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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**

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

*Partie 5: Indices de blessure et analyse risque/bénéfice*



Reference number  
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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 13232-5 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 22, *Motorcycles*.

This second edition cancels and replaces the first version (ISO 13232-5:1996), 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.

1

# 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 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; and
- a means of doing risk/benefit analysis of 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 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 13232-4, *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 13232-7, *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*

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

AIS-90, Association for the Advancement of Automotive Medicine (AAAM), Des Plaines, IL, USA, *The abbreviated injury scale. 1990 revision*

SAE J211, *Instrumentation for impact tests*, Warrendale, Pennsylvania, USA

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

## 3 Definitions and abbreviations

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 also listed in ISO 13232-1:

- 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  $Cl_{s,max,norm}$ );
- upper (or lower) sternum maximum velocity-compression ( $VC_{us,max}$  or  $VCl_{s,max}$ );
- 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 ( $a_{r,H,max}$ );
- neck injury index ( $NII$ );

- 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 ( $p_{A,max}$ ).

#### 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  $\geq 1$  through the highest level, using the methods described in 5.3:

closed head  $ISP_H$ ;

upper neck combined loading  $ISP_n$ ;

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 five body regions: the head, upper neck, thorax, abdomen, and lower extremities, using the procedures described in 5.4.

The medical and ancillary costs associated with injuries to each of the five 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** 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 are able to 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 provide 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.

#### 4.5 Risk/benefit analysis

Any risk/benefit analysis of a proposed rider crash protective device fitted to a motorcycle, 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:

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

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:

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

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:

$$G = \left( \left( \frac{a_{r,H}}{250} \right)^2 + \left( \frac{\alpha_{r,H}}{25000} \right)^2 \right)^{1/2}$$

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<sup>1)</sup>:

---

1) SAE J885, July 1986.

$$HIC = \max \left( (t_2 - t_1) \left( \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a_{r,H}(t) dt \right)^{2,5} \right)$$

where

$HIC$  is the head injury criterion;

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

$HIC$  values are only calculated during periods of head contact as defined by head engagement ( $t_e$ ) and head disengagement ( $t_d$ ) times determined according to ISO Technical Report TR 12351.

$t_1$  and  $t_2$  (in seconds) are all possible initial and final times for each contact interval which are separated by not more than 0,015 s, and where  $t_1 \geq t_e$  and  $t_2 \leq t_d$ .

An example computer code for the calculation of head contacts is found in Annex I.

#### 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;

$\Delta l_{uL}$  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;

$\Delta l_{uR}$  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.

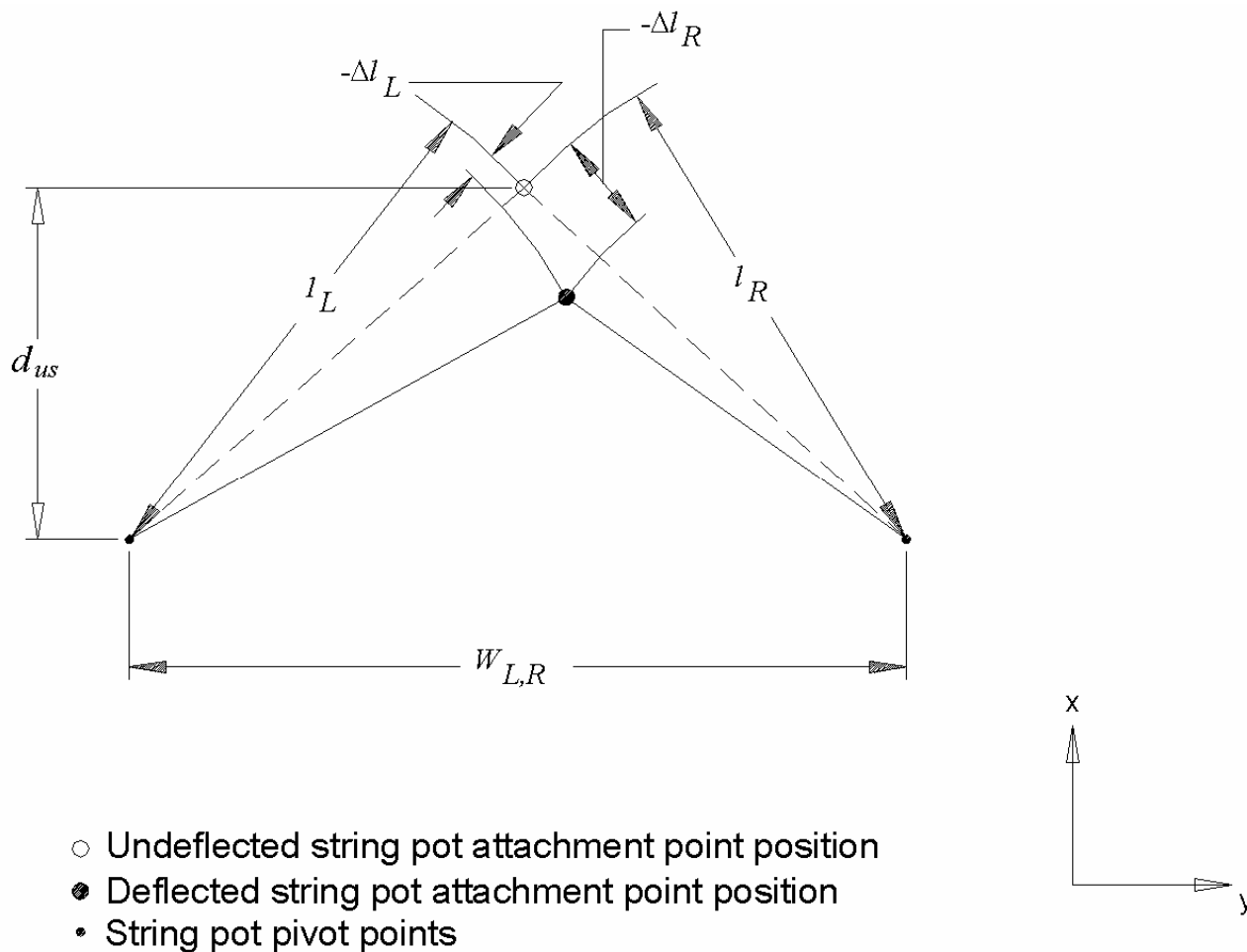


Figure 1 — Chest potentiometer geometry shown for the upper sternum

### 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.

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

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:

$$V_{x,h,i} = \frac{x_{h,i+1} - x_{h,i-1}}{1000(t_{i+1} - t_{i-1})}$$

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.

### 5.1.8 Neck injury index (NII)

Calculate  $NII$  using the equation given below:

$$NII(t) = \max \left( \left( \left( \frac{F_C(t)}{F_C^*} + \frac{F_T(t)}{F_T^*} + \left( \left( \frac{M_X(t)}{M_X^*} \right)^2 + \left( \frac{M_E(t)}{M_E^*} + \frac{M_F(t)}{M_F^*} \right)^2 \right)^{1/2} \right)^2 + \left( \frac{M_Z(t)}{M_Z^*} \right)^2 \right)^{1/2}, 3,1 \left( \frac{F_C(t)}{F_C^*} + \frac{F_T(t)}{F_T^*} \right) \right)$$

where

$F_C(t)$  is the neck axial compression force (the minimum of  $F_z$  or 0 (never a positive number));

$F_C^*$  is the normalization factor for compression ( $F_C^* = -6,53$  kN);

$F_T(t)$  is the neck tension force (the maximum of  $F_z$  or 0 (never a negative number));

$F_T^*$  is the normalization factor for tension ( $F_T^* = 3,34$  kN);

$M_X(t)$  is the neck lateral flexion moment at the occipital condyle;

$M_X^*$  is the normalization factor for occipital condyle lateral flexion ( $M_X^* = 62,66$  Nm);

$M_E(t)$  is the neck extension moment at the occipital condyle (the minimum of  $M_y$  or 0 (never a positive number));

$M_E^*$  is the normalization factor for occipital condyle extension bending ( $M_E^* = -58,0$  Nm);

$M_F(t)$  is the neck flexion moment at the occipital condyle (the maximum of  $M_y$  or 0 (never a negative number));

$M_F^*$  is the normalization factor for occipital condyle flexion ( $M_F^* = 204,2$  Nm);

$M_Z(t)$  is the neck torsion moment;

$M_Z^*$  is the normalization factor for torsion ( $M_Z^* = 47,1$  Nm).

Identify by means of time series analysis  $NII_{max}$  the maximum value of  $NII$ .

Note - Assumptions and limitations for predicting neck injuries are given in subclause O.3.1.5 and Annex J.

## 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 GAMBIT  $ISP_{Gmax,H}$  and the closed head HIC  $ISP_{HIC,H}$  as a function of  $G_{max}$  and  $HIC$  respectively, for each  $AIS \geq j$  injury severity level, using the injury assessment functions given in Tables 1a and 1b respectively. If any of the head injury assessment values are less than the minimum required value for the injury severity level, then the corresponding ISP value is 0.

The closed head  $ISP$ ,  $ISP_H$ , for each AIS injury severity level,  $j$ , is defined as the larger of either  $ISP_{Gmax,H,j}$  or  $ISP_{HIC,H,j}$ .

