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Road vehicles — Injury risk functions for advanced pedestrian legform impactor (aPLI)

Véhicules routiers — Critères lésionnels et courbes de risques pour l'impacteur en forme de jambe de piéton (aPLI).

PROOF/ÉPREUVE

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Foreword

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This document was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 36, *Safety and impact testing.*

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document has been prepared on the basis of the existing injury probability functions (IPFs) to be used with an advanced pedestrian legform impactor (aPLI) standard build level B (SBL-B). The purpose of this document is to document the IPFs for an aPLI in a form suitable and intended for worldwide harmonized use.

In 2014, development of the aPLI hardware and associated IPFs started, with the aim of defining a globally accepted next-generation pedestrian legform impactor with enhanced biofidelity and injury assessment capability, along with its IPFs, suitable for harmonized use. Participating in the development were research institutes, dummy and instrumentation manufacturers, governments, and car manufacturers from around the world.

IPFs for aPLI specified in this document predict injury probability to specific regions of the lower limb of a pedestrian that correspond to maximum values of injury metrics obtained by the aPLI in a subsystem test, as described in References [1] and [2]. As the IPFs do not provide any threshold values, users will need to determine target injury probability, based on their specific needs, to define injury assessment reference values to be used for their test protocol.

It is also important to note that the subsystem test procedure (STP) for pedestrian protection may not be representative of pedestrian accidents for specific injury metrics, depending on their sensitivity to pedestrian impact conditions such as lower-limb posture and muscle tone. The IPFs for aPLI have been validated against accident data and some ideas to compensate for the discrepancy against accident data are presented in Annex B.

Road vehicles — Injury risk functions for advanced pedestrian legform impactor (aPLI)

1 Scope

This document provides definitions, symbols and injury probability functions (IPFs) for the thigh, leg and knee intended to be used with an advanced pedestrian legform impactor (aPLI), a standardized pedestrian legform impactor with an upper mass for pedestrian subsystem testing of road vehicles. They are applicable to impact tests using an aPLI at 11,1 m/s involving:

— vehicles of category M1, except vehicles with a maximum mass above 2 500 kg and which are derived from N1 category vehicles and where the driver's position, the R-point, is either forward of the front axle or longitudinally rearwards of the front axle transverse centreline by a maximum of 1 100 mm;

— vehicles of category N1, except where the driver's position, the R-point, is either forward of the front axle or longitudinally rearwards of the front axle transverse centreline by maximum of 1 100 mm;

— impacts to the bumper test area defined by References [1] and [2];

— pedestrian subsystem tests involving use of a legform for the purpose of evaluating compliance with vehicle safety standards.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
adult
person who is sixteen years old or older

3.2
advanced pedestrian legform impactor
aPLI
modified pedestrian legform impactor which incorporates a mass representing the inertial effect of the upper part of a pedestrian body to enhance biofidelity and *injury assessment capability* (3.10) of conventional pedestrian legforms

3.3
biofidelity
aspect of an *advanced pedestrian legform impactor (aPLI)* (3.2) capability to represent the impact response of human subjects

3.4
BLE height
bonnet leading edge height
height of the geometric trace of the upper most points of contact between a straight edge and the front-end of a car

3.5
bumper test area
test area of the legform to bumper impact test

3.6
bumper system
component installed at the hip joint inside the upper mass composed of the bumper, the bumper mount and the compression surface, designed to apply a force on the upper part of the femur in adduction to enhance *injury assessment capability* (3.10) of an *advanced pedestrian legform impactor (aPLI)* (3.2)

3.7
EE method
energy-equivalent method
method of developing *injury probability functions (IPFs)* (3.11) for an *advanced pedestrian legform impactor (aPLI)* (3.2) by transferring human injury values to those of an aPLI using the absorbed energy

3.8
high-bumper car
car with a *lower bumper reference line height* (3.14) of 425 mm or more

3.9
hip joint
uniaxial joint that allows abduction and adduction and connects the upper mass with the lower limb

3.10
injury assessment capability
aspect of an *advanced pedestrian legform impactor (aPLI)* (3.2) capability to produce peak injury values that correlate with those obtained from human body model impact simulations

