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Road vehicles — Injury risk curves for the evaluation of occupant protection in side impact tests

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National foreword

This Published Document is the UK implementation of ISO/TR 12350:2013. It supersedes PD ISO/TR 12350:2004 which is withdrawn.

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Road vehicles — Injury risk curves for the evaluation of occupant protection in side impact tests

Véhicules routiers — Courbes de risques de blessures pour l'évaluation de la protection des occupants en choc latéral

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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The committee responsible for this document is ISO/TC 22, *Road vehicles*, Subcommittee SC 12, *Passive safety crash protection systems.*

This second edition cancels and replaces the first edition (ISO/TR 12350:2004), which has been technically revised.

Road vehicles — Injury risk curves for the evaluation of occupant protection in side impact tests

1 Scope

This Technical Report provides injury risk curves to assess occupant protection in side impact tests. The curves are given for the WorldSID 50th, a mid-size adult male side impact dummy. Injury risk curves for other side impact dummies could be added as soon as the necessary material is available and processed as described in this Technical Report. These dummies are used during tests carried out according to ISO 10997 or which are under investigation by regulatory bodies and consumer testing organizations.

2 Methodology

2.1 Selection of PMHS sample to be used for the construction of the injury risk curves

An in-depth review of the postmortem human subjects (PMHS) tests available in the literature and in the NHTSA database (http://www-nrd.nhtsa.dot.gov/database/aspx/biodb/querytesttable.aspx) was performed. The listed tests were analysed in order to determine if they could be accurately repeated with dummies and included in the construction of injury risk curves.

This clause summarizes the series of tests that were conducted by body region and type of loading. Reasons for including or excluding each particular test series are detailed. The PMHS characteristics are provided in the form of related electronic documents available through the ISO website and detailed in Clause 4. The detailed descriptions of the PMHS configurations allowing the reproduction of the test with a dummy are presented in Annex A to Annex F, as well as the reasons for inclusion or exclusion.

The rigid and padded head impactor tests conducted by Calspan[18] were included and are detailed in Annex A. The head impactor tests of the Highway Safety Research Institute (HSRI)[51] were excluded because the impact speeds were not known. The head impactor tests of the University of Michigan Transportation Research Institute (UMTRI) (NHTSA database) were excluded because the impactor characteristics were not known.

The whole body drop tests with head impact conducted by Wayne State University (WSU)[22], those conducted by the Association Peugeot-Renault (APR) without helmet, and the head drop tests conducted by Medical College of Wisconsin (MCW)[56] were included and are detailed in Annex A. The whole body drop tests with head impact conducted by APR with helmet were excluded because the helmet properties were unknown.

The shoulder impactor tests performed by APR[2], INRETS[14] [15] [17], and WSU[26] [30] were included. The shoulder impactor tests conducted by Ohio State University (OSU) on a rigid bench were also included[3] [4]. These configurations are detailed in Annex B. The oblique shoulder impactor tests performed by OSU on a 1996 Ford Taurus seat were excluded because the characteristics of the seat were unknown.

All, but one, of the thorax impactor tests conducted by HSRI[43] [44] [45] were included. The single-impact WSU thorax impactor test[54] [55] was also included. The UMTRI[34] [35] and OSU[49] thorax impactor tests were included when the level of load was deemed to be below the threshold of rib fracture (700 N), such that the fractures could be attributed to the final high-speed impact. These test configurations are detailed in Annex C. The 76T038 HSRI test was excluded because the data were questionable. The HSRI tests 77T079 and 77T080 were excluded because it does not seem realistic to have 18 rib fractures for 2 165 N of impact force. All the WSU and INRETS[16] multi-impact tests, as well as some UMTRI tests (83E085, 83E086, 83E106, 83E107, 83E108) and OSU tests (0505OTH25L01, 0505LTH25R01, 0506OTH25R01, 0506LTH25L01, 0601LTH25L01, 0601OTH25R01), were excluded because it was not possible to determine which impact caused each injury.

Only one of the abdomen impactor tests performed by WSU[54] [55] (WSU063-34) was included because all the other subjects were impacted more than once in the abdomen and/or thorax. All the OSU abdomen impactor tests but two (93VRTAB08, 93VRTAB09) were included. These two tests were excluded because the abdomen deflection exceeded the target level of 16 % of the chest breadth. The test configurations are detailed in Annex D.

The Laboratory of Accidentology and Biomechanics (LAB) abdomen impactor tests[52] were excluded because a measurement system was positioned at the level of the liver and could have influenced the abdominal injuries.

Most of the reviewed pelvis impactor tests were multi-impact tests. The pelvis impactor tests performed by WSU[54] [55], UMTRI[33] [36], ONSER[11] [12], and INRETS[5] [6] were included when an increase in impactor speed was accompanied by an increase in energy for a given PMHS, as this was assumed to be an indication of no injury. The configurations are detailed in Annex E. Two UMTRI tests (83E087, 83E109) were conducted with an APR pad that is no longer available. The ONSER multi-impact tests C3, C4, D3, E2, F2, F3, H4, H5, I6, J2, J3, N7, S3, S4, X1, X2, Y2, Z1, and Z2 were excluded because there was a possible weakening of the pelvis bone.

APR conducted lateral drop tests with PMHS[2] [53]. A review of the films failed to confirm the position of the subjects' lower extremities and whether or not an impact surface was provided to catch the lower extremities. The test films revealed that some tests were conducted with the subjects' head, some were conducted without the head, and for the others, the film coverage did not reveal if the head was attached or removed. Some subjects were observed to rotate during the free fall. For these reasons, and because the APR padding cannot be reproduced, all of the whole body drop tests were excluded from the construction of injury risk curves for the thorax, abdomen, and pelvis.

Some sled tests performed by Heidelberg[25] [29], MCW/OSU[39] [40] [28] [27], and WSU[7] [8] [9] [10] [23] were included and are detailed in Annex F. Several checks were done to select the PMHS to be included in the construction of the injury risk curves. The checks are detailed in Annex G.

— The position of the PMHS at the time of impact was first checked. The Heidelberg tests (H82014, H82018, H82019, H82015) and MCW/OSU tests (SC126, SC105, SC131) were then excluded.

— The consistency between the thorax-pelvis transmissibility and the contact times of the thorax and pelvis plates were also checked. The Heidelberg tests (H82014, H82018, H82019, H82015) and MCW/OSU (SC126, SC105) were then excluded.

— The total momentum was checked. Tests for which the total momentum differed from other tests with the same impact wall configuration were excluded (MCW/OSU SC131).

— The absence of shoulder interaction with the wall was checked in the MCW/OSU configuration. Sled tests with PMHS seating height under 826 mm and shoulder interaction with the wall observed on the film were excluded from the shoulder, thorax, and abdomen injury risk curves (MCW/OSU SC137, SC138, SC119, 94LSI32P04, LSI32R08, SC30A102).

— PMHS characteristics were checked. The PMHS having sternotomy wires were excluded because the PMHS response and injuries were questionable (MCW/OSU SC122, SC132, LSI32P11, SC103, SC112, SC30A103, SC20A101).

— PMHS injuries were checked. PMHS from the MCW/OSU SC114 test with a right hemithorax, which could have resulted from secondary impact, was excluded.

— Some of the checks required the analysis of the wall plates loads. Some tests were excluded because the impact wall was not instrumented with load cells or because the data were questionable and then the checks could not be done. This was the case for the HSRI sled tests[31], the first test series conducted by WSU (NHTSA database), some Heidelberg tests (H82009, H80011, H80013, H80014, H80017, H80024, H81002, H81004, H81006, H81016, H81022, H81025, H81027, H82002, H82020, H80018, H80020, H80021, H80023, H81011, H81012, H81015, H81021, H83008, H83016, H83021, H83030, H83031), as well as some MCW/OSU sled tests (98LSI32R17, SC106, SC127, 96LSI32R07, SC123).

— Finally, sled tests for which the impact wall padding or the airbag was no longer available were excluded (Heidelberg tests H82008, H82021, H82022, H83008, H83016, H83021, H83030, H83031, H83011, H83020, H84008, H83010, H83012, HSRI tests 76T029, 76T034, 76T039, 76T042, MCW/OSU tests SAC 101, SAC 103, SAC 104, SAC 105, WSU 2nd test series SIC-09, SIC-10, SIC-11, SIC-12, SIC-13, SIC-14, SIC-15, SIC-16, SIC-17).

— The severity of PMHS injuries were coded according to the Abbreviated Injury Scale 2005[1]. Table 1 summarizes the body regions and injury severity levels for which PMHS data are available to construct injury risk curves. There were no AIS ≥ 3 shoulder injuries from the PMHS tests. Therefore, injury risk curves for the shoulder can only be constructed for the AIS ≥ 2 level of injury. For the thorax, abdomen, and pelvis, injury risk curves were constructed at the AIS ≥ 3 injury level and either the AIS ≥ 2 or AIS ≥ 4 level if the PMHS injury/no injury results were better balanced at these AIS levels. Note that all rib fractures are coded in thoracic skeletal AIS, including those that resulted from abdominal impacts.

Table 1 — Body regions and AIS levels for which injury risk curves are constructed

Body region	AIS levels used in the injury risk curve construction
Head	AIS ≥ 3
Shoulder	AIS ≥ 2
Thorax (skeletal)	AIS ≥ 3 and AIS ≥ 4
Thorax (soft tissue)	AIS ≥ 2 and AIS ≥ 3
Abdomen	AIS ≥ 2 and AIS ≥ 3
Pelvis	AIS ≥ 2 and AIS ≥ 3

2.2 Dummy data

Once the PMHS sample to build the injury risk curves is selected, the dummy results reproducing these PMHS test configurations are collected.

The injury risk curves are proposed in this Technical Report for a 50th percentile male dummy. Only WorldSID 50th percentile results are presented in the current version of this Technical Report. It is intended to add injury risk curves for the WorldSID 5th percentile adult female dummy to a future edition of the ISO/TR 12350. There are no plans to add injury risk curves for the ES-2 or ES-2re, and it is not appropriate to use the WorldSID injury risk curves with measures from either ES-2 or ES-2re.

The dummy test results reproducing the PMHS test configurations selected for the injury risk curve construction are presented in Annex H. The build level of the production version used was not provided with the results. It is to be noted that there was no head result available. Moreover, the shoulder deflection was only available for the impactor test and not for the sled test configurations.

The test results presented in Annex H are filtered data (according to Reference[50] and according to filters indicated in Annex H) that have not been scaled and should not be used directly to construct dummy-specific injury risk curves.

The PMHS used in the biomechanical tests described in Annex A to Annex F were generally not mid-size adult males. Ideally, the test condition for the dummy tests should be scaled such that the test poses an equally severe impact as the individual PMHS test. However, many of the dummy tests used in this Technical Report were conducted at the same velocity and the same impactor mass as the PMHS tests. It is therefore necessary to scale the results of the dummy tests before they are paired with the PMHS injuries. The dummy data from impactor tests, drop tests, and sled tests were scaled using the formulae included in Annex I. The scaled dummy data are included in Annex A to Annex F.

2.3 Age adjustment

The injury risk curves are provided with age adjustment. It is out of the scope of this Technical Report to recommend an age to be used. The injury risk curves can be built for any age using the formulae included in Table 5. However, the quality index cannot be computed from these formulae. As it was not possible to include the quality index for all ages, only two ages were considered. As indicated in Petitjean et al. (2009), the injury risk curves were constructed for a dummy representing a 45-year-old male, as this age has been used previously to represent the average age of an adult male in the field data. The injury risk curves were also constructed for median age of the PMHS included in the samples available for the construction of the WorldSID 50th injury risk curves (67 years old). This latest age was used because it provides the values with the higher confidence because the PMHS data are mostly around that age.

2.4 Statistical analysis

Guidelines for the construction of the injury risk curves were agreed on within ISO/TC 22/SC 12 (Resolution 2, N851).

The guidelines include several steps.

2.4.1 Step 1: Collect the relevant data

The first step is to collect the relevant data, including injuries and injury criterion.

According to the methodology developed in this Technical Report, relevant data corresponded to the paired PMHS injuries and scaled dummy measurements from tests performed in similar configurations.

2.4.2 Step 2: Assign the censoring status (left, right, interval censored, exact)

Once the biomechanical data were available, the censoring status was assigned (left, right, interval censored, exact). After this step, the dataset included one column with the injury criteria values associated with the censoring status indicated in a second column.

2.4.3 Step 3: Build the injury risk curve with the Consistent Threshold Estimate (CTE)[37] and check for dual injury mechanism

The step function was visually investigated in order to detect potential change in slope corresponding to different injury mechanisms.

2.4.4 Step 4:

— If there was an evidence of dual injury mechanism, the sample was separated into samples with single injury mechanism and Step 1 was performed.

— If there was no evidence of dual injury mechanism, the injury risk curve was built with the survival analysis according to the following steps.

2.4.5 Step 5: Estimate the parameters of the Weibull, log-normal, and log-logistic distributions with the survival analysis method

2.4.6 Step 6: Identify overly influential observations using the dfbetas statistics

The overly influential observations were identified using the dfbetas statistics.

2.4.7 Step 7: Check the distribution assumption graphically using a qq-plot or the CTE method

2.4.8 Step 8: Choose the distribution with the best fit, based on the Akaike information criterion (AIC)

The distribution with the lowest AIC among the three distributions was selected.

2.4.9 Step 9: Check the validity of the predictions against existing results (such as accidentology outcome), if available

2.4.10 Step 10:

— Step 10.1: The 95 % confidence intervals of the injury risk curve were calculated with the normal approximation of the error.

— Step 10.2: The relative sample size of the confidence interval was defined as the width of the 95 % confidence interval at a given risk relative to the value of the stimulus at this same risk. They were calculated at 5 %, 25 %, and 50 % risk.

2.4.11 Step 11: Provide the injury risk curve associated with the quality index based on the relative sample size of the 95 % confidence interval

A scale of quality indexes based on the relative sample size was defined with four categories (“good” from 0 to 0,5, “fair” from 0,5 to 1, “marginal” from 1 to 1,5, “unacceptable” over 1,5). The injury risk curves associated with the quality indexes were provided. The scale was determined using biomechanical samples in order to distribute injury risk curves in the four categories. Illustrations for one example of each class of quality index are provided in Table 2.

Table 2 — Illustrations of the width of the 95 % confidence interval for an injury risk curve for each of the quality indexes

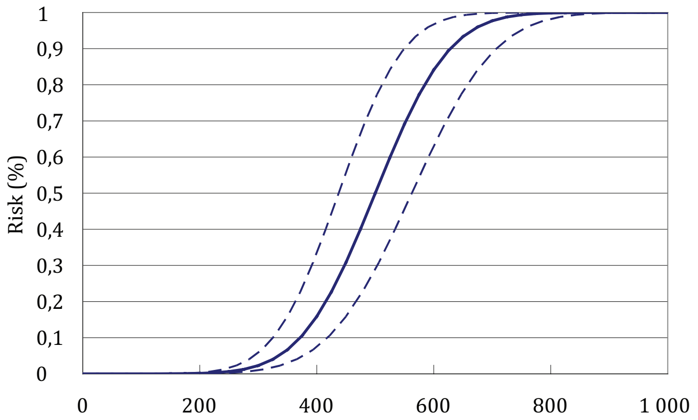
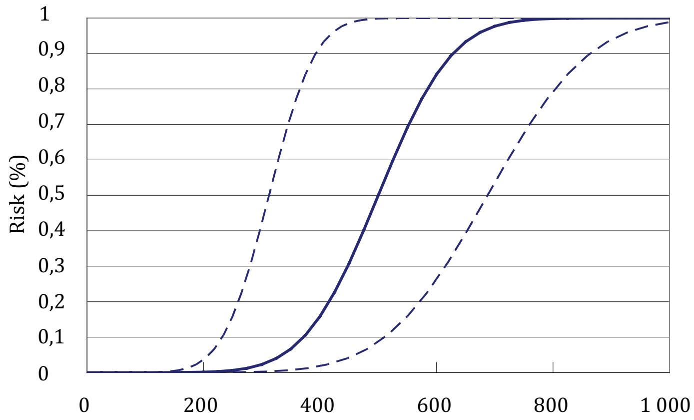
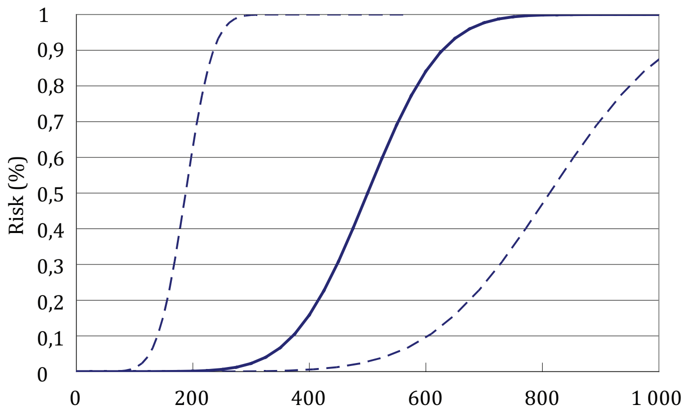
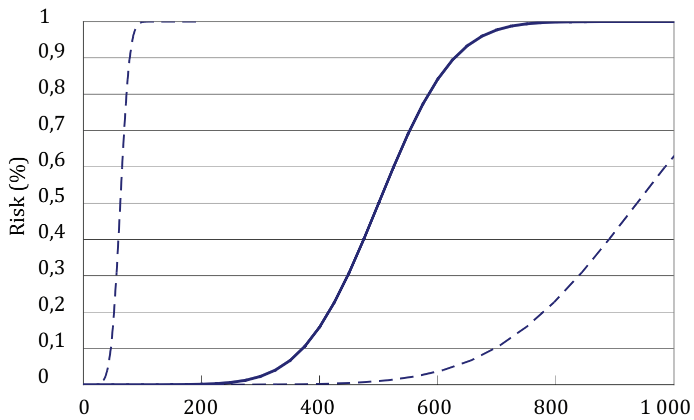
Quality index	Width of the confidence interval at that particular risk divided by the criterion value at that risk	Example (solid line: injury risk curve, dotted line: 95 % confidence intervals)
Good	0-0,5	 width of the confidence interval at that particular risk divided by the criterion value at that risk = 0,25

Table 2 *(continued)*

<table>
<tr><th>Quality index</th><th>Width of the confidence interval at that particular risk divided by the criterion value at that risk</th><th>Example (solid line: injury risk curve, dotted line: 95 % confidence intervals)</th></tr>
<tr><td>Fair</td><td>0,5-1</td><td>

width of the confidence interval at that particular risk divided by the criterion value at that risk = 0,75</td></tr>
<tr><td>Marginal</td><td>1-1,5</td><td>

width of the confidence interval at that particular risk divided by the criterion value at that risk = 1,25</td></tr>
<tr><td>Unacceptable</td><td>>1,5</td><td>

width of the confidence interval at that particular risk divided by the criterion value at that risk = 1,75</td></tr>
</table>

2.4.12 Step 12: Recommend one curve per body region, injury type, and injury level

— Step 12.1: If several injury risk curves could be compared with the AIC and if the difference of the AIC was greater than 2, then the curve with the lowest AIC was recommended over the others.

— Step 12.2: If an injury risk curve had an “unacceptable” quality index, it should not be recommended.

— Step 12.3: If several injury risk curves were still available for a given injury type and level, engineering judgment was used to recommend one curve over another.

The recommended injury thresholds should be provided with their associated quality indexes.

3 Injury risk curves for the WorldSID 50th

The injury risk curves were constructed by correlating the dummy responses to the PMHS injuries in the same test configurations.

The injury risk curves were built with the following steps:

Step 1: Paired PMHS injuries and dummy measurements were collected, after having selected the PMHS sample and checking the dummy data.

Step 2: The censoring status was assigned to each pair depending on if it was left, right, interval censored, or exact. The WorldSID 50th injury risk curves were computed with the R software[42]. With the R software, the right, exact, left, and interval censored data are coded 0, 1, 2, and 3 respectively.