### 5.3.2 Chest

For each  $AIS \geq j$  injury severity level, 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. If any of the chest injury assessment values are less than the minimum required value for the injury severity level, then the corresponding ISP value is 0.

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  $AIS > j$  injury severity level 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 1a — Closed head injury severity probability as a function of  $G_{max}$ 

| Severity level                                                                                                                                                                                                             | Minimum $G_{max}$ required | Injury assessment function                                           |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|----------------------------------------------------------------------|
| $AIS \geq 1$                                                                                                                                                                                                               | 0                          | $ISP_{H,1} = 1 - \exp\left[-(G_{max} / 0,755)^{3,5}\right]$          |
| $AIS \geq 2$                                                                                                                                                                                                               | 0,125                      | $ISP_{H,2} = 1 - \exp\left[-((G_{max} - 0,125) / 0,70)^{3,5}\right]$ |
| $AIS \geq 3$                                                                                                                                                                                                               | 0,375                      | $ISP_{H,3} = 1 - \exp\left[-((G_{max} - 0,375) / 0,64)^{3,5}\right]$ |
| $AIS \geq 4$                                                                                                                                                                                                               | 0,438                      | $ISP_{H,4} = 1 - \exp\left[-((G_{max} - 0,438) / 0,62)^{3,5}\right]$ |
| $AIS \geq 5$                                                                                                                                                                                                               | 0,650                      | $ISP_{H,5} = 1 - \exp\left[-((G_{max} - 0,65) / 0,54)^{2,2}\right]$  |
| $AIS = 6$                                                                                                                                                                                                                  | 0,680                      | $ISP_{H,6} = 1 - \exp\left[-((G_{max} - 0,680) / 0,60)^{1,8}\right]$ |
| <p>where</p> <p><math>ISP_{H,j}</math> is the probability of a head injury of at least AIS severity level <math>j</math>;</p> <p>AIS is defined in AIS-90;</p> <p><math>G_{max}</math> is the maximum value of GAMBIT.</p> |                            |                                                                      |

Table 1b — Closed head injury severity probability as a function of  $HIC$ 

| Severity level | Minimum $HIC$ required | Injury assessment function                                                          |
|----------------|------------------------|-------------------------------------------------------------------------------------|
| $AIS \geq 1$   | 0                      | $ISP_{HIC,H,1} = 1 - \exp\left[-(HIC / 560)^{2,98}\right]$                          |
| $AIS \geq 2$   | 0                      | $ISP_{HIC,H,2} = ISP_{HIC,H,3} + (ISP_{HIC,H,1} - ISP_{HIC,H,3}) \times (55 / 123)$ |
| $AIS \geq 3$   | 0                      | $ISP_{HIC,H,3} = 1 - \exp\left[-((HIC - 500) / 1990)^{4,5}\right]$                  |
| $AIS \geq 4$   | 450                    | $ISP_{HIC,H,4} = ISP_{HIC,H,6} + (ISP_{HIC,H,3} - ISP_{HIC,H,6}) \times (24 / 41)$  |
| $AIS \geq 5$   | 450                    | $ISP_{HIC,H,5} = ISP_{HIC,H,6} + (ISP_{HIC,H,3} - ISP_{HIC,H,6}) \times (14 / 41)$  |
| $AIS \geq 6$   | 450                    | $ISP_{HIC,H,6} = 1 - \exp\left[-((HIC - 450) / 3275)^{1,36}\right]$                 |

**Table 2 — Thoracic compression injury severity probability as a function of  $C_{us,max}$  and  $C_{ls,max}$** 

| Severity level                                                                                                                                                                                                                                                                               | Minimum $C_{us,max}$ required | Injury assessment function <sup>a</sup>                                            |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|------------------------------------------------------------------------------------|
| $AIS \geq 1$                                                                                                                                                                                                                                                                                 | 1,77                          | $ISP_{C,us,1} = 1 - \exp\left[-\left((C_{us,max} - 1,77)/24\right)^{6,00}\right]$  |
| $AIS \geq 2$                                                                                                                                                                                                                                                                                 | 7,47                          | $ISP_{C,us,2} = 1 - \exp\left[-\left((C_{us,max} - 7,47)/24\right)^{6,00}\right]$  |
| $AIS \geq 3$                                                                                                                                                                                                                                                                                 | 13,22                         | $ISP_{C,us,3} = 1 - \exp\left[-\left((C_{us,max} - 13,22)/24\right)^{6,00}\right]$ |
| $AIS \geq 4$                                                                                                                                                                                                                                                                                 | 18,97                         | $ISP_{C,us,4} = 1 - \exp\left[-\left((C_{us,max} - 18,97)/24\right)^{6,00}\right]$ |
| $AIS \geq 5$                                                                                                                                                                                                                                                                                 | 24,72                         | $ISP_{C,us,5} = 1 - \exp\left[-\left((C_{us,max} - 24,72)/24\right)^{6,00}\right]$ |
| $AIS = 6$                                                                                                                                                                                                                                                                                    | 32,52                         | $ISP_{C,us,6} = 1 - \exp\left[-\left((C_{us,max} - 32,52)/24\right)^{6,00}\right]$ |
| <p>where</p> <p><math>ISP_{C,us,j}</math> is the probability of an upper thoracic compression injury of at least AIS severity level <math>j</math>;</p> <p>AIS is defined in AIS-90;</p> <p><math>C_{us,max}</math> is the upper sternum maximum compression, expressed as a percentage.</p> |                               |                                                                                    |
| <sup>a</sup> The $ISP$ calculation shown is for $C_{us,max}$ . Calculate the $ISP$ for $C_{ls,max}$ also.                                                                                                                                                                                    |                               |                                                                                    |

**Table 3 — Thoracic injury velocity-compression severity probability as a function of  $VC_{us,max}$  and  $VC_{ls,max}$** 

| Severity level                                                                                                                                                                                                                                                                                              | Minimum $VC_{us,max}$ required | Injury assessment function <sup>a</sup>                                                |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|----------------------------------------------------------------------------------------|
| $AIS \geq 1$                                                                                                                                                                                                                                                                                                | 0                              | $ISP_{VC,us,1} = 1 - \exp\left[-(VC_{us,max}/0,30)^{0,99}\right]$                      |
| $AIS \geq 2$                                                                                                                                                                                                                                                                                                | 0                              | $ISP_{VC,us,2} = 1 - \exp\left[-(VC_{us,max}/0,68)^{1,46}\right]$                      |
| $AIS \geq 3$                                                                                                                                                                                                                                                                                                | 0                              | $ISP_{VC,us,3} = 1 - \exp\left[-(VC_{us,max}/1,40)^{2,85}\right]$                      |
| $AIS \geq 4$                                                                                                                                                                                                                                                                                                | 0,4                            | $ISP_{VC,us,4} = 1 - \exp\left[-\left((VC_{us,max} - 0,4)/1,291\right)^{3,10}\right]$  |
| $AIS \geq 5$                                                                                                                                                                                                                                                                                                | 1,00                           | $ISP_{VC,us,5} = 1 - \exp\left[-\left((VC_{us,max} - 1,00)/0,995\right)^{3,10}\right]$ |
| $AIS = 6$                                                                                                                                                                                                                                                                                                   | 1,50                           | $ISP_{VC,us,6} = 1 - \exp\left[-\left((VC_{us,max} - 1,50)/0,78\right)^{3,10}\right]$  |
| <p>where</p> <p><math>ISP_{VC,us,j}</math> is the probability of an upper thoracic velocity-compression injury of at least AIS severity level <math>j</math>;</p> <p>AIS is defined in AIS-90;</p> <p><math>VC_{us,max}</math> is the upper sternum maximum velocity-compression, in metres per second.</p> |                                |                                                                                        |
| <sup>a</sup> The $ISP$ calculation shown is for $VC_{us,max}$ . Calculate the $ISP$ for $VC_{ls,max}$ also.                                                                                                                                                                                                 |                                |                                                                                        |

Table 4 — Intra-abdominal penetration injury severity probability as a function of  $P_{A,max}$ 

| Severity level                                                                                                                                                                                                          | Injury assessment function <sup>a</sup>                      |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|
| $AIS \geq 1$                                                                                                                                                                                                            | $ISP_{A,1} = 1,57 \times 10^{-2} \times p_{A,max}$           |
| $AIS \geq 2$                                                                                                                                                                                                            | $ISP_{A,2} = 1,23 \times 10^{-2} \times p_{A,max}$           |
| $AIS \geq 3$                                                                                                                                                                                                            | $ISP_{A,3} = 1,55 \times 10^{-4} \times (p_{A,max})^{2,00}$  |
| $AIS = 4$                                                                                                                                                                                                               | $ISP_{A,4} = 9,36 \times 10^{-13} \times (p_{A,max})^{6,50}$ |
| where<br><br>$ISP_{A,j}$ is the probability of an abdominal injury of at least AIS severity level $j$ ;<br>AIS is defined in AIS-90;<br>$p_{A,max}$ is the maximum penetration of the abdominal insert, in millimetres. |                                                              |
| a The ISP calculation assumes that the $p_{A,max}$ is less than 60 mm. Values larger than this are extremely rare.                                                                                                      |                                                              |

### 5.3.4 Neck

Calculate the neck  $ISP_n$  as a function of  $NII$  for each  $AIS \geq j$  injury severity level using the injury assessment functions given in Table 5. If  $NII_{max}$  is less than the minimum required value then  $ISP_{n,j} = 0$ .

