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Motorcycles — Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles —

Part 7: Standardized procedures for performing computer simulations of motorcycle impact tests

Motocycles — Méthodes d'essai et d'analyse de l'évaluation par la recherche des dispositifs, montés sur les motocycles, visant à la protection des motocyclistes contre les collisions —

Partie 7: Méthodes normalisées de simulation par ordinateur d'essais de choc sur motocycles

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

ISO 13232-7 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 22, *Motorcycles*.

This second edition cancels and replaces the first version (ISO 13232-7:1996), which has been technically revised.

ISO 13232 consists of the following parts, under the general title *Motorcycles — Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles*:

— *Part 1: Definitions, symbols and general considerations*

— *Part 2: Definition of impact conditions in relation to accident data*

— *Part 3: Motorcyclist anthropometric impact dummy*

— *Part 4: Variables to be measured, instrumentation and measurement procedures*

— *Part 5: Injury indices and risk/benefit analysis*

— *Part 6: Full-scale impact-test procedures*

— *Part 7: Standardized procedures for performing computer simulations of motorcycle impact tests*

— *Part 8: Documentation and reports*

Introduction

ISO 13232 has been prepared on the basis of existing technology. Its purpose is to define common research methods and a means for making an overall evaluation of the effect that devices which are fitted to motorcycles and intended for the crash protection of riders, have on injuries, when assessed over a range of impact conditions which are based on accident data.

It is intended that all of the methods and recommendations contained in ISO 13232 should be used in all basic feasibility research. However, researchers should also consider variations in the specified conditions (for example, rider size) when evaluating the overall feasibility of any protective device. In addition, researchers may wish to vary or extend elements of the methodology in order to research issues which are of particular interest to them. In all such cases which go beyond the basic research, if reference is to be made to ISO 13232, a clear explanation of how the used procedures differ from the basic methodology should be provided.

ISO 13232 was prepared by ISO/TC 22/SC 22 at the request of the United Nations Economic Commission for Europe Group for Road Vehicle General Safety (UN/ECE/TRANS/SCI/WP29/GRSG), based on original working documents submitted by the International Motorcycle Manufacturers Association (IMMA), and comprising eight interrelated parts.

This revision of ISO 13232 incorporates extensive technical amendments throughout all the parts, resulting from extensive experience with the standard and the development of improved research methods.

In order to apply ISO 13232 properly, it is strongly recommended that all eight parts be used together, particularly if the results are to be published.

Motorcycles — Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles —

Part 7:
Standardized procedures for performing computer simulations of motorcycle impact tests

1 Scope

The purposes of this part of ISO 13232 are to provide:

- conventions for calibrating and documenting the important features of the simulation models;
- guidelines for definition and use of mathematical models for motorcycle impact simulations, which can be correlated against data for full-scale tests;
- a means for identifying possible additional impact conditions for full-scale testing; and
- a standardized tool, of optional use, for risk/benefit analysis of rider crash protective devices fitted to motorcycles, based upon the population of impact conditions identified in ISO 13232-2.

ISO 13232 specifies the minimum requirements for research into the feasibility of protective devices fitted to motorcycles, which are intended to protect the rider in the event of a collision.

ISO 13232 is applicable to impact tests involving:

- two-wheeled motorcycles;
- the specified type of opposing vehicle;
- either a stationary and a moving vehicle or two moving vehicles;
- for any moving vehicle, a steady speed and straight-line motion immediately prior to impact;
- one helmeted dummy in a normal seating position on an upright motorcycle;
- the measurement of the potential for specified types of injury by body region;
- evaluation of the results of paired impact tests (i.e. comparisons between motorcycles fitted and not fitted with the proposed devices).

ISO 13232 does not apply to testing for regulatory or legislative purposes.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6487, *Road vehicles — Measurement techniques in impact tests — Instrumentation*

ISO 13232-1, *Motorcycles — Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles — Part 1: Definitions, symbols, and general considerations*

ISO 13232-2, *Motorcycles — Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles — Part 2: Definition of impact conditions in relation to accident data*

ISO 13232-3, *Motorcycles — Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles — Part 3: Motorcyclist anthropometric impact dummy*

ISO 13232-4, *Motorcycles — Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles — Part 4: Variables to be measured, instrumentation, and measurement procedures*

ISO 13232-5, *Motorcycles — Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles — Part 5: Injury indices and risk/benefit analysis*

ISO 13232-6, *Motorcycles — Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles — Part 6: Full-scale impact test procedures*

ISO 13232-8, *Motorcycles — Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles — Part 8: Documentation and reports*

49 CFR Part 572, subpart E: 1993, Anthropomorphic test dummies, United States of America Code of Federal Regulations issued by the National Highway Traffic Safety Administration (NHTSA) Washington, D.C

3 Definitions

The following terms are defined in ISO 13232-1. For the purposes of this part of ISO 13232, those definitions apply. Additional definitions which could apply to this part of ISO 13232 are listed in ISO 13232-1:

— body;

— failure mode and effects analysis (FMEA);

— maximum thickness;

— motion;

— risk/benefit analysis; overall evaluation;

— system.

4 Requirements

4.1 Modelling

The simulation model shall be based upon accepted laws and principles of physics and mechanics. The model shall consist of portions describing a motorcycle (MC) and the opposing vehicle (OV), as described in ISO 13232-6, the dummy, as described in ISO 13232-3, the dummy mounting position, joint tensions, and helmet, as described in ISO 13232-6, the protective device, if present, and the road surface. In the model, the following impact conditions shall be able to be varied, across the range of conditions described in Annex B of ISO 13232-2:

— MC impact speed;

— OV impact speed;

— MC contact point;

— OV contact point;

— relative heading angle.

The model of the dummy should include the following bodies, at a minimum:

a) helmeted head;

b) neck;

c) upper torso;

d) lower torso;

e) left and right:

   1) upper legs;

   2) lower legs;

   3) feet;

   4) upper arms;

   5) lower arms;

   6) hands.

The model of the MC should include the following bodies at a minimum:

— front wheel;

— rear wheel;

— main frame;

— upper front fork assembly;

— lower front fork assembly.

The model of the OV should include the following bodies at a minimum:

— four unsprung assemblies;

— sprung body.

The upper leg, knee, and lower leg bodies shall be modelled so that the bone fracture/knee dislocation kinematics effects are simulated (e.g., resulting in reduced bending moment in the leg at the appropriate location after fracture).

If any of the bodies listed in Tables 1 and 2 can fracture, the masses of the bodies resulting from the fracture shall be modelled.

For a given MC/protective device combination, the same model formulation shall be used for all impact configurations. The only differences between a model of a MC with a protective device and a model of a MC without a protective device shall be in those portions directly related to the protective device.

4.2 Parameters

For each body listed in 4.1, the parameter values used should correspond to the actual measured:

— mass;

— centre of gravity location;

— moments of inertia;

— principal axes orientations;

— joint locations;

— joint physical degrees of freedom;

— joint orientations;

— maximum thickness of each undeformed body.