Step 3: The injury risk curve should be built with the Consistent Threshold Estimate (CTE)[37] in order to check for dual injury mechanism.

Step 4:

— If there was an evidence of dual injury mechanism, the sample was separated into samples with single injury mechanism and Step 1 was performed.

— If there was no evidence of dual injury mechanism, the injury risk curve was built with the survival analysis according to the following steps.

However, the injury risk curves here included the age as a covariable so it would be necessary to separate the sample into different classes of age before building the CTE injury risk curves. The resulting sub-sample was too small to build reliable injury risk curves so dual injury mechanisms were not checked for the WorldSID 50th.

Step 5: The parameters of the Weibull, log-normal, and log-logistic distributions with the survival analysis method were estimated (see Table J.1).

Step 6: The overly influential observations were identified with the dfbetas test (see Table J.2 to Table J.7). These observations were checked for any specificity. As there was no evidence of difference between these observations and the others included in the sample, these observations were kept in the construction of the injury risk curve.

Step 7: The distribution assumption should be checked graphically using a qq-plot or the CTE method. However, the injury risk curves here included the age as a covariable so it would be necessary to separate the sample into age classes before building the CTE injury risk curves. The resulting sub-sample was too small to build reliable injury risk curves so distribution assumption was not checked in this Technical Report.

Step 8: The distribution with the best fit, based on the Akaike information criterion (AIC), was chosen (see Table J.1 and Table 3).

Step 9: Check the validity of the predictions against existing results (such as accidentology), if available. In the case of the WorldSID 50th, there was no prediction to be validated.

Step 10: The 95 % confidence intervals were calculated, as well as the relative sample size of the confidence interval (width of the confidence intervals at 5 %, 25 %, and 50 % relative to the value of the stimulus at 5 %, 25 %, and 50 % of risk, respectively) (see Table J.8).

Step 11: The injury risk curves were provided with their associated quality indexes based on the relative sample size of the confidence interval (see Table 4).

Step 12: Recommend one curve per body region, injury type, and injury level.

— Step 12.1: If several injury risk curves could be compared with the AIC and if the difference of the AIC was greater than 2, then the curve with the lowest AIC was recommended over the others.

The samples that could be compared were those with the same PMHS sample and the same level and type of injury. The AIC were then compared between:

— the skeletal risk AIS3+ as a function of the maximum thoracic rib deflection and viscous criterion;

— the skeletal risk AIS4+ as a function of the maximum thoracic rib deflection and viscous criterion;

— the abdomen risk AIS2+ as a function of the maximum abdomen rib deflection and viscous criterion, as well as of the lower spine Y acceleration 3 ms;

— the abdomen risk AIS3+ as a function of the maximum abdomen rib deflection and viscous criterion.

There was no comparison possible for the shoulder and pelvis injury risk curves.

Table 3 — AIC values for the WorldSID 50th injury risk curves

Injury risk	WorldSID measurement	AIC
Skeletal thoracic AIS3+	Maximum thoracic rib deflection (measured by 1D IR-TRACC) (mm)	24,883 7
	Maximum thoracic rib VC (measured by 1D IR-TRACC) (m/s)	29,691 1
Skeletal thoracic AIS4+	Maximum thoracic rib deflection (measured by 1D IR-TRACC) (mm)	29,735 4
	Maximum thoracic rib VC (measured by 1D IR-TRACC) (m/s)	30,650 7
Abdomen AIS2+	Maximum abdomen rib deflection (measured by 1D IR TRACC) (mm)	14,988 9
	Maximum abdomen rib VC (measured by 1D IR-TRACC)(m/s)	14,977 7
	Lower spine Y acceleration 3 ms (m/s^2)	27,576 8
Abdomen AIS3+	Maximum abdomen rib deflection (measured by 1D IR-TRACC) (mm)	11,959 1
	Maximum abdomen rib VC (measured by 1D IR-TRACC) (m/s)	11,869 6

Based on the comparison of the AIC values (see Table 3), the skeletal thoracic risks AIS3+ and AIS4+ were recommended to be predicted as a function of the maximum thoracic rib deflection rather than as a function of the maximum thoracic rib vital capacity (VC). The abdomen risks AIS2+ and AIS3+ were recommended to be predicted as a function of the maximum abdomen rib deflection or VC rather than as a function of the lower spine Y acceleration 3 ms.

— Step 12.2: If an injury risk curve had an "unacceptable" quality index, it should not be recommended.

There was no "unacceptable" quality index for the shoulder, abdomen, and pelvis injury risk curves AIS2+ (see Table J.8). For the skeletal thoracic risk as a function of the maximum thoracic deflection, the 50 % AIS4+ risk for a 45-year-old occupant was "unacceptable". All the thoracic soft tissue injury risk curves were "unacceptable" at 5 % risk. All the abdomen injury risk curves AIS3+ were "unacceptable". This was probably due to the very limited number (only one) of AIS3+ cases. Among the pelvis injury risk curves AIS3+, the curve as a function of the pelvis Y acceleration 3 ms for a 45-year-old occupant was "unacceptable".

— Step 12.3: If several injury risk curves were still available for a given injury type and level, engineering judgment was used to recommend one curve over another.

The shoulder injury risk AIS2+ could still be predicted by the maximum shoulder rib deflection or by the maximum shoulder **Y** force. The available sample for the construction of the injury risk curve as a function of the maximum shoulder deflection was composed of impactor tests only. On the other side, the available sample for the construction of the injury risk curve as a function of the maximum shoulder **Y** force was composed of impactor tests, as well as sled tests. The injury risk curve as a function of the maximum shoulder **Y** force was recommended because the sample was composed of impactor tests, as well as sled tests.

The abdomen soft tissue injury risk AIS2+ could be predicted by the maximum abdomen rib deflection or by the maximum abdomen rib VC. The injury risk curve as a function of the maximum abdomen rib deflection was recommended as the quality indexes associated with this curve were better.

The pelvis injury risk AIS2+ could be predicted by the maximum pubic force or by the pelvis Y acceleration 3 ms. Most of the injuries observed in the PMHS tests used to build the injury risk curves were related to ilio-ischio rami and pubic symphysis. It was then recommended to predict the risk as a function of the pubic force, as this dummy measurement was the more closely related to these injuries.

The recommended injury thresholds should be provided with their associated quality indexes.

It is out of the scope of this Technical Report to recommend a probability of risk as a limit to be respected. However, the dummy measurement values corresponding to all the probabilities cannot be provided in a table. As a consequence, the dummy measurement values are given for a few levels of risk. The values at 5 % risk are provided because the risk is close to the Injury Assessment Reference Values (IARV). It was also decided to provide the injury thresholds for the 25 % and 50 % risk because values used in regulations can reach those levels (as for example, the limit for the thorax compression criterion in the regulation ECE/R94). These injury thresholds associated with their quality indexes are provided in Table 4 for the WorldSID 50th. Other injury thresholds could be calculated using the estimated parameters of the survival analysis of the recommended injury risk curves given in Table 5.

Table 4 — WorldSID 50th recommended injury thresholds with its quality index

	5 % risk (quality index)	25 % risk (quality index)	50 % risk (quality index)
shoulder AIS ≥ 2	Maximum shoulder force **Y** adjusted to 67 year old (N)		
	1 594 (good)	2 011 (good)	2 265 (good)
	Maximum shoulder force Y adjusted to 45 year old (N)		
	1 799 (fair)	2 270 (fair)	2 556 (fair)
Skeletal thoracic AIS ≥ 3	Maximum thoracic rib deflection adjusted to 67 year old (measured by 1D IR-TRACC) (mm)		
	28,0 (fair)	35,1 (good)	40,2 (good)
	Maximum thoracic rib deflection adjusted to 45 year old (measured by 1D IR-TRACC) (mm)		
	38,5 (fair)	48,4 (good)	55,4 (good)
Abdomen AIS ≥ 2	Maximum abdomen rib deflection adjusted to 67 year old (measured by 1D IR-TRACC) (mm)		
	37,1 (fair)	45,3 (good)	50,2 (good)
	Maximum abdomen rib deflection adjusted to 45 year old (measured by 1D IR-TRACC) (mm)		
	58,9 (fair)	72,0 (fair)	79,8 (fair)

Table 4 *(continued)*

	5 % risk (quality index)	25 % risk (quality index)	50 % risk (quality index)
Pelvis AIS ≥ 2	Maximum pubic force adjusted to 67 year old (N)		
	1 340 (fair)	1 950 (good)	2 361 (good)
	Maximum pubic force adjusted to 45 year old (N)		
	1 818 (fair)	2 645 (marginal)	3 202 (marginal)
Pelvis AIS ≥ 3	Maximum pubic force adjusted to 67 year old (N)		
	1 714 (good)	2 262 (good)	2 605 (good)
	Maximum pubic force adjusted to 45 year old (N)		
	2 214 (marginal)	2 922 (marginal)	3 365 (marginal)

The formulae of the injury risk curves are presented in Table 5.

The risk according to the Weibull distribution is

$$Risk(\%) = 1 - \exp\left[-\left(\frac{Dummy\_measurement}{\exp(\text{int} + PMHS\_age \times coef\_age} \right)^{\frac{1}{\exp(\log\_scale)}} \right] \qquad (1)$$

The risk according to the log-normal distribution is

$$Risk(\%) = \log\_normal\_distribution\left[mean = \text{int} + age \times coef\_age, std = \exp(\log\_scale) \right] \qquad (2)$$

The risk according to the log-logistic distribution is

$$Risk(\%) = \frac{1}{1 + \exp\left\{ -\left[\ln(Dummy\_measurement) - (\text{int} + age \times coef\_age) \right] / \exp(\log\_scale) \right\}} \qquad (3)$$

where

Dummy_measurement corresponds to the dummy measurement;

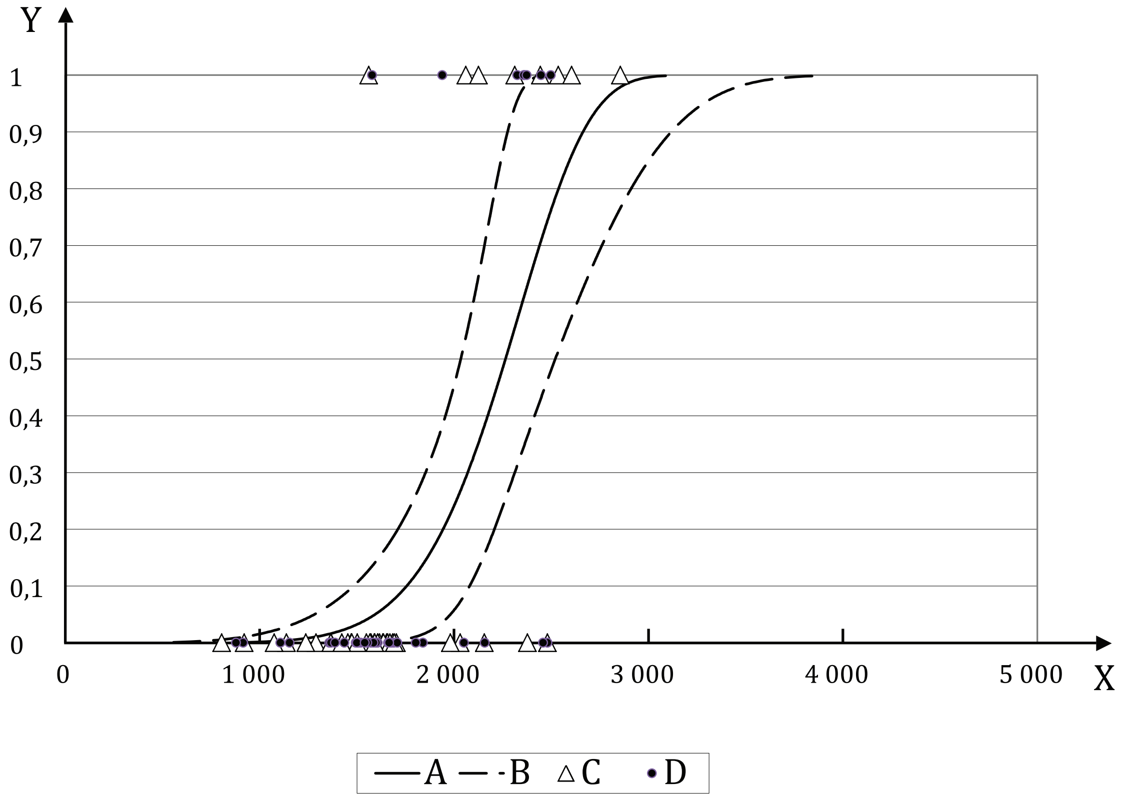
PMHS_age corresponds to the PMHS age.

Table 5 — Formulae of the recommended WorldSID 50th injury risk curves built with the survival analysis

Injury risk	Dummy measurement	Distribution	int	Coef_age	Log_scale
Shoulder AIS2+	Maximum shoulder rib **Y** force (N)	Weibull	8,143 5	−0,005 5	−2,002 8
Skeletal thoracic AIS3+	Maximum thoracic rib deflection (measured by 1D IR-TRACC) mm)	Log-logistic	4,669 9	−0,014 6	−2,094 5
Abdomen soft tissue AIS2+	Maximum abdomen rib deflection (measured by 1D IR-TRACC) (mm)	Weibull	5,367 8	−0,021 0	−2,153 1
Pelvis AIS2+	Maximum pubic force (N)	Weibull	8,774 8	−0,013 9	−1,525 9
Pelvis AIS3+	Maximum pubic force (N)	Weibull	8,704 1	−0,011 6	−1,827 4

Injury risk curves for the WorldSID 50th percentile are given in Figures 1 to 10.

Figures 1 and 2 present the shoulder injury risk curves AIS ≥ 2 as a function of the maximum shoulder **Y** force for the WorldSID 50th, with adjustment to 67 year old and 45 year old.



Key

X maximum shoulder **Y** force (N)

Y shoulder injury risk AIS2+

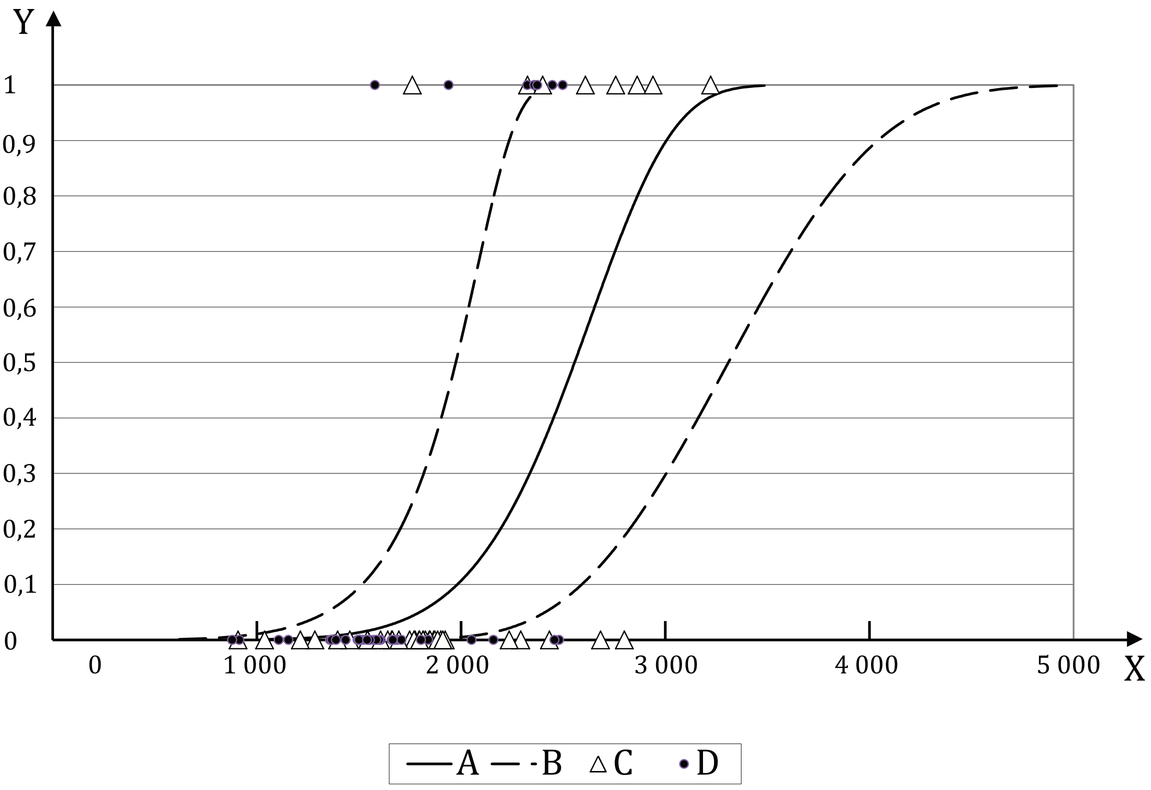
A 67 year old

B 95 % confidence interval, 67 year old

C data adjusted to 67 year old

D data non-adjusted

Figure 1 — Shoulder injury risk curve AIS ≥ 2 as a function of the maximum shoulder Y force adjusted to 67 year old for the WorldSID 50th



Key

X maximum shoulder **Y** force (N)

Y shoulder injury risk AIS2+

A 45 year old

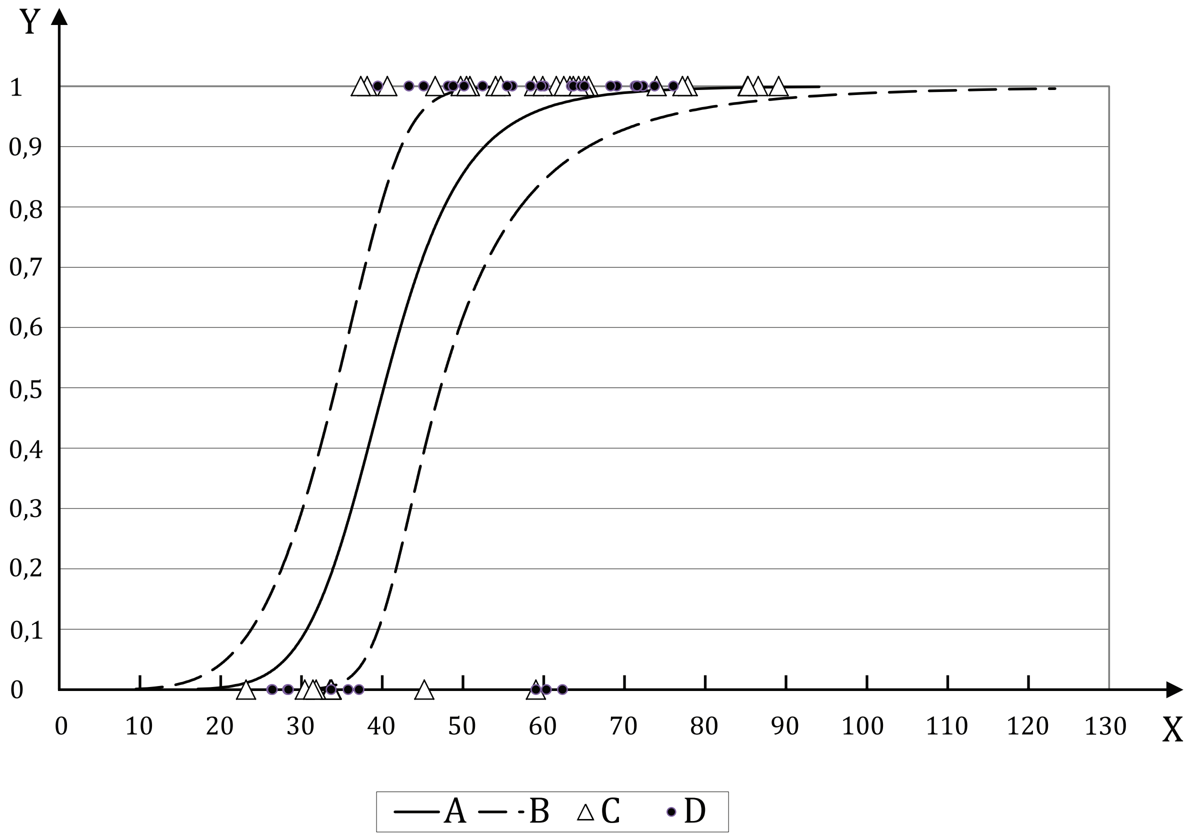
B 95% confidence interval, 45 year old

C data adjusted to 45 year old

D data non-adjusted

Figure 2 — Shoulder injury risk curve AIS ≥ 2 as a function of the maximum shoulder Y force adjusted to 45 year old for the WorldSID 50th

Figures 3 and 4 present the thoracic skeletal injury risk curves AIS ≥ 3 as a function of the maximum thoracic rib deflection for the WorldSID 50th, with adjustment to 67 year old and 45 year old.



