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

Part 5:
Injury indices and risk/benefit analysis

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 5: Indices de blessure et analyse risque/bénéfice

STANDARD 13232-5

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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.

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.

This part of ISO 13232 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 22, *Motorcycles*.

At the request of the United Nations Economic Commission for Europe, Group for Road Vehicle General Safety (UN/ECE/TRANS/SCI/WP29/GRSG), this International Standard has been prepared by ISO/TC 22/SC 22, *Motorcycles*, as eight interrelated parts, on the basis of original working documents submitted by the International Motorcycle Manufacturers Association (IMMA).

This is the first version of the standard.

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: 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*

Annexes A and B form an integral part of this part of ISO 13232. Annexes C, D, E, F, G and H are for information only.

Introduction

This International Standard 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 motor cycles and intended for the crash protection of riders, have on injuries, when assessed over a range of impact conditions based on accident data.

It is intended that the methods and recommendations contained in this International Standard 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 this International Standard, a clear explanation of how the procedures used differ from the basic methodology should be provided.

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

Part 5:
Injury indices and risk/benefit analysis

1 Scope

This International Standard specifies the minimum requirements for research into the feasibility of protective devices fitted to motor cycles, which are intended to protect the rider in the event of a collision.

This International Standard is applicable to impact tests involving

- two wheeled motor cycles;
- 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 motor cycle;
- 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 motor cycles fitted and not fitted with the proposed devices).

This part of ISO 13232 provides

- performance indices which can be correlated with human injuries;
- formulae which relate injury indices to probable injury cost;
- a consistent means of interpreting impact test results;
- a means of relating the results obtained from film analysis and instrumentation of the dummy to injuries sustained in accidents;
- a means of assessing both the combined and relative effects of multiple injuries;
- an objective means of quantifying injury cost using a single index;
- a means of verifying the analysis;
- a means of doing risk/benefit analysis of protective devices fitted to motor cycles, based upon the population of impact conditions identified in ISO 13232-2.

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

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 13232 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 13232-1: 1996, Motor cycles - Test and analysis procedures for research evaluation of rider crash protective devices fitted to motor cycles - Part 1 - Definitions, symbols and general considerations.

ISO 13232-2: 1996, Motor cycles - Test and analysis procedures for research evaluation of rider crash protective devices fitted to motor cycles - Part 2 - Definition of impact conditions in relation to accident data.

ISO 13232-4: 1996, Motor cycles - Test and analysis procedures for research evaluation of rider crash protective devices fitted to motor cycles - Part 4 - Variables to be measured, instrumentation and measurement procedures.

ISO 13232-7: 1996, Motor cycles - Test and analysis procedures for research evaluation of rider crash protective devices fitted to motor cycles - Part 7 - Standardized procedures for performing computer simulations of motor cycle impact tests.

ISO 13232-8: 1996, Motor cycles - Test and analysis procedures for research evaluation of rider crash protective devices fitted to motor cycles - Part 8 - Documentation and reports.

AIS-90: 1990, American Association of Automotive Medicine (AAAM). The abbreviated injury scale. 1990 revision. Des Plaines, Il.

SAE J211: 1980, Instrumentation for impact tests.

SAE J885: 1986, Human tolerance to impact conditions as related to motor vehicle design. Warrendale, Pennsylvania, USA.

3 Definitions and abbreviations

For the purposes of this part of ISO 13232, the definitions given in ISO 13232-1 apply, of which the following are of particular relevance to this part of ISO 13232.

- abbreviated injury scale (AIS);
- abdomen maximum residual penetration ($p_{A,max}$);
- ancillary costs (AC);
- cost of fatality (CF);
- entire impact sequence;
- generalized acceleration model for brain injury tolerance (GAMBIT, G);
- head injury criterion (HIC);
- injury assessment function;
- injury assessment variable;
- injury costs (IC);
- injury index;
- injury potential variable;
- injury severity probability (ISP);
- lower extremities (IE);
- maximum PAIS;

- medical costs (MDC);
- normalized injury cost (IC_{norm});
- permanent partial incapacity (PPI);
- primary impact period;
- probability of fatality (PF);
- probable AIS (PAIS);
- secondary impact period;
- total PAIS;
- upper (or lower) sternum maximum normalized compression ($C_{us,max,norm}$ or $C_{ls,max,norm}$);
- upper (or lower) sternum maximum velocity-compression ($VC_{us,max}$ or $VC_{ls,max}$);
- upper (or lower) sternum velocity (V_{us} or V_{ls}).