For a given MC/protective device combination, the same parameter values shall be used for all impact configurations. All of the parameter values for a given MC/protective device combination shall correspond to the parameter values used to calibrate the simulation, as described in 4.5. The only difference between a parameter set for a MC with a protective device and a parameter set for a MC without a protective device shall be in those parameters directly related to the protective device.

4.3 Outputs

Force, moment, and motion time histories which are compatible with the injury variables and injury indices listed in ISO 13232-5 shall be output to allow computation of the injury indices. The form shall be consistent with the full-scale test time histories documented as described in ISO 13232-8. The data shall be output and plotted at 0,001 s intervals for the time period up to but not including dummy to ground contact, or 0,500 s after the first MC/OV contact, whichever is sooner.

Indication of frangible damage shall be output for all of the frangible components defined in ISO 13232-3, along with the time at which the damage occurred, for the time period described above. The damage shall be expressed as occurrence of component failure for each frangible femur, knee (varus valgus or torsion), and tibia; and as maximum penetration for the frangible abdominal insert.

The linear and angular displacement and velocity time histories of the MC main frame and helmeted head centres of gravity and the shoulder, pelvis, knee, and ankle targets corresponding to those used in full-scale tests shall be output and plotted, at the intervals and for the time period described above.

For each simulation run and for each interaction which occurs between any of the MC bodies in Table 1 and any of the OV bodies in Table 2, the maximum force and maximum deflection of the MC body and of the OV body, along the directions indicated in Table 1 and Table 2, shall be output.

Table 1 — MC laboratory component tests

Body	Impactor or impact surface[a]	Test type	Characteristics
MC fuel tank	400 mm cylinder	Dynamic	z_{cyl} force vs z_{cyl} displacement z_{cyl} force vs time
MC seat	400 mm cylinder	Static	z_{cyl} force vs i displacement
Protective device	(As required)	Dynamic	Force vs displacement Force vs time
MC rear spring damper	None	Static	x force vs x displacement
MC rear spring damper	Flat	Dynamic	x_{imp} force vs x_{imp} velocity
MC front wheel	Barrier (as part of the MC laboratory test described in 4.5.2)	Dynamic	$x_{barrier}$ force vs x_{MC} displacement
[a] Refer to Figure 1.			

Table 2 — OV laboratory component tests

Body	Impactor or impact surface[a]	Test type	Characteristics
OV roof rail	300 mm sphere	Dynamic	x_{sphere} force vs x_{sphere} displacement x_{sphere} force vs time
OV side	Disc (edge)	Static	x_{disc} force vs x_{disc} displacement
OV side	Disc (side)	Static	y_{disc} force vs y_{disc} displacement
OV front bumper	Disc (edge)	Static	x_{disc} force vs x_{disc} displacement
OV front bumper	Disc (side)	Static	y_{disc} force vs y_{disc} displacement
OV rear bumper	Disc (edge)	Static	x_{disc} force vs x_{disc} displacement
OV rear bumper	Disc (side)	Static	y_{disc} force vs y_{disc} displacement
OV bonnet	300 mm sphere	Dynamic	z_{sphere} force vs z_{sphere} displacement z_{sphere} force vs time
OV front windscreen	300 mm sphere	Dynamic	x_{sphere} force vs x_{sphere} displacement x_{sphere} force vs time
OV front suspension	Ground	Dynamic	z_g force vs z_{OV} displacement z_g force vs time
OV rear suspension	Ground	Dynamic	z_g force vs z_{OV} displacement z_g force vs time

[a] Refer to Figure 1.

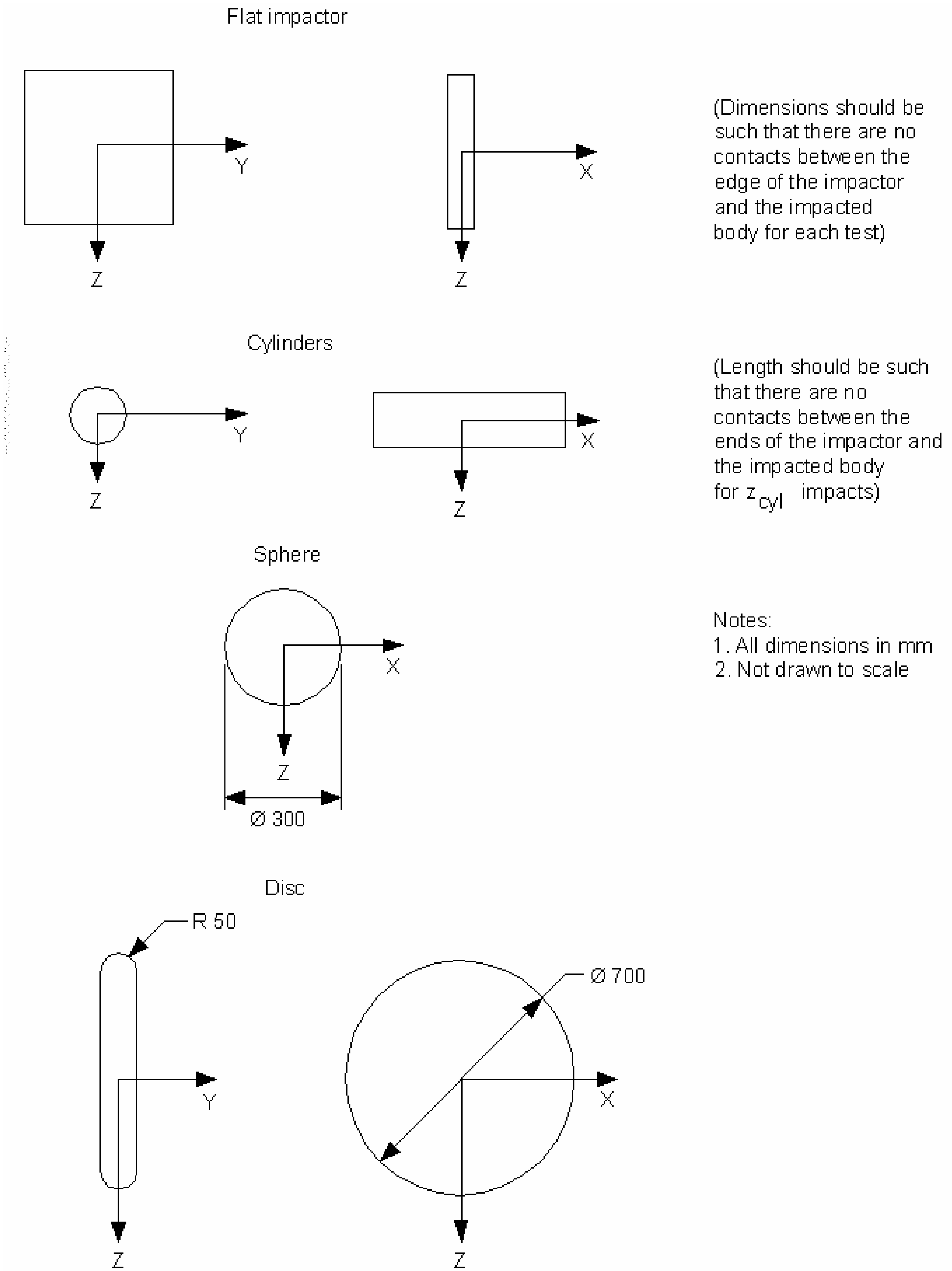

Figure 1 — Impactors and axes to be used for component test

If a three dimensional animation is done, then the linear and angular positions of any and all rigid bodies and the positions of any and all finite element nodes, shall be output at equal increments of time.

