in Fig 5, namely:

- IC1 : broadside
- IC2 : angled car front
- IC3 : T-bone, moving/moving
- IC4 : angled car side, similar direction
- IC5: angled car side, opposing direction
- IC6 : offset frontal
- IC7 : T-bone, stationary car

Summary of Test Results

Across the seven impact configurations tested and during the entire impact sequence (except as noted), and based on the analysis methods specified in ISO 13232-5, fitment of leg protectors resulted in the following changes:

- Head maximum GAMBIT (Generalized Acceleration Model for Brain Injury Trauma, Ref 32):
  - increased in 5 out of 7 cases;
  - decreased in 2 out of 7 cases;

- Head HIC (Head Injury Criterion, Ref 32):
  - increased in 4 out of 7 cases;
  - decreased in 3 out of 7 cases;

- Head AIS (Abbreviated Injury Scale, Ref 32):
  - increased in 3 out of 7 cases;
  - remained the same in 3 out of 7 cases;
  - decreased in 1 out of 7 cases;

- Risk of life threatening head injury:
  - increased in 1 out of 7 cases;
  - remained the same in 4 out of 7 cases;
  - decreased in 2 out of 7 cases;

- Neck shear injury index:
  - increased in 4 out of 7 cases;
  - decreased in 3 out of 7 cases;

- Neck tension injury index:
  - increased in 4 out of 7 cases;
  - decreased in 3 out of 7 cases;

- Neck compression injury index:
  - increased in 5 out of 7 cases;
  - decreased in 2 out of 7 cases;

- Neck flexion injury index:
  - increased in 3 out of 7 cases;
  - decreased in 4 out of 7 cases;

- Neck extension injury index:
  - increased in 2 out of 7 cases;
  - decreased in 5 out of 7 cases;

- Neck torsion injury index:
  - increased in 4 out of 7 cases;
  - decreased in 3 out of 7 cases;

- Chest AIS was zero in all cases;

- Abdomen AIS was zero in all cases;

- Femur AIS=3 fractures:
  - increased in 1 out of 7 cases;
  - remained the same in 5 out of 7 cases;
  - decreased in 1 out of 7 cases;

- There were no knee AIS=2 or 3 dislocations in any of the tests;

- Tibia AIS=2 fractures:
  - remained the same in 5 out of 7 cases;
  - decreased in 2 out of 7 cases;

- There were no tibia AIS=3 fractures in any of the tests;

- Helmet maximum vertical difference in trajectory (compared to the baseline trajectory)during the primary impact period was:
  - lower in 6 out of 7 cases;
  - undefined in 1 out of 7 cases;

- Percentage change in helmet velocity, at first helmet/OV contact was:
  - positive in 1 out of 7 cases;
  - negative in 4 out of 7 cases;
  - undefined in 2 cases;

- Permanent partial incapacity index:
  -increased in 1 out of 7 cases;
  - remained the same in 5 out of 7 cases;
  - decreased in 1 out of 7 cases;

- Probability of fatality:
  - increased in 4 out of 7 cases;
  - remained the same in 1 out of 7 cases;
  - decreased in 2 out of 7 cases.

Note that some of the indicated body region changes were at less than injurious levels, whilst others were at injurious levels, and this important difference should be considered when evaluating these results. ISO 13232 takes this into account by requiring the "normalized injury cost" - which includes changes for all body regions and injury severity levels - to be evaluated. In this regard, the:

-Normalized injury cost (NIC):
  - increased in 4 out of 7 cases;
  - remained the same in 1 out of 7 cases;
  - decreased in 2 out of 7 cases.

In the case of the neck, ISO 13232 does not yet quantify probable injury severities (as it does for other body regions), and the neck is not included in the normalized injury cost. However, it was observed in the test data that, of the six neck injury indices, the neck compression injury index tended to have the largest values in these tests (ie, be the closest to the levels for potential serious injury indicated in ISO 13232-5). Fitment of leg protectors increased the neck compression injury index in 5 out of 7 cases.

After taking into account the frequency of occurrence of each of the seven impact configurations, as listed in ISO 13232-2, the overall normalized injury cost summed across the seven configurations increased by 315%, as a result of fitment of UKDS leg protectors.

Discussion of Cause/Effect Relationships

The high speed films, electronic data and helmet trajectory and velocity data were examined in order to identify the causes of the leg protector harmful effects in the two cases in which such effects were most pronounced: the stationary T-bone (IC7) and angled car front (IC2) configurations.