3.11
IPF
injury probability function
function which defines the relationship between a peak value of an injury metric and probability of injury for a specific load case

3.12
ISO metric
objective rating metric used in this document to verify time histories of sensor output against experimentally or computationally produced target time histories

3.13
low-bumper car
car with a *lower bumper reference line height* (3.14) less than 425 mm

3.14
LBRL height
lower bumper reference line height
height of the geometric trace of the lowermost points of contact between a straight edge and the bumper, measured from the ground

3.15
low-pass filter
filter which permits only low-frequency (100 Hz or less) oscillations

3.16
paired test method
method of developing *injury probability functions (IPFs)* (3.11) by correlating human injury occurrence in a specific impact configuration with the injury value measured by an ATD subjected to the same impact as detailed in ISO/TR 12350:2013

3.17
subsystem test
test to evaluate safety performance of cars where subsystem impactors representing individual body regions of a pedestrian are propelled into a front end of a stationary car, in impact conditions representing specific load cases in car-pedestrian accidents

3.18
transfer function
TF
linear regression function between human injury values predicted by human body models and *advanced pedestrian legform impactor (aPLI)* (3.2) injury values

3.19
TF method
transfer-function method
method of developing *injury probability functions (IPFs)* (3.11) for an *advanced pedestrian legform impactor (aPLI)* (3.2) by converting human IPFs to those of aPLI using corresponding *transfer functions* (3.18)

4 Symbols and abbreviated terms

4.1 Symbols

See Table 1.

Table 1 — Symbols and their meanings

Symbol	Meaning
C_{Scale}	Parameter determined for the Weibull distribution for human IPFs
C_{Shape}	Parameter determined for the Weibull distribution for human IPFs
C_{Slope}	Slope of the transfer function
C_{μ}	Parameter determined for the Log-Normal distribution for human IPFs
C_{σ}	Parameter determined for the Log-Normal distribution for human IPFs
C_{TA1}	Correction factor determined to adjust to the real-world accident data
C_{TA2}	Correction factor determined to adjust to the real-world accident data
F	IPF for human
G	Transfer function
I_{human}	Injury metric for human
I_{aPLI}	Injury metric for an aPLI
P	Injury probability of human
P_{adj}	Adjusted injury probability for the MCL
x_{aPLI}	Value of the injury metric for an aPLI
x_{human}	Value of the injury metric for human

4.2 Abbreviated terms

See Table 2.

Table 2 — Abbreviated terms and their meanings

Abbreviation	Meaning
ACL	Anterior Cruciate Ligament
aPLI	advanced Pedestrian Legform Impactor
ATD	Anthropometric Test Device
BLE	Bonnet Leading Edge
BM	Bending Moment
EE	Energy Equivalent
EEVC	European Enhanced Vehicle-safety Committee
FE	Finite Element
HBM	Human Body Model
IPF	Injury Probability Function
LBRL	Lower Bumper Reference Line
MCL	Medial Collateral Ligament
PCL	Posterior Cruciate Ligament
PMHS	Post Mortem Human Subjects
RCM	Real Car Model
SCM	Simplified Car Model
STP	Subsystem Test Procedure
TF	Transfer Function
TG	Task Group

5 IPFs for an aPLI

5.1 General

The IPFs specified in this document are to be used with the aPLI for the thigh, leg and knee to predict the probability of injuries to pedestrians when involved in real-world car-pedestrian accidents. The IPFs provide a statistically derived relationship between the maximum values of injury metrics obtained from a test conducted using an aPLI by following the subsystem test procedure (STP), and the probability of injury to a corresponding body region of a pedestrian when subjected to load cases representative of the majority of real-world accidents.

The specific load case represented by the subsystem legform test is described below:

— pedestrian size and weight: 175,1 cm and 76,7 kg representing a 50th percentile adult male (Reference [3]);

— impact speed: 11,1 m/s;

— impact direction: lateral-to-medial direction to a pedestrian lower limb;

— lower-limb posture: upright (vertical to the ground) with the knee fully extended;

— impact height: sole of the foot positioned 25 mm above the ground to represent a shoe sole height.