4.4 Post processing

The following shall apply to post processing involving three dimensional animation, injury analysis, risk/benefit analysis and failure mode and effects analysis of proposed crash protective devices.

4.4.1 Three dimensional animation

Three dimensional animation should be used to display, graphically, the motions of the MC, OV, dummy, and protective device. The animation shall display only the actual modelled rigid body surfaces and/or finite elements, in their proper shapes and relative positions and orientations. Additional markers may be provided to assist the comparison between physical tests and simulations. These shall correspond to the photographic targets used in any corresponding full-scale impact test, including those defined in 4.3 of ISO 13232-4. If such markers are added, they shall appear in colours which contrast to the model's rigid body surfaces or finite elements, and a statement of this shall be made preceding the animation sequence.

The animation shall be driven only by the linear and angular position time histories, as described in 4.3. When comparisons are made with full-scale test films, the animations shall use the same viewpoint and focal length as the cameras designated for full-scale testing (see 4.6.2 of ISO 13232-4).

Still photographs of the animation from the perspective of the MC side view camera should be taken and included in the simulation documentation. Photographs shall include the dummy position:

— prior to first MC/OV contact;

— at first head/OV contact (if any);

— at 0,250 s and 0,500 s after first MC/OV contact.

4.4.2 Injury analysis

Evaluation of the computer simulation output, in terms of injury indices and injury cost analyses, may be done. If done, such analyses shall use the conventions described in ISO 13232-5.

4.4.3 Risk/benefit analysis and failure mode and effects analysis of proposed crash protective devices

Risk/benefit analysis and/or failure mode and effects analysis of proposed rider crash protective devices fitted to motorcycles, across a range of impact conditions, should be done using computer simulation. If failure mode and effects analysis is done using computer simulation, such analysis shall use the methods described in 5.1. If risk/benefit analysis is done using computer simulation, such analysis shall use the methods described in 5.10 of ISO 13232-5.

If risk/benefit analysis and/or failure mode and effects analysis are done using computer simulation, they shall only include impact configurations in which the simulated forces and deflections of the bodies listed in Tables 1 and 2 meet the following criteria:

— for all bodies which can fracture, none of the maximum simulated forces defined in 4.3 may equal or exceed the maximum forces measured in the corresponding laboratory tests defined in 4.5.1 and 4.5.2;

— for all other bodies, none of the maximum simulated forces or maximum simulated deflections defined in 4.3 may equal or exceed the corresponding maximum forces or maximum deflections measured in the laboratory tests defined in 4.5.1 and 4.5.2.

If in any simulated impact configuration, any of the measured forces or deflections occurring between the bodies listed in Tables 1 and 2 are exceeded, that impact configuration may only be included in the analyses if additional laboratory tests and simulation calibrations are done on those specific bodies. Each additional laboratory test and simulation calibration shall use an initial speed which corresponds to the maximum relative impact speed of the respective body observed among the simulated impact configurations.

4.5 Simulation calibration

The simulation shall be calibrated with at least the following tests, and the calibration results shall be documented in accordance with ISO 13232-8.

4.5.1 Laboratory component test calibration

The simulation shall be used to calculate the MC, OV, and dummy characteristics listed in Tables 1, 2, and 3, respectively, using the methods defined in 5.2. The results shall be documented using the format described in Annex A, and in accordance with ISO 13232-8.

If, for any laboratory component test, the test data are used as input parameter values for the simulation, only the relevant test data shall be included in the simulation documentation (since the input parameter values are equal to the test data).

4.5.2 Motorcycle laboratory dynamic test

One MC laboratory test and corresponding simulation shall be performed to calculate the following MC time histories, using the methods defined in 5.3:

- front axle displacement;
- front suspension compression;
- fork bending angle;
- x, y, and z accelerations of the MC (on the left and right sides of the MC, as close as possible to the MC centre of gravity);
- MC centre of gravity x and z displacements;
- MC pitch angle;
- barrier force.

4.5.3 Full-scale impact test correlation

For a given MC, which is fitted or not fitted with a given rider protective device design, the simulation shall be correlated against the data for any available, corresponding full-scale tests which have been performed in accordance with ISO 13232. The simulation shall be run using the same initial conditions as were used in the full-scale tests, the modelling and parameter constraints defined in 4.1 and 4.2, the laboratory component test characteristics defined in 4.5.1, and the MC parameters used in the MC laboratory dynamic test defined in 4.5.2. The required time histories shall be output according to 4.3. For such correlation, the results shall be documented as follows:

- if data for fewer than 14 tests are available, then overlaid comparison plots of the corresponding full-scale test and simulation time histories and trajectories, as described below, shall be made. For each full-scale and simulated test, the occurrence and/or extent of damage to frangible elements, as described in 5.2.3 of ISO 13232-4, shall be tabulated. A statistical correlation analysis should not be done in this case;
- if data for 14 or more tests are available, then the above overlaid comparison plots and damage tabulations shall be made, and in addition, the data shall be statistically correlated using the procedures described in 5.4.

Table 3 — Dummy laboratory component tests

Body	Impactor or impact surface[a]	Test type	Characteristics
Helmeted head	Flat anvil	Dynamic	z_h force vs z_h displacement z_h force vs time
Upper arm	Flat	Dynamic	x_{imp} force vs x_{imp} displacement x_{imp} force vs time
Lower arm	Flat	Dynamic	x_{imp} force vs x_{imp} displacement x_{imp} force vs time
Dummy thorax	Hybrid III thorax impact test probe[b]	Dynamic	x_{imp} force vs x_{imp} displacement x_{imp} force vs time
Abdomen	25 mm cylinder	Static	z_{cyl} force vs z_{cyl} displacement
Pelvis	Flat	Dynamic	x_{imp} force vs x_{imp} displacement x_{imp} force vs time
Upper leg	70 mm cylinder	Dynamic	z_{cyl} force vs z_{cyl} displacement z_{cyl} force vs time
Knee	Flat	Dynamic	x_{imp} force vs x_{imp} displacement x_{imp} force vs time
Lower leg	70 mm cylinder	Dynamic	z_{cyl} force vs z_{cyl} displacement z_{cyl} force vs time
Dummy knee torsion	(See 6.6 of ISO 13232-3)	Static	z_{lleg} moment vs θ_z displacement
Dummy knee varus valgus	(See 6.6 of ISO 13232-3)	Static	x_{lleg} moment vs θ_x displacement
Forward neck flexion	Hybrid III neck test pendulum[b]	Dynamic	y moment vs θ_y displacement y moment vs time z displacement vs x displacement x displacement vs time x acceleration vs time θ_y displacement vs time
Rearward neck extension	Hybrid III neck test pendulum[b]	Dynamic	y moment vs θ_y displacement y moment vs time z displacement vs x displacement x displacement vs time x acceleration vs time θ_y displacement vs time
Lateral neck flexion	Hybrid III neck test pendulum[b]	Dynamic	x moment vs θ_x displacement x moment vs time z displacement vs y displacement y displacement vs time y acceleration vs time θ_x displacement vs time