4 Requirements

4.1 Injury variables

4.1.1 Injury assessment variables

The following injury assessment variables shall be evaluated over the primary impact period and also over the entire impact sequence using the calculations presented in 5.1 and the measurement methods given in 5.2.1 and 5.2.3.3 of ISO 13232-4:

- head maximum GAMBIT (G_{max});
- head injury criterion (HIC);
- head maximum resultant linear acceleration ($a_{r,H,max}$);
- upper sternum maximum normalized compression ($C_{us,max,norm}$);
- lower sternum maximum normalized compression ($C_{ls,max,norm}$);
- upper sternum maximum velocity-compression ($VC_{us,max}$) for $V_{us} \geq 3$ m/s;
- lower sternum maximum velocity-compression ($VC_{ls,max}$) for $V_{ls} \geq 3$ m/s;
- abdomen maximum residual penetration ($p_{A,max}$).

For head protective device research, the following neck injury assessment variables shall also be evaluated over the same time periods:

- maximum resultant shear force ($F_{xy,n,max}$);
- maximum tension force ($F_{z,n,max}$);
- minimum compression force ($F_{z,n,min}$);
- maximum flexion moment ($M_{y,n,max}$);
- minimum extension moment ($M_{y,n,min}$);
- peak torsion moment ($M_{z,n,peak}$).

4.1.2 Injury potential variables

The following injury potential variables shall be determined by evaluating them using the methods described in 5.2.4.2 of ISO 13232-4. the variables shall be evaluated over the interval from 0,050 s before first MC/OV contact until first helmet/OV contact, or until the helmet leaves the field of view, whichever occurs sooner, unless otherwise stated. In order to calculate velocities, the results shall be differentiated according to 5.1.7 of this part of ISO 13232, over this same time interval. The specific values listed below shall be identified from the velocity time histories:

- helmet trajectory in initial longitudinal-vertical plane of MC travel (z_h versus x_h);
- helmet resultant velocity at first helmet/OV contact ($V_{r,h,fc}$);
- helmet longitudinal velocity at first helmet/OV contact ($V_{x,h,fc}$);
- helmet lateral velocity at first helmet/OV contact ($V_{y,h,fc}$);
- helmet vertical velocity at first helmet/OV contact ($V_{z,h,fc}$).

4.2 Lower extremity injuries

The following lower extremity injuries shall be evaluated, based on observations and measurements of the frangible components, as described in 5.2.3 of ISO 13232-4:

- non-displaced bone fractures;
- displaced bone fractures;
- knee partial dislocations;
- knee complete dislocations.

4.3 Injury severity probabilities

The following injury severity probabilities (ISP) shall be determined for each severity level, AIS ≥ 1 through the highest level, using the methods described in 5.3:

- closed head ISP_H;
- upper sternum compression $ISP_{C,us}$;
- lower sternum compression $ISP_{C,ls}$;
- upper sternum velocity-compression $ISP_{VC,us}$;
- lower sternum velocity-compression $ISP_{VC,ls}$;
- intra-abdominal penetration ISP_A.

4.4 Injury indices

The probability of each discrete AIS injury severity level shall be calculated for each of the four body regions: the head, thorax, abdomen, and lower extremities, using the procedures described in 5.4.

The medical and ancillary costs associated with injuries to each of the four body regions shall be calculated using the procedures described in 5.5.1 and 5.5.2, respectively. The cost of fatality shall be determined as defined in annex A.

The probability of fatality shall be calculated using the procedures described in 5.6.

The risk of life threatening brain injury shall be calculated from HIC using the procedures described in 5.6.4.

The probable AIS (PAIS) shall be determined by body region, using the procedures described in 5.7.1. The maximum PAIS and total PAIS shall be determined across all body regions using the procedures described in 5.7.2 and 5.7.3, respectively.