In the stationary T-bone test, with the baseline motorcycle, the helmet contacted the top of the car with a head acceleration of 112 g and no head injury. With the leg protector motorcycle, the helmet trajectory was 123 mm (4.8 inches) lower than with the baseline motorcycle, and the helmet impacted the edge of the roof, resulting in a head acceleration of 193 g and an AIS 5 head injury. The lower helmet trajectory was the result of large restraint forces of the leg protector acting on the knees, which caused the torso to pitch downward about the hips.

In the angled car front configuration, a similar lower helmet trajectory (ie, 88 mm (3.5 inches) lower) occurred with leg protectors; and the resultant head acceleration was increased (from 42 g for baseline to 75 g with leg protectors) during primary impact. The leg protector acted to eliminate lower leg fracture by preventing initial car contact to the leg, thereby decreasing the tibia bending moment. However, impact of the left knee with the leg protector increased the femur compression force by 38 percent. More importantly, the femur forward bending moment was more than doubled by the leg protector, resulting in bending fracture of the femur. Examination of the high speed films and electronic data indicated that this was the result of the knee being forced into the deformable knee protection element, followed by an upward movement of the hip during the impact, resulting in very large forces and torques at the knee. This same "jamming" or "fixity" effect was observed in previous research (eg, Ref 5) and appears to be a fundamental deficiency of systems which concentrate all of the rider restraint forces on the knees, whilst the hip and upper body continue to move in other directions.

Computer Simulations and Results

Computer simulations were done involving the same UKDS leg protector device, motorcycle and opposing vehicle, in accordance with ISO 13232. This is described in further detail in Ref 28. The simulation preparation and analysis involved the following main steps:

- Modeling the leg protectors, motorcycle, dummy and opposing vehicle;
- Calibrating the models against instrumented laboratory and full scale impact tests;
- Using the calibrated model to simulate 200 motorcycle/car impact configurations - based on accidents in Los Angeles and Hannover described in ISO 13232 - with and without leg protectors;
- Analyzing the results for this larger sample of accidents in terms of injury benefits (ie, decreases of injuries resulting from fitment of the leg protectors); injury risks (ie, increases in injuries resulting from fitment of the leg protectors); and injury risk-to-benefit ratio.

Models of the leg protector, motorcycle, dummy and opposing vehicle were formulated in accordance with ISO 13232-7, and are summarized in Table 6. The models were implemented by means of the Articulated Total Body program (Ref 29).

Calibration of the models against 20 dynamic laboratory tests, 11 static laboratory tests and a motorcycle barrier test is described in Ref 28. The simulation data indicated close agreement with the test data.

The simulation was also calibrated and correlated with data from the 14 full scale impact tests previously described. This indicated that the level of the correlation between the simulations and the full scale tests was high, as follows:

- Head acceleration (g): $r^2 = 0.91$
- Percent correctly predicted:
  - Femur fractures/non fractures: 92.9%
  - Knee dislocations/non dislocations: 100.0%
  - Tibia dislocations/non dislocations: 92.9%

The calibrated simulation was then used to calculate dummy motions, forces and injuries in the 200 impact configurations - with and without leg protectors. As reported in Ref 28, the results indicated that the total injury risk (ie, total increase in injury cost resulting from leg protector fitment) *exceeded* the total injury benefit. The risk-to-benefit ratio was found to be 116%.

Further analysis described in Ref 28 indicated that this was the result of the increases in femur injuries (which are more costly) outweighing the decreases in tibia injuries, which occurred when leg protectors were fitted.

An injury risk-to-benefit ratio (or "harm"-to-benefit ratio) of 116% is also observed to be very much larger than corresponding ratios for, for example, car protective systems which are in use, such as seatbelts or head restraints. The latter are observed to have risk-to-benefit ratios in the range of 7 percent or less (eg, Refs 30, 31).

CONCLUSIONS AND RECOMMENDATIONS

The motorcycle industry has recently completed an overall evaluation of a UKDS leg protector device — designed and fitted by the UK's Transport Research Laboratory — using the test and analysis procedures specified in ISO 13232. The effects of leg protectors on rider injuries were assessed by means of seven pairs of full scale impact tests and 200 pairs of calibrated computer simulations.