Body	Impactor or impact surface[a]	Test type	Characteristics
Neck torsion	See 6.8 of ISO 13232-3)	Dynamic	z moment vs θ_z displacement z moment vs time

a Refer to Figure 1.

b Described in 49 CFR Part 572.

All full-scale tests used for simulation correlation shall be selected from the 200 impact configurations described in ISO 13232-2, and each test (with the exception of the second test in each paired comparison) shall be for a different impact configuration.

4.5.4 Full-scale impact test comparisons

In addition, each simulated variable listed in Table 4 shall be plotted using the methods defined in ISO 13232-4 and A.8.3 and B.6.3 of ISO 13232-8, and overlaid with the corresponding full-scale test variable, for the time period from first MC/OV contact to 0,010 s before first helmet/OV contact, or until the helmet leaves the field of view, whichever occurs sooner. The plots shall be documented according to ISO 13232-8. In addition, calculate the following correlation factor for each variable listed in Table 4:

$$C = 1 - \frac{\sum_{i,k} \left(d_{i,k} - \bar{d}_i\right)^2}{\sum \left(r_{i,k} - \bar{r}_i\right)^2}$$

Where:

C is the correlation factor;

i is the subscript for each impact configuration;

k is the subscript for each time step;

$d_{i,k}$ is equal to $r_{i,k}$ minus $\hat{r}_{i,k}$.

$\bar{d}_i$ is the average value (over time) of $d_{i,k}$;

$r_{i,k}$ is the value of the variable for test i at time step k;

$\bar{r}_i$ is the average value (over time) of the variable for test i;

$\hat{r}_{i,k}$ is the value of the variable for computer simulation i at time step k.

The values for the full-scale test and computer simulation shall be sampled at 0,001 s intervals. The data may be linearly interpolated, if necessary, to achieve the 0,001 s sampling interval. The average of all of the correlation factors across all tests and all variables in Table 4 shall be greater than or equal to 0,80. The values of the correlation factors shall be documented in accordance with B.6.3.4.1 of ISO 13232-8.

In addition, the shoulder, hip, knee, and ankle target trajectories in the initial longitudinal-vertical plane of MC travel (x vs. z) shall be plotted for the simulation and overlaid with the corresponding full-scale test data, for the side of the dummy nearest the MC side view high speed camera, and for the time period from first MC/OV contact to first helmet/OV contact, or until the helmet leaves the field of view, whichever occurs sooner. The plots shall be documented in accordance with ISO 13232-8.

Table 4 — Comparison parameters

Item	Variable	Component
Helmet centroid[a]	Displacement	x
Helmet centroid[a]	Displacement	y
Helmet centroid[a]	Displacement	z
Helmet centroid[a]	Displacement	Resultant
Hip target[b]	Displacement	x
Hip target[b]	Displacement	z
Hip target[b]	Displacement	Resultant
Head (centre of gravity)	Velocity	Resultant
Pelvis (centre of gravity)	Velocity	Resultant
Torso angle	Angular displacement	Pitch[c]

[a] The definition of "helmet centroid" should be consistent with that described in Annex A of ISO 13232-4.

[b] The location of the hip target in the simulation shall be consistent with that described in 5.3.6 of ISO 13232-6.

[c] Angular displacement about an inertially fixed lateral horizontal axis of a line joining the near side hip target to the near side of the shoulder target.

5 Methods

5.1 Failure mode and effects analysis

Analyse the failure mode and effects data as described below.

5.1.1 Calculations of injury assessment variables and injury indices

For each of the 200 impact configurations defined in ISO 13232-2, and the simulation calibrated according to 4.5, calculate the values of the injury assessment variables and injury indices listed in Table 5, using the injury assessment variables and injury indices defined in ISO 13232-5.

5.1.2 Potential failure modes and effects

Tabulate the results of Table 5, across all 200 impact configurations. Designate impact configurations where there is a positive change due to the protective device, in one or more of the injury assessment variables or injury indices, as a potential failure mode of the protective device, for possible further consideration.

5.2 Simulated characteristics for laboratory component tests

Complete the test and simulation procedures below. Then overlay graphs of the resulting test and simulation characteristics according to the format shown in Annex A. Anti alias filter, sample, and bandpass filter at CFC 1 000 all test data according to the procedures in ISO 13232-4. Use impactors which have a minimum resonance frequency greater than 1 650 Hz. Complete the information describing the body, impactor, aligned axes, mass, and initial velocity, and show a sketch of the apparatus set up.

Table 5 — Injury assessment variables and injury indices to be calculated for each impact configuration

Injury assessment variable, injury index	Values to calculate		
	MC without protective device (1)	MC with protective device (2)	Change due to protective device (2) - (1)
Head maximum resultant linear acceleration	X	X	X
Head maximum resultant angular acceleration	X	X	X
Head maximum GAMBIT	X	X	X
HIC	X	X	X
Head PAIS	X	X	X
Neck PAIS	X	X	X
Chest PAIS	X	X	X
Abdomen PAIS	X	X	X
Sum of left and right femur PAIS	X	X	X
Sum of left and right knee PAIS	X	X	X
Sum of left and right tibia PAIS	X	X	X
Total normalized injury cost	X	X	X

5.2.1 Static force/displacement tests

For each body listed in Tables 1, 2, and 3 do the laboratory tests. Do the tests in a quasi-static manner, unless otherwise indicated, and with the impactor, contact points, axis alignments, orientations, and supports which are indicated in Table 6. Measure the force versus displacement characteristics up to a force level corresponding to the most severe injury of the respective dummy part for dummy parts, and corresponding to maximum expected force and deflection for MC and OV parts.

Use the simulation to calculate the corresponding force versus displacement characteristics for the bodies listed in Tables 1, 2, and 3.

5.2.2 Dynamic force/time and force/displacement tests

Do the dynamic tests defined in Tables 7, 8, and 9 for the dummy, MC, and OV, respectively. Use the bodies and impactors shown in Figure 1; and the contact points, axis alignments, orientations, supports, and nominal initial speeds listed in Tables 7, 8, and 9.