The normalized injury costs of survival and fatality and the total normalized injury cost shall be determined using the procedures described in 5.8.

NOTE 1 - The term "cost" is used in this subclause in a specific and limited sense, and for test comparison purposes only (see def 3.5.7 of ISO 13232-1 for specific cost definitions). The "costs," as used here, represent average costs based on a simplified model of samples of bioeconomic data; collected over a particular time period and region; and for a limited range of specific injury types, severities, and body regions, which may be monitored in crash tests, and which can exclude the majority of the types, severities, and locations of human body injuries, and some types of cost components. In no way do such injury costs consider, nor are they intended to consider, the market level costs of a proposed protective device. The "costs" described herein are only intended to provided a convenient, common basis for combining and comparing across body regions and crash tests and on a relative basis, different types, locations, and severities of injuries. For the foregoing reasons, such costs have limited applicability and are not intended nor appropriate for calculating, for example, the actual cost of a specific real accident, or the total societal or economic cost of a given device or design.

In addition, for head protective device research, the neck injury indices for shear, tension, compression, flexion, extension, and torsion shall be calculated using the procedures described in 5.9.

NOTE 2 - Extreme caution should be used in interpreting the neck injury indices. Evaluation of neck loads is considered to be crucial for head protective device research. However, the critical force and moment values given in the denominators in 5.9 are based on an extrapolation of the Hybrid III injury assessment curves, in order to represent the possible neck strength of the target population. In addition, the Hybrid III neck and injury assessment curves were developed for fore/aft inertial loading of the head, and not for oblique, direct loading and displacement of the head, which can occur in motor cycle impact testing. In addition, cadaver based research suggests that the critical loads specified in 5.9 might be too large; whereas some full-scale test and computer simulation research suggests they might be too small, in comparison to the observed frequency of neck injury in motor cycle accident data. It is unknown the extent to which the source of such uncertainty may be shortcomings in the dummy neck biofidelity for specific types of loading; in the measurement method; or in the injury indices (e.g., due to the time dependency or type of loading); and this can only be resolved through further research.

4.5 Risk/benefit analysis

Any risk/benefit analysis of a proposed rider crash protective device fitted to a motor cycle, which forms a part of the overall evaluation described in ISO 13232-2 or which may be used to identify potential failure modes of a proposed device for purposes of further testing, shall use the methods described in 5.10.

5 Procedures

5.1 Injury variables

Compute the maximum values of the variables over time, for example, G_{max} (t).

5.1.1 Resultants

Calculate the head resultant linear and angular accelerations, using the time histories of the linear and angular accelerations as calculated in 5.2.1 of ISO 13232-4, and shown in the example for the resultant linear acceleration, given below:

$$a_r = \left(a_x^2 + a_y^2 + a_z^2\right)^{1/2}$$

where

a_r is the resultant linear acceleration, in g units;

a_x is the linear acceleration in the x direction, in g units;

a_y is the linear acceleration in the y direction, in g units;

a_z is the linear acceleration in the z direction, in g units.

Where only two components are included in a resultant, calculate the resultant of those two components, as shown in the example for the resultant shear force, given below:

$$F_{xy} = \left(F_x^2 + F_y^2\right)^{1/2}$$

where

F_{xy} is the resultant force, in kilonewtons;

F_x is the force in the x direction, in kilonewtons;

F_y is the force in the y direction, in kilonewtons.

5.1.2 GAMBIT

Calculate GAMBIT using the equation given below:

$$G = \left(\left(\frac{a_{r,H}}{250}\right)^2 + \left(\frac{\alpha_{r,H}}{25\ 000}\right)^2\right)^{1/2}$$

where

G is GAMBIT

$a_{r,H}$ is the head resultant linear acceleration, in g units;

$\alpha_{r,H}$ is the head resultant angular acceleration, in radians per second squared.

250 is the normalization factor for linear acceleration in GAMBIT, in g units;

25 000 is the normalization factor for angular acceleration in GAMBIT, in radians per second squared.