Table 5 — Neck combined loading injury severity probability as a function of  $NII$ 

| Severity level | Minimum $NII_{max}$ required | Injury assessment function                                              |
|----------------|------------------------------|-------------------------------------------------------------------------|
| $AIS \geq 1$   | 1,06                         | $ISP_{n,1} = 1 - e^{-\left(\frac{NII_{max} - 1,06}{4,38}\right)^{3,5}}$ |
| $AIS \geq 2$   | 1,86                         | $ISP_{n,2} = 1 - e^{-\left(\frac{NII_{max} - 1,86}{4,38}\right)^{3,5}}$ |
| $AIS \geq 3$   | 2,29                         | $ISP_{n,3} = 1 - e^{-\left(\frac{NII_{max} - 2,29}{4,38}\right)^{3,5}}$ |
| $AIS \geq 4$   | 4,73                         | $ISP_{n,4} = 1 - e^{-\left(\frac{NII_{max} - 4,73}{4,38}\right)^{3,5}}$ |
| $AIS \geq 5$   | 4,73                         | $ISP_{n,5} = 1 - e^{-\left(\frac{NII_{max} - 4,73}{4,38}\right)^{3,5}}$ |

| Severity level                                                                                                                                                                                                                                             | Minimum $NII_{max}$ required | Injury assessment function                                                           |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|--------------------------------------------------------------------------------------|
| AIS = 6                                                                                                                                                                                                                                                    | 6,13                         | $ISP_{n,6} = 1 - e^{-\left(\left(\frac{NII_{max} - 6,13}{4,38}\right)^{3,5}\right)}$ |
| <p>where</p> <p><math>ISP_{n,j}</math> is the probability of a neck injury of at least AIS severity level <math>j</math>;</p> <p>AIS is defined in AIS-90;</p> <p><math>NII_{max}</math> is the maximum value of neck injury index (<math>NII</math>).</p> |                              |                                                                                      |

## 5.4 Probability of discrete AIS injury severity level

### 5.4.1 Head, neck, thorax, abdomen

For each of the four body regions and each of the AIS injury severity levels, calculate the probability of sustaining an injury of the specific AIS injury severity level. Use the equation given below:

$$P_{ij} = ISP_{ij} - ISP_{ij+1}$$

where

$P_{ij}$  is the probability of sustaining an injury of specific severity level  $j$  to the body region  $i$ ;

$ISP_{ij}$  is the probability of sustaining an injury of at least severity level  $j$  to the body region  $i$ .

### 5.4.2 Lower extremities

#### 5.4.2.1 Number of injuries

Based upon the frangible leg component damage recorded in 5.2, determine the number of injuries and AIS injury severity level of each, for the femur, tibia, and knee, using Table 6.

#### 5.4.2.2 Probability of an injury of a specific severity level

Because of the nature of the frangible leg components used, the probability of sustaining a lower extremity injury of a specific AIS injury severity level,  $P_{IE,j}$  is equal to either 0 or 1 for each of the three AIS injury severity levels listed in Table 6. Determine the highest AIS injury severity level among all six leg components. Set  $P_{IE,j}$  equal to 1 for that AIS injury severity level,  $j$ , and set  $P_{IE,j}$  equal to 0 for the other two AIS injury severity levels.

**Table 6 — AIS injury severity level for frangible component damage**

| Femur mid-shaft fracture type | Knee dislocation | Tibia mid-shaft fracture type | AIS severity level |
|-------------------------------|------------------|-------------------------------|--------------------|
| None                          | None             | None                          | 0                  |
|                               | Partial          | Non-displaced                 | 2                  |
| Displaced or non-displaced    | Complete         | Displaced                     | 3                  |

For example, if there are only two leg components damaged during the test, a left knee partial dislocation and a right femur displaced fracture,  $P_{IE,j}$  is determined to be 1 for AIS injury severity level 3 and 0 for AIS injury severity levels 0 and 2, as shown in Table 7.

Table 7 — Example  $P_{IE,j}$  determination

| Damaged component                                                                                                      | Damage type            | AIS | $P_{IE,j}$ |
|------------------------------------------------------------------------------------------------------------------------|------------------------|-----|------------|
| Left tibia                                                                                                             | None                   | 0   | 0          |
| Right tibia                                                                                                            | None                   | 0   | 0          |
| Left knee                                                                                                              | Partial dislocation    | 2   | 0          |
| Right knee                                                                                                             | None                   | 0   | 0          |
| Left femur                                                                                                             | None                   | 0   | 0          |
| Right femur                                                                                                            | Non-displaced fracture | 3   | 1          |
| where<br>$P_{IE,j}$ is the probability of sustaining any lower extremity injury of the AIS injury severity level $j$ . |                        |     |            |

#### 5.4.2.3 Permanent partial incapacity

Determine the number of damaged frangible leg components and the AIS injury severity level for each one. Using the criteria listed in Table 8, determine the maximum permanent partial incapacity (PPI) which would result from sustaining comparable injuries to the lower extremities.

Table 8 — Permanent partial incapacity determination

| If                                                                                                                                                                                                                      |          | PPI = |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|-------|
| $N_{F,3} + N_{K,3} + N_{K,2} + N_{T,3} + N_{T,2}$                                                                                                                                                                       | $\geq 3$ | 0,38  |
| $N_{F,3} + N_{K,3} + N_{K,2} + N_{T,3} + N_{T,2}$                                                                                                                                                                       | $= 2$    | 0,27  |
| $N_{F,3}$ or $N_{T,3}$ or $N_{K,2}$                                                                                                                                                                                     | $= 1$    | 0,15  |
| $N_{K,3}$                                                                                                                                                                                                               | $= 1$    | 0,22  |
| $N_{T,2}$                                                                                                                                                                                                               | $= 1$    | 0,07  |
| $N_{leg}$                                                                                                                                                                                                               | $= 0$    | 0,0   |
| where<br><br>$N_{i,j}$ is the number of damaged frangible leg components $i$ of AIS injury severity level $j$ ;<br><br>$F$ is the femur component;<br><br>$T$ is the tibia component;<br><br>$K$ is the knee component. |          |       |

For the example given in 5.4.2.2, the PPI is determined as follows:

$$N_{K,2} + N_{F,3} = 2, \text{ therefore PPI} = 0,27$$

## 5.5 Injury costs

**NOTE** 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 provide 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.

### 5.5.1 Medical costs

Tabulate the injuries by body region and AIS injury severity level. Determine the medical costs associated with each body region injury and each discrete AIS injury severity level, for each country, using the cost data listed in Annex A. Calculate the total medical cost associated with the injuries for each of the four body regions, including the head, neck, thorax, and abdomen, using the equation given below:

$$MDC_{i,tot} = \sum_{j=1}^5 P_{i,j} \times MDC_{i,j}$$

where

$MDC_{i,tot}$  is the total medical cost associated with injuries to the body region  $i$ ;

$P_{i,j}$  is the probability of sustaining an injury of specific severity level  $j$  to the body region  $i$ ;

$MDC_{i,j}$  is the medical cost associated with an injury to the body region  $i$  of AIS injury severity level  $j$ .

Determine the medical cost associated with the lower extremity injuries, having the maximum AIS severity using the respective cost data listed in Annex A.

Determine the overall medical cost of injuries to the head, neck, thorax, abdomen, and lower extremities as given below:

$$MDC = \max(MDC_{i,tot})$$

where

$MDC$  is the overall medical cost;

$MDC_{i,tot}$  is the total medical cost associated with injuries to the body region  $i$ .

### 5.5.2 Ancillary costs

Tabulate the injuries by body region and AIS injury severity level. Determine the ancillary costs associated with each body region injury and each discrete AIS injury severity level, for each country in the cost data listed in Annex A. Calculate the total ancillary cost associated with the injuries for each of the four body regions, including the head, neck, thorax, and abdomen, using the equation given below:

$$AC_{i,tot} = \sum_{j=1}^5 P_{i,j} \times AC_{i,j}$$

where

$AC_{i,tot}$  is the total ancillary cost associated with injuries sustained to the body region  $i$ ;

$P_{ij}$  is the probability of sustaining an injury of AIS injury severity level  $j$  to the body region  $i$ ;

$AC_{ij}$  is the ancillary cost associated with an injury to the body region  $i$  of AIS injury severity level  $j$ .

Determine the total ancillary cost associated with lower extremity injuries using the maximum PPI value, as determined in 5.4.2.3, and the respective cost data table given in Annex A.

Determine the overall ancillary cost of injuries to the head, neck, thorax, abdomen, and lower extremities as given below:

$$AC = \max(AC_{i,tot})$$

where

$AC$  is the overall ancillary cost;

$AC_{i,tot}$  is the total ancillary cost associated with injuries sustained to the body region  $i$ .

### 5.5.3 Fatality cost

Determine the cost of fatality as defined in Annex A.