Use the simulation to calculate the corresponding force versus time and force versus displacement characteristics for those bodies listed in Tables 7, 8, and 9.

5.3 Motorcycle barrier test

Orthogonally impact a rigid, flat barrier having a width and height of at least 2 m each with the MC at a speed of 13,4 m/s ± 5% and the relative heading angle, MC roll angle, and MC speed tolerances in accordance with 4.5.4.3 of ISO 13232-6. Measure the test data with two triaxial accelerometers mounted on each side of the MC, as close as possible to the MC centre of gravity along the MC y axis, and with a rigid barrier face plate having three or more load cells. Filter the data in accordance with ISO 6487 at frequency response class 60.

Using procedures consistent with ISO 13232-4, determine the displacements of the respective MC parts from two high speed cameras at 1 000 f/s: one camera, a left side wide view of the entire MC; the other camera a right side narrow view of the front forks and front wheel.

Table 6 — Set up for static laboratory component tests

Body	Impactor or impact surface[a]	Contact points	Aligned axes	Orientation	Supports
Dummy abdomen	(See 6.7 of ISO 13232-3)		x_A with z_{cyl}	(See 6.7 of ISO 13232-3)	
Dummy knee torsion	(See 6.6 of ISO 13232-3)		z_{lleg} with z_g	(See 6.6 of ISO 13232-3)	
Dummy knee varus valgus	(See 6.6 of ISO 13232-3)		z_{lleg} with z_g	(See 6.6 of ISO 13232-3)	
MC seat	400 mm cylinder	Top of seat, 200 mm aft of forward edge of seat	z_{seat} with z_{cyl}	z_{seat} vertical	Rigidly fixed MC frame
MC rear spring-damper	-	Bottom end of rear spring-damper	-	-	Rigidly fixed at upper end of spring-damper
OV side	Disc (edge)	1/2 overall OV length 350 mm above road	y_{OV} with x_{disc}	z_{OV} vertical	Rigidly fixed OV frame
OV side	Disc (side)	1/2 overall OV length 500 mm above road	y_{OV} with y_{disc}	z_{OV} vertical	Rigidly fixed OV frame
OV front bumper	Disc (edge)	Centre of front bumper	x_{OV} with x_{disc}	z_{OV} vertical	Rigidly fixed OV frame
OV front bumper	Disc (side)	Centre of front bumper	x_{OV} with y_{disc}	z_{OV} vertical	Rigidly fixed OV frame
OV rear bumper	Disc (edge)	Centre of rear bumper	x_{OV} with x_{disc}	z_{OV} vertical	Rigidly fixed OV frame
OV rear bumper	Disc (side)	Centre of rear bumper	x_{OV} with y_{disc}	z_{OV} vertical	Rigidly fixed OV frame

[a] Refer to Figure 1.

Table 7 — Set up for dynamic laboratory dummy component tests

Body	Impactor or impact surface[a]	Contact points	Aligned axes	Orientation	Supports	Impactor mass kg	Nominal initial speed m/s
Helmeted head	Flat	Top of helmet	z_{hH} with z_g	z_{hH} downward	Helmeted head in guided free fall	fixed to ground	6
Upper arm	Flat	Middle of upper arm on the outer (lateral) surface	y_{uarm} with x_{imp}	y_{uarm} vertical	Shoulder and elbow supported by ground	10	5
Lower arm	Flat	Middle of lower arm on the outer (lateral) surface	y_{larm} with x_{imp}	y_{larm} vertical	Elbow and wrist supported by ground	10	5
Dummy thorax	(See 49 CFR Part 572, 572.36 (a))		x_{Th} with x_{imp}	(See 49 CFR Part 572, 572.34)			
Pelvis	Flat	Lower front of pelvis	45° below x_p with x_{imp}	x_p 45° from vertical	Pelvis supported by ground	10	2
Upper leg	70 mm cylinder	Middle of flesh covered upper leg at femur mid-span on the front surface of the leg	x_{uleg} with z_{cyl}	x_{uleg} vertical	Hip and knee supported by ground	50	7,5
Knee	Flat	Front of knee (knee flexed 90°)	z_{uleg} with x_{imp}	z_{uleg} horizontal	Dummy seated on flat, rigid, horizontal surface	5	2
Lower leg	70 mm cylinder	Middle of flesh covered lower leg at tibia mid-span on the front surface of the leg	x_{lleg} with z_{cyl}	x_{lleg} vertical	Knee and ankle supported by ground	50	7,5
Forward neck flexion	(See 49 CFR Part 572, 572.33)						
Rearward neck extension	(See 49 CFR Part 572, 572.33, with neck mounted as appropriate to induce rearward neck extension)						
Lateral neck flexion	(See 49 CFR Part 572, 572.33, with neck mounted as appropriate to induce lateral neck flexion)						
Neck torsion	(See 6.8 of ISO/DIS 13232-3)						

a Refer to Figure 1.

Table 8 — Set up for dynamic laboratory MC component tests

Body	Impactor or impact surface[a]	Contact points	Aligned axes	Orientation	Supports	Impactor mass kg	Nominal initial speed m/s
MC fuel tank	400 mm cylinder	Rear of fuel tank with bottom of cylinder at height of top of seat	x_{MC} with z_{cyl}	x_{MC} horizontal	Tank mounting brackets	50	20
Protective device	(As required)						
MC rear spring-damper	Flat	Bottom end of rear spring-damper	z_{rs} with x_{imp}	z_{rs} vertical	Rigidly fixed upper end of spring-damper	100	2

a Refer to Figure 1.

Table 9 — Set up for dynamic laboratory OV component tests

Body	Impactor or impact surface[a]	Contact points	Aligned axes	Orientation	Supports	Impactor mass kg	Nominal initial speed m/s
OV roof rail	300 mm sphere	Middle of OV roof rail	45° above y_{OV} with x_{sphere}	z_{OV} vertical	Rigidly fixed OV frame	10	10
OV bonnet	300 mm sphere	Centre of bonnet	x_{sphere} perpendicular to bonnet	z_{OV} vertical	Rigidly fixed OV frame	10	10
OV front windscreen	300 mm sphere	Centre of windscreen	x_{sphere} perpendicular to windscreen	z_{OV} vertical	Rigidly fixed OV frame	10	10
OV front suspension	Ground	Front wheels	z_{OV} with z_g	z_{OV} vertical	Sprung body at rear axle	-	1
OV rear suspension	Ground	Rear wheels	z_{OV} with z_g	z_{OV} vertical	Sprung body at rear axle	-	1

a Refer to Figure 1.

For each variable listed in 4.5.2, plot the output time histories from the test and from the simulation on the same graph.

