TECHNICAL REPORT

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Road vehicles — Injury risk curves for evaluation of occupant protection in frontal impact

Véhicules routiers — Courbes de risques de blessures pour évaluer la protection des occupants en choc frontal

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Foreword

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In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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ISO/TR 7861 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 12, *Passive safety crash protection systems*.

Introduction

A number of researchers have proposed injury risk curves for various dummy measurements, based on their analyses of published biomechanical data. These curves, summarized in this Technical Report, can be used by regulatory authorities as well as car manufacturers to set occupant protection levels based on the injury risks they believe are acceptable for the frontal collision being simulated. No limits are given because it is the view of ISO/TC 22 that the setting of performance levels is a responsibility for regulatory authorities.

Road vehicles — Injury risk curves for evaluation of occupant protection in frontal impact

1 Scope

This Technical Report presents injury risk curves that can be used for injury risk assessment in the evaluation of occupant protection in road-vehicle frontal impact. The measurements were made on frontal-impact crash test dummies which present acceptable levels of biofidelity response in accordance with ISO/TR 12349-1 and ISO/TR 12349-2 and which are used in the frontal-impact test procedures of existing International Standards.

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 TR 12349-1, *Road vehicles — Dummies for restraint system testing — Part 1: Adult dummies*

ISO TR 12349-2, *Road vehicles — Dummies for restraint system testing — Part 2: Child dummies*

3 Injury risk curves

3.1 General

All the injury risk curves, presented in Annex A, are shown plotted on normal probability graph paper. Values for mean value (denoted with a superscript dash over the parameter) and standard deviation (σ) for each risk curve are shown on the graphs.

3.2 Head injury risk curves

Three head injury risk curves are given for forehead impacts. The bases for these curves are discussed by Prasad and Mertz [1] and Mertz et al. [2, 3]. The risk of skull fracture as functions of 15 ms HIC (head impact criteria) and peak acceleration of the centre of gravity of the head are given in Figures A.1 and A.2, respectively. The risk of AIS (abbreviated injury scale) $\geqslant$ 4 brain injury as a function of 15 ms HIC is given in Figure A.3.

3.3 Neck injury risk curves

Three normalized risk curves for AIS $\geqslant$ 3 neck injury based on measurements made at the occipital condylar joint for tension-extension neck loading are given for CRABI and Hybrid III dummy families. These curves are based on the work described by Mertz et al. [4] and Mertz and Prasad [5] and include a factor for variation in failure stress as a function of age [5]. Figures A.4, A.5 and A.6 are the risk curves for peak normalized neck tension, peak extension moment and an index for the peak combination of tension and extension moment, respectively. Normalizing values for various dummy sizes are listed in the legends of the graphs and correspond to 3 %, 5 % and 2 % risks of AIS $\geqslant$ 3 neck injury with minimum passive muscle tone, respectively. These normalizing values are the limit values for out-of-position airbag testing specified in FMVSS 208 [20].

These curves can also be used to estimate injury risk with various amounts of muscle pretension. The procedure for making such estimates is as follows.

a) Determine the maximum values of each normalized function from the test data.

b) Subtract from these values the values of loading assumed to be carried by the muscles, or

1) neck tension, F_T/F_3

$$\frac{F_T}{F_3} = \left[\frac{F_T}{F_3}\right]_{max} - m\left[\frac{F_M}{F_3}\right]$$

2) neck extension moment, M_E/M_5

$$\frac{M_E}{M_5} = \left[\frac{M_E}{M_5}\right]_{max} - m\left[\frac{M_M}{M_5}\right]$$

3) combined tension and extension moment, N_{TE}

$$N_{TE} = \left[\frac{M_E}{M_2} + \frac{F_T}{F_2}\right]_{max} - m\left[\frac{F_M}{F_2}\right]$$

where

F_M, M_M are the maximum tension and extension moment due to pretensing of the neck muscles;

m is the fraction of the maximum passive muscle tensing assumed ($0 \leqslant m \leqslant 1$).

These differences are used to estimate the injury risks from the curves of Figures A.4, A.5 and A.6.

Mertz and Prasad [5] provide estimates for the maximum values for tension and extension moment due to pretensioning of the neck muscles for various sizes of dummies based on static strength tests. These values are given in Table A.1. No values are listed for the CRABI infant dummies because it is unreasonable to expect an infant to be aware of an impending collision.

3.4 Thoracic injury risk curves

3.4.1 General

There are two types of thoracic loadings for which injury risk curves have been developed:

a) shoulder belt loading with and without air bags;

b) distributed thoracic loading such as is produced by air bags without belts.

3.4.2 Shoulder belt loading

Mertz et al. [6] correlated field accident observations of thoracic injuries of occupants restrained with three-point belts with force-limiting shoulder belts to Hybrid III sternal deflections measured for the simulated accident conditions. These data were used to formulate the AIS $\geqslant$ 3 thoracic injury risk curve of Figure A.7 as a function of Hybrid III sternal deflection. This risk curve can be used whenever the torso is restrained by a shoulder belt, even if an air bag is part of the restraint system. Since the field accident data was not normalized for size of occupants, the curve overestimates the injury risk for the 50th percentile adult male at low risk levels.