As in previous research reported in 1988, 1989, 1991, 1994 and 1996, it was found that fitment of leg protectors resulted in a mixture of beneficial and harmful effects. In the full scale tests, upper and lower leg fractures were eliminated in the offset frontal configuration (which ISO 13232 indicates is the least frequently occurring among the seven standard impact configurations). However, fitment of UKDS leg protectors resulted in increased head injury severity in 3 out of 7 impact configurations; increased probability of fatality and normalized injury costs in 4 out of 7 impact configurations; and increased neck compression injury index in 5 out of 7 impact configurations. This was observed to be the result of forward and/or lateral torso pitch, caused by a robust restraint of the knee, by leg protectors.

With regard to injury cost, fitment of leg protectors increased the overall normalized injury cost of the seven full scale impact configurations specified by ISO 13232 by more than 300%.

Other harmful effects resulting from leg protector fitment include transfer of injury - from the lower leg to the upper leg - in the angled car front impact (the second most frequently occurring of the seven standard full scale impact configurations). This transfer of injury is a fundamental result of the way in which the knee is restrained, which applies large forces and torques sufficient to fracture the femur. Such femur fractures are more severe (and in some cases life threatening) than the lower leg fractures which leg protectors are intended to reduce.

Calibrated computer simulations of 200 pairs of impacts which occur in accidents - with and without leg protectors fitted - indicated that the total injury risks (ie, increases in injury costs resulting from leg protector fitment) exceeded the total injury benefits, with a risk-to-benefit ratio of 116%. This was observed to be much larger than risk-to-benefit ratios of 7% or less observed in car occupant protection systems, such as seatbelts or head restraints. The simulation results also indicated that leg protectors increased more costly upper leg injuries, whilst decreasing less costly lower leg injuries.

All of the foregoing results indicated that this concept of rider protection would produce a net harmful effect, which is undesirable and unacceptable in any device intended to improve safety. Based on these results and the previous research, this type of device should not be fitted to production motorcycles. For the same reasons, there appears to be no merit in the further development of this protection concept.

Research into the feasibility of other rider protection devices and concepts, and refinement of research methods, should continue.

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REFERENCES

1. Rogers, NM, "A Technical Evaluation of Motorcycle Leg Protectors," 13th International Technical Conference on Experimental Safety Vehicles, Paris, November 1991.

2. Sporner, A, Langwieder, K, Polauke, J, "Passive Safety for Motorcyclists - From Leg Protectors to the Airbag," Society of Automotive Engineers Paper 900756, February 1990.

3. Anon, Draft Specification: Leg Protection for Riders of Motorcycles, United Kingdom Department of Transport, 1987(Amended June 1988, February 1989).

4. Anon, TRRL Review of Research on Motorcycle Leg Protection - 1991, Transport and Road Research Laboratory, Crowthorne, United Kingdom, 1991.

5. Rogers, NM, "Further Crash Tests of Motorcycle Leg Protectors as Proposed in the UK Draft Specification," 13th International Technical Conference on Experimental Safety Vehicles, Paris, November 1991.

6. Rogers, NM, "Evaluation of TRL Designed Leg Protectors for a Medium Sport Motorcycle," 14th International Technical Conference on Enhanced Safety of Vehicles, Munich, May 1994.

7. Anon, Leg Protectors: Do They Work?, Proceedings of the International Seminar on Leg Protectors, at Chantilly, France, International Motorcycle Manufacturers Association, 1991.

8. Bothwell, PW, Knight, RE, Peterson, HC, Dynamics of Motorcycle Impact, Volume II, Motorcycle Crash Test Program, DOT-HS-5-01160, 1971.

9. Bothwell, PW, Peterson, HC, Dynamics of Motorcycle Impact, Volume II, Motorcycle Crash Test Program, DOT-HS-800-907, 1973.

10. Uto, T, Side Collision Test of Motorcycle Equipped with Side Protection Devices, Japan Automobile Manufacturers Association, 1975.

11. Livers, GD, An Analysis of Motorcycle Side Impact, DOT-HS-801-840, Final Report, 1976.

12. Bartol, JA, Livers, GD, Miennert, R, Near Term Safety Improvements for Motorcycles - Phase II, DOT-HS-801-653, 1975.

13. Bothwell, PW, Dynamics of Motorcycle Impact - Volume I, Motorcycle Crash Test Program, Interim Report, DOT-HS-126-3-632, 1975.

14. Chinn, BP, Macaulay, MA, "Leg Protection for Motorcycles," IRCOBI Conference on the Biomechanics of Impacts, 1984.

15. Tadokoro, H, Fukuda, S, Miyazaki, K, "A Study of Motorcycle Leg Protection," 10th International Technical Conference on Experimental Safety Vehicles, Oxford, May 1985.