First, human IPFs were determined using human biomechanical data available from the literature. Data obtained by the experiments conducted under the loading conditions equivalent to those specified in the STP were referred to. The statistical method used to derive human IPFs follows that recommended by ISO/TS 18506 with the covariates of pedestrian size, weight and age. The pedestrian size and weight were determined from those specified in STP. The age was set at 60 years old that corresponds to the average age of the subjects of the biomechanical data as this choice was found to provide the most reasonable set of assumptions when the IPFs were fitted to the accident data. The recommended method estimates parameters of any one of the Weibull, Log-Normal or Log-Logistic distribution (choose the one that best fits to data) with survival analysis method. In this document, one of the three distributions (Weibull distribution, Log-Normal distribution or Log-Logistic distribution) is used to define human IPFs for each of the injury metrics. The formulae of the aPLI IPFs for these distributions are presented below.

The injury probability when the Weibull distribution is applied following Formula (1):

$$P = 1 - \exp\left\{ -\left(\frac{C_{\mathrm{Slope}} \times x_{\mathrm{aPLI}}}{C_{\mathrm{Scale}}} \right)^{C_{\mathrm{Shape}}} \right\} \tag{1}$$

where

P	is the injury probability of human;
C_{Scale}	is the parameter determined for the Weibull distribution for human IPFs;
C_{Shape}	is the parameter determined for the Weibull distribution for human IPFs;
C_{Slope}	is the slope of the transfer function (TF);
x_{aPLI}	is the value of the injury metric for aPLI.

The injury probability when the Log-Normal distribution is applied following Formula (2):

$$P = \frac{1}{C_{\sigma}\sqrt{2\pi}} \int_0^{C_{\mathrm{Slope}} \times x_{\mathrm{aPLI}}} \frac{1}{t} \exp\left\{ \frac{-\left(\ln t - C_{\mu}\right)^2}{2{C_{\sigma}}^2} \right\} \mathrm{d}t \tag{2}$$

where

P	is the injury probability of human;
C_{μ}	is the parameter determined for the Log-Normal distribution for human IPFs;
C_{σ}	is the parameter determined for the Log-Normal distribution for human IPFs;
C_{Slope}	is the slope of the TF;
x_{aPLI}	is the value of the injury metric for the aPLI.

The injury probability when the Log-Logistic distribution is applied following Formula (3):

$$P = \frac{1}{1 + \left(\frac{C_{\mathrm{Slope}} \times x_{\mathrm{aPLI}}}{\exp\left(C_{\mathrm{Scale}}\right)} \right)^{\frac{-1}{C_{\mathrm{Shape}}}}} \tag{3}$$

where

P	is the injury probability of human;
C_{Scale}	is the parameter determined for the Log-Logistic distribution for human IPFs;
C_{Shape}	is the parameter determined for the Log-Logistic distribution for human IPFs;

C_{Slope} is the slope of the TF;

x_{aPLI} is the value of the injury metric for the aPLI.

For each of the thigh, leg and knee, IPFs for a human body are then transferred to those of the aPLI using a TF, which is a linear function between the maximum values of a human and aPLI injury metrics. Due to the lack of biomechanical data, the TFs were determined from the results of computational impact simulations using FE human body models (HBMs) and aPLI FE models in loading conditions specified in the STP. Details of the human IPFs from which IPFs for the aPLI are derived can be found in A.2.3. For the determination of TFs, see A.2.4 for more details.

As the IPFs converted from human IPFs using TFs are for the specific load case defined in the STP, the number of injuries calculated from each of the injury probabilities predicted by the IPFs were compared with that of real-world accidents. The IPFs for the knee and the leg were compensated for the real-world observations for the injury metrics showing a significant inconsistency with accident data. Details of the compensation to real-world accidents can be found in Annex B.

Supplemental information related to the TFs and IPFs for human is provided in Annex C and Annex D, respectively.

5.2 Thigh

The IPF for the thigh defines probability of femur shaft fracture to a pedestrian subjected to the load cases representative of the majority of real-world accidents as a function of maximum value of the femur bending moment measured by the aPLI.