Key

X maximum thoracic rib deflection (mm)

Y skeletal thoracic injury risk AIS3+

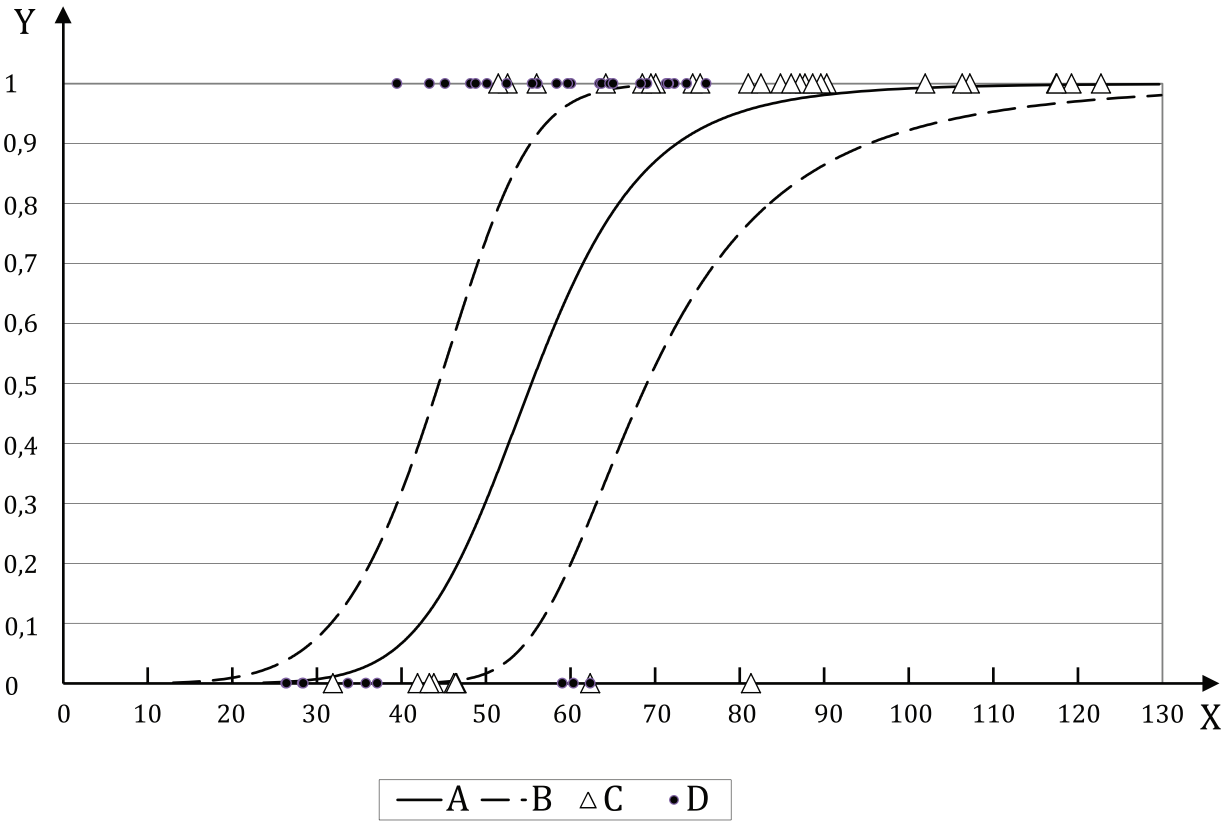
A 67 year old

B 95 % confidence interval, 67 year old

C data adjusted to 67 year old

D data non-adjusted

Figure 3 — Thoracic skeletal injury risk curve AIS ≥ 3 as a function of the maximum thoracic rib deflection adjusted to 67 year old for the WorldSID 50th



Key

X maximum thoracic rib deflection (mm)

Y skeletal thoracic injury risk AIS3+

A 45 year old

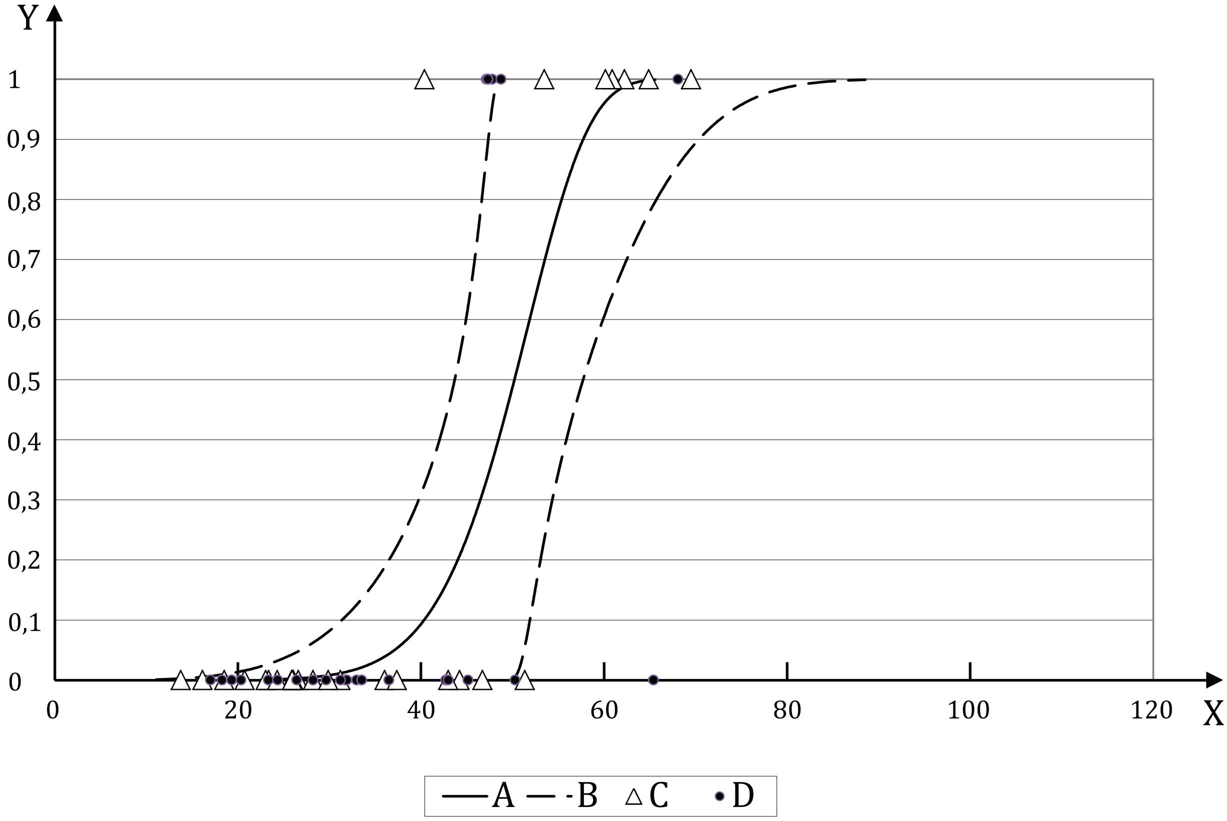
B 95 % confidence interval, 45 year old

C data adjusted to 45 year old

D data non-adjusted

Figure 4 — Thoracic skeletal injury risk curve AIS ≥ 3 as a function of the maximum thoracic rib deflection adjusted to 45 year old for the WorldSID 50th

Figures 5 and 6 present the abdomen soft tissue injury risk curves AIS ≥ 2 as a function of the maximum abdomen rib deflection with adjustment to 67 year old and 45 year old.



Key

X maximum abdomen rib deflection (mm)

Y abdomen soft tissue injury risk AIS2+

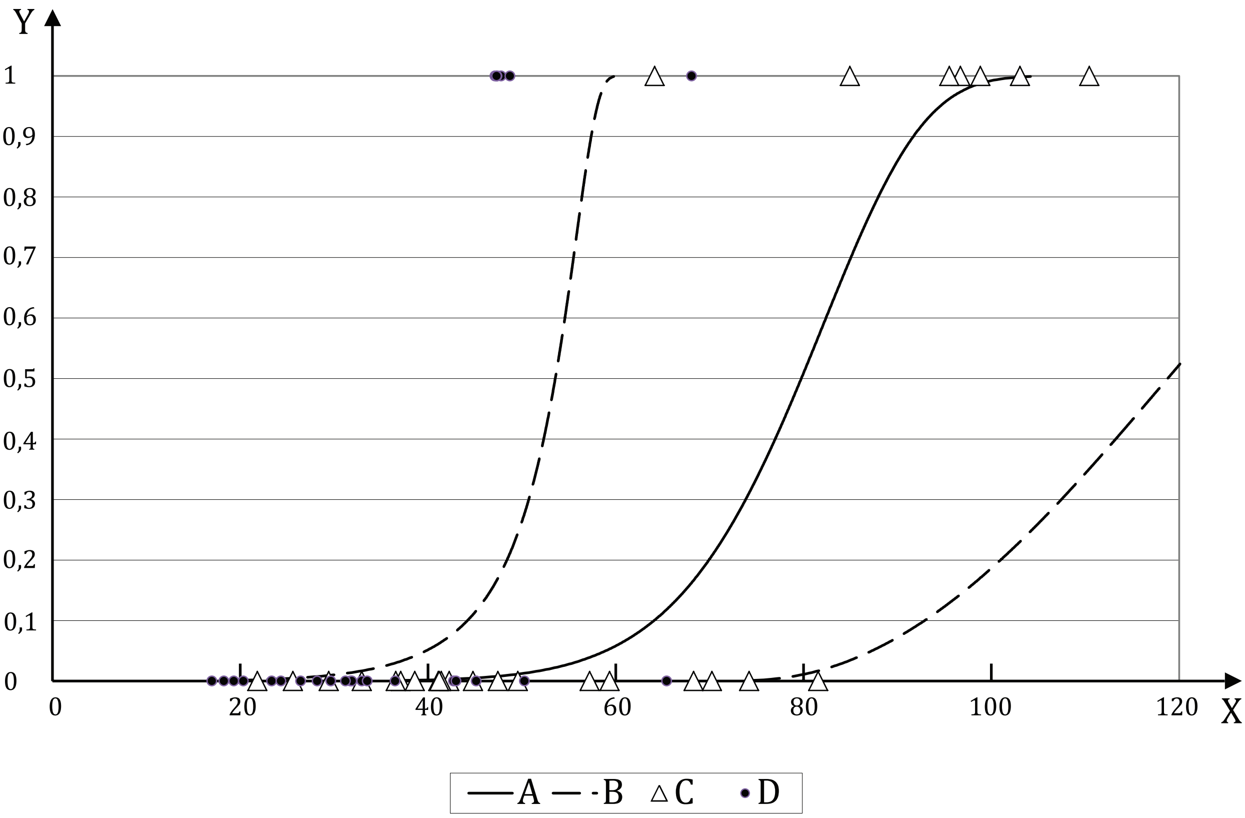
A 67 year old

B 95 % confidence interval, 67 year old

C data adjusted to 67 year old

D data non-adjusted

Figure 5 — Abdomen soft tissue injury risk curve AIS ≥ 2 as a function of the maximum abdomen rib deflection adjusted to 67 year old for the WorldSID 50th



Key

X maximum abdomen rib deflection (mm)

Y abdomen soft tissue injury risk AIS2+

A 45 year old

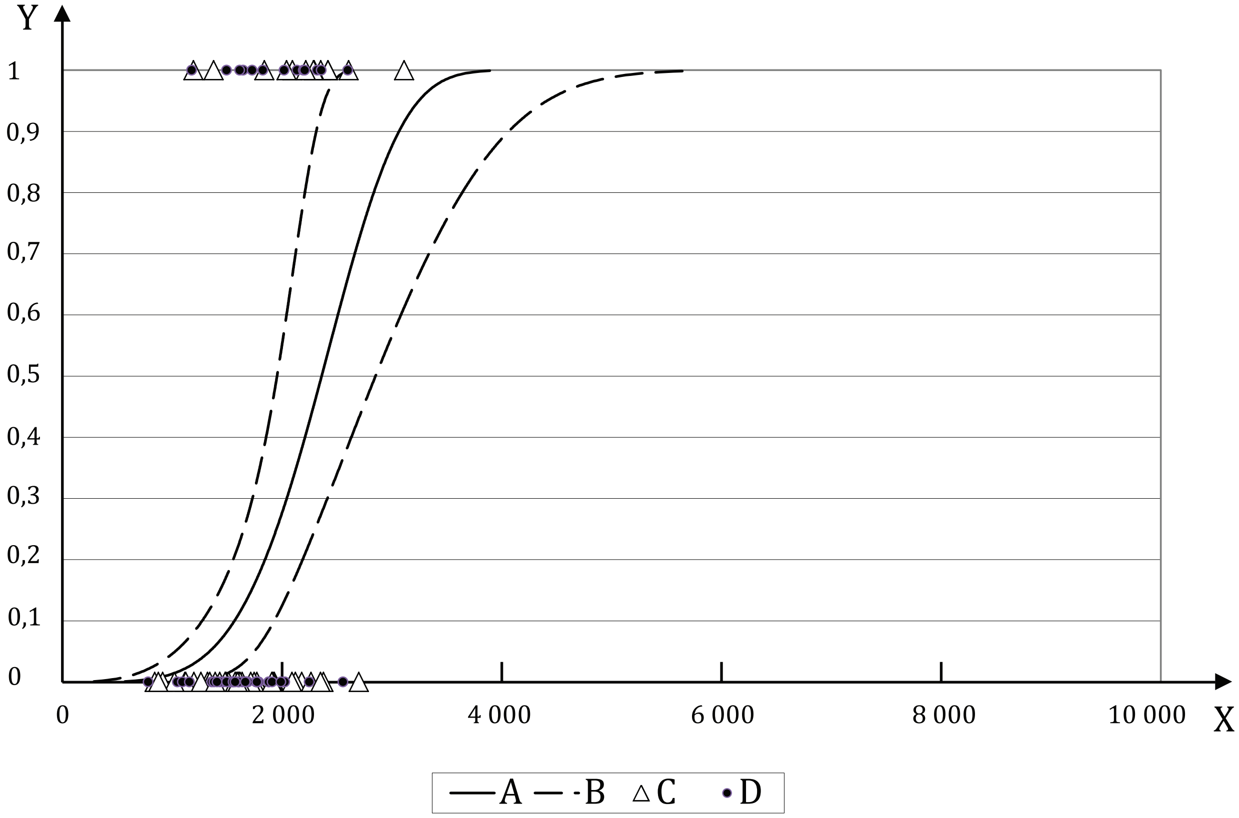
B 95 % confidence interval, 45 year old

C data adjusted to 45 year old

D data non-adjusted

Figure 6 — Abdomen soft tissue injury risk curve AIS ≥ 2 as a function of the maximum abdomen rib deflection adjusted to 45 year old for the WorldSID 50th

Figures 7 and 10 present the pelvis injury risk curves AIS ≥ 2 and AIS ≥ 3 as a function of the maximum pubic force for the WorldSID 50th, with adjustment to 67 year old and 45 year old.



Key

X maximum pubic force (N)

Y pelvis injury risk AIS2+

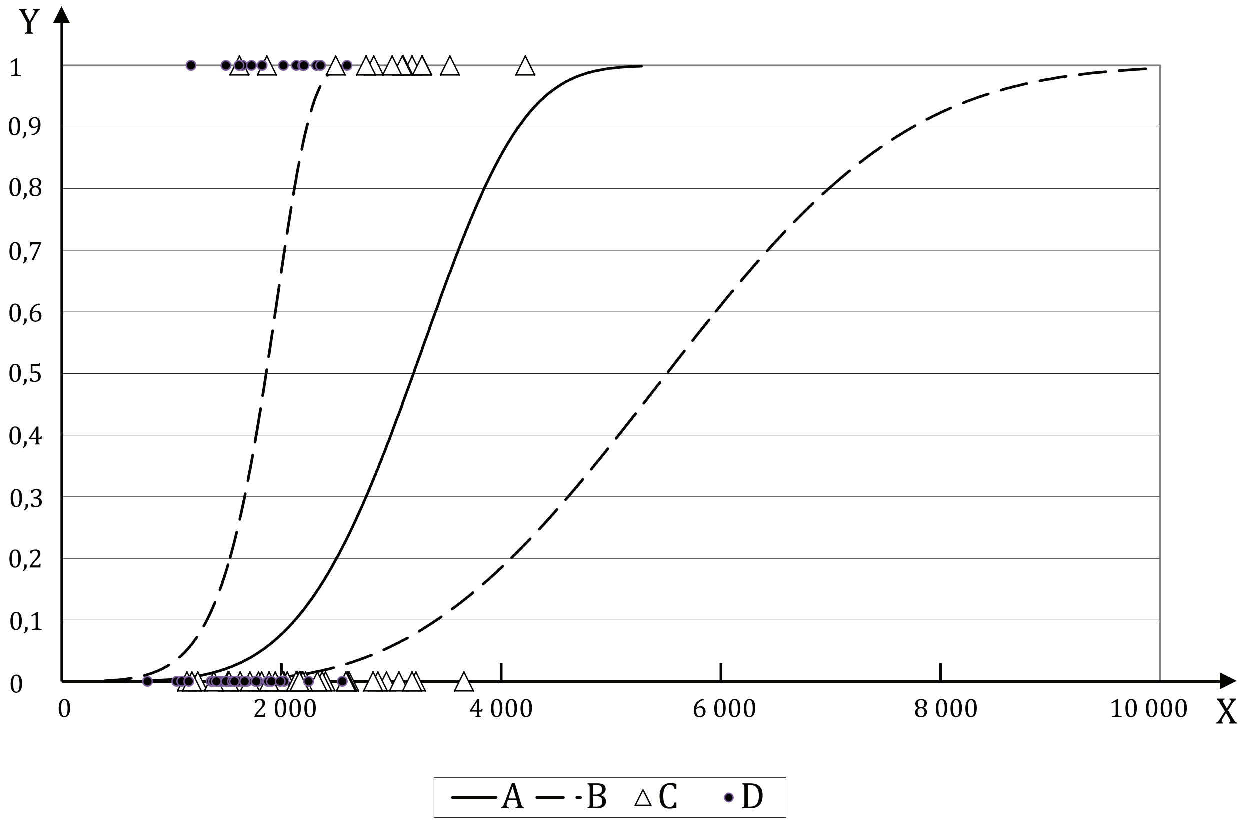
A 67 year old

B 95 % confidence interval, 67 year old

C data adjusted to 67 year old

D data non-adjusted

Figure 7 — Pelvis injury risk curve AIS ≥ 2 as a function of the maximum pubic force adjusted to 67 year old WorldSID 50th



Key

X maximum pubic force (N)