Identify the maximum value of GAMBIT, G_{max}.

5.1.3 HIC

Calculate HIC using the equation given below[1]:

$$HIC = \max\left((t_2 - t_1)\left(\frac{1}{t_2 - t_1}\int_{t_2}^{t_1} a_{r,H}(t)\,dt\right)^{2.5}\right)$$

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1) SAE J885, July 1986.

where

HIC is the head injury criterion;

$a_{r,H}$ is the head resultant linear acceleration, in *g* units;

t_1 and t_2 are all possible initial and final times which are separated by not more than 0,036 s, in seconds.

5.1.4 Upper and lower sternum compression

Use the upper and lower sternum displacement time histories recorded and reduced as described in 4.4.1.3 and 5.2.1 of ISO 13232-4. Calculate the upper and lower sternum deflections and compressions, as shown in the example equations for the upper sternum, given below and referring to figure 1:

$$D_{y,us} = \frac{(l_{uL} + \Delta l_{uL})^2 - (l_{uR} + \Delta l_{uR})^2}{2W_{L,R}}$$

$$D_{x,us} = \left((l_{uR} + \Delta l_{uR})^2 - \left(\frac{W_{L,R}}{2} - D_{y,us}\right)^2\right)^{1/2} - d_{us}$$

$$C_{us,norm} = \frac{-D_{x,us}}{187,5} \times 100$$

where

$D_{y,us}$ is the upper sternum deflection in the y direction, in millimetres;

l_{uL} is the cable length of the upper left string pot, in millimetres;

Δl_{uL} is the change in cable length of the upper left string pot (positive is longer), in millimetres;

l_{uR} is the cable length of the upper right string pot, in millimetres;

Δl_{uR} is the change in cable length of the upper right string pot (positive is longer), in millimetres;

$W_{L,R}$ is the lateral distance between the left and right string pots, in millimetres;

$D_{x,us}$ is the upper sternum deflection in the x direction, in millimetres;

d_{us} is the undeformed perpendicular distance from the plane containing the string pot pivot axes to the upper sternum, at the centre of rib 2 where the strings are attached, in millimetres;

187,5 is the dimensional factor used to normalize compression of the Hybrid III chest, in millimetres;

$C_{us,norm}$ is the normalized upper sternum compression for a Hybrid III dummy, expressed as a percentage.

Identify the maximum normalized upper and lower sternum compressions, $C_{us,max}$ and $C_{ls,max}$, respectively. If at any time $D_{x,us}$ or $D_{x,ls}$ exceeds 75 mm, document this result in accordance with ISO 13232-8.