## 5.6 Probability of fatality

### 5.6.1 Due to AIS 6 injuries

Calculate the probability of fatality due to AIS 6 injuries to the head, neck, and/or the thorax using the equation given below:

$$P_{fatal,6} = 1 - [(1 - P_{H,6}) \times (1 - P_{n,6}) \times (1 - P_{Th,6})]$$

where

$P_{fatal,6}$  is the probability of fatality due to an AIS 6 injury;

$P_{H,6}$  is the probability of sustaining an AIS 6 head injury;

$P_{n,6}$  is the probability of sustaining an AIS 6 neck injury;

$P_{Th,6}$  is the probability of sustaining an AIS 6 thoracic injury.

### 5.6.2 Due to non-AIS 6 injuries

Construct a table as shown in Table 9. In the table, for each AIS injury severity level, list the values for the previously calculated probabilities of injury for the head, neck, thorax, abdomen, and lower extremities, and the number of lower extremity injuries. Consider that both of the legs comprise a single body region named lower extremities.

Table 9 — Injury probability and probable AIS

| AIS          | Body region |           |             |           |                   |                    |
|--------------|-------------|-----------|-------------|-----------|-------------------|--------------------|
|              | Head        | Neck      | Thorax      | Abdomen   | Lower extremities |                    |
|              |             |           |             |           | Probability       | Number of injuries |
| 0            | $P_{H,0}$   | $P_{n,0}$ | $P_{Th,0}$  | $P_{A,0}$ | $P_{IE,0}$        | -                  |
| 1            | $P_{H,1}$   | $P_{n,1}$ | $P_{Th,1}$  | $P_{A,1}$ | 0                 | -                  |
| 2            | $P_{H,2}$   | $P_{n,2}$ | $P_{Th,2}$  | $P_{A,2}$ | $P_{IE,2}$        | $N_{IE,2}$         |
| 3            | $P_{H,3}$   | $P_{n,3}$ | $P_{Th,3}$  | $P_{A,3}$ | $P_{IE,3}$        | $N_{IE,3}$         |
| 4            | $P_{H,4}$   | $P_{n,4}$ | $P_{Th,4}$  | $P_{A,4}$ | 0                 | -                  |
| 5            | $P_{H,5}$   | $P_{n,5}$ | $P_{Th,5}$  | 0         | 0                 | -                  |
| 6            | $P_{H,6}$   | $P_{n,6}$ | $P_{Th,6}$  | 0         | 0                 | -                  |
| Probable AIS | $PAIS_H$    | $PAIS_n$  | $PAIS_{Th}$ | $PAIS_A$  | $PAIS_{IE}$       | -                  |

The probability of fatality due to non-AIS 6 injuries includes the probability of fatality from all possible combinations of non-AIS 6 injuries. Calculate the probability of fatality for each possible combination of five non-AIS 6 injuries, one from each body region, and total them.

For each combination of five injury probabilities, determine the three largest corresponding AIS injury severity levels. Using these three AIS injury severity levels and Table B.1 in Annex B, determine the associated mortality rate for that combination of AIS injury severity levels. Calculate the probability of dying from that combination of non-AIS 6 severity levels.

EXAMPLE calculate the probability of fatality from a given combination of non-AIS 6 injuries, as shown below, for:

- head AIS 4;
- neck AIS 1;
- thorax AIS 1;
- abdomen AIS 2;
- lower extremities AIS 3.

Determine the mortality rate for the given combination of non-AIS 6 injuries using AIS 4, 3, and 2, because they are the three largest AIS injury severity levels. The mortality rate is, then:

$$MR_{432} = 23,7099$$

where

$MR_{432}$  is the mortality rate, from Table B.1, for the three largest AIS values of the five body regions,

4, 3, 2, expressed as a percentage.

Calculate the probability of fatality for the given combination of non-AIS 6 injuries using the following equation:

$$P_{fatal,41123} \frac{1}{100} \times 23,7099 \times P_{H,4} \times P_{n,1} \times P_{Th,1} \times P_{A,2} \times P_{IE,3}$$

where

$P_{fatal,41123}$  is the probability of fatality for the given combination of non-AIS 6 injuries;

$P_{H,4}$  is the probability of a head injury of AIS 4;

$P_{n,1}$  is the probability of a neck injury of AIS 1;

$P_{Th,1}$  is the probability of a thorax injury of AIS 1;

$P_{A,2}$  is the probability of an abdomen injury of AIS 2;

$P_{IE,3}$  is the probability of a lower extremities injury of AIS 3.

Calculate the probability of fatality from all combinations of non-AIS 6 injuries using the equation given below:

$$P_{fatal,5} = \frac{1}{100} \times \sum_{jH=0}^5 \sum_{jn=0}^5 \sum_{jTh=0}^5 \sum_{jA=0}^5 \sum_{jIE=0}^5 MR_{jH,jn,jTh,jA,jIE} \times P_{H,jH} \times P_{n,jn} \times P_{Th,jTh} \times P_{A,jA} \times P_{IE,jIE}$$

where

$P_{fatal,5}$  is the probability of fatality from all combinations of non-AIS 6 injuries;

$MR$  is the mortality rate, from Table B.1, with the three largest AIS values in descending order;

$P_{ij}$  is the probability of sustaining an injury to the body region  $i$  of the AIS injury severity level  $j$ , where  $i$  is  $H$ ,  $n$ ,  $Th$ ,  $A$ , or  $IE$ ;

$jH$  is the AIS injury severity level for the head;

$jn$  is the AIS injury severity level for the neck;

$jTh$  is the AIS injury severity level for the thorax;

$jA$  is the AIS injury severity level for the abdomen;

$jIE$  is the AIS injury severity level for the lower extremities.

### 5.6.3 Overall

Calculate the overall probability of fatality using the equation below:

$$P_{fatal} = P_{fatal,6} + P_{fatal,5}$$

where

$P_{fatal}$  is the overall probability of fatality;

$P_{fatal,6}$  is the probability of fatality from an AIS 6 injury;

$P_{fatal,5}$  is the probability of fatality from non-AIS 6 injuries.

### 5.6.4 Risk of life threatening brain injury

Determine the risk of life threatening brain injury using the value for HIC calculated in 5.1.3 and the plot given in Figure 2. Locate the calculated HIC value on the horizontal axis and determine the corresponding risk of life threatening brain injury on the vertical axis.

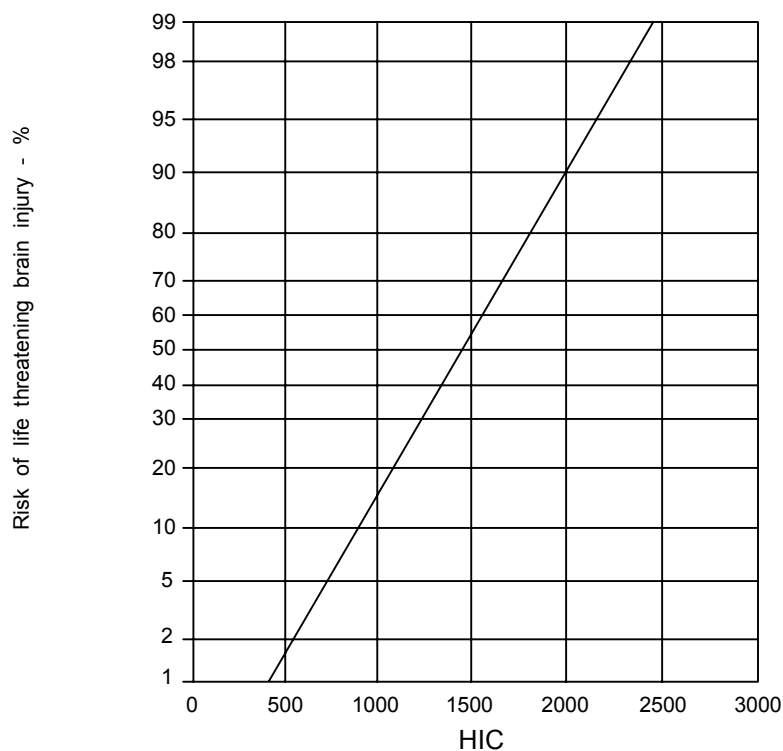


Figure 2 — Risk of life threatening brain injury for HIC for  $t_2 - t_1 \leq 0,015$  s

## 5.7 Probable AIS

### 5.7.1 By body region

Calculate a single weighted average PAIS for each body region as shown in the equation below:

$$PAIS_i = \frac{\sum_{j=0}^6 j \times P_{i,j}}{\sum_{j=0}^6 P_{i,j}}$$

where

$PAIS_i$  is the weighted average probable AIS for the body region  $i$ , rounded to the nearest integer;

$j$  is the AIS injury severity level;

$P_{i,j}$  is the probability of sustaining an injury of the AIS injury severity level  $j$  to the body region  $i$ .

Insert these calculated PAIS values into Table 8 in the appropriate boxes.

Total the number of lower extremity injuries for each AIS level and include that number in Table 9. For example:

$$N_{IE,3} = N_{F,3} + N_{T,3} + N_{K,3}$$

where

$N_{IE,3}$  is the number of AIS 3 injuries to the lower extremities;

$F$  indicates femur injuries;

$T$  indicates tibia injuries;

$K$  indicates knee injuries.

### 5.7.2 Maximum PAIS

Calculate the maximum PAIS for all body regions as shown in the equation below:

$$PAIS_{max} = \max(PAIS_i)$$

where

$PAIS_{max}$  is the maximum PAIS for all body regions;

$PAIS_i$  is the PAIS for the body region  $i$ .