Y pelvis injury risk AIS2+

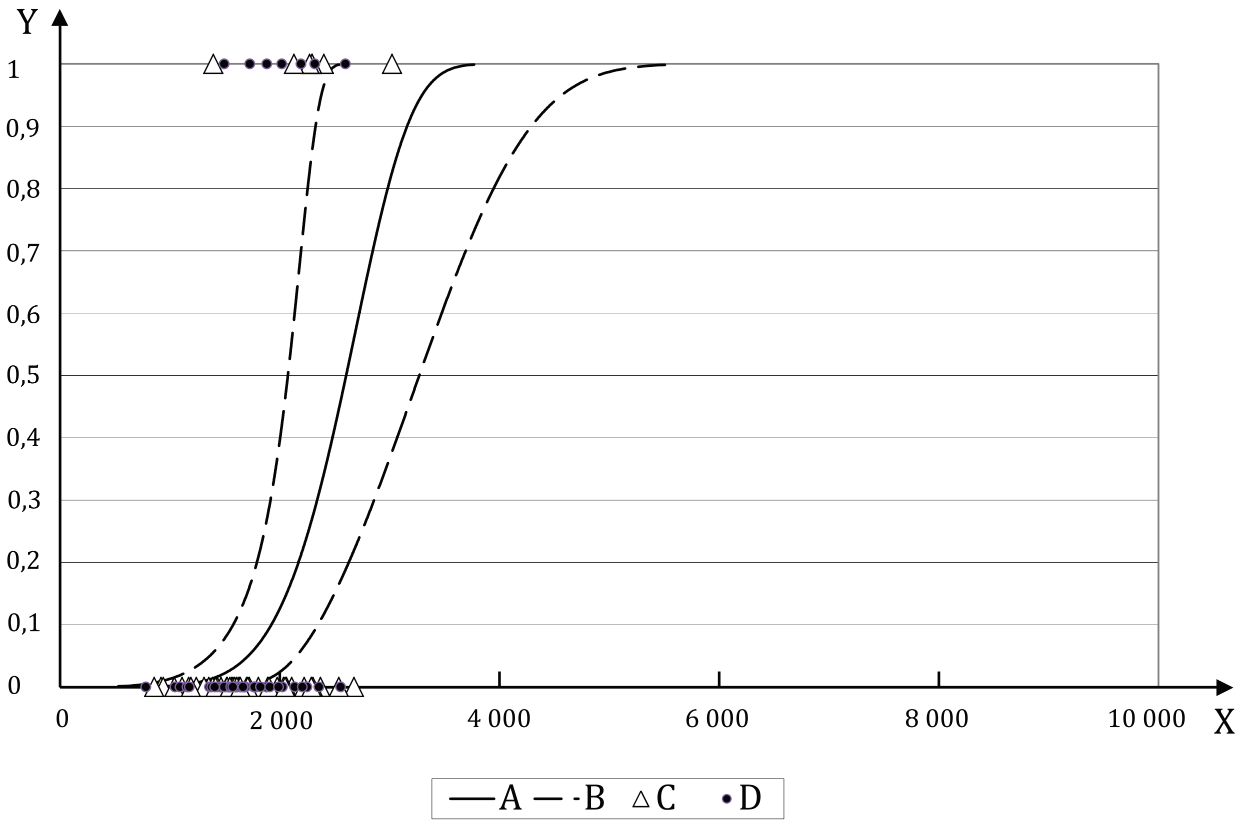
A 45 year old

B 95 % confidence interval, 45 year old

C data adjusted to 45 year old

D data non-adjusted

Figure 8 — Pelvis injury risk curve AIS ≥ 2 as a function of the maximum pubic force adjusted to 45 year old for the WorldSID 50th



Key

X maximum pubic force (N)

Y pelvis injury risk AIS3+

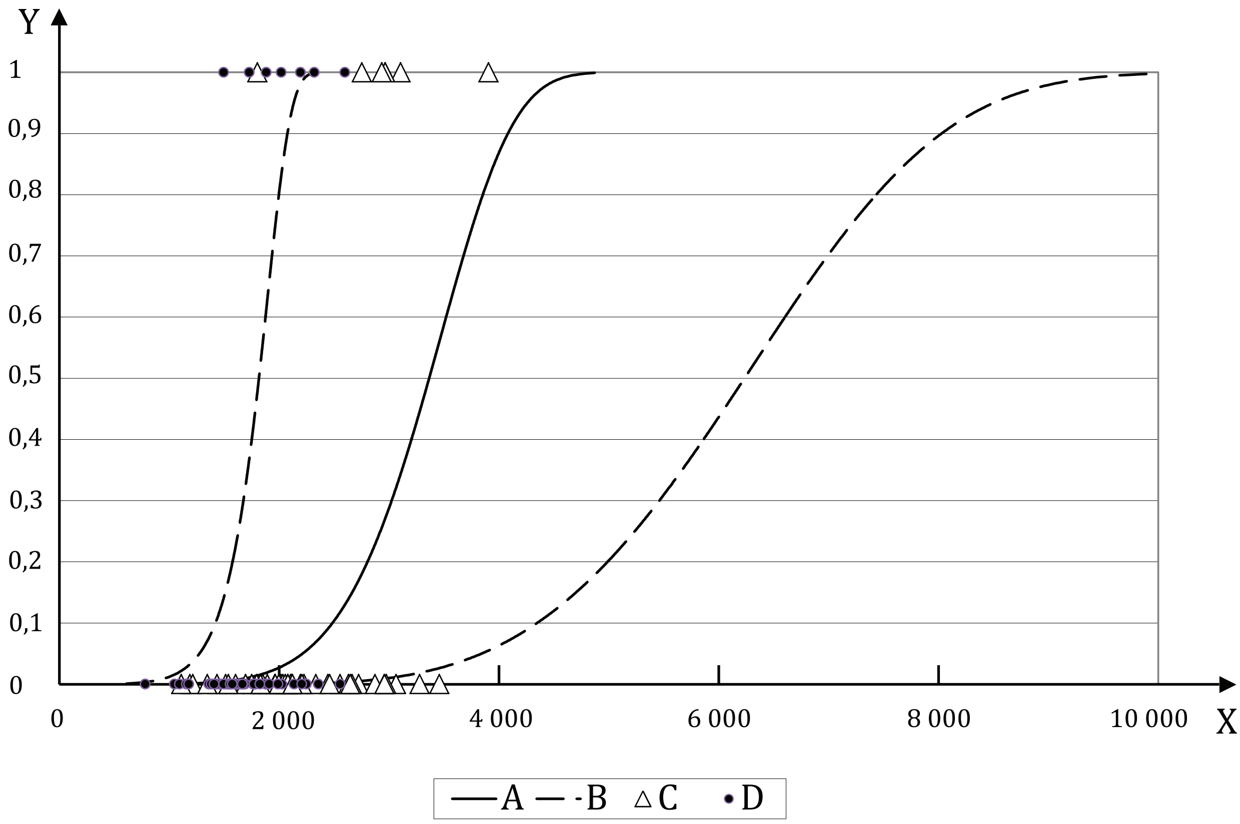
A 67 year old

B 95 % confidence interval, 67 year old

C data adjusted to 67 year old

D data non-adjusted

Figure 9 — Pelvis injury risk curve AIS ≥ 3 as a function of the maximum pubic force adjusted to 67 year old for the WorldSID 50th



Key

X maximum pubic force (N)

Y pelvis injury risk AIS3+

A 45 year old

B 95 % confidence interval, 45 year old

C data adjusted to 45 year old

D data non-adjusted

Figure 10 — Pelvis injury risk curve AIS ≥ 3 as a function of the maximum pubic force adjusted to 45 year old for the WorldSID 50th

4 Related electronic documents

The files providing the characteristics of the PMHS sample to be used for the construction of the injury risk curves, as well as the dummy responses, are gathered in related electronic documents posted on the ISO website at the following link: http://standards.iso.org/iso/tr/12350

— RED1: Head impactor and drop tests

— RED2: Shoulder impactor tests

— RED3: Thorax impactor tests

— RED4: Abdomen impactor tests

— RED5: Pelvis impactor tests

— RED6: Sled tests

Annex A
(informative)

PMHS head test data

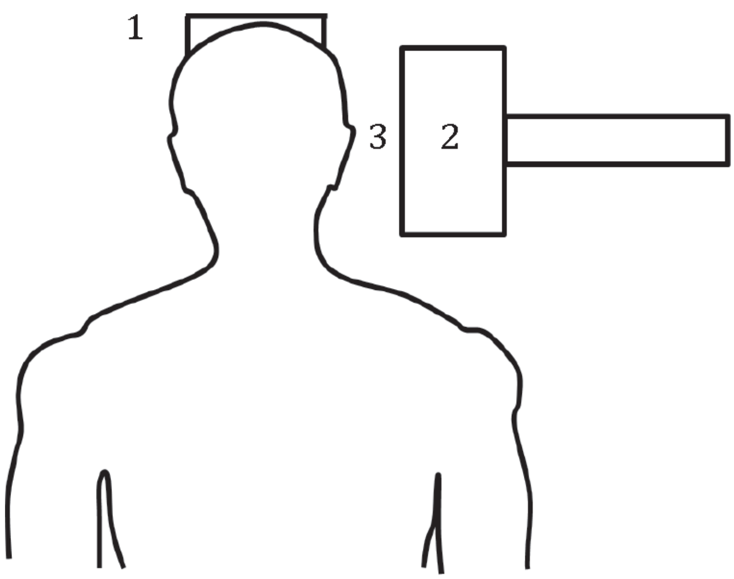
Annex A includes the description of the PMHS head impactor and drop tests used in the construction of the injury risk curves.

A.1 Head impactor tests

The Highway Safety Research Institute (HSRI) conducted a series of impactor tests to the heads of five PMHS[51]. The results of the HSRI impactor tests were excluded because the impact speeds are unknown. Therefore, the tests cannot be repeated with dummies.

The University of Michigan Transportation Research Institute (UMTRI) performed lateral impactor tests. The results of the UMTRI impactor tests were excluded because the impactor characteristics were not documented in the literature. Therefore, the tests cannot be repeated with dummies.

Calspan conducted a series of impactor tests to the heads of PMHS, as illustrated in Figure A.1 [18]. Each PMHS was seated in an upright posture, but the presence or absence of a back support was not documented. The position of the head was maintained by a chin strap that would break away upon impact. The impactor masses were 23,4 kg, 24,4 kg, and 25,3 kg. The impactor face was either rectangular (203 mm × 254 mm or 171,5 mm × 203 mm) or circular (152 mm diameter). The impactor face was either rigid or padded with a 213 foam (polyurethane) padding. The impactor face was centred on the level of the external auditory meatus.



Key

1 acceleration unit

2 impactor face

3 centreline of impactor at level of Frankfort plans and external auditory meatus

Figure A.1 — Impactor test configuration from the lateral head impacts conducted by Calspan (front view)[18]

Table A.1 summarizes the Calspan PMHS tests that are included in constructing the injury risk curves for the head in lateral impact. The details of all the head impactor test configurations are provided in Table A.1 and in the related electronic document RED1. The padding used in dummy tests should be identical to the padding used in the original PMHS tests.

Table A.1 — PMHS impactor tests included in constructing injury risk curves for the head

Test performer	Impact angle	Test number	PMHS number	PMHS age	PMHS mass kg	Impactor surface	Impactor mass kg	Impactor face geometry	Impact speed m/s	AIS2005 skull
CALSPAN	Pure lateral	SR2-CM25	CALMAN 25	55	83,66	R	25,3	SQ80	4,0	0
CALSPAN		SR2-CM29	CALMAN 29	71	67,195	R	25,3	SQ80	4,0	2
CALSPAN		SR2-CM30	CALMAN 30	66	82,325	R	25,3	SQ80	4,0	0
CALSPAN		SR2-CM31	CALMAN 31	57	71,645	R	25,3	SQ80	4,0	0
CALSPAN		SR2-CM32	CALMAN 32	60	56,07	R	24,4	SQ54	2,2	0
CALSPAN		SR2-CM33	CALMAN 33	70	58,295	R	24,4	SQ54	3,9	0
CALSPAN		SR2-CM34	CALMAN 34	55	62,745	R	23,4	SQ28	4,0	0
CALSPAN		SR2-CM35	CALMAN 35	69	66,75	R	23,4	SQ28	4,0	2
CALSPAN		SR2-CM36	CALMAN 36			PU	24,4	SQ54	3,9	0
CALSPAN		SR2-CM37	CALMAN 37			PU	24,4	SQ54	3,9	0
CALSPAN		SR2-CM42	CALMAN 42	60	84,55	R	25,3	SQ80	3,2	0

PU Padded 2,54-cm-thick 213 foam (polyurethane)

R rigid

SQ80 515,6 cm^2 square flat plate (20,3 cm × 25,4 cm)

SQ54 347,1 cm^2 square flat plate (17,1 cm× 20,3 cm)

SQ28 180,6 cm^2 wooden face (15,2 cm circle)

No WorldSID test results were available for these test conditions at the time when this Technical Report was published. This annex is kept for future use.

A.2 Head drop tests

The Association Peugeot-Renault (APR) conducted two series of whole body drop tests that involved impact to the temporoparietal region of the PMHS head[20] [21] [13]. The first series, illustrated in Figure A.2, strapped the torso into a cradle, with the head and upper torso protruding past the edge of the cradle. A device was used to maintain head alignment until impact. The second series suspended the body from several points, without the cradle. The subject was released from a height of 0,3 m to 3,0 m. The head impact surface was at an angle of 1° to 44° relative to horizontal and either rigid or padded. Both tests on a rigid impact surface were with bare heads. The height of the mattress was chosen to avoid neck kinematics that would cause cervical injuries.

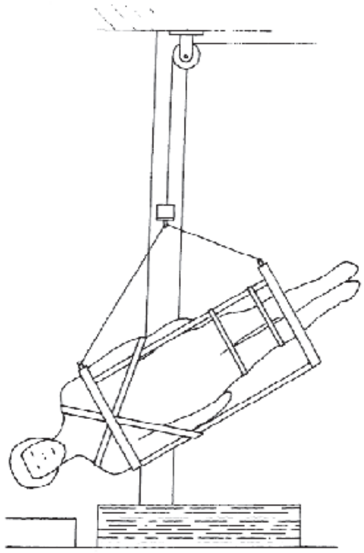


Figure A.2 — APR head lateral drop test configuration (front view)

Wayne State University (WSU) conducted whole body drop tests with head impact[22]. In this series, the torso was strapped to a pallet that was free to pivot about one end. The PMHS head and neck were extended beyond the edge of the free end of the pallet. The pallet was rotated until the subject's head was positioned 0,46 m above the head impact surface. The impact surface was a rigid cylinder with a 1 inch radius. The pallet was released to produce the desired head impact.

The Medical College of Wisconsin (MCW) conducted lateral drop tests with heads, separated at the level of the occipital condyles[56]. Each head was dropped multiple times, from increasing heights (0,3 m to 3 m), until skull fracture was detected by a decrease in force associated with an increase in velocity. The head was oriented such that the temporoparietal region impacted either a flat or cylindrical impact surface, padded with 50 mm of rubber (either 40 durometer or 90 durometer), as illustrated in Figure A.3. Some tests were conducted with the brain intact and other tests were conducted with Sylgard gel in place of the brain.

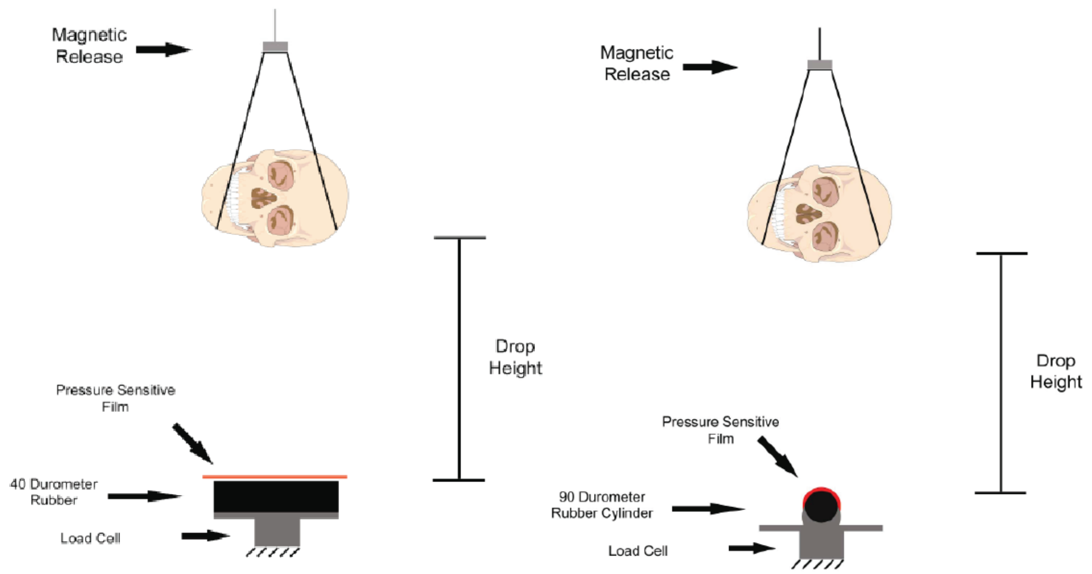


Figure A.3 — Impactor test configuration from the lateral head impacts conducted by MCW (front view)[56]

Table A.2 summarizes the APR, WSU, and MCW PMHS tests that could be included in constructing injury risk curves for the head drop tests. The details of all the head drop test configurations are provided in Table A.2 and the related electronic document RED1.