Foret-Bruno et al. [7] have done a correlation study of field accident observations of thoracic injuries of occupants restrained with three-point belts with force-limiting shoulder belts and head air bags and shoulder belt loads measured in accidents. Figure A.8 is their risk curve for AIS ⩾ 3 thoracic injury as a function of shoulder belt load. To use this curve, the belt geometry shall be similar to the simulated tests.

3.4.3 Distributed loading

Figure A.9 gives the injury risk curves for the AIS ⩾ 3 thoracic injuries. The normalizing values which correspond to 5 % risk are given in the legend. No AIS ⩾ 3 risk curves are given for infants and children. This is because the low bending modulus of their ribs allows them to experience large sternal deflections without rib fractures which is the predominant. AIS = 3 thoracic injury. Figure A.10 gives injury risk curves of Mertz et al. [4] for AIS ⩾ 4 thoracic injuries for distributed chest loading, such as an air bag, as a function of normalized sternal deflection. Normalizing values which correspond to a 5 % risk for different dummy types are given on the graph.

The curve for AIS ⩾ 4 heart/lung injuries as a function of the rate of sternal risk compression that was developed by Mertz et al. [4] is given in Figure A.11. These curves can be used with all dummy sizes since the internal organ stress level is dependent only on the rate of sternal compression and not on size.

Viano et al. [8] hypothesized that heart/lung trauma would be caused by the product of the sternal deflection rate and the normalized sternal deflection: the viscous criterion, V*C. Figure A.12 gives the risk curve of AIS ⩾ 4 heart/lung injury as a function of the viscous criterion. Normalizing values are not given for the CRABI family because these dummies are not instrumented to measure sternal compression. Caution must be used when using the viscous criterion since the instrumentation used to process the original biomechanical data lacked the required high frequency fidelity needed to obtain accurate V*C values.

3.5 Lower extremity fracture curves

3.5.1 Knee-thigh-hip fractures

The cadaver data summarized by Morgan et al. [10, 11, 12, 13, 14, 15, 16] for knee impacts were analyzed using the Mertz-Weber technique [17] to obtain a risk curve for knee–thigh–hip fracture as a function of axial compressive knee load, as shown in Figure A.13.

3.5.2 Tibia shaft fractures

Nyquist et al. [18] conducted three-point bending tests on the intact leg of 16 male specimens. Median rank analysis [19] of the maximum bending moments at fracture gave the fracture risk curve shown in Figure A.14.

3.5.3 Ankle/foot fractures

Crandall et al. [19] conducted impact tests to the feet of 50 amputated cadaver lower limbs that produced fractures of the calcaneus, talus and malleroli, as well as ligamentous tears. These data were analyzed using the Mertz-Weber technique [17] to obtain a risk curve for ankle or foot fractures, or both, as a function of the axial compressive tibia shaft load shown in Figure A.15.

Annex A
(normative)