16. Chinn, BP, Hopes, PD, Macaulay, MA, "Leg Protection for Riders of Motorcycles," 10th International Technical Conference on Experimental Safety Vehicles, Oxford, May 1985.

17. Chinn, BP, Hopes, PD, "Protecting Motorcyclists Legs," 11th International Technical Conference on Experimental Safety Vehicles, Washington, DC, May 1987.

18. Chinn, BP, Macaulay, MA, "Leg Protection for Motorcyclists," IRCOBI Conference on the Biomechanics of Impacts, 1986.

19. Anon, Comments on the UK Draft Specification for Leg Protection for Riders of Motorcycles, Dynamic Research Inc Technical Memorandum 88-2, Torrance California, January 1988.

20. Bothwell, PW, Bothwell, R, Motorcycle Leg Protectors - Response of the Motorcycle Association of Great Britain, Ltd to D.P. Legislative Proposals, Motorcycle Association of Great Britain, January 1988.

21. Sakamoto, S, Preliminary Evaluation of a Motorcycle Leg Protector Design as Proposed by the United Kingdom Department of Transport, Japan Automobile Manufacturers Association, June 1988.

22. Anon, Summary of Industry Position on Motorcycle Leg Protectors, International Motorcycle Manufacturers Association, Paris, 1990.

23. Sakamoto, S, "Research History of Motorcycle Leg Protection," Society of Automotive Engineers Paper 900755, February 1990.

24. Zellner, JW, Wiley, KD, Broen, NL, Newman JA, "A Standardized Motorcyclist Impact Dummy for Protective Device Research," 15th International Technical Conference on the Enhanced Safety of Vehicles, Melbourne, May 1996.

25. St-Laurent, A, Szabo, T, Shewchenko, N, Newman, J, "Design of a Motorcyclist Anthropometric Test Device," 12th International Technical Conference on Experimental Safety Vehicles, Goteborg, May 1989.

26. Van Driessche, H, "Development of an ISO Standard for Motorcycle Research Impact Test Procedures," 14th International Technical Conference on Enhanced Safety of Vehicles, Munich, May 1994. 1994.

27. Rogers, NM, "Application of ISO 13232 to Motorcyclist Protective Device Research," 15th International Technical Conference on the Enhanced Safety of Vehicles, Melbourne, May 1996.

28. Kebschull, SA, Zellner, JW, Van Auken, M, "Injury Risk/Benefit Analysis of Motorcyclist Protective Devices Using Computer Simulation and ISO 13232," 16th International Technical Conference on the Enhanced Safety of Vehicles, Windsor, Ontario, June 1998.

29. Obergefell, LA, Fleck, JT, Kaleps, I, Gardner, TR, Articulated Total Body Model Enhancements, US Air Force AAMRL-TR-88-009, January 1988.

30. Malliaris, AC, Hitchcock, R, Hedlund, J, "A Search for Priorities in Crash Protection," Society of Automotive Engineers Paper 820242, 1982.

31. Huelke, DF, O'Day, J, "The Federal Motor Vehicle Safety Standards: Recommendations for Increased Occupant Safety," Fourth International Congress on Automotive Safety, July 1975.

32. Anon, International Standard ISO 13232: 1996(E), Motorcycles - Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles, Parts 1 to 8, International Standardization Organization, Geneva, December 1996.

Table 1
Comparison of Some of the Past Test Methods used in Leg Protector Research

Test Element	TRRL	IMMA
Dummy	Modified OPAT	Modified Hybrid III
Injury indicating dummy legs	Aluminum honeycomb on metal plates	Breakable composite bones
Dummy knees	1 axis	3 axis
Data acquisition system	External, via cable	Internal to dummy (to avoid motion distortion due to cable)
Dummy hand position	Taped to fuel tank	Grippable hands on handlebars
Opposing vehicle	GM Vauxhaul Ford Sierra various others	Toyota Crown Toyota Celica
Relative angle between motorcycle and car	various, at 30° increments	various, at 45° increments
Motorcycle wheels prior to release from trolley	Stationary	Rolling (for increased stability, accuracy, realism)

Table 2
Example Leg Protector Types
Examined Through 1987

Time Period	Proposed Device	Reference
1971	Accessor bars	8
1973	Revised heavy duty crash bars	9
1975	Side protection devices	10
1973-76	Experimental Safety Motorcycle (ESM) structure	11, 12
1975	Crash bar with energy absorbing bucket seat	11
1975-81	Reinforced leg shield fairing device	13
1984	Hard leg protector	14, 16
1984-87	Soft leg protector	14, 15, 16, 17
1985	Crushable leg protector	15