Table A.2 — PMHS drop tests included in constructing injury risk curves for the head

Test series	Impact surface shape	Impact surface	Head impact angle	Drop height m	PMHS test number
APR	Flat	Rigid	27°	2,5	MS76
			35°	1,8	MS68
	Flat	Padded	From 1° to 44°	0,3 to 3	MS63, MS64, MS65, MS69, MS70, MS83, MS85, MS86, MS99, MS100, MS66, MS67, MS73, MS74, MS87, MS111
WSU	Flat	Rigid	Pure lateral	0,46	DOT-36-1, DOT-37-1, DOT-38-1
MCW	Flat	Padded 40 durometer rubber	Pure lateral	From 0,3 to 3	CHD1801, CHD1802, CHD1803, CHD1804, CHD1501, CHD1502, CHD1503, CHD1504, CHD1505, CHD1506, CHD1701, CHD1702, CHD1703, CHD1704, CHD1705, CHD1706, CHD901, CHD902, CHD903, CHD1101, CHD1102, CHD1103, CHD1104, CHD1301, CHD1302, CHD1303, CHD1304, CHD1305, CHD1306, CHD1307, CHD1001, CHD1002, CHD1003, CHD1004, CHD1005, CHD1006, CHD1007, CHD1008, CHD1601, CHD1602, CHD1603, CHD1604, CHD1605, CHD1606, CHD1607, CHD1401, CHD1402, CHD1403, CHD1404, CHD1405, CHD1901, CHD1902, CHD1903, CHD1904, CHD1905
			From 11° to 14°		CHD2101, CHD2102, CHD2103, CHD2104, CHD2105, CHD2106, CHD2107, CHD2108, CHD2001, CHD2002, CHD2003, CHD2004, CHD2005, CHD2006, CHD2007
		Padded 90 durometer rubber	Pure lateral		CHD601, CHD602, CHD501, CHD502, CHD503, CHD504, CHD505, CHD506, CHD507
			From 11° to 14°		CHD2501, CHD2502, CHD2503, CHD2401, CHD2402, CHD2403, CHD2404, CHD2405, CHD2406, CHD2301, CHD2302, CHD2303, CHD2304, CHD2305, CHD2201, CHD2202, CHD2203, CHD2204
	Cylinder	Padded 90 durometer rubber	From 11° to 14°		CHD2901, CHD2902, CHD2903, CHD2904, CHD2801, CHD2802, CHD2803, CHD2804, CHD2805, CHD2806, CHD2701, CHD2702, CHD2703, CHD2704, CHD2705, CHD2706, CHD2601, CHD2602, CHD2603, CHD2604

Table A.3 — Head drop tests from the bibliography

Test number	PMHS number	PMHS age	PMHS mass kg	Test performer	Angle of impact °	Impact surface	Impact surface geometry	Drop height m	AIS2005 skull
MS68	MS68	49		APR	35	R	flat	1,83	2
MS76	MS76	75		APR	27	R	flat	2,5	4
DOT-36-1	2326	78	NA	WSU	270	R	1-inch-radius rigid cylinder	0,457 2	2
DOT-37-1	2312	71	NA	WSU	270	R	1-inch-radius rigid cylinder	0,457 2	2
DOT-38-1	2310	67	85	WSU	270	R	1-inch-radius rigid cylinder	0,457 2	2
CHD1801	HS325	44	91	MCW	0	40D	flat	0,609 6	0
CHD1802	HS325	44	91	MCW	0	40D	flat	1,219	0
CHD1803	HS325	44	91	MCW	0	40D	flat	1,524	0
CHD1804	HS325	44	91	MCW	0	40D	flat	1,829	0
CHD1501	HS543	56	95	MCW	0	40D	flat	0,609 6	0
CHD1502	HS543	56	95	MCW	0	40D	flat	0,914	0
CHD1503	HS543	56	95	MCW	0	40D	flat	1,219	0
CHD1504	HS543	56	95	MCW	0	40D	flat	1,524	0
CHD1505	HS543	56	95	MCW	0	40D	flat	1,829	0
CHD1506	HS543	56	95	MCW	0	40D	flat	2,134	2
CHD1701	HS360	71	81	MCW	0	40D	flat	0,609 6	0
CHD1702	HS360	71	81	MCW	0	40D	flat	0,914 4	0
CHD1703	HS360	71	81	MCW	0	40D	flat	1,219	0
CHD1704	HS360	71	81	MCW	0	40D	flat	1,524	0
CHD1705	HS360	71	81	MCW	0	40D	flat	1,829	0
CHD1706	HS360	71	81	MCW	0	40D	flat	2,134	0
CHD901	HS477	68	66	MCW	0	40D	flat	0,609 6	0
CHD902	HS477	68	66	MCW	0	40D	flat	1,219 2	0
CHD903	HS477	68	66	MCW	0	40D	flat	1,524	2
CHD1101	HS348	77	71	MCW	0	40D	flat	0,609 6	0
CHD1102	HS348	77	71	MCW	0	40D	flat	1,219 2	0
CHD1103	HS348	77	71	MCW	0	40D	flat	1,524	0
CHD1104	HS348	77	71	MCW	0	40D	flat	1,828 8	0
CHD1301	HS329	65	75	MCW	0	40D	flat	0,61	0
CHD1302	HS329	65	75	MCW	0	40D	flat	1,219	0
CHD1304	HS329	65	75	MCW	0	40D	flat	1,524	0
CHD1305	HS329	65	75	MCW	0	40D	flat	1,83	0

R rigid

40D 50-mm-thick 40-durometer padding

90D 50-mm-thick 90-durometer padding

Angle A Resulting specimen orientation was such that the sagittal plane was rotated between −11° to −14° from horizontal about the X-axis and −1° to −4° from horizontal about the Z-axis

Table A.3 *(continued)*

Test number	PMHS number	PMHS age	PMHS mass kg	Test performer	Angle of impact °	Impact surface	Impact surface geometry	Drop height m	AIS2005 skull
CHD1306	HS329	65	75	MCW	0	40D	flat	2,134	0
CHD1307	HS329	65	75	MCW	0	40D	flat	2,438	2
CHD1001	HS209	87	48	MCW	0	40D	flat	0,609 6	0
CHD1002	HS209	87	48	MCW	0	40D	flat	1,219 2	0
CHD1003	HS209	87	48	MCW	0	40D	flat	1,524	0
CHD1004	HS209	87	48	MCW	0	40D	flat	1,828 8	0
CHD1005	HS209	87	48	MCW	0	40D	flat	2,133 6	0
CHD1006	HS209	87	48	MCW	0	40D	flat	2,438 4	0
CHD1007	HS209	87	48	MCW	0	40D	flat	2,743 2	0
CHD1008	HS209	87	48	MCW	0	40D	flat	3,048	0
CHD1601	HS491	30	41	MCW	0	40D	flat	0,609 6	0
CHD1602	HS491	30	41	MCW	0	40D	flat	0,914 4	0
CHD1603	HS491	30	41	MCW	0	40D	flat	1,219	0
CHD1604	HS491	30	41	MCW	0	40D	flat	1,524	0
CHD1605	HS491	30	41	MCW	0	40D	flat	1,829	0
CHD1606	HS491	30	41	MCW	0	40D	flat	2,314	0
CHD1607	HS491	30	41	MCW	0	40D	flat	2,438	2
CHD1401	HS378	70	80	MCW	0	40D	flat	0,609 6	0
CHD1402	HS378	70	80	MCW	0	40D	flat	1,219	0
CHD1403	HS378	70	80	MCW	0	40D	flat	1,524	0
CHD1404	HS378	70	80	MCW	0	40D	flat	1,829	0
CHD1405	HS378	70	80	MCW	0	40D	flat	2,134	0
CHD1901	HS337	59	100	MCW	0	40D	flat	0,914 4	0
CHD1902	HS337	59	100	MCW	0	40D	flat	0,914 4	0
CHD1903	HS337	59	100	MCW	0	40D	flat	1,219	0
CHD1904	HS337	59	100	MCW	0	40D	flat	1,524	0
CHD1905	HS337	59	100	MCW	0	40D	flat	1,829	0
CHD2901	HS532	71	80	MCW	Angle A	90D	cylinder	0,304 8	0
CHD2902	HS532	71	80	MCW	Angle A	90D	cylinder	0,609 6	0
CHD2903	HS532	71	80	MCW	Angle A	90D	cylinder	0,914 4	0
CHD2904	HS532	71	80	MCW	Angle A	90D	cylinder	1,219 2	3
CHD2801	HS542	61	65	MCW	Angle A	90D	cylinder	0,304 8	0
CHD2802	HS542	61	65	MCW	Angle A	90D	cylinder	0,609 6	0
CHD2803	HS542	61	65	MCW	Angle A	90D	cylinder	0,914 4	0
CHD2804	HS542	61	65	MCW	Angle A	90D	cylinder	1,219 2	0

R rigid

40D 50-mm-thick 40-durometer padding

90D 50-mm-thick 90-durometer padding

Angle A Resulting specimen orientation was such that the sagittal plane was rotated between −11° to −14° from horizontal about the X-axis and −1° to −4° from horizontal about the Z-axis

Table A.3 *(continued)*

Test number	PMHS number	PMHS age	PMHS mass kg	Test performer	Angle of impact °	Impact surface	Impact surface geometry	Drop height m	AIS2005 skull
CHD2805	HS542	61	65	MCW	Angle A	90D	cylinder	1,524	0
CHD2806	HS542	61	65	MCW	Angle A	90D	cylinder	1,828 8	3
CHD2701	HS518	60	102	MCW	Angle A	90D	cylinder	0,304 8	0
CHD2702	HS518	60	102	MCW	Angle A	90D	cylinder	0,609 6	0
CHD2703	HS518	60	102	MCW	Angle A	90D	cylinder	0,914 4	0
CHD2704	HS518	60	102	MCW	Angle A	90D	cylinder	1,219 2	0
CHD2705	HS518	60	102	MCW	Angle A	90D	cylinder	1,524	0
CHD2706	HS518	60	102	MCW	Angle A	90D	cylinder	1,828 8	2
CHD2601	HS544	68	81	MCW	Angle A	90D	cylinder	0,304 8	0
CHD2602	HS544	68	81	MCW	Angle A	90D	cylinder	0,609 6	0
CHD2603	HS544	68	81	MCW	Angle A	90D	cylinder	0,914 4	0
CHD2604	HS544	68	81	MCW	Angle A	90D	cylinder	1,219 2	3
CHD2501	HS354	76	58	MCW	Angle A	90D	flat	0,304 8	0
CHD2502	HS354	76	58	MCW	Angle A	90D	flat	0,609 6	0
CHD2503	HS354	76	58	MCW	Angle A	90D	flat	0,914 4	2
CHD2401	HS501	67	87	MCW	Angle A	90D	flat	0,304 8	0
CHD2402	HS501	67	87	MCW	Angle A	90D	flat	0,609 6	0
CHD2403	HS501	67	87	MCW	Angle A	90D	flat	0,914 4	0
CHD2404	HS501	67	87	MCW	Angle A	90D	flat	1,219 2	0
CHD2405	HS501	67	87	MCW	Angle A	90D	flat	1,524	0
CHD2406	HS501	67	87	MCW	Angle A	90D	flat	1,828 8	3
CHD2301	HS351	81	60	MCW	Angle A	90D	flat	0,304 8	0
CHD2302	HS351	81	60	MCW	Angle A	90D	flat	0,609 6	0
CHD2303	HS351	81	60	MCW	Angle A	90D	flat	0,914 4	0
CHD2304	HS351	81	60	MCW	Angle A	90D	flat	1,219 2	0
CHD2305	HS351	81	60	MCW	Angle A	90D	flat	1,524	3
CHD2201	HS473	74	51	MCW	Angle A	90D	flat	0,609 6	0
CHD2202	HS473	74	51	MCW	Angle A	90D	flat	0,914 4	0
CHD2203	HS473	74	51	MCW	Angle A	90D	flat	1,219 2	0
CHD2204	HS473	74	51	MCW	Angle A	90D	flat	1,524	2
CHD2101	HS516	48	75	MCW	Angle A	40D	flat	0,914 4	0
CHD2102	HS516	48	75	MCW	Angle A	40D	flat	1,219 2	0
CHD2103	HS516	48	75	MCW	Angle A	40D	flat	1,524	0
CHD2104	HS516	48	75	MCW	Angle A	40D	flat	1,828 8	0
CHD2105	HS516	48	75	MCW	Angle A	40D	flat	2,133 6	0

R rigid

40D 50-mm-thick 40-durometer padding

90D 50-mm-thick 90-durometer padding

Angle A Resulting specimen orientation was such that the sagittal plane was rotated between −11° to −14° from horizontal about the X-axis and −1° to −4° from horizontal about the Z-axis

Table A.3 *(continued)*

Test number	PMHS number	PMHS age	PMHS mass kg	Test performer	Angle of impact °	Impact surface	Impact surface geometry	Drop height m	AIS2005 skull
CHD2106	HS516	48	75	MCW	Angle A	40D	flat	2,438 4	0
CHD2107	HS516	48	75	MCW	Angle A	40D	flat	3,022 6	0
CHD2108	HS516	48	75	MCW	Angle A	40D	flat	3,327 4	0
CHD2001	HS373	68	84	MCW	Angle A	40D	flat	0,609 6	0
CHD2002	HS373	68	84	MCW	Angle A	40D	flat	0,914 4	0
CHD2003	HS373	68	84	MCW	Angle A	40D	flat	0,914 4	0
CHD2004	HS373	68	84	MCW	Angle A	40D	flat	1,219 2	0
CHD2005	HS373	68	84	MCW	Angle A	40D	flat	1,524	0
CHD2006	HS373	68	84	MCW	Angle A	40D	flat	1,828 8	0
CHD2007	HS373	68	84	MCW	Angle A	40D	flat	2,133 6	3
CHD601	HS439	68	34	MCW	0	90D	flat	0,609 6	0
CHD602	HS439	68	34	MCW	0	90D	flat	0,914 4	3
CHD501	HS271	67	50	MCW	0	90D	flat	0,304 8	0
CHD502	HS271	67	50	MCW	0	90D	flat	0,609 6	0
CHD503	HS271	67	50	MCW	0	90D	flat	0,914 4	0
CHD504	HS271	67	50	MCW	0	90D	flat	1,219 2	0
CHD505	HS271	67	50	MCW	0	90D	flat	1,524	0
CHD506	HS271	67	50	MCW	0	90D	flat	1,828 8	0
CHD507	HS271	67	50	MCW	0	90D	flat	2,133 6	3

R rigid

40D 50-mm-thick 40-durometer padding

90D 50-mm-thick 90-durometer padding

Angle A Resulting specimen orientation was such that the sagittal plane was rotated between −11° to −14° from horizontal about the X-axis and −1° to −4° from horizontal about the Z-axis

No WorldSID test results were available for these test conditions at the time when this Technical Report was published. This annex is kept for future use.

Annex B
(informative)

PMHS shoulder test data (shoulder impactor tests)

Annex B includes the description of the PMHS shoulder impactor tests used in the construction of the injury risk curves.

APR conducted a series of impactor tests to the shoulders of four PMHS[2]. Each PMHS was seated on a horizontal hardwood surface. The position of the head was maintained by taping it to a stick located behind the subject's back. The impactor mass was 23 kg and its flat circular impact face had a diameter of 150 mm. The impact face was centred at the shoulder level of each subject. Three subjects (MS202, MS203, and MS204) were impacted in a pure lateral direction and the fourth (MS201) was impacted at an angle of 15° forward of pure lateral. Each subject was impacted once.

INRETS conducted a series of shoulder impactor tests, as illustrated in Figure B.1 [14] [15] [17]. Each PMHS was seated upright, without back support. The 23,4 kg rigid impactor had a rectangular impact face (150 mm wide and 80 mm high) with rounded edges. The impactor face was centred on the glenohumeral joint. Each subject was impacted three times on the right shoulder (pure lateral, 15° rearward of lateral, and 15° forward of lateral) and once, at higher speed, on the left shoulder in the pure lateral direction.

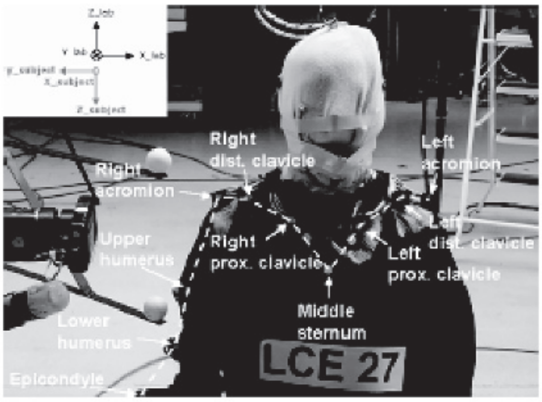
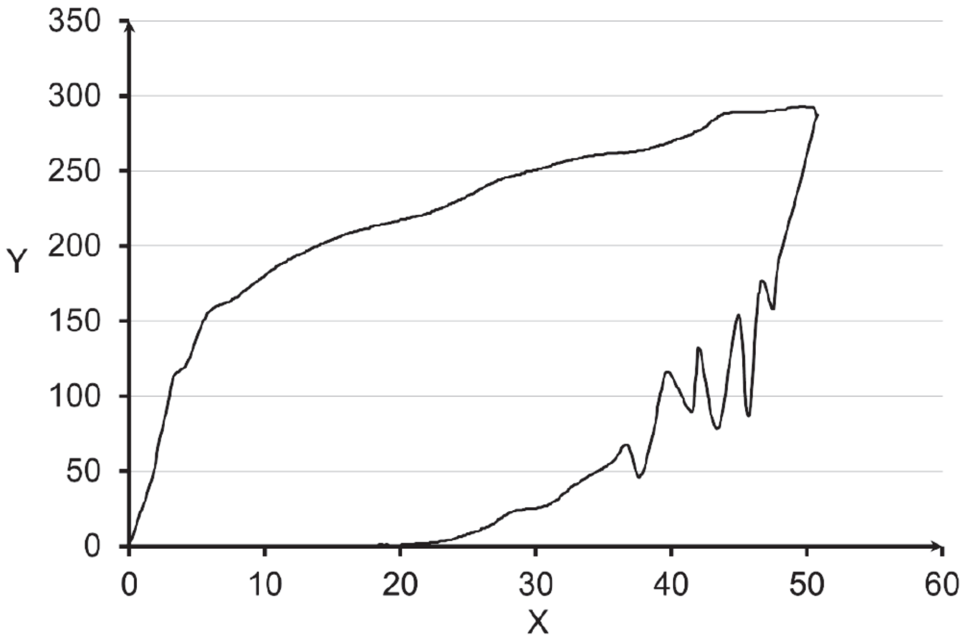


Figure B.1 — Impactor test configuration from the lateral and oblique-lateral shoulder impacts conducted by INRETS (front view)[14] [15] [17]

Ohio State University (OSU) conducted a series of shoulder impact tests[3] [4]. In the first test series, each PMHS was seated on a Teflon sheet on a rigid bench with backrest, as shown in Figure B.2. The 23 kg impactor had a rectangular impact face (203,2 mm wide and 152,4 mm high). The impactor face was padded with a 58-mm-thick piece of Arcel 310 foam (26,4 kg/m^3 density). The characteristics of the padding are presented in Figure B.3.

Figure B.2 — Impactor test configuration from the lateral shoulder impacts conducted by OSU (front view)[3],[4]



Key

X compression in %

Y pressure in kPa

Figure B.3 — Characteristic pressure versus compression curve for Arcel 310 padding tested at 6,0 m/s

The impactor face was centred on the glenohumeral joint. After the first impact, the shoulder was palpated for fractures. If a fracture was detected, the impact velocity for the opposite shoulder was reduced by 10 %. If no fracture was detected, then the impact velocity was increased by 10 %. Each subject was impacted once on each shoulder.

In the second test series of OSU tests (see Figure B.4), four subjects were tested on a rigid bench, in the pure lateral direction, with the same impactor configuration as the first series[4]. Supports were placed under the subject's elbows to position the acromion 25 mm above the spinous process of T1. The impactor face was centred 25 mm below the glenohumeral joint. Each subject was impacted once.

Figure B.4 — Impactor test configuration from the oblique-lateral shoulder impacts conducted by OSU[4] (frontal and overhead views of a 30° impact to the left shoulder of a PMHS)

WSU conducted a series of impactor tests to the shoulder, as shown in Figure B.5 [26] [30]. Each PMHS was seated on a plastic sheet on a wooden seat, without back support. The position of the head was maintained by light tension to webbing that was taped to the subject's head. The webbing was attached to a ring that slid off of a hook during impact to minimize the effect on PMHS movement. The impactor mass was 23 kg and its flat, circular impact face had a diameter of 152,4 mm. The impact face was made of plywood and it was centred on the acromion of the subject. Each PMHS was impacted once in the pure lateral direction.

Figure B.5 — Impactor test configuration from the lateral shoulder impacts conducted by WSU (back view)[26] [30]

Table B.1 summarizes the shoulder impact tests conducted by INRETS, OSU, and WSU that are included in constructing injury risk curves for the shoulder and details all the shoulder impactor test configurations. They are also provided in the related electronic document RED2. It includes the scaled WorldSID results.

Tests selected and for which no WorldSID test results are available for the construction of the injury risk curves are in bold.