5.4 Full-scale impact test statistical correlation

Determine the values of the following injury assessment variables and injury indices according to ISO 13232-5, for each of the 14 or more simulated tests, from the time of first MC/OV contact, until the last 0,001 s interval prior to initial dummy/ground contact, or 0,500 s after first MC/OV contact, whichever is sooner:

- head maximum resultant linear acceleration, $a_{r,H,max}$;
- fracture occurrence for the left and right femurs;
- fracture occurrence for the left and right tibias;
- dislocation occurrence for the left and right knees.

Correlate and tabulate these data for the 14 or more simulated tests against the measured full-scale data, using the following procedures.

5.4.1 Head maximum resultant linear acceleration correlation

Calculate the correlation coefficient r^2 as:

$$r^2 = \left(\frac{N_{fs}\left(\sum a_{r,H,fs}\, a_{r,H,cs}\right) - \left(\sum a_{r,H,fs}\right)\left(\sum a_{r,H,cs}\right)}{\sqrt{N_{fs}\left(\sum a_{r,H,fs}{}^2\right) - \left(\sum a_{r,H,fs}\right)^2}\,\sqrt{N_{fs}\left(\sum a_{r,H,cs}{}^2\right) - \left(\sum a_{r,H,cs}\right)^2}} \right)^2$$

where

r^2 is the correlation coefficient;

N_{fs} is the number of individual full-scale tests;

$a_{r,H,fs}$ is the head maximum resultant linear acceleration from a full-scale test;

$a_{r,H,cs}$ is the head maximum resultant linear acceleration from the corresponding simulation.

5.4.2 Leg injury correlations

For each of the six leg components, calculate the fraction correctly predicted, by first using Table 10, and then applying the following equation:

$$f = \frac{N_{ci}}{2N_{fs}}$$

where

f is the fraction correctly predicted;

N_{ci} is the total number of correct injuries;

N_{fs} is the number of individual full-scale tests.

Table 10 — Truth table for leg injury correlation

Full-scale test result		Simulated test result		Prediction is:
Leg component	Result	Leg component	Result	
right	uninjured	right	uninjured	correct
right	injured	right	injured	correct
right	uninjured	right	injured	incorrect
right	injured	right	uninjured	incorrect
left	uninjured	left	uninjured	correct
left	injured	left	injured	correct
left	uninjured	left	injured	incorrect
left	injured	left	uninjured	incorrect

6 Documentation

6.1 Simulation

For a given set of simulation calibrations and any risk/benefit or failure mode and effects analyses, the simulation model and parameters shall be documented in accordance with ISO 13232-8. The information listed in Table 11 shall be included in the documentation.

6.2 Laboratory component test calibration

Report the simulated characteristics for laboratory component tests as shown in Annex A and document the component tests in accordance with IS0 13232-8.

6.3 Motorcycle dynamic laboratory test

Document the results of the MC dynamic laboratory test in accordance with ISO 13232-8.

6.4 Full-scale test correlation

Document the results of the full-scale impact test correlation in accordance with ISO 13232-8.

Table 11 — Information to be included in the simulation documentation

OV a) manufacturer, model, year; b) total mass; c) overall length; d) overall width; e) overall height: f) if used, list of: 1) rigid bodies and associated: — joint types, — contact surface types; 2) types and numbers of finite elements for each body. MC a) manufacturer, model, year; b) total mass; c) wheelbase; d) highest point of the seat behind the dummy (immediately prior to impact); e) overall handlebar width; f) if used, a list of: 1) rigid bodies and associated: — joint types, — contact surface types; 2) types and numbers of finite elements for each body.	Dummy a) total mass; b) overall height; c) overall width; d) overall thickness; e) if used, a list of: 1) rigid bodies and associated: — joint types, — contact surface types; 2) types and numbers of finite elements for each body. Protective device a) description; b) total mass; c) overall x_{MC} dimension; d) overall y_{MC} dimension (from MC centre line); e) overall z_{MC} dimension; f) if used, a list of: 1) rigid bodies and associated: — joint types, — contact surface types; 2) types and numbers of finite elements for each body.

Annex A
(normative)

Example simulated component characteristics reports

A.1 Principle

An example report and documentation of the simulated characteristics for the laboratory component tests.

A.2 Procedure

Report the results of the simulated component laboratory tests using the form shown in Figure A.1.

Component characteristics

Body ______________________________

Impactor ______________________________

Aligned axes ______________ / ______________

Mass ______________________________ kg

Nominal initial velocity ______________________ m/s

Sketch of test setup

Description/comments:

____

____

____

Overlay of test and simulation data

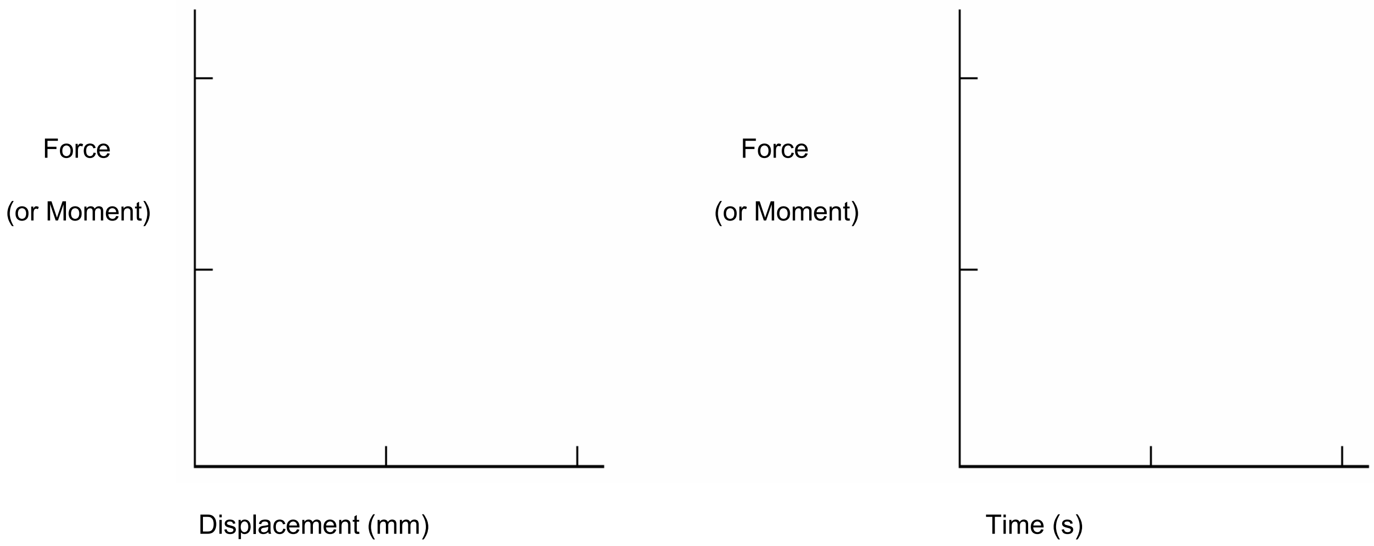

Figure A.1 — Format for component characteristic graphs

Annex B
(informative)

Rationale for ISO 13232-7

Any references cited in Annex B are listed in Annex B of ISO 13232-1.