Table 3.
Leg Protector Description

Element		Material
PIE	External	Sheet metal
	Internal	Polyurethane
RSE		Sheet metal + solid bar with notch
KPE		Aluminum honeycomb

Table 4.
Specifications of Test Motorcycle

Size:	Medium
UKDS category:	3a
Manufacturer:	Kawasaki
Overall length:	2 125 mm
Overall width:	675 mm
Overall height:	1 165 mm
Weight - Motorcycle with LP:	189 kg (dry)

Table 5.
Specifications of Opposing Vehicle

Type:	Saloon
Manufacturer:	Toyota
Model:	Corolla
Model year:	1988 - 1990
Overall length:	4 200 mm
Overall width:	1 660 mm
Overall height:	1 340 mm
Weight:	1 100 kg ± 20 kg

Table 6.
General Description of Leg Protector,
Motorcycle, Dummy, and Opposing Vehicle Models

Model	Number of :			
	Bodies	Joints	Ellipsoids	Planes
Leg protector (L + R)	2	2	4	10
Motorcycle	7	6	18	0
Dummy	30	29	28	0
Opposing Vehicle	7	6	26	4

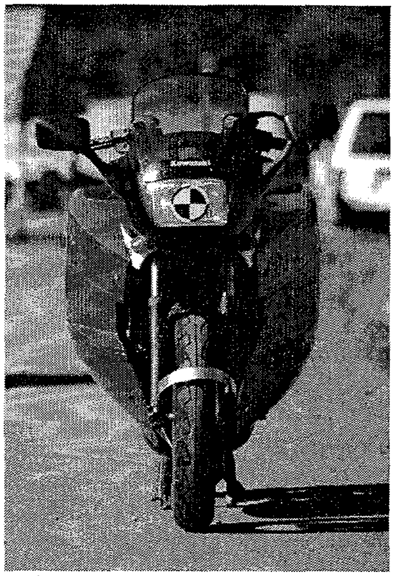

Figure 1. Front View of Leg Protector, Fitted to Test Motorcycle

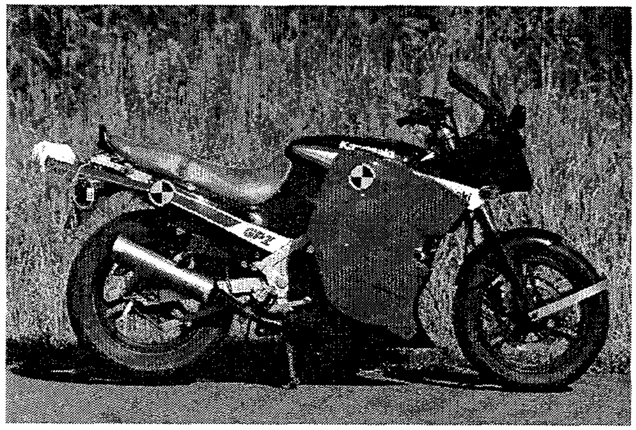

Figure 2. Side View of Leg Protector Fitted to Test Motorcycle

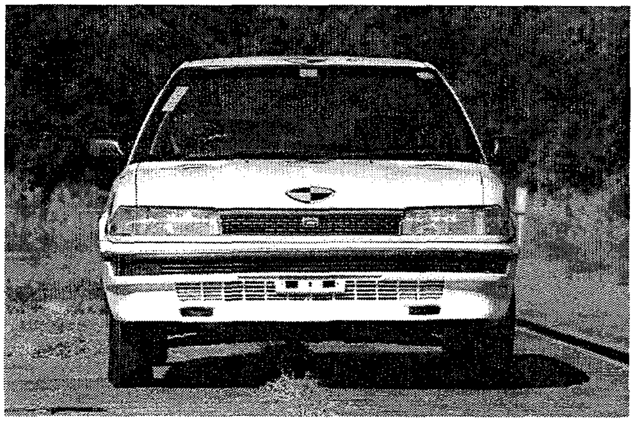

Figure 3. Front View of Opposing Vehicle

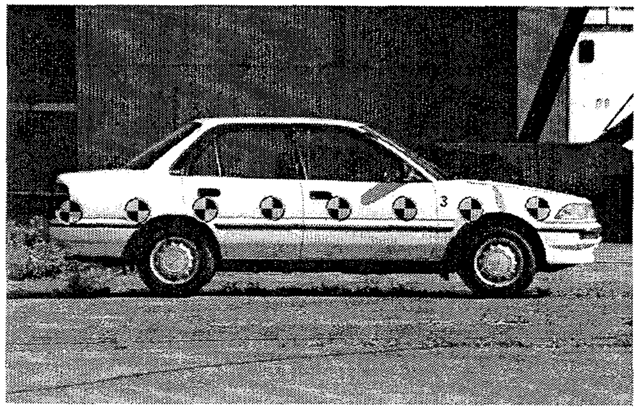

Figure 4. Side View of Opposing Vehicle

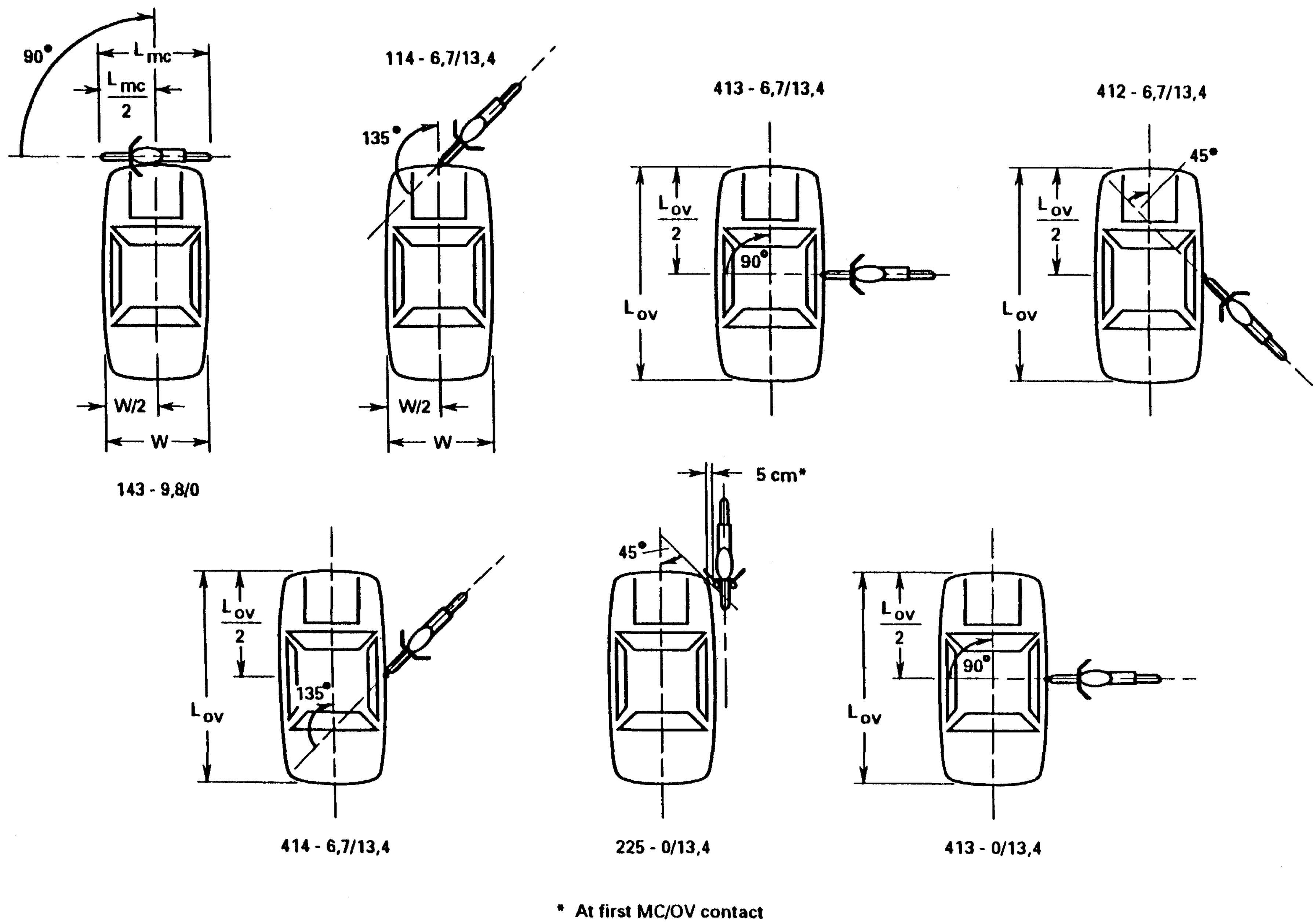

Figure 5. Target impact geometries at first MC/OV contact for seven full scale impact configurations.