Table B.1 — PMHS tests included in constructing injury risk curves for the shoulder

Test performer	Impactor surface	Angle of impact °	Impact speed m/s	Test number	PMHS number	PMHS age	PMHS mass kg	PMHS effective mass kg	Impactor mass kg	Impactor face geometry mm	Max. impact force N	AIS2005 shoulder	Vo50 m/s	Scaled peak shoulder rib deflection mm (CFC600)	Scaled peak shoulder force Y N (CFC1000)
INRETS	R	90	1,41	LCE01	#01	77	67	16,5	23,4	rectangular 150×80 with rounded edges	470	0	1,4		
INRETS	R	105	1,43	LCE02	#01	77	67	14,8	23,4		650	0	1,4		
INRETS	R	75	1,6	LCE03	#01	77	67	13,3	23,4		550	0	1,6		
INRETS	R	270	5,87	LCE04	#01	77	67	11,8	23,4		3 340	2	6,2		
INRETS	R	90	1,27	LCE07	#02	88	33	8,4	23,4		480	0	1,4		
INRETS	R	90	1,39	LCE08	#02	88	33	7,8	23,4		510	0	1,6		
INRETS	R	105	1,51	LCE09	#02	88	33	10,2	23,4		620	0	1,6		
INRETS	R	75	1,58	LCE10	#02	88	33	7,6	23,4		440	0	1,8		
INRETS	R	270	6,07	LCE11	#02	88	33	7,6	23,4		1 960	2	6,8		
INRETS	R	0	1,5	LCE12	#03	79	52	15,3	23,4		550	0	1,5		
INRETS	R	105	1,5	LCE13	#03	79	52	11,3	23,4		530	0	1,6		
INRETS	R	75	1,53	LCE14	#03	79	52	14,5	23,4		450	0	1,6		
INRETS	R	0	1,56	LCE15	#03	79	52	13,8	23,4		570	0	1,6		
INRETS	R	270	4,24	LCE16	#03	79	52	8,3	23,4		1 580	2	4,7		
INRETS	R	0	1,54	LCE17	#04	82	50	9,6	23,4		480	0	1,7		
INRETS	R	105	1,54	LCE18	#04	82	50	9,9	23,4		500	0	1,7		
INRETS	R	75	1,52	LCE19	#04	82	50	NA	23,4		NA	0	1,6		
R rigid															

Table B.1 *(continued)*

Test performer	Impactor surface	Angle of impact °	Impact speed m/s	Test number	PMHS number	PMHS age	PMHS mass kg	PMHS effective mass kg	Impactor mass kg	Impactor face geometry mm	Max. impact force N	AIS2005 shoulder	Vo50 m/s	Scaled peak shoulder rib deflection mm (CFC600)	Scaled peak shoulder force Y N (CFC1000)
INRETS	R	75	1,55	LCE20	#04	82	50	7,5	23,4		410	0	1,7		
INRETS	R	0	1,55	LCE21	#04	82	50	8,6	23,4		450	1	1,7		
INRETS	R	270	4,27	LCE22	#04	82	50	8,7	23,4		1 640	2	4,7		
INRETS	R	0	1,52	LCE23	#05	91	50	9	23,4		550	0	1,7		
INRETS	R	105	1,5	LCE24	#05	91	50	9,9	23,4		580	0	1,6		
INRETS	R	75	1,48	LCE25	#05	91	50	10,7	23,4		470	0	1,6		
INRETS	R	270	2,94	LCE26	#05	91	50	11,1	23,4		1 170	1	3,1		
INRETS	R	0	1,54	LCE27	#06	94	50	10,9	23,4		470	0	1,6		
INRETS	R	105	1,52	LCE28	#06	94	50	13,2	23,4	rectangular 150×80 with rounded edges	520	0	1,6		
INRETS	R	75	1,53	LCE29	#06	94	50	10,2	23,4		380	0	1,6		
INRETS	R	0	1,54	LCE30	#06	94	50	9,7	23,4		480	1	1,7		
INRETS	R	270	2,95	LCE31	#06	94	50	8,7	23,4		1 220	1	3,3		
INRETS	R	0	1,49	LCE32	#07	93	67	7,6	23,4		490	0	1,7		
INRETS	R	105	1,54	LCE33	#07	93	67	7,2	23,4		460	0	1,7		
INRETS	R	75	1,5	LCE34	#07	93	67	8	23,4		450	0	1,7		
INRETS	R	0	1,54	LCE35	#07	93	67	7	23,4		460	0	1,7		
INRETS	R	270	4,09	LCE36	#07	93	67	6,3	23,4		1 710	0	4,7		
OSU	**P**	**270**	**4,33**	**lat01**	**lat01**	**64**	**103**	**NA**	**23**		**NA**	**0**	**4,1**	**33,4**	**NA**
OSU	**P**	**270**	**4,49**	**lat02**	**lat02**	**76**	**57**	**NA**	**23**	rectangular 200 (wide) ×150 (high)	**NA**	**1**	**4,7**	**39,0**	**NA**
OSU	**P**	**270**	**3,95**	**lat03**	**lat03**	**84**	**64**	**NA**	**23**		**NA**	**2**	**4,1**	**33,6**	**NA**
OSU	**P**	**270**	**4,49**	**lat04**	**lat04**	**64**	**64**	**NA**	**23**		**NA**	**0**	**4,6**	**38,2**	**NA**

R rigid

Table B.1 *(continued)*

Test performer	Impactor surface	Angle of impact °	Impact speed m/s	Test number	PMHS number	PMHS age	PMHS mass kg	PMHS effective mass kg	Impactor mass kg	Impactor face geometry mm	Max. impact force N	AIS2005 shoulder	Vo50 m/s	Scaled peak shoulder rib deflection mm (CFC600)	Scaled peak shoulder force Y N (CFC1000)
OSU	P	0	5,08	2009-R1	2009	73	81	NA	23	rectangular 203,2 (wide) ×152,4 (high	2 850	2	5,0		
OSU	P	270	4,1	2009-L2	2009	73	81	NA	23		2 560	1	4,1		
OSU	P	270	4,6	3009-L1	3009	82	73	NA	23		3 250	1	4,6		
OSU	P	0	4,98	3009-R2	3009	82	73	NA	23		3 020	1	5,0		
OSU	P	0	4,48	4009-R1	4009	79	50	NA	23		2 010	2	4,8		
OSU	P	270	4,23	4009-L2	4009	79	50	NA	23		1 550	2	4,6		
OSU	P	270	4,35	5009-L1	5009	40	65	NA	23		2 990	0	4,5		
OSU	P	0	4,73	5009-R2	5009	40	65	NA	23		3 150	0	4,9		
OSU	P	0	4,08	6009-R1	6009	68	50	NA	23		1 920	2	4,4		
OSU	P	270	4,55	6009-L2	6009	68	50	NA	23	rectangular 203,2 (wide) ×152,4 (high)	2 180	2	4,9		
OSU	P	270	3,79	7009-L1	7009	83	49	NA	23		1 770	1	4,1		
OSU	P	0	4,15	7009-R2	7009	83	49	NA	23		1 850	1	4,5		
OSU	P	270	3,71	8009-L2	8009	76	42	NA	23		1 490	1	4,1		
OSU	P	270	5,53	9009-L1	9009	72	79	NA	23		3 050	1	5,5		
OSU	P	0	6,18	9009-R2	9009	72	79	NA	23		3 420	2	6,1		
OSU	P	270	4,05	100009-L2	10009	58	43	NA	23		2 120	1	4,5		
OSU	P	270	6,81	1109-L1	1109	74	89	NA	23		4 080	2	6,6		
OSU	P	0	6,06	1109-R2	1109	74	89	NA	23		4 130	1	5,9		

R rigid

Table B.1 *(continued)*

Test performer	Impactor surface	Angle of impact °	Impact speed m/s	Test number	PMHS number	PMHS age	PMHS mass kg	PMHS effective mass kg	Impactor mass kg	Impactor face geometry mm	Max. impact force N	AIS2005 shoulder	Vo50 m/s	Scaled peak shoulder rib deflection mm (CFC600)	Scaled peak shoulder force Y N (CFC1000)
WSU	**R**	**0**	**4,47**	**01-UM29840**	**UM29840**	**75**	**84**	**NA**	**23**	152,4 mm diameter with flat	**3 561**	**0**	**4,4**	**39,7**	**1 501**
WSU	**R**	**270**	**6,71**	**02-UM29899**	**UM29899**	**80**	**51**	**13,5**	**23**		**3 886**	**2**	**6,9**	**62,4**	**2 362**
WSU	**R**	**0**	**6,68**	**03-UM29844**	**UM29844**	**85**	**65**	**NA**	**23**		**4 361**	**2**	**6,9**	**62,4**	**2 359**
WSU	**R**	**270**	**6,68**	**04-UM29850**	**UM29850**	**47**	**66**	**12,8**	**23**		**4 400**	**2**	**6,9**	**62,7**	**2 374**
WSU	**R**	**270**	**4,49**	**05-UM29852**	**UM29852**	**78**	**96**	**24,3**	**23**		**3 647**	**0**	**4,1**	**36,7**	**1 388**
WSU	**R**	**0**	**4,51**	**06-UM29851**	**UM29851**	**65**	**75**	**13,9**	**23**		**2 544**	**2**	**4,6**	**41,7**	**1 579**
WSU	**R**	**0**	**7,03**	**07-WSU025**	**WSU025**	**63**	**72**	**12,8**	**23**	152,4 mm diameter with flat	**4 483**	**2**	**7,3**	**66,0**	**2 498**
WSU	**R**	**0**	**4,33**	**08-UM30356**	**UM30356**	**47**	**35**	**NA**	**23**		**1 902**	**0**	**4,9**	**44,3**	**1 677**
WSU	**R**	**0**	**6,8**	**09-WSU170**	**WSU170**	**95**	**77**	**11,9**	**23**		**4 863**	**2**	**7,2**	**64,7**	**2 447**
WSU	**R**	**270**	**4,5**	**10-WSU091**	**WSU091**	**80**	**62**	**13,4**	**23**		**2 880**	**0**	**4,6**	**41,9**	**1 586**
WSU	**R**	**270**	**4,53**	**11-WSU164**	**WSU164**	**51**	**59**	**15,4**	**23**		**3 358**	**0**	**4,5**	**41,1**	**1 554**
WSU	**R**	**270**	**6,79**	**12-UM30436**	**UM30436**	**61**	**49**	**11,5**	**23**		**4 101**	**0**	**7,2**	**65,0**	**2 458**
APR	**R**	**0**	**4,6**	**MS201**	**MS201**	**63**	**48**	**NA**	**23**	diameter 150 mm	**3 600**	**0**	**5,0**	**45,2**	**1 708**
APR	**R**	**0**	**4,2**	**MS202**	**MS202**	**73**	**52**	**NA**	**23**		**2 200**	**0**	**4,5**	**40,7**	**1 541**
APR	**R**	**0**	**4,5**	**MS203**	**MS203**	**70**	**49**	**NA**	**23**		**1 600**	**0**	**4,9**	**44,0**	**1 666**
APR	R	75	4,5	MS204	MS204	73	56	NA	23		2 040	0	4,8		

R rigid

Annex C
(informative)

PMHS thorax test data (thorax impactor tests)

Annex C includes the description of the PMHS thoracic impactor tests used in the construction of the injury risk curves.

HSRI conducted a series of impactor tests to the thorax of PMHS, as shown in Figure C.1 [43][44] [45]. Each PMHS was seated upright, with the arms positioned above the shoulder and the hands above the head. The impactor was 23,4 kg and its flat circular impact face had a diameter of 152,4 mm. The impact face was aligned vertically at the junction of the fourth rib and the sternum. In the fore-aft direction, it was aligned midway between the front and the back of the subject. Each PMHS was impacted three times. The first two tests were either a frontal impactor test followed by a lateral impactor test or vice versa. The first two impacts were 0,9 m/s. The third test was either a lateral or a frontal impactor test at higher speed or a lateral sled test. Only one HSRI lateral test was excluded (76T038) due to questionable data.

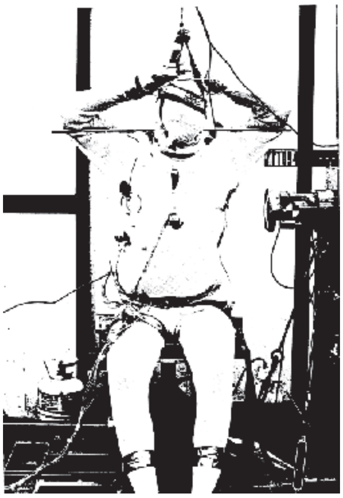


Figure C.1 — Impactor test configuration from the lateral thorax impacts conducted by HSRI (front view)[43] [44] [45]

WSU conducted a series of impactor tests to the thorax of PMHS, as illustrated in Figure C.2 [54] [55]. Each PMHS was suspended in a standing position, with the arms positioned above the shoulder and the hands above the head. The impactor mass was 23,4 kg and its flat circular impact face had a diameter of 152,4 mm and rounded edges. For the thorax impacts, the impact face was aligned vertically 75 mm below mid-sternum and struck at an angle of 30° forward of pure lateral. Only tests WSU935-4 and WSURNY1-3 were included because the injuries could be clearly attributed to the single test that each PMHS was subjected to.

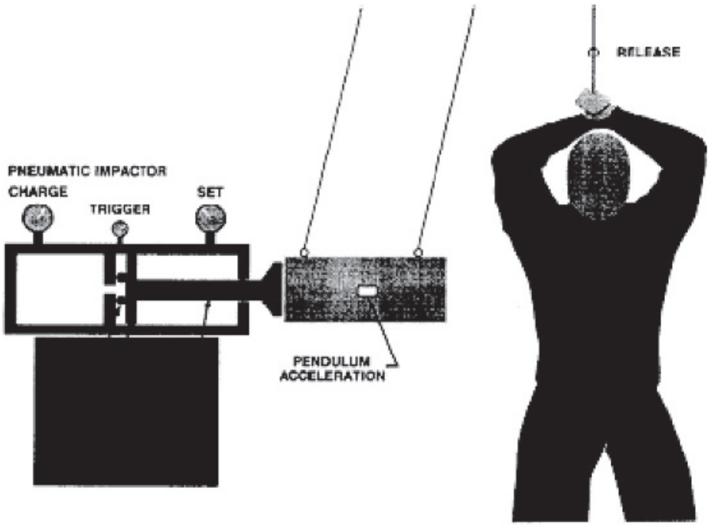


Figure C.2 — Impactor test configuration from the oblique-lateral thorax impacts conducted by WSU (front view)[54] [55]

UMTRI conducted a series of impactor tests to the thorax of PMHS, as illustrated in Figure C.3 [34] [35]. Each PMHS was suspended in a seated position, either with the arms positioned above the shoulder and the hands above the head or with the arms down. The impactor mass was 25 kg and its flat circular impact face had a diameter of 150 mm. The metal impact face had various materials affixed to it to produce different force-time histories and load distributions. The impact face was aligned mid-sternum in the vertical direction and midway between the front and the back of the subject in the fore-aft direction. Each subject was impacted multiple times. The tests at 2 m/s included a frontal impact, an impact at 45° forward of pure lateral, and up to three pure lateral impacts. The final test was a pure lateral impact at 8 m/s. The pure lateral test results were included if all low-speed impacts on a subject measured a peak force below 700 N. This level of load was deemed to be below the threshold of rib fracture and the fractures could be attributed to the final high-speed impact.

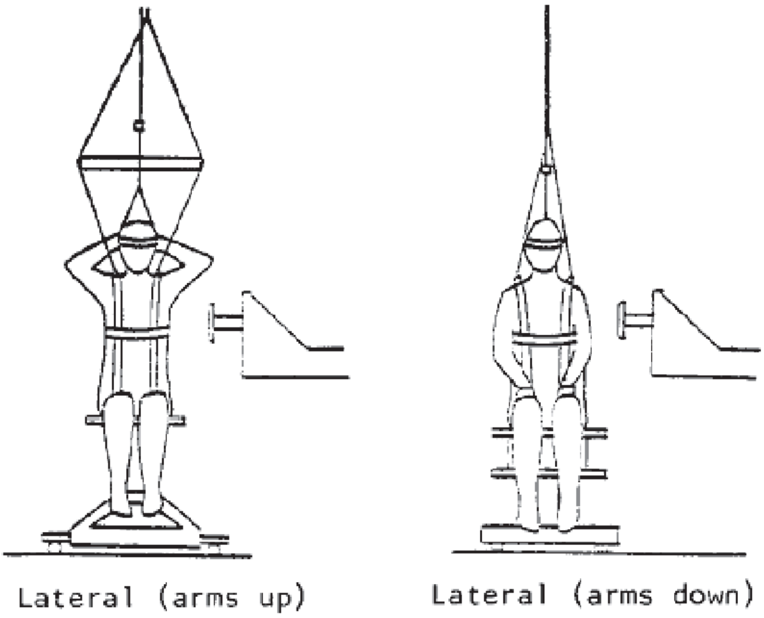


Figure C.3 — Impactor test configuration from the lateral thorax impacts conducted by UMTRI (front view)[34] [35]

OSU conducted a series of impactor tests to the thorax of PMHS, as illustrated in Figure C.4 [49]. Each PMHS was seated, with the arms horizontal and perpendicular to the torso and the forearms taped together on a horizontal support. The impactor mass was 23 kg and its flat circular impact face had a diameter of 152,4 mm, with an edge radius of 12,7 mm. The impact face was aligned vertically with the fourth interspace of the sternum. Each subject was impacted twice at a speed of approximately 2,5 m/s. One side of the subject was impacted in the pure lateral direction and the other side was impacted 30° forward of pure lateral. The order of the impacts was varied. The results were included if no fractures were found during autopsy or if the first impact on a subject measured a peak force below 700 N, both for the lateral and the oblique impacts. This level of load was deemed to be below the threshold of rib fracture and the fractures could be attributed to the second impact.

Figure C.4 — Impactor test configuration from the lateral and oblique-lateral thorax impacts conducted by OSU (front view)[49]

INRETS conducted a series of thorax impactor tests as illustrated in Figure B.1 [16]. The results of the INRETS tests were excluded because it was not possible to determine whether the fractures resulted from the shoulder impact or the thorax impact.

Table C.1 summarizes the HSRI, WSU, UMTRI, and OSU tests that are included in constructing injury risk curves for the thorax and details of all the thorax impactor test configurations. They are also provided in the related electronic document RED3. It includes the scaled WorldSID results.

Tests selected and for which no WorldSID test results are available for the construction of the injury risk curves are in bold.

Table C.1 — PMHS tests included in constructing injury risk curves for the thorax

Test performer	Impactor surface	Angle of impact °	Impact speed m/s	Test number	PMHS number	PMHS age	PMHS mass kg	PMHS effective mass kg	Impactor mass kg	Impactor face geometry	Max. impact force kN	Thorax skeletal AIS2005	Thoracic soft tissue AIS2005	Vo50 for deflection and force m/s	Vo50 for VC m/s	Scaled peak thoracic rib deflection mm (IR-TRACC 1D) (CFC600)	Scaled peak thoracic rib VC m/s (IR-TRACC 1D) (CFC180 for deflection) (thorax breadth = 170 mm)
WSU	R	300	5,99	WSU935-4	WSU935	63	69,9		23,4		2 241	3		6,15	6,07		
WSU	R	300	8,70	WSURNY1-3	WSURNY1	76	44		23,4		5 543	4		10,01	9,33		
HSRI	R	270	0,90	76T033	76T034	62	59	NA	23,4	diameter 152,4 mm	423	0		0,96	0,93		
HSRI	R	270	0,91	76T041	76T042	58	64,5	NA	23,4		305	0		0,95	0,93		
HSRI	R	270	0,90	76T049	20597	61	83	NA	23,4		265	0		0,88	0,89		
HSRI	R	270	0,90	76T051	20606	63	105	NA	23,4		422	0		0,82	0,86		
HSRI	R	270	0,90	76T054	20616	40	70	NA	23,4		236	0		0,92	0,91		
HSRI	R	270	0,90	76T057	20615	76	88	NA	23,4		402	0		0,86	0,88		
HSRI	R	270	0,90	76T061	20621	69	50,1	20,2	23,4		388	0		1,00	0,95		
HSRI	**R**	**270**	**4,25**	**76T062**	**20621**	**69**	**50,1**	**21,2**	**23,4**		**1 957**	**3**	**3**	**4,66**	**4,45**	**39,5**	**0,51**
HSRI	R	270	0,90	76T064	20629	63	94,7	33	23,4		544	0		0,88	0,89		
HSRI	**R**	**270**	**4,26**	**76T065**	**20629**	**63**	**94,7**	**31,2**	**23,4**		**3 355**	**0**	**0**	**4,23**	**4,24**	**35,8**	**0,47**
HSRI	R	270	0,91	77T066	20761	52	62	22,2	23,4		396	0		0,99	0,95		
HSRI	R	270	0,91	77T070	20765	60	80,7	47	23,4		555	0		0,80	0,85		