B.1 Specific portion of the Scope

"Conventions for calibrating and documenting the important features of the simulation models" refers to methods for comparing the response of the simulation models to the measured response in laboratory and full-scale tests, in order to gain assurance of their accuracy, and methods for documenting the models so that they can be understood by other researchers. This part provides "guidelines for definition and use of mathematical models" in order to assure that a common, basic methodology for "motorcycle impact simulations" is used by all researchers. "A means for identifying possible additional impact conditions for full-scale testing" refers to the "permissible configurations from failure mode and effects analysis" described in 4.3.2 of ISO 13232-2. A standardized optional tool for "risk/benefit analysis of rider crash protective devices fitted to motorcycles" refers to the "overall evaluation" across 193 impact conditions described in 4.5 of ISO 13232-6. ISO 13232 recommends that an appropriately calibrated and correlated computer simulation model be used to perform such an overall evaluation.

B.2 Modelling (see 4.1)

It is considered necessary that the simulation model be based on "accepted laws and principals of physics and mechanics" rather than, for example, a purely empirical statistical "black box", or some other approach. It is also considered essential that the model "consist of portions describing a motorcycle and the opposing vehicle, . . . and the dummy" since these are essential for describing the basic phenomena and also for quantitative comparison and correlation against full-scale and laboratory test data. In addition, the other important features of the test procedures, including the dummy mounting position, joint tensions, helmet, the protective device, and the road surface can have strong influences on the simulation and test results, and therefore, must be included. The ability to vary the five impact condition variables is also essential, in order to be able to apply the model to the 200 impact configurations defined in ISO 13232-2.

The dummy model has a minimum number of specified bodies because: the actual impact dummy, defined in ISO 13232-3, has the same list of separable assemblies; the assemblies have mechanical degrees of freedom relative to one another; and the test data, against which the simulation is correlated, has different degrees of freedom and measured variables for many of the different assemblies.

Similarly, the MC model is recommended to consist of at least five bodies, these being the assemblies which can be observed to have mechanical degrees of freedom relative to one another during an impact test.

It is recommended that the OV have a minimum of five bodies in order to properly simulate the motion of the sprung body of the OV during an impact test, which can be quite large relative to the four unsprung assemblies which tend to remain on the road surface. In particular, the motion of the OV roof structure, for example, after impact, relative to the ground, can be important in its interaction with the motion of the rider, and therefore, rider injury potential.

Frangible bone and knee kinematics are required to be modelled because these can affect the motion of the dummy (as described in the rationale to ISO 13232-3); and also the forces to which the remainder of the lower extremities are exposed, during the impact test. A simulation model which merely predicts a "fracture" without simulating the results of that fracture would not be expected to give accurate results.

Regarding the fracture behavior of the MC and OV bodies, it is possible, though unlikely, for one of the bodies to fracture; and in doing so, for the force on the fractured portion to increase (due to its sudden acceleration), and for its displacement to increase without limit. In order to account for this possibility, which can have an effect on the predictive use of the model in 4.4.3, it is required that the masses of the bodies resulting from the fracture be modelled.

B.3 Outputs (see 4.3)

In a typical multi-body simulation there are many hundreds or perhaps thousands of time history outputs which are available. However, it is considered that it is those related to the injury variables and indices which are a minimum essential set. Note that "motion" and time histories refer to kinematic variables (e.g., accelerations, velocities, and displacements). The data are "output and plotted" at 0.001 s intervals because this is considered to be sufficiently short to describe typical impact phenomena, and yet not excessively short so as to result in impractical volumes of data. The "time period is up to but not including dummy to ground contact" because at the time of development of ISO 13232, data were not available which indicated the level of correlation achievable in dummy to ground contact. (However, dummy to ground contact had been modelled and some capability of predicting injuries existed.) An alternative of 0,5 s is also suggested because this includes all of the primary impact period and covers the situations in which the dummy may never reach the ground (e.g., the dummy may come to rest on the OV or MC).

The frangible damage is required to be output because it is an essential aspect of the injury analysis; and the time at which the damage occurred is output in order to help identify cause/effect relationships.

The "linear and angular displacement and velocity time histories" of various MC and dummy reference points are output in order to support the required calibration procedures.

The maximum force and maximum displacement of each of the MC and OV bodies in specified directions are needed in order to provide information used in the "predictive limits" check which is done in 4.4.3.

B.4 Three dimensional animation (see 4.4.1)

It is important that the three dimensional graphic displays of the simulation output be presented in an objective and scientific manner which shows only the actual geometry and motions used and computed by the equations of motion. It is important that the animation should not mislead the viewer about the complexity or operation of the model. It is not desirable for there to be artistic embellishment or subjective enhancement of the visual displays since this can distort and mislead the understanding of the model or the results. In particular, it is inappropriate to use an elaborate depiction of a MC with many detailed visual elements when the model in the simulation may be very crude or simple. It is desired that there be a one to one objective relationship between the graphics and the model. This also applies to the motion time histories used to drive the graphics, and to the viewpoint and focal length used to display the graphics.

B.5 Risk/benefit analysis and failure mode and effects analysis of proposed crash protective devices (see 4.4.3)

"Failure mode and effects analysis" refers to the identification of additional permissible impact configurations for full-scale testing, as described in ISO 13232-2.

Risk/benefit analysis" refers to the overall evaluation of the potential beneficial and harmful effects of a proposed protective device, across 200 impact configurations, and is described in 5.10 of ISO 13232-5; and which should be done using computer simulation (according to 4.5 of ISO 13232-6).

If risk/benefit or failure mode and effects analysis is done by means of computer simulation, then a set of criteria are imposed, in order to ensure that the simulation predictions are substantiated by measured vehicle characteristics ("predictive limits" check). This is done at the MC and OV component level (since the simulation is built up from the force properties of the individual components). The only impact configurations which may be used are those where the simulated force (for each component) is smaller than the largest value measured in the corresponding laboratory component test (i.e., it lies within the range of the measured data). Other provisions are: for bodies which can fracture, that the mass of the fractured portion be included (since this will tend to increase the force above the measured range if the body fractures); and for non-fracturing bodies, that the simulated displacement be less than that measured in laboratory tests (to prevent an inappropriate "force limiter" model from being used).

For impact configurations which do not meet these criteria, the analyst has two options: to exclude that impact configuration from the risk/benefit or FMEA; or to do additional laboratory tests and simulation calibrations, at higher impact speeds (since that, in principal, is the most likely way to increase the measured force and displacement ranges). If the latter option is chosen, then the laboratory component impact speed must correspond to the highest "relative" speed observed in the simulation runs which do not meet the criteria. For example, if the nominal laboratory impact speed for the MC fuel tank is 2 m/s, and several full-scale computer simulations (say at 20,1 m/s MC speed) give tank forces which are higher than that measured at 2 m/s, then the fuel tank laboratory test should also be run at the highest relative impact speed observed in those simulations (corresponding to, say, a pelvis to tank relative speed of 6 m/s). The simulation is next calibrated against the new measured data (in addition to the original, lower speed data); and then these impact configurations may be appropriately used in the risk/benefit or FMEA.