Figure 1 presents the IPF for the thigh. The injury probability function is shown in a solid line, with the 95 % confidence interval shown in dotted lines. The horizontal axis represents the maximum value of the femur bending moment measured by the aPLI, and the vertical axis represents the probability of injury.

The IPF for the thigh is given by Formula (4):

$$P = 1 - \exp\left\{ -\left(\frac{C_{Slope} \times x_{aPLI}}{C_{Scale}} \right)^{C_{Shape}} \right\} \quad (4)$$

where

P is the injury probability for the femur shaft of human;

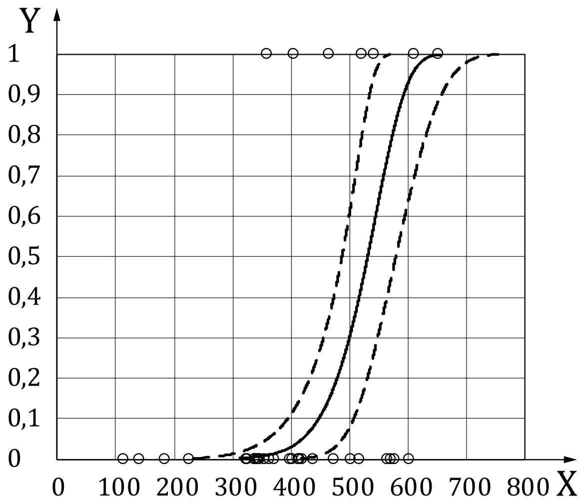
C_{Scale} is the parameter determined for the Weibull distribution for the human IPF for the femur shaft as described in A.2.3.4.1;

C_{Shape} is the parameter determined for the Weibull distribution for the human IPF for the femur shaft as described in A.2.3.4.1;

C_{Slope} is the slope of the TF for the thigh as described in A.2.4.4.1;

x_{aPLI} is the femur BM measured by the aPLI in Nm.

The parameters needed to define the IPF (C_{Scale}, C_{Shape} and C_{Slope}) for the function are described in Table 3.



Key

X	aPLI femur BM [Nm]
Y	probability of femur shaft fracture
———	aPLI IPF for femur shaft
– – –	95 % confidence interval
○	observed data

Figure 1 — IPF for the femur shaft

Table 3 — Parameters of IPF for the femur shaft

C_{Scale}	C_{Shape}	C_{Slope}
571	11,0	1,04

5.3 Leg

The IPF for the leg defines probability of tibia shaft fracture to a pedestrian subjected to the specific load cases representative of the majority of real-world accidents as a function of maximum value of the tibia bending moment measured by the aPLI.

Figure 2 presents the IPF for the leg. The injury probability function is shown in a solid line, with the 95 % confidence interval shown in dotted lines. The horizontal axis represents the maximum value of the tibia bending moment measured by the aPLI, and the vertical axis represents the probability of injury.

The IPF for the leg is given by the Formula (5):

$$\boldsymbol{P} = \mathbf{1} - \mathbf{exp}\left\{ -\left(\frac{\boldsymbol{C}_{\mathbf{Slope}} \times \boldsymbol{x}_{\mathbf{aPLI}}}{\boldsymbol{C}_{\mathbf{Scale}}} \right)^{\boldsymbol{C}_{\mathbf{Shape}}} \right\} \tag{5}$$

where

P is the injury probability for the tibia shaft of human;