P10: 10 cm Ensolite

P0.5: 0,5 cm Ensolite

NA: Not Available

Table C.1 *(continued)*

Test performer	Impactor surface	Angle of impact °	Impact speed m/s	Test number	PMHS number	PMHS age	PMHS mass kg	PMHS effective mass kg	Impactor mass kg	Impactor face geometry	Max. impact force kN	Thorax skeletal AIS2005	Thoracic soft tissue AIS2005	Vo50 for deflection and force m/s	Vo50 for VC m/s	Scaled peak thoracic rib deflection mm (IR-TRACC 1D) (CFC600)	Scaled peak thoracic rib VC m/s (IR-TRACC 1D) (CFC180 for deflection) (thorax breadth = 170 mm)
HSRI	**R**	**270**	**4,34**	**77T071**	**20765**	**60**	**80,7**	**40,6**	**23,4**	diameter 152,4 mm	**2 683**	**0**	**3**	**3,98**	**4,16**	**33,7**	**0,45**
HSRI	R	270	0,90	77T073	20774	60	54	26,7	23,4		533	0		0,93	0,92		
HSRI	**R**	**270**	**4,25**	**77T074**	**20774**	**60**	**54**	**27**	**23,4**		**2 320**	**2**	**0**	**4,39**	**4,32**	**37,1**	**0,48**
HSRI	R	270	0,90	77T076	20777	79	73,7	31,4	23,4		493	0		0,89	0,90		
HSRI	R	270	6,11	77T077	20777	79	73,7	33,5	23,4		3 261	3		5,94	6,02		
HSRI	R	270	0,90	77T081	20800	60	64	36,2	23,4		454	1		0,85	0,88		
HSRI	R	270	0,92	77T084	20806	54	78	32	23,4		305	3		0,91	0,91		
HSRI	R	270	0,90	77T088	20818	66	55	32	23,4		434	0		0,89	0,89		
HSRI	R	0	0,90	77T090	20822	45	58	20,4	23,4		229	0		1,00	0,95		
HSRI	R	270	0,91	77T091	20822	45	58	24,5	23,4		227	0		0,96	0,94		
HSRI	R	270	0,90	77T094	20837	77	93	34,1	23,4		471	0		0,87	0,89		
HSRI	R	270	0,90	77T097	20853	71	59	32,4	23,4		318	0		0,88	0,89		

P10: 10 cm Ensolite

P0.5: 0,5 cm Ensolite

NA: Not Available

Table C.1 *(continued)*

Test performer	Impactor surface	Angle of impact °	Impact speed m/s	Test number	PMHS number	PMHS age	PMHS mass kg	PMHS effective mass kg	Impactor mass kg	Impactor face geometry	Max. impact force kN	Thorax skeletal AIS2005	Thoracic soft tissue AIS2005	Vo50 for deflection and force m/s	Vo50 for VC m/s	Scaled peak thoracic rib deflection mm (IR-TRACC 1D) (CFC600)	Scaled peak thoracic rib VC m/s (IR-TRACC 1D) (CFC180 for deflection) (thorax breadth = 170 mm)
UMTRI	R	270	1,92	82E006	0	60	52	NA	25	diameter 150 mm	701	0		2,12	2,02		
UMTRI	P10	270	8,41	82E007	0	60	52	NA	25		NA	3		9,26	8,82		
UMTRI	P0.5	270	2,01	82E025	20	67	77	NA	25		494	0		2,01	2,01		
UMTRI	P0.5	270	2,01	82E026	20	67	77	NA	25		496	0		2,01	2,01		
UMTRI	P0.5	270	8,49	82E027	20	67	77	NA	25		9 112	3		8,48	8,49		
UMTRI	P0.5	270	2,01	82E045	40	65	87	NA	25		564	0		1,94	1,98		
UMTRI	P0.5	270	2,01	82E046	40	65	87	NA	25		347	0		1,94	1,98		
UMTRI	P10	270	2,01	82E047	40	65	87	NA	25		390	0		1,94	1,98		
UMTRI	P10	270	8,49	82E048	40	65	87	NA	25		7 118	3		8,19	8,34		
UMTRI	P0.5	270	2,01	82E065	60	60	67	NA	25		515	0		2,08	2,05		
UMTRI	P0.5	270	8,49	82E066	60	60	67	NA	25		NA	3		8,80	8,65		
OSU	R	300	2,58	0503OTH25L01	OT0503	79	65,8	24,9	23	diameter 152,4 mm with a radius of 12,7 mm	1 041	0		2,72	2,73	NA	NA
OSU	**R**	**90**	**2,51**	**0503LTH25R01**	**OT0503**	**79**	**65,8**	**15,1**	**23**		**1 211**	**0**	**0**	**2,97**	**2,73**	**28,3**	**0,20**
OSU	**R**	**270**	**2,43**	**0504LTH25L01**	**OT0504**	**80**	**80,7**	**18,2**	**23**		**1 185**	**0**	**0**	**2,77**	**2,59**	**26,3**	**0,18**
OSU	R	60	2,61	0504OTH25R02	OT0504	80	80,7	21,9	23		1 123	0		2,85	2,73	NA	NA
OSU	**R**	**270**	**2,48**	**0507LTH25R01**	**OT0507**	**53**	**65,3**	**13,9**	**23**		**945**	**0**	**0**	**2,98**	**2,72**	**28,4**	**0,20**
OSU	R	60	2,57	0507OTH25L01	OT0507	53	65,3	20,9	23		815	0		2,77	2,62	NA	NA
OSU	**R**	**90**	**2,48**	**0602LTH25R01**	**OT0602**	**79**	**74,8**	**19,7**	**23**		**972**	**0**	**0**	**2,8**	**2,64**	**26,7**	**0,19**
OSU	R	300	2,44	0602OTH25L01	OT0602	79	74,8	25,2	23		843	0		2,6	2,52	NA	NA

P10: 10 cm Ensolite

P0.5: 0,5 cm Ensolite

NA: Not Available

Annex D
(informative)

PMHS abdomen test data (abdomen impactor tests)

Annex D includes the description of the PMHS abdomen impactor tests used in the construction of the injury risk curves.

WSU conducted a series of impactor tests to the abdomen of PMHS [54] [55]. Only one test (WSU063-34) was included because all the other subjects were impacted more than once in the abdomen and/or thorax. The PMHS was suspended in a standing position, with the arms positioned above the shoulder and the hands above the head. The impactor mass was 23,4 kg and its flat, circular impact face had a diameter of 152,4 mm, with rounded edges. The impact face was aligned vertically 150 mm below mid-sternum and struck at an angle of 30° forward of pure lateral.

OSU conducted a series of abdomen impact tests [47]. Each PMHS was seated, with the arms positioned above the shoulder and the hands above the head, as shown in Figure D.1. The impactor mass was 9,1 kg and its flat, rectangular impact face was 200 mm wide and 150 mm high. The impactor face was padded with a 152,4-mm-thick piece of foam, either Arcel 310 (1,5 lb/f^3), Ethafoam LC-200, or Arcel 310 (3 lb/f^3). The impactor face was centred at the height of the lateral aspect of the eighth rib. Each subject was impacted once in the pure lateral direction. The impact speed was selected such that the abdomen deflection would not exceed 16 % of the PMHS chest breadth. The results from two subjects (93VRTAB08, 93VRTAB09) were excluded because the abdomen deflection exceeded the target level of 16 % of the chest breadth.

Figure D.1 — Impactor test configuration from the lateral abdomen impacts conducted by OSU (forward oblique view)[47]

The Laboratory of Accidentology and Biomechanics (LAB) conducted a series of impactor tests to the abdomen of PMHS[52]. A measurement system was positioned at the level of the liver and could have influenced the abdominal injuries. Therefore, the results from this series were excluded.

Table D.1 summarizes the single WSU test and the OSU tests that are included in constructing injury risk curves for the abdomen and details of all the abdomen impactor test configurations. They are also provided in the related electronic document RED4. No WorldSID test results were available for these test conditions at the time when this Technical Report was published. This annex is kept for future use.

Table D.1 — PMHS tests included in constructing injury risk curves for the abdomen

Test performer	Impactor surface	Angle of impact °	Impact speed m/s	Test number	PMHS number	PMHS age	PMHS mass kg	PMHS effective mass kg	Impactor mass kg	Impactor face geometry	Max. impact force kN	Abdomen AIS2005	Vo50 for deflection and acceleration m/s	Vo50 for VC m/s	Scaled peak abdomen rib deflection mm (IR-TRACC 1D) (CFC600)	Scaled peak abdomen rib VC mm (IR-TRACC 1D) (CFC180 for deflection) (abdomen breadth = 170 mm)	Scaled lower spine acceleration 3 ms m/s² (CFC180)
WSU	Rigid	60	9,8	WSU063-34	WSU63	64	48,5	NA	23,4		6 870	3	11,2	10,5			
OSU	Arcel 310 (1,5 lb/f³)	90	9,7	93VRTAB01	3515	59	49,9	23	9,1	flat, rectangular 150 mm high × 200 mm wide	4 411	2	11,8	10,7			
OSU	Ethafoam LC-200	90	9,7	93VRTAB02	9302	70	98,4	32	9,1		4 651	2	10,5	10,1			
OSU	Arcel 310 (3 lb/f³)	90	9,0	94VRTAB03	9303	73	86,2	63	9,1		4 592	2	7,3	8,1			
OSU	Ethafoam LC-200	90	6,0	94VRTAB04	9304	69	49,9	24,8	9,1		2 601	2	7,1	6,5			
OSU	Arcel 310 (1,5 lb/f³)	90	6,3	94VRTAB05	9305	69	61,7	NA	9,1		2 241	2	6,9	6,6			
OSU	Ethafoam LC-200	90	11,1	95VRTAB06	9306	80	45,4	10,7	9,1		14 265	2	17,2	13,8			
OSU	Ethafoam LC-200	90	12,3	95VRTAB07	9307	57	80,3	62.5	9,1		16 051	0	10,0	11,1			

Annex E
(informative)

PMHS pelvis test data (pelvis impactor tests)

Annex E includes the description of the PMHS pelvis impactor tests used in the construction of the injury risk curves.

WSU conducted a series of impactor tests to the pelvis of PMHS [54] [55]. Each PMHS was suspended in a standing position, with the arms positioned above the shoulder and the hands above the head. The impactor mass was 23,4 kg and its flat, circular impact face had a diameter of 152,4 mm, with rounded edges. For the pelvis impacts, the impact face was centred on the greater trochanter. Each subject was impacted up to three times in the pure lateral direction.

UMTRI conducted a series of impactor tests to the pelvis of PMHS, as illustrated in Figure E.1 [33] [36]. Each PMHS was suspended in a seated position and, for some of the tests, seated on a block of balsa wood upon a mobile table. The arms were down and the hands were positioned on the lap. The impactor mass was 20 kg, 25 kg, or 56 kg and its flat, circular impact face had a diameter of 150 mm. The metal impact face had various materials affixed to it to produce different force-time histories and load distributions. The impact face was aligned 80 mm anterior to the greater trochanter. Some subjects were impacted once or twice in the pure lateral direction, and others were subjected to a frontal impact to the knee prior to a pure lateral impact to the pelvis.

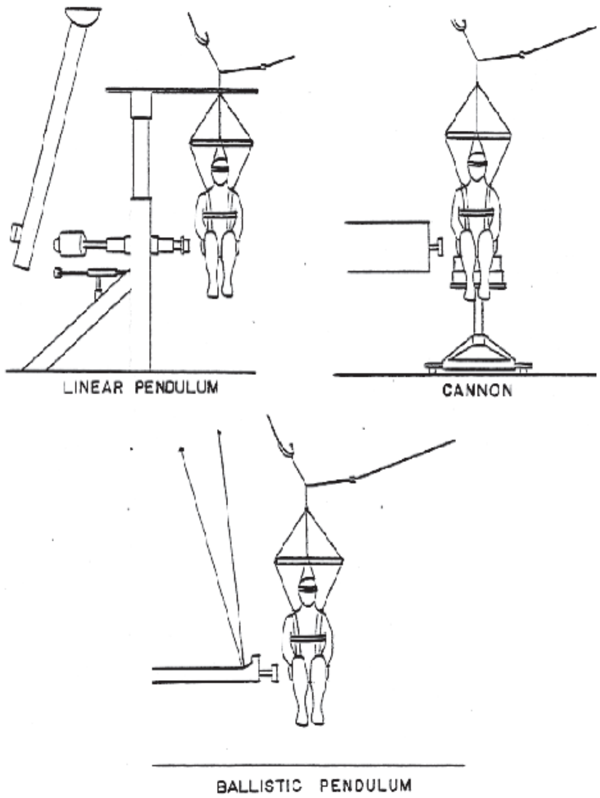


Figure E.1 — Impactor test configuration from the lateral pelvis impacts conducted by UMTRI (front view)[33] [36]

ONSER conducted a series of impactor tests to the pelvis of PMHS, as illustrated in Figure E.2 [11] [12]. Each PMHS was seated on a rigid seat. The arms were down and the hands were positioned on the lap.

The impactor mass was 17,3 kg. The impact face was a segment of a sphere (R=175 mm, r=60 mm) and it was either rigid or padded. The impact face was aligned on the greater trochanter. Each subject was impacted multiple times on the right side in a pure lateral direction. After each impact, x-ray was conducted to check for fractures. If the x-ray revealed no fractures, then the velocity was increased. If the x-ray revealed a fracture, then no additional tests were conducted on that subject.

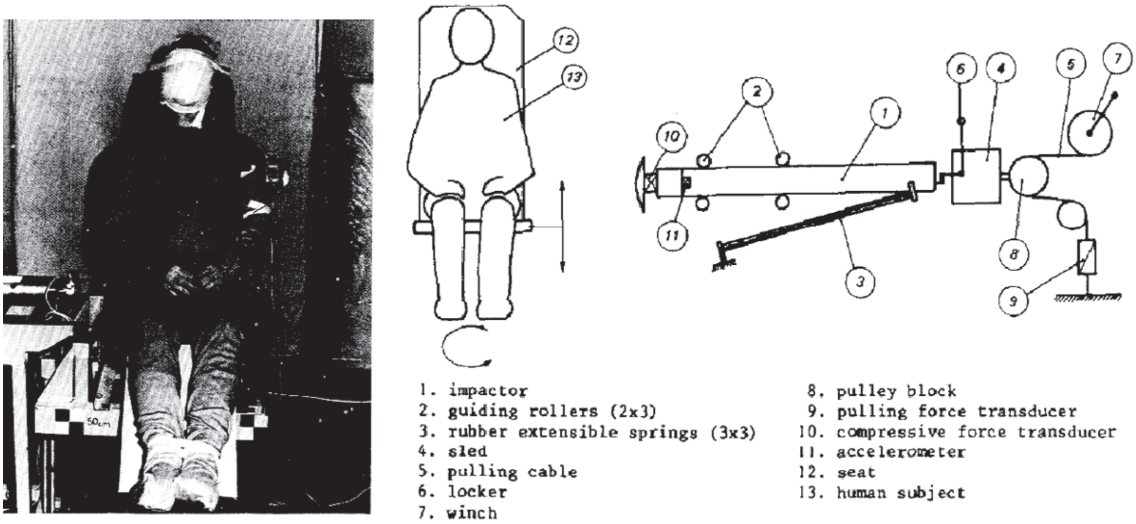


Figure E.2 — Impactor test configuration from the lateral pelvis impacts conducted by ONSER (front view)[11] [12]

INRETS conducted two series of pelvis impact tests[5]. In the first series, each PMHS was seated on a Teflon sheet on a rigid seat. The impactor mass was 23,4 kg and its flat, rectangular impact face was 200 mm wide and 100 mm high. The impactor was centred on the greater trochanter. Each subject was impacted twice, on the same side, once at 3,5 m/s and once at 6,5 m/s. All of the results from INRETS first test series were included in the construction of injury risk curves for the pelvis.

In the second series of INRETS tests[6], the same test setup was used, but the impactor mass was either 12 kg or 16 kg and the impact speed was higher (9 m/s to 14 m/s). Each subject was impacted once. All of the results from INRETS second test series were included in the construction of injury risk curves for the pelvis.

The pelvis multi-impact tests were included when an increase in impactor speed was accompanied by an increase in energy, as this was assumed to be an indication of no injury.

Table E.1 summarizes the WSU, UMTRI, ONSER, and INRETS tests that could be included in constructing injury risk curves for the pelvis and details of all the pelvis impactor test configurations. They are also provided in the related electronic document RED5. It includes the scaled WorldSID results. No dummy tests were conducted with padding that was identical to that used in the PMHS tests.

Tests selected and for which no WorldSID test results are available for the construction of the injury risk curves are in bold.

Table E.1 — PMHS tests included in constructing injury risk curves for the pelvis

Test performer	Impactor surface	Angle of impact °	Impact speed m/s	Impactor mass kg	Test number	PMHS number	PMHS age	PMHS mass kg	PMHS effective mass kg	Impactor face geometry	Max. impact force kN	Pelvis AIS2005	Vo50 for force and acceleration m/s	Scaled peak pubic force N (CFC1000)	Scaled pelvis acceleration 3 ms m/s^2 (CFC1000)
WSU	no	270	6,8	23,4	WSU956-13	WSU956	40	76,2	NA	diameter 150 mm with rounded edges	5 677	0	6,8	NA	444
WSU	no	270	8,5	23,4	WSU993-16	WSU993	49	70,8	NA		10 853	0	8,7	NA	565
WSU	no	270	5,1	23,4	WSU986-21	WSU986	29	70,3	NA		6 413	0	5,2	NA	340
WSU	no	90	9,6	23,4	WSU986-22	WSU986	29	70,3	NA		12 218	0	9,8	NA	640
WSU	no	90	5,3	23,4	WSU047-25	WSU047	62	83,9	NA		6 937	0	5,2	NA	338
WSU	no	270	5,3	23,4	WSU047-26	WSU047	62	83,9	NA		7 306	0	5,2	NA	338
WSU	no	270	9,9	23,4	WSU047-27	WSU047	62	83,9	NA		12 858	0	9,7	NA	631

PA: 2,5 cm Ensolite + 1,3 cm Styrofoam

PB: 0,5 cm Ensolite

PC: 2,5 cm Ensolite + 2,5 cm Styrofoam

PD: 5,0 cm Foam + 2,5 cm A.L. Ensolite

PE: 2,5 cm Styrofoam

PF: 7,5 cm A.L. Ensolite + 2,5 cm Styrofoam

Table E.1 *(continued)*

Test performer	Impactor surface	Angle of impact °	Impact speed m/s	Impactor mass kg	Test number	PMHS number	PMHS age	PMHS mass kg	PMHS effective mass kg	Impactor face geometry	Max. impact force kN	Pelvis AIS2005	Vo50 for force and acceleration m/s	Scaled peak pubic force N (CFC1000)	Scaled pelvis acceleration 3 ms m/s^2 (CFC1000)
WSU	no	270	5,1	23,4	WSU008-31	WSU008	52	53,1	NA	diameter 150 mm with rounded edges	4 391	0	5,5	NA	362
WSU	no	90	9,5	23,4	WSU008-32	WSU008	52	53,1	NA		9 370	2	10,3	NA	674
WSU	no	270	10,1	23,4	WSU063-35	WSU63	64	48,5	NA		10 084	2	11,2	NA	730
WSU	no	270	4,2	23,4	WSU-UOMI-38	WSUUOMI	37	67,6	NA		4 261	0	4,3	NA	282
WSU	no	90	10,3	23,4	WSU-UOMI-39	WSUUOMI	37	67,6	NA		12 481	0	10,6	NA	693
WSU	no	90	3,98	23,4	WSU-UOM2-44	WSU-UOM2	64	75,8	NA		3 286	0	4,0	NA	260
WSU	no	270	6,7	23,4	WSU-UOM2-45	WSU-UOM2	64	75,8	NA		7 935	0	6,7	NA	438