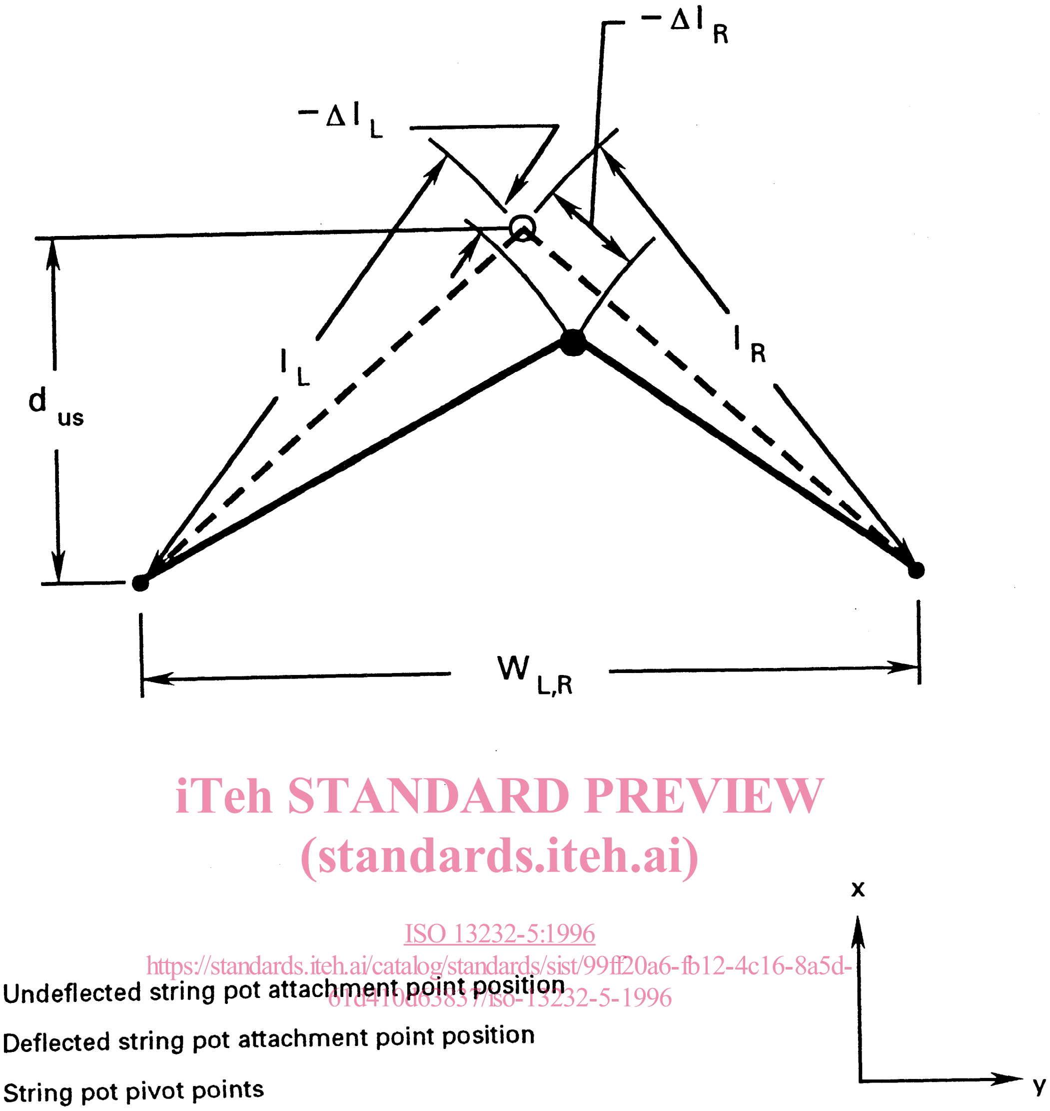

Figure 1 - Chest potentiometer geometry shown for the upper sternum

5.1.5 Upper and lower sternum velocity

Calculate the upper and lower sternum compression velocities by differentiating the upper and lower sternum deflections, respectively, using the trapezoidal rule, as shown below for the upper sternum. Filter the velocities using the SAE J211 Class 60 and convert the velocities to metres per second.

$$V_{us} = \frac{\left(\frac{d\ D_{x,us}}{dt}\right)}{1\ 000}$$

where

V_{us} is the upper sternum velocity, in metres per second;

$D_{x,us}$ is the upper sternum deflection in the x direction, in millimetres;

t is the time, in seconds;

1 000 is the conversion factor from millimetres to metres.

5.1.6 Upper and lower sternum velocity-compression

Calculate the upper and lower sternum velocity-compressions, as shown in the example equation for the upper sternum, given below:

$$VC_{us} = \frac{1{,}3 \times V_{us}\ D_{x,us}}{229}$$

where

VC_{us} is the upper sternum velocity-compression, in metres per second;

V_{us} is the upper sternum velocity, in metres per second;

$D_{x,us}$ is the upper sternum deflection in the x direction, in millimetres;

1,3 is the factor to correct internally measured upper (or lower) sternum variables to external application;

229 is the dimensional factor used to normalize upper (or lower) sternum deflection for the VC calculation, in millimetres.

Identify the maximum upper and lower sternum velocity-compressions, $VC_{us,max}$ and $VC_{ls,max}$ for V_{us} and $V_{ls} \geq 3$ m/s, respectively, considering only cases where both V and D_x have negative values.

5.1.7 Helmet centroid point component velocities

Plot the helmet centroid point trajectory as described in 4.1.2. Evaluate $V_{x,h,fc}$, $V_{y,h,fc}$, and $V_{z,h,fc}$ relative to the inertial axis system and using the procedures described in annex A of ISO 13232-4.