### 5.7.3 Total PAIS

Calculate the total PAIS for all body regions as shown in the equation below:

$$PAIS_{tot} = PAIS_H + PAIS_n + PAIS_{Th} + PAIS_A + \sum_{j=2}^3 j \times N_{IE,j}$$

where

$PAIS_{tot}$  is the total PAIS for all body regions;

$PAIS_H$  is the PAIS for the head;

$PAIS_n$  is the PAIS for the neck;

$PAIS_{Th}$  is the PAIS for the thorax;

$PAIS_A$  is the PAIS for the abdomen;

$j$  is the AIS injury severity level;

$N_{IE,j}$  is the number of lower extremity injuries for AIS injury severity level  $j$ .

## 5.8 Normalized injury costs

**NOTE** 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 provide 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.

Calculate the normalized cost of survival as shown in the equation below:

$$CS_{norm} = \frac{(\text{minimum of } ((MDC + AC) \text{ or } CF))(1 - P_{fatal})}{CF}$$

where

$CS_{norm}$  is the normalized cost of survival;

$MDC$  is the medical cost;

$AC$  is the ancillary cost;

$P_{fatal}$  is the probability of fatality;

$CF$  is the cost of fatality;

The maximum value of  $CS_{norm}$  is  $(1 - P_{fatal})$ .

The normalized cost of fatality ( $CF_{norm}$ ) is equal to the probability of fatality ( $P_{fatal}$ ).

Calculate the total normalized injury cost as shown in the equation below:

$$C_{norm} = CS_{norm} + CF_{norm}$$

where

$IC_{norm}$  is the total normalized injury cost;

$CS_{norm}$  is the normalized cost of survival;

$CF_{norm}$  is the normalized cost of fatality;

the maximum value of  $IC_{norm}$  is 1,0.

### 5.8.1 Incremental normalized injury cost for each body region

Calculate the incremental normalized injury cost for each body region (head, neck, chest, abdomen, femurs, knees, tibias) according to 5.8 using for each body region only the injury assessment values associated with that body region, and setting the injury assessment values for all other body regions equal to zero.

**NOTE** In general the sum of the incremental normalized injury costs across all body regions will not equal the total normalized injury cost, due to injury cost interactions among the body regions and other non-linearities in their relationships.

## 5.9 Risk/benefit analysis

**NOTE** 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 provide 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.

### 5.9.1 Calculations of injury assessment variables and injury indices

For each of the 200 impact configurations defined in ISO 13232-2, calculate the values of the injury assessment variables and injury indices listed in Table 10.

**Table 10 — Injury assessment variables, change in head injury potential, and injury indices to be calculated for each impact configuration**

| Injury assessment variable, change in head injury potential, injury index | Values to calculate                 |                                  |                                              |
|---------------------------------------------------------------------------|-------------------------------------|----------------------------------|----------------------------------------------|
|                                                                           | MC without protective device<br>(1) | MC with protective device<br>(2) | Change due to protective device<br>(2) - (1) |
| Head maximum resultant linear acceleration                                | X                                   | X                                | X                                            |
| Head maximum resultant angular acceleration                               | X                                   | X                                | X                                            |
| Head maximum GAMBIT                                                       | X                                   | X                                | X                                            |
| Change in helmet trajectory                                               | -                                   | -                                | X                                            |
| Percentage change in helmet velocity at helmet impact                     | -                                   | -                                | 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                                            |
| Head incremental normalized injury cost                                   | X                                   | X                                | X                                            |
| Neck incremental normalized injury cost                                   | X                                   | X                                | X                                            |
| Chest incremental normalized injury cost                                  | X                                   | X                                | X                                            |
| Abdomen incremental normalized injury cost                                | X                                   | X                                | X                                            |
| Femur incremental normalized injury cost                                  | X                                   | X                                | X                                            |
| Knee incremental normalized injury cost                                   | X                                   | X                                | X                                            |
| Tibia incremental normalized injury cost                                  | X                                   | X                                | X                                            |
| Total normalized injury cost                                              | X                                   | X                                | X                                            |

### 5.9.2 Change in head injury potential

For each of the 200 impact configurations defined in ISO 13232-2, determine the following head injury potential indices for each set of paired comparison tests.

### 5.9.2.1 Change in helmet trajectory

Calculate the maximum vertical difference at the same  $x_h$  value between the helmet trajectories for the baseline case and for the protective device case over the evaluation time interval defined in 4.1.2.

### 5.9.2.2 Percentage change in helmet velocity at helmet impact

Calculate the percentage change of the resultant helmet velocity at first helmet/OV contact, from the baseline case to the protective device case over the evaluation time interval defined in 4.1.2.

### 5.9.3 Distributions of injury assessment variables, change in head injury potential, and injury indices

Using the tabulation described in Tables 10 and 11, plot the cumulative distribution function of the change due to the protective device for each injury assessment variable, change in head injury potential, and injury index, as follows:

- for a given injury assessment variable, change in head injury potential, or injury index, rank order the changes due to the protective device from the most negative to the most positive element, across the total number of impact configurations;
- for each impact configuration, list the frequency of occurrence ( $FO$ ) using Table B.1 of ISO 13232-2;
- for each element, sum the  $FO$  up to and including the  $FO$  for that element, to determine the cumulative  $FO$  for each element;
- for each element, divide the cumulative  $FO$  by the total cumulative  $FO$  to determine the cumulative distribution function;
- graph the cumulative distribution function with the values of the change, column 5 in Table 10, along the abscissa and the cumulative distribution function, column 6, along the ordinate.

### 5.9.4 Risk/benefit calculations

For each injury assessment variable, each body region's incremental normalized injury cost, and  $IC_{norm}$  calculate the following, according to 5.9.4.1 to 5.9.4.4:

- the percentage of accidents which are beneficial, which indicate no effect, and which are harmful,
- the average benefit and average risk per accident,
- the risk/benefit percentage,
- the average net benefit per accident,
- the average benefit per beneficial case, and
- the average risk per harmful case.

Compare the resulting values for  $IC_{norm}$  to the reference values given in Annex E.

#### 5.9.4.1 Percentages beneficial, no effect and harmful

For each of the cumulative distribution functions plotted in 5.9.3, calculate the:

- per cent of impacts having a negative change in the given cumulative distribution function. Designate this percentage as "beneficial";

- per cent of impacts having zero change in the given cumulative distribution function. Designate this percentage as "no effect";
- per cent of impacts having a positive change in the given cumulative distribution function. Designate this percentage as "harmful".

**Table 11 — Example table used to calculate the weighted cumulative distribution of change in maximum head acceleration due to a protective device**

Injury assessment variable, change in head injury potential, or injury index: Maximum head acceleration

| Rank order | Impact configuration |          |          | FO from Table B.1, ISO 13232-2 | Cumulative FO | Change due to protective device <i>g</i> | Cumulative distribution function |
|------------|----------------------|----------|----------|--------------------------------|---------------|------------------------------------------|----------------------------------|
|            | Code                 | OV speed | MC speed |                                |               |                                          |                                  |
| 1          | 413                  | 0        | 13,4     | 5                              | 5             | -212                                     | 0,01                             |
| 2          | 115                  | 6,7      | 6,7      | 4                              | 9             | -208                                     | 0,02                             |
| 3          | 314                  | 6,7      | 13,4     | 6                              | 15            | -189                                     | 0,03                             |
| .          | .                    | .        | .        | .                              | .             | .                                        | .                                |
| .          | .                    | .        | .        | .                              | .             | .                                        | .                                |
| .          | .                    | .        | .        | .                              | .             | .                                        | .                                |
| 198        | 313                  | 0        | 9,8      | 2                              | 489           | 153                                      | 0,98                             |
| 199        | 711                  | 0        | 9,8      | 2                              | 491           | 192                                      | 0,98                             |
| 200        | 414                  | 0        | 13,4     | 10                             | 501           | 247                                      | 1,0                              |

#### 5.9.4.2 Average risk/benefit percentage

Across all impact configurations or events, calculate the average risk/benefit percentage for each injury assessment variable, each body region's incremental normalized injury cost, and  $IC_{norm}$  as follows:

$$\text{average benefit } j = \text{average decrease in injury index } j = \frac{1}{N} \sum_{\ell=1}^{N_{ben}} (-\Delta x_{l,j} \times FO_{\ell})$$

$$\text{average risk } j = \text{average increase in injury index } j = \frac{1}{N} \sum_{k=1}^{N_{risk}} (-\Delta x_{k,j} \times FO_k)$$

$$\text{risk/benefit percentage } j = \frac{\text{average risk } j}{\text{average benefit } j} \times 100\%$$

where

$N_{ben}$  is the number of configurations in which the protective device was beneficial (i.e., resulted in a decrease in the injury index value) for a given injury index;

$N_{risk}$  is the number of configurations in which the protective device is harmful (i.e., resulted in an increase in the injury index value) for a given injury index;

$\Delta x$  is the change in injury index value (protective device - baseline);

$P$  is the subscript for each impact configuration in which there was a decrease in the injury index value;

$k$  is the subscript for each impact configuration in which there was an increase in the injury index value;

$N$  is the total number of accidents;

EXAMPLE For MC/OV impacts, ISO 13232-2 indicates  $N=501$ .