Injury risk curves

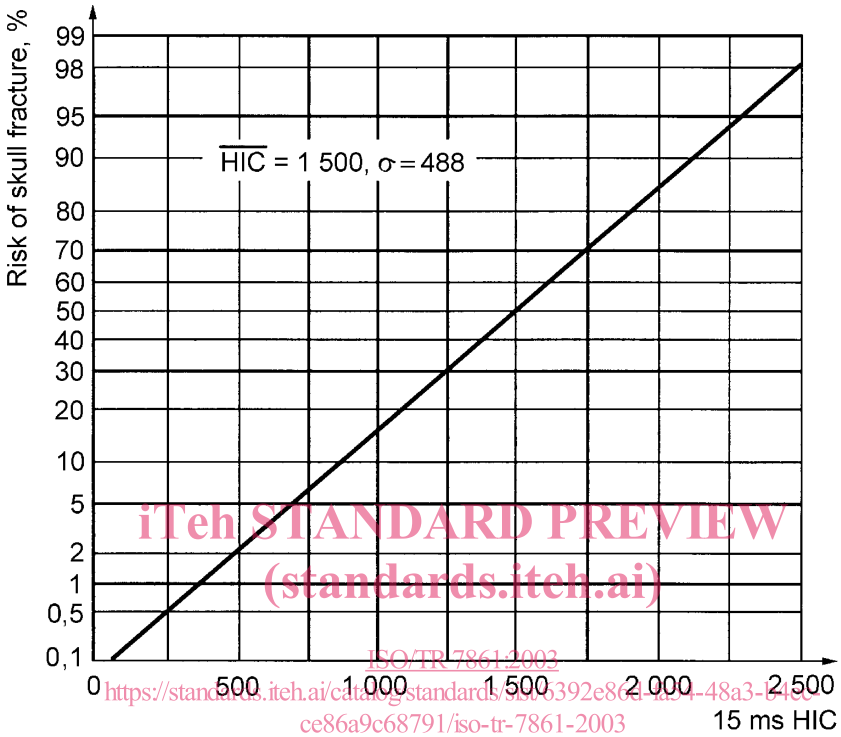

Figure A.1 — Risk of AIS ⩾ 2 skull fracture as function of max. 15 ms HIC

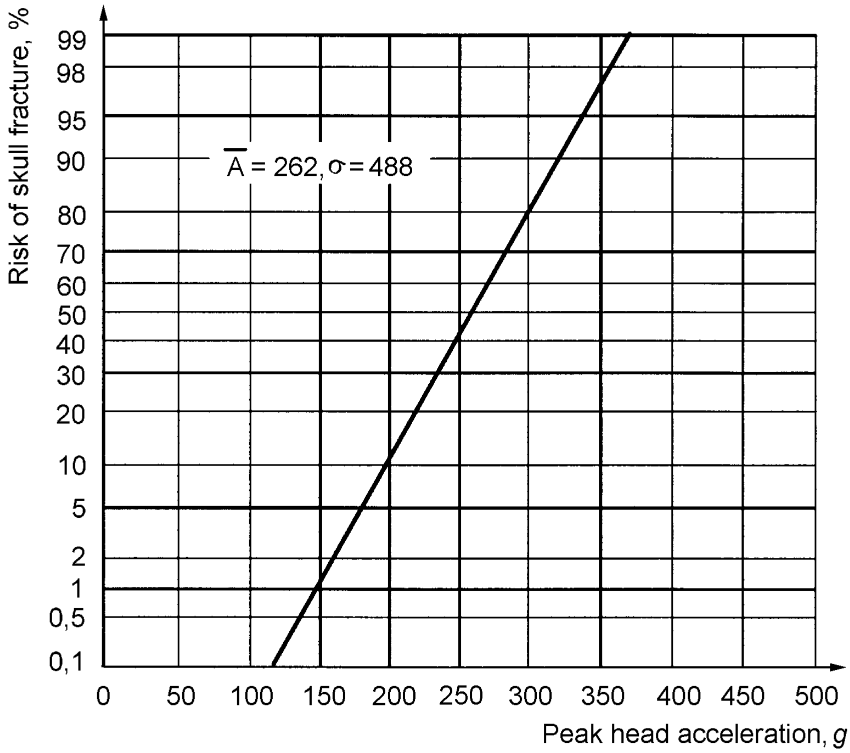

Figure A.2 — Risk of AIS ⩾ 2 skull fracture as function of the peak resultant acceleration of centre of gravity of head

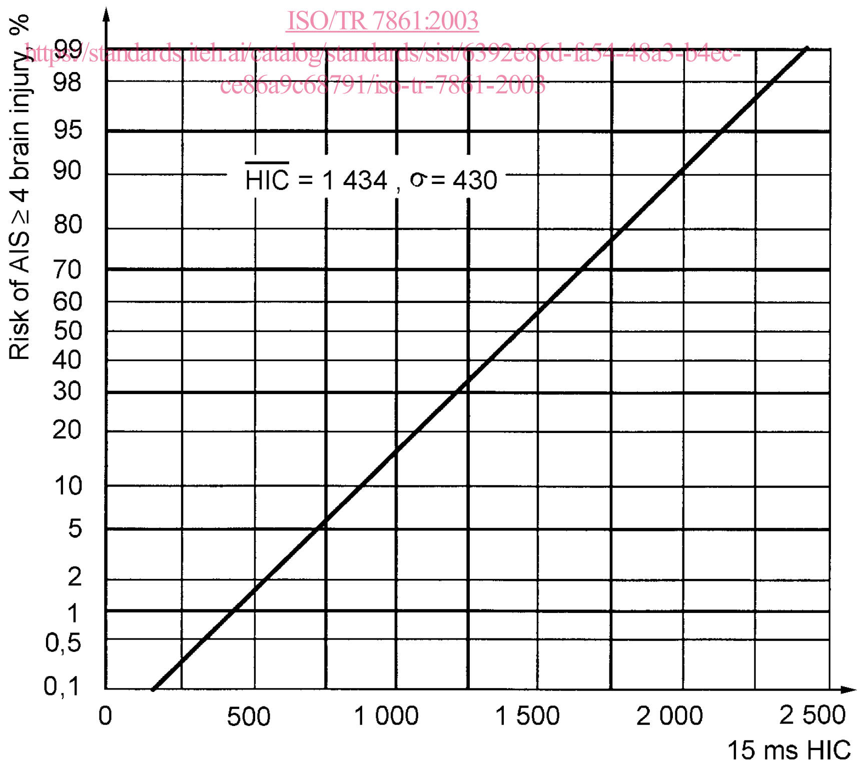

Figure A.3 — Risk of AIS ⩾ 4 brain injury as function of max. 15 ms HIC