Calculate the helmet centroid point component velocities in the x, y, and z directions from the high speed film data, as shown in the example for the x direction helmet centroid point velocity, given below:

$$V_{x,h,i} = \frac{x_{h,i+1} - x_{h,i-1}}{1\ 000\ (t_{i+1} - t_{i-1})}$$

where

$V_{x,h,i}$ is the helmet centroid point velocity in the x direction at analysis frame i, in metres per second;

$x_{h,i+1}$ is the position of the helmet centroid point in the x direction at analysis frame i + 1, in millimetres;

t_{i+1} is the time of analysis frame i + 1, in seconds;

1 000 is the conversion factor from millimetres to metres.

5.2 Frangible component damage

Record the number of displaced and non-displaced fractures for each femur and tibia frangible bone. Record partial or complete dislocation or no injury for each knee. Record $p_{A,max}$. Use the evaluation methods described in 5.2.3 of ISO 13232-4.

5.3 Injury severity probabilities

Insert the injury variable values into the following relationships to determine the injury severity probability (ISP) for each AIS injury severity level, for each body region.

5.3.1 Head

Calculate the closed head ISP_H as a function of G_{max} for each minimum AIS using the injury assessment functions given in table 1.

5.3.2 Chest

For each minimum AIS calculate the upper and lower thoracic compression $ISP_{C,us}$ and $ISP_{C,ls}$ as a function of $C_{us,max}$ and $C_{ls,max}$, respectively, and the upper and lower thoracic velocity-compression $ISP_{VC,us}$ and $ISP_{VC,ls}$, as a function of $VC_{us,max}$ and $VC_{ls,max}$, respectively, using the injury assessment functions given tables 2 and 3, respectively.

The thoracic compression ISP_C for each AIS injury severity level, j, is defined as the larger of either $ISP_{C,us,j}$ or $ISP_{C,ls,j}$. The thoracic velocity-compression ISP_{VC} for each severity level, j, is defined as the larger of either $ISP_{VC,us,j}$ or $ISP_{VC,ls,j}$. The overall thoracic ISP, ISP_{Th}, for each AIS injury severity level, j, is defined as the larger of either $ISP_{C,j}$ or $ISP_{VC,j}$.

5.3.3 Abdomen

Calculate the intra-abdominal penetration ISP_A as a function of $p_{A,max}$ for each minimum AIS using the injury assessment functions given in table 4.

NOTE - The researcher may choose to calculate ISP_A, the injury indices, and the injury costs by:

- replacing the measured value of $p_{A,max}$ with a zero;
- calculating the injury indices and injury costs as described in this part of ISO 13232;
- reporting both sets of values and the measured value of $p_{A,max}$ in the documentation;
- noting this deviation in the documentation.

Table 1 - Closed head injury severity probability as a function of G_{max}

Severity level	Minimum G_{max} required	Injury assessment function
AIS ≥ 1	0	$ISP_{H,1} = 1 - \exp[-(G_{max} / 0{,}755)^{3{,}5}]$
AIS ≥ 2	0,125	$ISP_{H,2} = 1 - \exp[-((G_{max} - 0{,}125)/0{,}70)^{3{,}5}]$
AIS ≥ 3	0,375	$ISP_{H,3} = 1 - \exp[-((G_{max} - 0{,}375)/0{,}64)^{3{,}5}]$
AIS ≥ 4	0,438	$ISP_{H,4} = 1 - \exp[-((G_{max} - 0{,}438)/0{,}62)^{3{,}5}]$
AIS ≥ 5	0,650	$ISP_{H,5} = 1 - \exp[-((G_{max} - 0{,}650)/0{,}54)^{2{,}2}]$
AIS = 6	0,680	$ISP_{H,6} = 1 - \exp[-((G_{max} - 0{,}680)/0{,}60)^{1{,}8}]$

where

$ISP_{H,j}$ is the probability of a head injury of at least AIS severity level j;

AIS is defined in AIS-90;

G_{max} is the maximum value of GAMBIT.