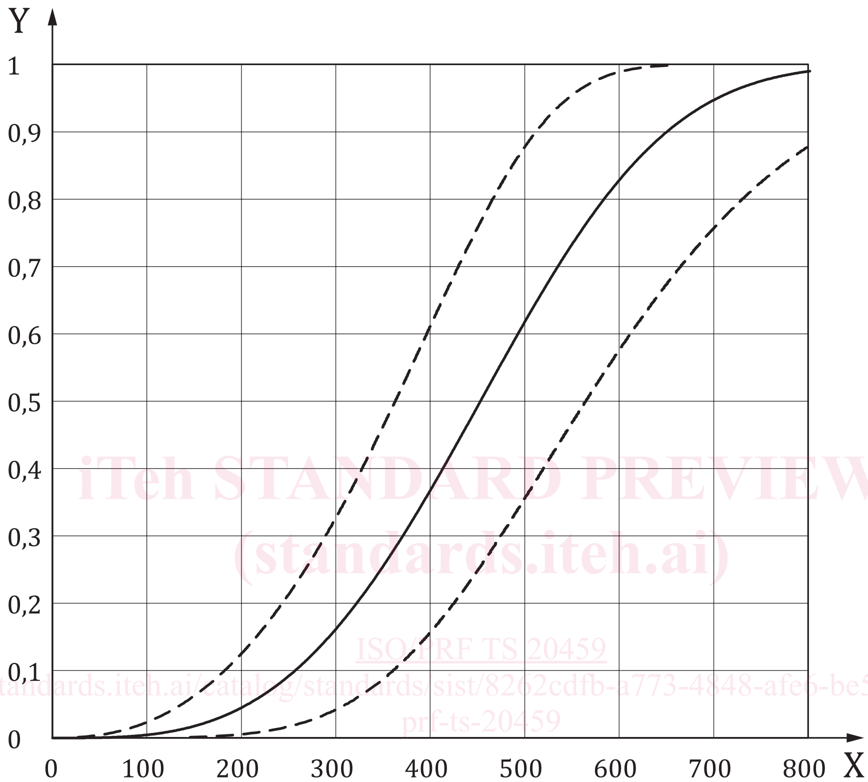
C_{Scale} is the parameter determined for the Weibull distribution for the human IPF for the tibia shaft as described in B.3.3;

C_{Shape} is the parameter determined for the Weibull distribution for the human IPF for the tibia shaft as described in B.3.3;

C_{Slope} is the slope of the TF for the leg as described in A.2.4.4.2;

x_{aPLI} is the tibia BM measured by the aPLI in Nm.

The parameters needed to define the IPF (C_{Scale}, C_{Shape} and C_{Slope}) for the function are described in Table 4.



Key

X aPLI tibia BM [Nm]

Y probability of tibia shaft fracture

——— aPLI IPF for tibia shaft

– – – 95 % confidence interval

Figure 2 — IPF for the tibia shaft

Table 4 — Parameters of IPF for the tibia shaft

C_{Scale}	C_{Shape}	C_{Slope}
446	3,32	0,881

5.4 Knee

The IPF for the knee defines probability of complete failure of the MCL to a pedestrian subjected to the specific load cases representative of the majority of real-world accidents as a function of maximum value of MCL elongation measured by the aPLI.

Figure 3 presents the IPF for the knee. The injury probability function is shown in a solid line, with the 95 % confidence interval shown in dotted lines. The horizontal axis represents the maximum value of the MCL elongation measured by the aPLI, and the vertical axis represents the probability of injury.

The IPF for the knee is given by Formula (6):

$$\boldsymbol{P} = \frac{1}{C_\sigma \sqrt{2\pi}} \int_0^{C_{\text{Slope}} \times x_{\text{aPLI}} \times C_{\text{TA1}} \times C_{\text{TA2}}} \frac{1}{t} \exp\left\{ \frac{-\left(\ln t - C_\mu\right)^2}{2{C_\sigma}^2} \right\} \mathrm{d}t \tag{6}$$

where

P	is the injury probability for the MCL of human;
C_μ	is the parameter determined for the Log-Normal distribution for human IPFs for the MCL as described in A.2.3.4.3;
C_σ	is the parameter determined for the Log-Normal distribution for human IPFs for the MCL as described in A.2.3.4.3;
C_{Slope}	is the slope of the TF for the knee as described in A.2.4.4.3;
C_{TA1}	is the correction factor for lower-limb posture and impact angle determined to adjust to the real-world accident data as described in B.3.2.2.4;
C_{TA2}	is the correction factor for muscle tone determined to adjust to the real-world accident data as described in B.3.2.3;
x_{aPLI}	is the MCL elongation measured by the aPLI in mm.

The parameters needed to define the IPF (C_μ, C_σ, C_{Slope}, C_{TA1} and C_{TA2}) for the function are described in Table 5.