$j$  is the subscript for each injury index or injury assessment value;

$FO$  is the frequency of occurrence of a given impact configuration or event in accidents, based on ISO 13232-2, Table B.1 for impact configurations.

#### 5.9.4.3 Average net benefit

Across all configurations or events, calculate the average net benefit for each injury assessment variable, each component normalized injury cost, and  $IC_{norm}$  as follows:

$$\text{average net benefit}_j = \text{average benefit}_j - \text{average risk}_j$$

#### 5.9.4.4 Average benefit per beneficial case and average risk per harmful case

Across all configurations or events, calculate the average benefit per beneficial case and average risk per harmful case for each injury assessment variable, each component normalized injury cost, and  $IC_{norm}$  as follows:

$$\text{average benefit per beneficial case}_j = \frac{N}{N_{ben}} \times \text{average benefit}_j$$

$$\text{average risk per harmful case}_j = \frac{N}{N_{risk}} \times \text{average risk}_j$$

## 6 Documentation

All injury assessment variables, injury potential variables, injury severity probabilities, and injury indices shall be documented for each of the national cost databases included in Annex A in accordance with ISO 13232-8. The results of any risk/benefit analysis shall be documented in accordance with Annex C of ISO 13232-8.

## Annex A (normative)

### Injury costs

Use the tables in Annex A to determine the medical and ancillary costs for each body region and AIS injury severity level when calculating the overall costs in 5.5.1 and 5.5.2, respectively.

Tables A.1 and A.2 list respective medical and ancillary costs in 1988 U.S. dollars.

NOTE At the time of preparation of ISO 13232, the only cost data available were those of the USA, which are given below.

**Table A.1 — Medical costs**

| Body region       | AIS injury severity level | Cost      |
|-------------------|---------------------------|-----------|
| Head              | 1                         | \$ 784    |
| Head              | 2                         | 3 807     |
| Head              | 3                         | 14 169    |
| Head              | 4                         | 72 349    |
| Head              | 5                         | 263 306   |
| Neck              | 3                         | \$ 20 509 |
| Neck              | 4                         | 440 037   |
| Neck              | 5                         | 530 695   |
| Thorax            | 1                         | \$ 696    |
| Thorax            | 2                         | 3 410     |
| Thorax            | 3                         | 10 147    |
| Thorax            | 4                         | 19 577    |
| Thorax            | 5                         | 32 790    |
| Abdomen           | 1                         | \$ 696    |
| Abdomen           | 2                         | 3 410     |
| Abdomen           | 3                         | 10 147    |
| Abdomen           | 4                         | 19 577    |
| Lower extremities | 2                         | \$ 7 881  |
| Lower extremities | 3                         | 22 732    |

Table A.2 — Ancillary costs

| Body region                                                  | AIS injury severity level | PPI | Cost      |
|--------------------------------------------------------------|---------------------------|-----|-----------|
| Head                                                         | 1                         | -   | \$ 2 664  |
| Head                                                         | 2                         | -   | 10 818    |
| Head                                                         | 3                         | -   | 47 819    |
| Head                                                         | 4                         | -   | 91 497    |
| Head                                                         | 5                         | -   | 320 571   |
| Neck                                                         | 3                         | -   | \$ 76 267 |
| Neck                                                         | 4                         | -   | 391 007   |
| Neck                                                         | 5                         | -   | 463 314   |
| Thorax                                                       | 1                         | -   | \$ 1 372  |
| Thorax                                                       | 2                         | -   | 10 886    |
| Thorax                                                       | 3                         | -   | 31 051    |
| Thorax                                                       | 4                         | -   | 46 853    |
| Thorax                                                       | 5                         | -   | 64 256    |
| Abdomen                                                      | 1                         | -   | \$ 1 372  |
| Abdomen                                                      | 2                         | -   | 10 886    |
| Abdomen                                                      | 3                         | -   | 31 051    |
| Abdomen                                                      | 4                         | -   | 46 853    |
| Lower extremities                                            | -                         | 07  | \$ 27 370 |
| Lower extremities                                            | -                         | 15  | 58 650    |
| Lower extremities                                            | -                         | 22  | 86 020    |
| Lower extremities                                            | -                         | 27  | 105 570   |
| Lower extremities                                            | -                         | 38  | 148 580   |
| NOTE The cost of fatality is \$596 580 in 1988 U.S. dollars. |                           |     |           |

## Annex B (normative)

### Mortality rate

Use Table B.1 to determine the mortality rate for each combination of the three largest of five AIS injury severity levels, one for each body region. Use the mortality rates to calculate the probability of fatality due to non-AIS 6 injuries, as described in 5.6.2.

**Table B.1 — Mortality rates for all AIS combinations**

| Largest 3 AIS severity levels | Mortality rate<br>% | Largest 3 AIS severity levels | Mortality rate<br>% |
|-------------------------------|---------------------|-------------------------------|---------------------|
| 0 0 0                         | 0                   | 4 3 3                         | 26,7080             |
| 1 0 0                         | 0,1502              | 4 4 0                         | 30,0853             |
| 1 1 0                         | 0,3481              | 4 4 1                         | 33,8896             |
| 1 1 1                         | 0,8068              | 4 4 2                         | 38,1750             |
| 2 0 0                         | 0,9379              | 4 4 3                         | 43,0022             |
| 2 1 0                         | 1,2140              | 4 4 4                         | 48,4399             |
| 2 1 1                         | 1,5713              | 5 0 0                         | 24,5181             |
| 2 2 0                         | 2,0339              | 5 1 0                         | 25,8821             |
| 2 2 1                         | 2,6327              | 5 1 1                         | 27,3220             |
| 2 2 2                         | 3,4077              | 5 2 0                         | 28,8420             |
| 3 0 0                         | 1,8198              | 5 2 1                         | 30,4465             |
| 3 1 0                         | 2,0789              | 5 2 2                         | 32,1403             |
| 3 1 1                         | 2,3750              | 5 3 0                         | 33,9283             |
| 3 2 0                         | 2,7133              | 5 3 1                         | 35,8158             |
| 3 2 1                         | 3,0997              | 5 3 2                         | 37,8083             |
| 3 2 2                         | 3,5412              | 5 3 3                         | 39,9117             |
| 3 3 0                         | 4,0456              | 5 4 0                         | 42,1321             |
| 3 3 1                         | 4,6218              | 5 4 1                         | 44,4759             |
| 3 3 2                         | 5,2800              | 5 4 2                         | 46,9502             |
| 3 3 3                         | 6,0320              | 5 4 3                         | 49,5622             |
| 4 0 0                         | 9,1459              | 5 4 4                         | 52,3194             |
| 4 1 0                         | 10,3025             | 5 5 0                         | 55,2300             |
| 4 1 1                         | 11,6052             | 5 5 1                         | 58,0236             |
| 4 2 0                         | 13,0727             | 5 5 2                         | 61,5461             |
| 4 2 1                         | 14,7258             | 5 5 3                         | 64,9700             |
| 4 2 2                         | 16,5879             | 5 5 4                         | 68,5844             |
| 4 3 0                         | 18,6855             | 5 5 5                         | 72,3999             |
| 4 3 1                         | 21,0483             | 6 - -                         | 100,0000            |
| 4 3 2                         | 23,7099             |                               |                     |

## Annex C (informative)

### ICM Variable and subscript definitions

The tables given in Annex C define the variables (Table C.1) and subscripts (Tables C.2 and C.3) used in ISO 13232-5.

**Table C.1 — Variable definitions**

| Variable                       | Definition                                                                                              |
|--------------------------------|---------------------------------------------------------------------------------------------------------|
| $PAIS_{ij}$                    | Probable AIS of severity level $j$ for a given body region $i$ .                                        |
| $ISP_{ij}$                     | Injury severity probability of an AIS injury severity level $j$ for a given body region $i$ .           |
| $P_{ij}$                       | Probability of sustaining a discrete injury of a specific AIS level $j$ to a specific body region $i$ . |
| $V_{x,h}$                      | Helmet centroid point velocity (in the x direction).                                                    |
| $a_{x,H}$                      | Head linear acceleration (in the x direction).                                                          |
| $\alpha_{x,H}$                 | Head angular acceleration (in the x direction).                                                         |
| $G$                            | GAMBIT                                                                                                  |
| $HIC$                          | Head injury criterion.                                                                                  |
| $D_{us}, D_{ls}$               | Upper and lower sternum deflection.                                                                     |
| $C_{us}, C_{ls}$               | Upper and lower sternum compression (normalized).                                                       |
| $\Delta l_{uL}, \Delta l_{uR}$ | Chest potentiometer displacements, upper left and right.                                                |
| $\Delta l_{lL}, \Delta l_{lR}$ | Chest potentiometer displacements, lower left and right.                                                |
| $p_A$                          | Abdominal penetration.                                                                                  |
| $N_{ij}$                       | Number of injuries to the body region $i$ of the AIS injury severity level $j$ .                        |
| $PPI$                          | Permanent partial incapacity index.                                                                     |
| $NII$                          | Neck injury index.                                                                                      |
|                                | Ancillary costs:                                                                                        |
| $AC_{ij}$                      | — to the body region $i$ of the AIS injury severity level $j$ ;                                         |
| $AC_{i,tot}$                   | — the total for body region $i$ ;                                                                       |
| $AC$                           | — overall.                                                                                              |
|                                | Medical costs:                                                                                          |
| $MDC_{ij}$                     | — to the body region $i$ of the AIS injury severity level $j$ ;                                         |
| $MDC_{i,tot}$                  | — the total for body region $i$ ;                                                                       |
| $MDC$                          | — overall.                                                                                              |

| Variable           | Definition                                                                                               |
|--------------------|----------------------------------------------------------------------------------------------------------|
| $IC_{norm}$        | Injury cost, normalized.                                                                                 |
| $CS_{norm}$        | Cost of survival, normalized.                                                                            |
| $CF_{norm}$        | Cost of fatality, normalized.                                                                            |
| $P_{fatal,5}$      | Probability of fatality due to all possible combinations of injuries with AIS injury severity level < 6. |
| $P_{fatal,6}$      | Probability of fatality due to an injury of AIS injury severity level 6.                                 |
| $P_{fatal}$        | Overall probability of fatality.                                                                         |
| $V_{us}, V_{ls}$   | Upper and lower sternum velocity.                                                                        |
| $VC_{us}, VC_{ls}$ | Upper and lower sternum velocity - compression.                                                          |
| $MR$               | Mortality rate.                                                                                          |