B.6 Simulation calibration (see 4.5)

"Calibration refers to a process of quality assurance applied to the computer simulation, in order to permit other researchers to assess the degree to which the model accurately describes the dynamic behaviour of the dummy, the MC, and the OV, their essential components, in both laboratory and full-scale impact tests.

B.7 Laboratory component test calibration (see 4.5.1)

The MC, OV, and dummy components in Tables 1, 2, and 3 are considered to be the minimum set of essential components needed to predict MC/OV/dummy interaction in an impact test, in addition to the whole MC barrier test described in 4.5.2. The impactor to be used (in both the simulation and in the actual laboratory test) is specified to be a rigid surface which is generally representative of possible impact objects in a full-scale test. In some cases, for the dummy, the impactor is the one used to define the properties of the actual dummy as in ISO 13232-3 and ISO 13232-6. The characteristics to be measured are, in general, the perpendicular force acting between the impactor and the body, which is essential for predicting impact dynamics.

In some simulation formulations it is possible to incorporate, directly, the force/deflection properties measured in laboratory tests. In this case, the simulation model of the respective component is identically equal to the relevant test data.

B.8 Motorcycle laboratory dynamic test (see 4.5.2)

A MC/barrier test is used to quantify the force/deflection and dynamic behaviour of the MC model and related components. The required measurements can be used to confirm (and quantify) the characteristics of the MC wheel, fork, front suspension, and main frame during impact.

B.9 Full-scale impact test correlation (see 4.5.3)

In addition to comparing simulation and test data for the specific components and the whole MC, as described above, it is required to compare the simulation with "any available, corresponding full-scale tests which have been performed in accordance with ISO 13232". This is useful in order to establish the accuracy of the simulation in predicting MC/OV/dummy dynamic interaction in actual full-scale tests. It is obvious that the closer the agreement between the simulation and full-scale time histories, and the greater the number of full-scale tests in which these comparisons are made, the greater the reliability of the simulation as a descriptive and predictive tool (because the fundamental laws of physics are incorporated). For such "correlations" it is important to use full-scale tests which have followed the detailed procedures of ISO 13232, so that the detailed initial conditions of the tests and the equipment used are known, and therefore, can be modelled accurately in the computer simulation.

When data for fewer than 14 tests are available then "overlaid comparison plots" of a large number of tests and simulation time histories for each test is required and considered to be an appropriate basis for allowing other researchers to assess the degree of accuracy of the simulation (in a subjective manner). A quantitative method for assessing the degree of agreement between the time histories is desirable but a general method was not available at the time of development of ISO 13232. The "occurrence and/or extent of damage to frangible elements" is also included in this comparison because this is an essential aspect and purpose of the full-scale tests and computer simulations.

When data for 14 or more tests are available, then, in addition, a quantitative statistical analysis of the degree of correlation is also performed. "Fourteen" is specified because this corresponds with the number of required full-scale tests in an "overall evaluation" as described in ISO 13232-6; and because statistical analysis for sample sizes much smaller than this is not so meaningful.

The tests used for correlation are selected from the 200 prescribed impact configurations because it is desired that the simulation work for these cases. Each test (or test pair) "shall be for a different impact configuration" in order to ensure that a variety of different impact dynamics are checked.

B.10 Full-scale impact test comparisons (see 4.5.4)

An additional quantitative comparison between simulated and measured motions is also required as an additional measure of quality assurance. In effect, this involves comparing the motion of the head, pelvis, torso, and MC at the time of first helmet/OV contact; and requiring that the simulation be within a certain tolerance of the measured test data at this point in time. The tolerance values were based on results obtained by TRL for a series of three or more simulated and full-scale tests.

In addition, the full trajectories of the shoulder, hip, knee, and ankle targets for the simulation and the full-scale tests are overlaid to provide a further basis for assessing the accuracy of the simulation.

B.11 Failure mode and effects analysis (see 5.1)

The method used to quantify the failure modes involves: simulating 200 paired comparison impacts (each impact with and without the protective device fitted to the MC); quantifying the injury variables and indices for each impact; and identifying impact configurations in which one or more of the injury variables or indices is increased by the presence of the protective device (indicating potential harm).

B.12 Simulated characteristics for laboratory component tests (see 5.2)

The essential characteristics to be measured in the laboratory tests and represented in the computer simulation are the force/displacement properties of the key components, for the most part, under dynamic impact conditions. It is desirable that such dynamic measurements be accurate up to frequencies of approximately 1 000 Hz in order to describe the impact response), and so corresponding procedures are specified. It is useful for such tests to be documented in some detail because there are many different ways in which to do such tests, and also because other researchers may wish to duplicate the tests.

The static tests are used in some cases because existing biomechanical data for these body regions may be in these terms; and/or for test convenience. Details of the static tests (and dynamic tests) are specified in order that there is some degree of comparability between the results of different researchers; and to maintain consistency with standardized procedures which may exist.

B.13 Motorcycle barrier test (see 5.3)

A speed of 13,4 m/s ± 5% is used for the barrier test to be consistent with the range of MC speeds used in the seven required full-scale impact configurations specified in ISO 13232-2. The MC heading angle, roll angle, and speed specifications, likewise are specified to be consistent with the full-scale test procedures. Two triaxial accelerometers are specified, as well as their locations, in order to provide for some averaging of the overall force/displacement characteristics of the MC); and for a similar reason three or more load cells in the barrier face are specified. The data are filtered at a relatively low frequency because it is the overall force/displacement characteristics which are of interest (rather than detailed structural modes of the MC frame).

Displacements are measured with two high speed cameras at 1 000 f/s in order to capture the rapid motions of interest of both the main frame of the MC and of the front wheel/fork assembly.

B.14 Full-scale impact test statistical correlation (see 5.4)

The quantitative correlations of injury variables are done for the head and lower extremities because these tend to be primary injury regions as indicated in the injury data (of ISO 13232-2, Annex D) and in the injury cost model (ISO 13232-5). In addition, these particular variables have been used in prior research for correlation purposes (Zellner, et al., 1991).

For the head maximum resultant linear acceleration, the correlation is expressed in terms of the standard statistical "correlation coefficient".

For the lower extremity injuries the correlation is expressed in terms of "truth table" results (e.g., type 1 and type 2 errors) with the "fraction correctly predicted" being the metric.

B.15 Documentation (see 6)

The information specified in Table 11 for the OV, MC, dummy, and protective device is considered to provide an overview of the main features of the simulation model.

The detailed results of the laboratory and full-scale calibration tests and comparisons specified in 6.2, 6.3, and 6.4 are considered to provide documentation of the essential characteristics and crucial properties of the simulation model.

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