Table C.2 — Body region subscript definition

| Subscript | Body region                   |
|-----------|-------------------------------|
| $A$       | abdomen                       |
| $C$       | thoracic compression          |
| $F$       | femur                         |
| $H$       | head                          |
| $K$       | knee                          |
| $lE$      | lower extremities             |
| $us$      | upper sternum                 |
| $ls$      | lower sternum                 |
| $n$       | neck                          |
| $T$       | tibia                         |
| $Th$      | thorax                        |
| $VC$      | thoracic velocity-compression |

Table C.3 — Other subscripts

| Subscript | Definition                | Subscript    | Definition |
|-----------|---------------------------|--------------|------------|
| $comp$    | compression               | No subscript | overall    |
| $ext$     | extension                 | $peak$       | peak value |
| $fatal$   | fatality                  | $R$          | right      |
| $fc$      | first contact             | $r$          | resultant  |
| $flex$    | flexion                   | $shear$      | shear      |
| $h$       | helmet                    | $tens$       | tension    |
| $i$       | index for body region     | $tors$       | torsion    |
| $j$       | AIS injury severity level | $tot$        | total      |

| Subscript   | Definition    | Subscript              | Definition                     |
|-------------|---------------|------------------------|--------------------------------|
| <i>L</i>    | left          | <i>uL, uR,</i>         | upper left, upper right,       |
| <i>max</i>  | maximum value | <i>lL, lR</i>          | lower left, lower right        |
| <i>min</i>  | minimum value | <i>x, y, z</i>         | <i>x, y, z</i> direction       |
| <i>norm</i> | normalized    | <i>xy, yz, xz, xyz</i> | resultant of two or three axes |

## Annex D (informative)

### Example computer code of the injury cost model

An example computer code is given, which evaluates the injury cost model for the data given in Annex D of ISO 13232-2. The generated output is similar to that presented in Annex F of this part of ISO 13232. The code is written in FORTRAN-77. Figure D.1 shows a flow diagram of the computation.

c...+...1....+...2....+...3....+...4....+...5....+...6....+...7....+...8

program ricm

```

C*****
C
C  name
C
C    ricm - Execute the Injury Cost Model subroutine and print out
C          the results
C
C  description
C
C    This program prompts the user for Injury Cost Model input values
C    and then calls the analysis subroutine icm and prints out the
C    results.
C
C  version history
C
C    - original version by RMV, DRI, April 1993
C    - first revision by RMV, DRI, March 1993
C      - added prompted inputs for both upper and lower sternum Cmax
C        and VCmax
C      - changed model and subroutine name from Injury Cost Model II
C        (icm2) to Injury Cost Model (icm)
C      - changed subroutine name from wricm2 to wricm
C      - minor output unit and format changes
C      - minor comment changes
C    - second revision by RMV, DRI, August 1994
C      - PPI output added
C      - Risk of life threatening brain injury based on HIC added
C    - include HIC ISP for head AIS, revision by DPC, DRI, March 1998
C    - fourth revision by SM, May 2001 (taken from RHO and EPM)
C      - spaces added between prompt and input
C      - pager added to output
C      - write to file option added with test number prompt
C      - prompt user for output file name
C      - use included make file(Makefile) to compile
C    - fifth revision by SM, May 2001
C      - added neck injury criteria
C    - sixth revision by KDW, DRI, February 2002
C      -added new neck ISPn equation coefficients
C
C*****
C

```

```

c  program parameters
c
c  integer stdout
c  parameter (stdout=6)
c
c  program variables
c
c  integer nldatin, nrldatin, ndatout
c  parameter (nldatin=5, nrldatin=6, ndatout=10)
c  integer ldatin(nldatin), lerr
c  integer lcmax, lvcmax
c  real Rldatin(nrldatin), Table(9,6), Datout(ndatout)
c  real Cmax, Cmaxls, Cmaxus, VCmax, VCmaxls, VCmaxus
c  character*50 sidatin(nldatin), srldatin(nrldatin), sdatout(ndatout)
c  character*13 sloc(2)
c  character*20 aformat
c  character tnumstr*12,hline*60, overwrite*1, wnum*1
c  character wdesc*10,tnum*12,tfile*50
c  integer cnt, fdout
c
c  program data
c
c  data tnumstr/'File Name'/
c
c  data sidatin/'Number of AIS 3 Femur Fractures',
c  &      'Number of AIS 2 Tibia Fractures',
c  &      'Number of AIS 3 Tibia Fractures',
c  &      'Number of AIS 2 Knee Dislocation Injuries',
c  &      'Number of AIS 3 Knee Dislocation Injuries'/
c  data srldatin/'maximum Abdomen Penetration',
c  &      'maximum GAMBIT',
c  &      'Cmax',
c  &      'VCmax',
c  &      'HIC',
c  &      'NII (2001 MATD Neck)'/
c  data sdatout/'MAIS',
c  &      'Total AIS',
c  &      'Normalized Injury Cost',
c  &      'Normalized Cost of Survival',
c  &      'Normalized Cost of Dying',
c  &      'Probability of Fatality',
c  &      'Probability of Fatality due to non AIS 6 injuries',
c  &      'Probability of Fatality due AIS 6 injuries',
c  &      'Permanent Partial Incapacity',
c  &      'Risk of life threatening brain injury (%)'/
c  data sloc/'upper sternum','lower sternum'/
c
c *****
c
c  write(stdout,*) 'Injury Cost Model - RICM (HIC ISP version)'
c
c  prompt the user for test name to be used in filename construction
c
c  do cnt = 1,60
c    hline(cnt:cnt) = char(45)
c  end do
c  write(stdout,101) hline
c  write(stdout,101)
c  * 'Injury Cost Model - RICM (HIC ISP version)'

```

```

c  * ' Injury Cost Model Program      (version 3.0)'
    write(stdout,101) hline
10  write(stdout,*)
    write(stdout,101)
    * 'Enter file name (8 characters maximum) to generate output file'
    write(stdout,101)
    * 'or Enter 0 for screen display only.'
    write(stdout,*)
    call aaccept('Enter '//tnumstr,tnum)
    if (lenstr(tnum).gt.8) then
        write(stdout,*)
    * 'Too many characters.'
        write(stdout,101)
        goto 10
    end if
c*****
c  prompt the window number if output file is to be made
c
    if (tnum.ne.'0') then
15  write(*,101)
        write(stdout,101)
    *   'Enter analysis window <1,2> or <e> for entire run: '
        call cread(wnum,1)
        if ( (wnum .eq. '1') .or. (wnum .eq. '2') ) then
            wdesc = wnum//'
        else if ( (wnum .eq. 'e') .or. (wnum .eq. 'E') ) then
            wnum(1:1) = 'E'
            wdesc = 'Entire Run'
        else
            write(stdout,*)
            write(stdout,101) 'That is not a valid window choice'
            goto 15
        end if

c
c  construct output file name and check to see if it already exists
c
        tfile= tnum
        write(aformat,'(a,i4,a)')(a',lenstr(tnum),',a,a')
        write(tfile,aformat) tnum,'.IC',wnum
        open(fdout, file = tfile, err = 900, status = 'new')
    end if
120 continue
    write(stdout,*)

c
c
c  prompt the user for Injury Cost Model inputs other than Cmax and VCmax
c
    do k=1,nidatin
        ldatin(k) = iaccept('Enter '//sidatin(k))
    end do
    do k=1,2
        Rdatin(k) = raccept('Enter '//srdatin(k))
    end do

c
c  prompt the user for Cmax and VCmax values for the upper and lower
c  sternum
c
    Cmaxus = raccept('Enter Cmax for upper sternum')

```

```

Cmaxls = raccept('Enter Cmax for lower sternum')
VCmaxus = raccept('Enter VCmax for upper sternum')
VCmaxls = raccept('Enter VCmax for lower sternum')

```

```

Rdatin(5) = raccept('Enter '//srdatin(5))
Rdatin(6) = raccept('Enter '//srdatin(6))

```

```

c
c determine the larger Cmax value and location

```

```

c
if(Cmaxus.gt.Cmaxls) then
    Cmax = Cmaxus
    lmax = 1
else
    Cmax = Cmaxls
    lmax = 2
end if
Rdatin(3) = Cmax

```

```

c
c determine the larger VCmax value and location

```

```

c
if(VCmaxus.gt.VCmaxls) then
    VCmax = VCmaxus
    lvcmax = 1
else
    VCmax = VCmaxls
    lvcmax = 2
end if
Rdatin(4) = VCmax

```

```

c
c call the Injury Cost Model
c
call icm(latin,Rdatin,Table,Datout,lerr)

```

```

if(lerr.eq.0) then

```

```

c
c write out model inputs and output to screen

```

```

c
write(stdout,*)
write(stdout,*)
write(stdout,101) 'Injury Cost Model input:'
write(stdout,*)
write(stdout,*)

```

```

do k=1,nidatin
    write(stdout,102) sidatin(k),idatin(k)
end do
do k=1,nrdatin
    if(k.ge.5) then
        write(stdout,105) srdatin(k),rdatin(k)
    else
        write(stdout,103) srdatin(k),rdatin(k)
    end if
end do
write(stdout,104) 'Location of Cmax ',sloc(lmax)
write(stdout,104) 'Location of VCmax',sloc(lvcmax)
write(stdout,*)
write(stdout,*)
write(stdout,*)
write(stdout,*)
write(stdout,*)

```

```

write(stdout,*)

pause

write(stdout,*)
write(stdout,101) 'Injury Cost Model output:'
write(stdout,*)
write(stdout,*)
do k=1,ndatout
  if( (k.eq.1) .or. (k.eq.2) .or. (k.eq.10) ) then
    write(stdout,105) sdatout(k),datout(k)
  else
    write(stdout,103) sdatout(k),datout(k)
  end if
end do
write(stdout,*)
write(stdout,*)
write(stdout,*)
write(stdout,*)
write(stdout,*)
write(stdout,*)
write(stdout,*)
write(stdout,*)

pause

write(stdout,*)
write(stdout,101) 'Injury Probability by Body Region Table:'
write(stdout,*)

c
c write out Table 1
c
c write(stdout,*)
c call wricm(stdout,Table)

c*****
c write out model inputs and output to file if needed
c

```

```

write(fdout,'(a, 2x, a)') 'Test Name    :',tnum

write(fdout,'(a, 2x, a)') 'Analysis Window :',wdesc
write(fdout,*)
write(fdout,*)

write(fdout,101) 'Injury Cost Model input:'
write(fdout,*)
write(fdout,*)

do k=1,nidatin
  write(fdout,102) sidatin(k),idatin(k)
end do
do k=1,nrdatin
  if(k.ge.5) then
    write(fdout,105) srdatin(k),rdatin(k)
  else
    write(fdout,103) srdatin(k),rdatin(k)
  end if
end do

```

```

        end if
    end do
    write(fdout,104) 'Location of Cmax ',sloc(lcmax)
    write(fdout,104) 'Location of VCmax',sloc(lvcmax)
    write(fdout,*)
    write(fdout,*)
    write(fdout,101) 'Injury Cost Model output:'
    write(fdout,*)
    write(fdout,*)
    do k=1,ndatout
        if ( (k.eq.1) .or. (k.eq.2) .or. (k.eq.10) ) then
            write(fdout,105) sdatout(k),datout(k)
        else
            write(fdout,103) sdatout(k),datout(k)
        end if
    end do
    write(fdout,*)
    write(fdout,*)
    write(fdout,101) 'Injury Probability by Body Region Table:'
    write(fdout,*)
C
C   write out Table 1
C
        write(fdout,*)
        call wrbcm(fdout,Table)

        close(fdout)

    else

        write(stdout,*) 'ICM subroutine error #',lerr

        close(fdout)

    end if
C
C   done
C
    stop

C
C   output file error stuff
C
900 write(stdout,*)
    write(stdout,101)
    * ' File exists'
    write(stdout,101) ' Overwrite current file? (y/n) '
    call cread(overwrite,1)
    if (overwrite .eq. 'y' .or. overwrite .eq. 'Y') then
        open(fdout, file = tfile, err = 901, status = 'old')
    else
        goto 10
    end if
    goto 120

901 write(stdout,*) 'Error opening file - Exiting'
    stop

```

```

c
c  format statements
c
101 format(1x,a)
102 format(3x,a50,' = ',i4)
103 format(3x,a50,' = ',f8.3)
104 format(3x,a17,33x,' : ',a)
105 format(3x,a50,' = ',f6.1)

      end

c...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...8
c...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...8

      integer function iaccept(prompt)
      character*(*) prompt
c
c  this function prompts the user for integer valued input
c
      integer stdout, stdin
      parameter (stdout=6, stdin=5)

      write(stdout,101) prompt(:lenstr(prompt))//': '
      read(stdin,*) iaccept
      return

101 format(1x,a,1x,$)

      end

c...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...8
c...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...8

      subroutine aaccept(prompt,aval)
      character*(*) prompt
      character*50 aval
c
c  this function prompts the user for character input
c
      integer stdout, stdin
      parameter (stdout=6, stdin=5)

      write(stdout,101) prompt(:lenstr(prompt))//': '
      read(stdin,'(a)') aval
      return

101 format(1x,a,1x,$)

      end

c...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...8
c...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...8

      real function raccept(prompt)
      character*(*) prompt
c
c  this function prompts the user for real valued input
c
      integer stdout, stdin
      parameter (stdout=6, stdin=5)

```

```

write(stdout,101) prompt(:lenstr(prompt))//': '
read(stdin,*) raccept
return

```

```

101 format(1x,a,1x,$)

```

```

end

```

```

c...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...8
c...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...8

```

```

integer function lenstr(string)
character*(*) string

```

```

c
c this function find the length of a string with trailing blanks
c removed
c
do lenstr=len(string),1,-1
  if(string(lenstr:lenstr).ne.' ') return
end do
return

```

```

end

```

```

c...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...8
c...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...8

```

```

subroutine icm(Idatin,Rdatin,Table,Datout,lerr)
integer Idatin(5), lerr
real Rdatin(6), Table(9,6), Datout(10)

```

```

c*****
c
c name
c
c icm - Evaluate the Injury Cost Model
c
c description
c
c This subroutine evaluates the Injury Cost Model for the inputs
c in arrays Idatin and Rdatin. Output is returned in arrays Table
c and Datout.
c
c calling sequence
c
c argument i/o description
c -----
c Idatin   i integer data input array, elements as follows:
c           element symbol description
c           -----
c           1   FF3   number of AIS 3 femur fractures
c           2   TF2   number of AIS 2 tibia fractures
c           3   TF3   number of AIS 3 tibia fractures
c           4   KDI2  number of AIS 2 knee dislocated
c                   injuries
c           5   KDI3  number of AIS 3 knee dislocated
c                   injuries
c
c Rdatin   i real data input array, elements as follows:

```

| element | symbol | units | description                                 |
|---------|--------|-------|---------------------------------------------|
| 1       | AP     | mm    | maximum abdomen penetration                 |
| 2       | Gmax   | -     | maximum GAMBIT                              |
| 3       | Cmax   | %     | maximum normalized chest compression        |
| 4       | VCmax  | m/s   | maximum chest viscous criteria when V>3 m/s |
| 5       | HIC    | -     | Head Injury Criteria                        |
| 6       | NII    | -     | Neck Injury Index                           |

Table o table 1 values

Datout o real data output array, elements as follows:  
element symbol units description

|    |       |   |                                       |
|----|-------|---|---------------------------------------|
| 1  | MAIS  |   | maximum AIS                           |
| 2  | TAIS  |   | total AIS                             |
| 3  | NIC   | - | Normalized Injury Cost                |
| 4  | NCOS  | - | Normalized Cost of Survival           |
| 5  | NCOD  | - | Normalized Cost of Dying              |
| 6  | POF   | - | Probability of Fatality               |
| 7  | POF5  | - | POF due to non AIS 6 injuries         |
| 8  | POF6  | - | POF due to AIS 6 injuries             |
| 9  | PPI   | - | Permanent Partial Incapacity          |
| 10 | Prisk | % | Risk of life threatening brain injury |

lerr o error code

- 0 - normal return
- 1- 5 - index of out of range ldatin
- 11-14 - index of out of range Rdatin

#### version history

- original version by RMV, DRI, March 1993
- first revision by RMV, DRI, April 1993
  - AIS 3 knee dislocation injuries added
  - Input range checking added
- second revision by RMV, DRI, March 1994
  - changed model and subroutine name from Injury Cost Model II (icm2) to Injury Cost Model (icm)
  - changed hospital cost (HC) to medical cost (MDC)
  - changed parameter names from AISmax to AIS6, AISsrv to AIS5
- third revision by RMV, DRI, August 1994
  - added PPI to Datout output array
  - added risk of life threatening brain injury calculation based on HIC, HIC input was added to Rdatin and Prisk output added to Datout arrays
- fourth revision by RMV, DRI, December 1994
  - Corrected PPI for 1 leg injury
- include HIC ISP for to head AIS, revision by DPC, DRI, March 1998
- include Neck Injury Criteria, revision by KDW,RMV,SM, DRI, May 2001
- sixth revision by KDW, DRI, February 2002
  - added new neck ISPn equation coefficients
- seventh revision by RMV, DRI, June 2004