PA: 2,5 cm Ensolite + 1,3 cm Styrofoam

PB: 0,5 cm Ensolite

PC: 2,5 cm Ensolite + 2,5 cm Styrofoam

PD: 5,0 cm Foam + 2,5 cm A.L. Ensolite

PE: 2,5 cm Styrofoam

PF: 7,5 cm A.L. Ensolite + 2,5 cm Styrofoam

Table E.1 *(continued)*

Test performer	Impactor surface	Angle of impact °	Impact speed m/s	Impactor mass kg	Test number	PMHS number	PMHS age	PMHS mass kg	PMHS effective mass kg	Impactor face geometry	Max. impact force kN	Pelvis AIS2005	Vo50 for force and acceleration m/s	Scaled peak pubic force N (CFC1000)	Scaled pelvis acceleration 3 ms m/s^2 (CFC1000)
UMTRI	PA	90	8,40	25	82E008	0	60	52	18	diameter 150 mm	11 654		9,0		
UMTRI	PB	90	8,40	25	82E028	20	67	77	39		13 788		7,3		
UMTRI	PC	90	8,60	25	82E049	40	65	87	43		13 370		7,3		
UMTRI	PD	90	20,0	20	82E051	50	60	67	NA		27 870		20,7		
UMTRI	PE	90	22,0	20	82E052	50	60	67	NA		23 040		22,8		
UMTRI	PE	?	26,0	20	82E053	50	60	67	NA		NA		26,9		
UMTRI	no	90	6,00	25	82E067	60	60	67	NA		NA		6,2		
UMTRI	PF	90	26,0	20	82E071	70	61	55	NA		43 694		28,3		
UMTRI	no	90	7,20	25	83E088	80	44	72	NA		3 980		7,3		
UMTRI	PC	90	10,2	20	83E091	89	62	76	NA		11 396		10,2		
UMTRI	PC	90	9,20	20	83E093	90	51	68	NA		24 027		9,5		
UMTRI	PH	90	5,10	56	80L095	4	63	106	NA		NA		4,8		
UMTRI	PH	90	5,70	56	80L099	5	67	35,3	NA		NA		6,2		
UMTRI	no	90	5,80	56	80L104	6	89	65,9	NA		NA		5,9		
UMTRI	no	90	5,80	56	80L111	7	76	68,1	NA		NA		5,9		
UMTRI	no	90	5,70	56	80L116	8	76	91,7	NA		NA		5,5		
UMTRI	no	90	5,90	56	80L121	9	66	41,6	NA		NA		6,4		
UMTRI	no	90	5,80	56	80L126	10	73	61,9	NA		NA		6,0		
UMTRI	no	90	5,50	56	80L131	11	56	91,2	NA		NA		5,3		
UMTRI	no	90	5,90	56	80L137	19	40	68,3	NA		NA		6,0		

PA: 2,5 cm Ensolite + 1,3 cm Styrofoam

PB: 0,5 cm Ensolite

PC: 2,5 cm Ensolite + 2,5 cm Styrofoam

PD: 5,0 cm Foam + 2,5 cm A.L. Ensolite

PE: 2,5 cm Styrofoam

PF: 7,5 cm A.L. Ensolite + 2,5 cm Styrofoam

Table E.1 *(continued)*

Test performer	Impactor surface	Angle of impact °	Impact speed m/s	Impactor mass kg	Test number	PMHS number	PMHS age	PMHS mass kg	PMHS effective mass kg	Impactor face geometry	Max. impact force kN	Pelvis AIS2005	Vo50 for force and acceleration m/s	Scaled peak pubic force N (CFC1000)	Scaled pelvis acceleration 3 ms m/s^2 (CFC1000)
ONSER	no	90	5,83	17,3	A1	A	70	58	NA	175 mm radius, 120 mm outer diameter	NA	0	6,3	1 139	272
ONSER	no	90	7,22	17,3	A2	A	70	58	NA		NA	0	7,8	1 410	336
ONSER	no	90	8,33	17,3	A3	A	70	58	NA		NA	0	9,0	1 698	415
ONSER	no	90	11,4	17,3	A4	A	70	58	NA		NA	3	12,3	2 321	568
ONSER	no	90	5,83	17,3	B1	B	84	70	NA		NA	0	6,0	1 083	258
ONSER	no	90	8,33	17,3	B2	B	84	70	NA		NA	2	8,5	1 614	395
ONSER	no	90	9,72	17,3	B3	B	84	70	NA		NA	3	10	1 884	461
ONSER	no	90	7,11	17,3	C1	C	69	78	NA		4 790	0	7,1	1 280	305
ONSER	no	90	8,89	17,3	C2	C	69	78	NA		8 046	0	8,8	1 670	409
ONSER	no	90	6,94	17,3	D1	D	63	52	14,7		4 019	0	7,9	1 426	340
ONSER	no	90	8,54	17,3	D2	D	63	52	21,3		4 069	0	8,8	1 667	408
ONSER	no	90	7,00	17,3	E1	E	72	60	17,3		4 547	0	7,6	1 383	330
ONSER	no	90	7,86	17,3	F1	F	59	55	NA		NA	0	8,6	1 556	371
ONSER	no	90	7,08	17,3	H1	H	69	86	NA		5 856	0	6,8	1 238	295
ONSER	no	90	8,39	17,3	H2	H	69	86	NA		9 537	0	8,1	1 531	375

PA: 2,5 cm Ensolite + 1,3 cm Styrofoam

PB: 0,5 cm Ensolite

PC: 2,5 cm Ensolite + 2,5 cm Styrofoam

PD: 5,0 cm Foam + 2,5 cm A.L. Ensolite

PE: 2,5 cm Styrofoam

PF: 7,5 cm A.L. Ensolite + 2,5 cm Styrofoam

Table E.1 *(continued)*

Test performer	Impactor surface	Angle of impact °	Impact speed m/s	Impactor mass kg	Test number	PMHS number	PMHS age	PMHS mass kg	PMHS effective mass kg	Impactor face geometry	Max. impact force kN	Pelvis AIS2005	Vo50 for force and acceleration m/s	Scaled peak pubic force N (CFC1000)	Scaled pelvis acceleration 3 ms m/s^2 (CFC1000)
ONSER	no	90	9,61	17,3	H3	H	69	86	37,5	175 mm radius, 120 mm outer diameter	9 319	0	8,3	1 575	385
ONSER	no	90	7,06	17,3	I1	I	65	63	16,1		8 878	0	7,8	1 420	339
ONSER	no	90	8,41	17,3	I2	I	65	63	17,8		10 490	0	9,1	1 722	421
ONSER	no	90	9,88	17,3	I3	I	65	63	18,4		9 448	0	10,6	2 006	491
ONSER	no	90	11,1	17,3	I4	I	65	63	17,6		10 804	0	12	2 269	555
ONSER	no	90	11,1	17,3	I5	I	65	63	15,5		10 337	2	12,5	2 358	577
ONSER	no	90	7,06	17,3	J1	J	75	63	16,6		5 894	0	7,8	1 409	336
ONSER	no	90	6,94	17,3	K1	K	75	55	NA		NA	0	7,6	1 374	328
ONSER	no	90	8,55	17,3	K2	K	75	55	NA		NA	0	9,3	1 766	432
ONSER	no	90	9,81	17,3	K3	K	75	55	NA		NA	0	10,7	2 026	496
ONSER	no	90	8,27	17,3	L1	L	71	85	18,9		7 533	0	8,8	1 667	408
ONSER	no	90	9,70	17,3	L2	L	71	85	20,6		8 916	0	10,1	1 911	467
ONSER	no	90	11,0	17,3	L3	L	71	85	21,8		10 926	0	11,3	2 134	522
ONSER	no	90	12,4	17,3	L4	L	71	85	17,3		13 323	0	13,5	2 555	625
ONSER	no	90	6,14	17,3	M3	M	68	62	NA		NA	2	6,5	1 178	281

PA: 2,5 cm Ensolite + 1,3 cm Styrofoam

PB: 0,5 cm Ensolite

PC: 2,5 cm Ensolite + 2,5 cm Styrofoam

PD: 5,0 cm Foam + 2,5 cm A.L. Ensolite

PE: 2,5 cm Styrofoam

PF: 7,5 cm A.L. Ensolite + 2,5 cm Styrofoam

Table E.1 *(continued)*

Test performer	Impactor surface	Angle of impact °	Impact speed m/s	Impactor mass kg	Test number	PMHS number	PMHS age	PMHS mass kg	PMHS effective mass kg	Impactor face geometry	Max. impact force kN	Pelvis AIS2005	Vo50 for force and acceleration m/s	Scaled peak pubic force N (CFC1000)	Scaled pelvis acceleration 3 ms m/s² (CFC1000)
ONSER	no	90	9,17	17,3	N5	N	54	86	NA	175 mm radius, 120 mm outer diameter	8 094	0	8,9	1 673	409
ONSER	no	90	10,5	17,3	N6	N	54	86	NA		9 073	0	10,1	1 911	467
ONSER	no	90	9,12	17,3	O4	O	70	79	NA		5 400	0	9,0	1 707	418
ONSER	no	90	10,5	17,3	O5	O	70	79	NA		5 294	0	10,4	1 966	481
ONSER	no	90	11,7	17,3	O6	O	70	79	NA		6 010	4	11,6	2 194	537
ONSER	no	90	10,1	17,3	R1	R	80	82	NA		8 549	0	9,9	1 877	459
ONSER	no	90	11,0	17,3	R2	R	80	82	NA		9 261	0	10,8	2 037	498
ONSER	no	90	12,1	17,3	R3	R	80	82	NA		8 876	0	11,8	2 232	546
ONSER	no	90	13,1	17,3	R4	R	80	82	NA		10 013	0	12,8	2 425	593
ONSER	no	90	14,0	17,3	R5	R	80	82	NA		10 022	4	13,8	2 599	636
ONSER	no	90	10,0	17,3	S1	S	79	64	NA		NA	0	10,5	1 992	487
ONSER	no	90	10,0	17,3	S2	S	79	64	NA		5 986	0	10,5	1 986	486
ONSER	no	90	9,61	17,3	T2	T	79	44	10.6		3 764	2	11,7	2 207	540
ONSER	no	90	7,69	17,3	V2	V	61	50	18.4		5 276	3	8,3	1 497	357
ONSER	no	90	8,33	17,3	W2	W	85	68	16.9		6 114	3	9,2	1 729	423

PA: 2,5 cm Ensolite + 1,3 cm Styrofoam

PB: 0,5 cm Ensolite

PC: 2,5 cm Ensolite + 2,5 cm Styrofoam

PD: 5,0 cm Foam + 2,5 cm A.L. Ensolite

PE: 2,5 cm Styrofoam

PF: 7,5 cm A.L. Ensolite + 2,5 cm Styrofoam

Table E.1 *(continued)*

Test performer	Impactor surface	Angle of impact °	Impact speed m/s	Impactor mass kg	Test number	PMHS number	PMHS age	PMHS mass kg	PMHS effective mass kg	Impactor face geometry	Max. impact force kN	Pelvis AIS2005	Vo50 for force and acceleration m/s	Scaled peak pubic force N (CFC1000)	Scaled pelvis acceleration 3 ms m/s^2 (CFC1000)
INRETS	no	90	11,4	12	LCB01	LCB01	65	54,5		square 200 mm × 200 mm	12 802		12,7		
INRETS	no	90	9,91	16	LCB02	LCB02	53	78			8 784		9,9		
INRETS	no	90	10	16	LCB03	LCB03	80	30			7 324		1,5		
INRETS	no	90	10	12	LCB04	LCB04	93	43			8 034		11,9		
INRETS	no	90	13,4	12	LCB05	LCB05	84	42			11 270		16		
INRETS	no	90	13,7	12	LCB06	LCB06	77	67,5			14 835		14,3		
INRETS	no	90	11,5	16,2	LCB07	LCB07	72	82			16 028		11,3		
INRETS	no	90	11,8	16,2	LCB08	LCB08	66	59			NA		12,7		
INRETS	no	90	9,47	16,2	LCB09	LCB09	65	66			10 292		9,9		
INRETS	no	90	10,4	12	LCB10	LCB10	69	56			1 564		11,5		
INRETS	no	90	11,8	12	LCB11	LCB11	71	71			11 553		12,1		

PA: 2,5 cm Ensolite + 1,3 cm Styrofoam

PB: 0,5 cm Ensolite

PC: 2,5 cm Ensolite + 2,5 cm Styrofoam

PD: 5,0 cm Foam + 2,5 cm A.L. Ensolite

PE: 2,5 cm Styrofoam

PF: 7,5 cm A.L. Ensolite + 2,5 cm Styrofoam

Table E.1 *(continued)*

Test performer	Impactor surface	Angle of impact °	Impact speed m/s	Impactor mass kg	Test number	PMHS number	PMHS age	PMHS mass kg	PMHS effective mass kg	Impactor face geometry	Max. impact force kN	Pelvis AIS2005	Vo50 for force and acceleration m/s	Scaled peak pubic force N (CFC1000)	Scaled pelvis acceleration 3 ms m/s^2 (CFC1000)
INRETS	no	270	3,5	23,4	MRB01	MRT01	76	82		rectangle 100 mm × 200 mm	5 531		3,4		
INRETS	no	270	6,74	23,4	MRB02	MRT01	76	82			8 669		6,3		
INRETS	no	90	3,4	23,4	MRB03	MRT02	57	76			6 205		3,5		
INRETS	no	90	6,5	23,4	MRB04	MRT02	57	76			9 568		6,8		
INRETS	no	90	3,41	23,4	MRB05	MRT03	66	69			3 186		3,5		
INRETS	no	90	6,77	23,4	MRB06	MRT03	66	69			9 300		6,2		
INRETS	no	90	3,43	23,4	MRB07	MRT04	69	52			4 192		3,6		
INRETS	no	90	6,46	23,4	MRB08	MRT04	69	52			6 516		6,5		
INRETS	no	90	3,29	23,4	MRB09	MRT05	78	54			3 208		3,6		
INRETS	no	90	6,5	23,4	MRB10	MRT05	78	54			5 612		7,0		
INRETS	no	90	3,34	23,4	MRB11	MRT06	38	86			4 175		3,3		
INRETS	no	90	6,64	23,4	MRB12	MRT06	38	86			9 844		6,8		
INRETS	no	90	3,35	23,4	MRB13	MRT07	63	60			2 064		3,6		
INRETS	no	90	6,44	23,4	MRB14	MRT07	63	60			4 936		6,8		
INRETS	no	90	3,26	23,4	MRB15	MRT08	69	59,5			3 120		3,0		
INRETS	no	90	6,57	23,4	MRB16	MRT08	69	59,5			6 809		6,9		
INRETS	no	90	3,22	23,4	MRB17	MRT09	81	82			4 486		3,1		
INRETS	no	90	6,57	23,4	MRB18	MRT09	81	82			9 940		6,5		
INRETS	no	90	3,26	23,4	MRB19	MRT10	70	70			4 877		3,4		
INRETS	no	90	6,43	23,4	MRB20	MRT10	70	70			9 284		6,6		

PA: 2,5 cm Ensolite + 1,3 cm Styrofoam

PB: 0,5 cm Ensolite

PC: 2,5 cm Ensolite + 2,5 cm Styrofoam

PD: 5,0 cm Foam + 2,5 cm A.L. Ensolite

PE: 2,5 cm Styrofoam

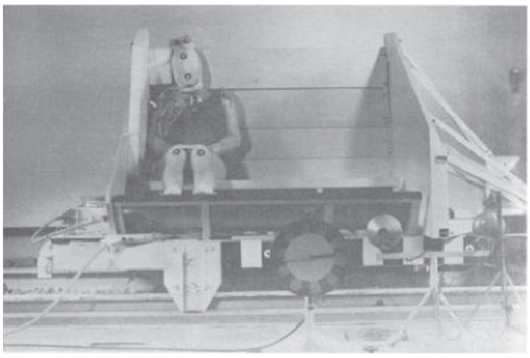
PF: 7,5 cm A.L. Ensolite + 2,5 cm Styrofoam

Annex F
(informative)

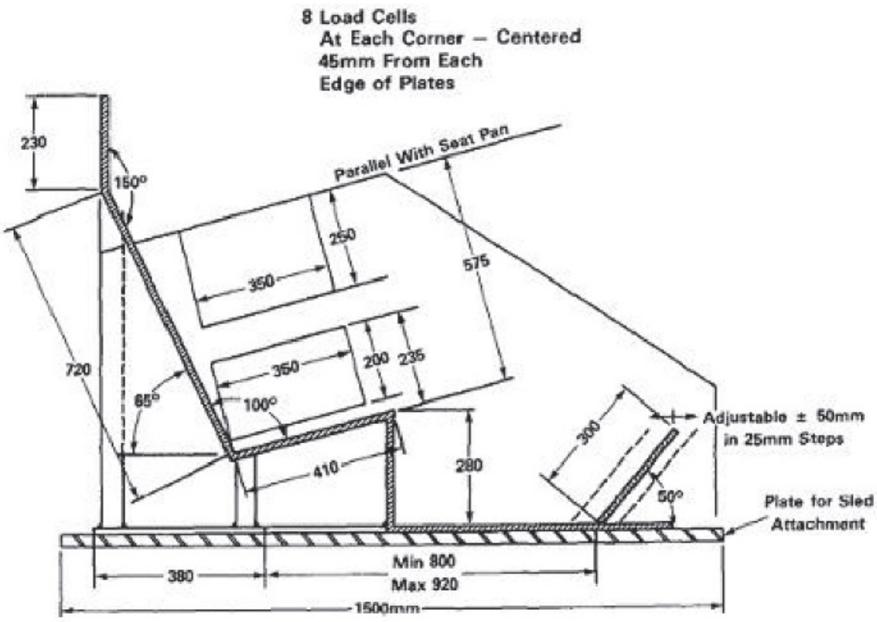
PMHS sled test data

Annex F includes the description of the PMHS sled tests used in the construction of the injury risk curves.

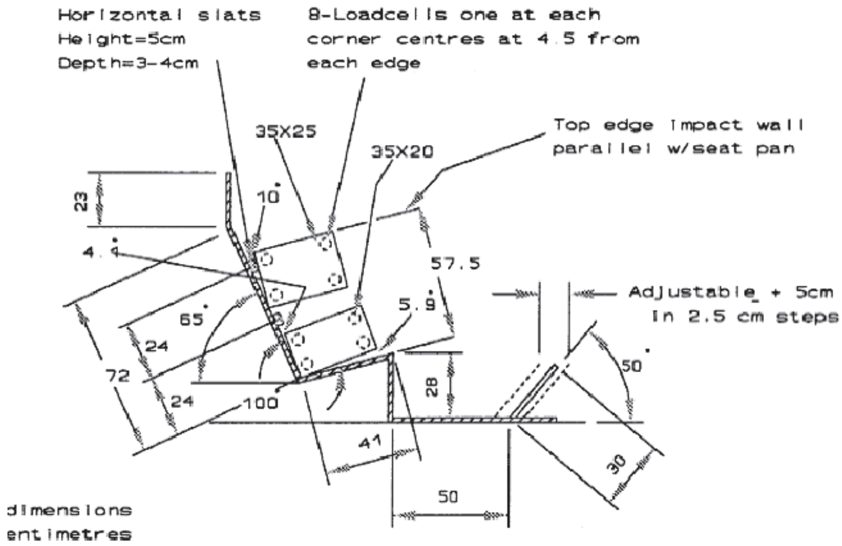
The University of Heidelberg conducted two series of whole body sled tests[25] [29]. In the first series of tests, shown in Figure F.1 a), the flat, rigid impact surface was tall enough that the subject's head impacted the wall. The impact wall was not instrumented in the first series of Heidelberg tests. In the second series of tests, illustrated in Figure F.1 b) or in Figure F.1 c), the impact wall consisted of separate instrumented plates that were impacted by the thorax and pelvis. The plates were either rigid or covered with blocks of APR pad. The second series had no impact surface for the head. The sled velocity ranged from 6,7 m/s to 12,7 m/s.



a) for tests without load measurements (front view)



b) for tests with load measurements according to[25][29] (side view)



c) for tests with load measurements according to[46] (side view)

Figure F.1 — Impact wall configuration from the lateral sled tests conducted by Heidelberg

HSRI conducted a series of whole body sled tests[31]. All of the HSRI sled tests were excluded because the impact wall was not instrumented with load cells.

MCW and OSU conducted a series of whole body sled tests[39] [40] [28] [27]. The impact wall configuration, illustrated in Figure F.2, was either flat, one plate was offset 110 mm closer to the subject, or the thorax and abdomen plates were angled, as shown in Figure F.3. The plates were either rigid, covered with 110-mm-thick Ethafoam LC-200, or covered with an airbag. The sled velocity ranged from 6,7 m/s to 8,9 m/s.

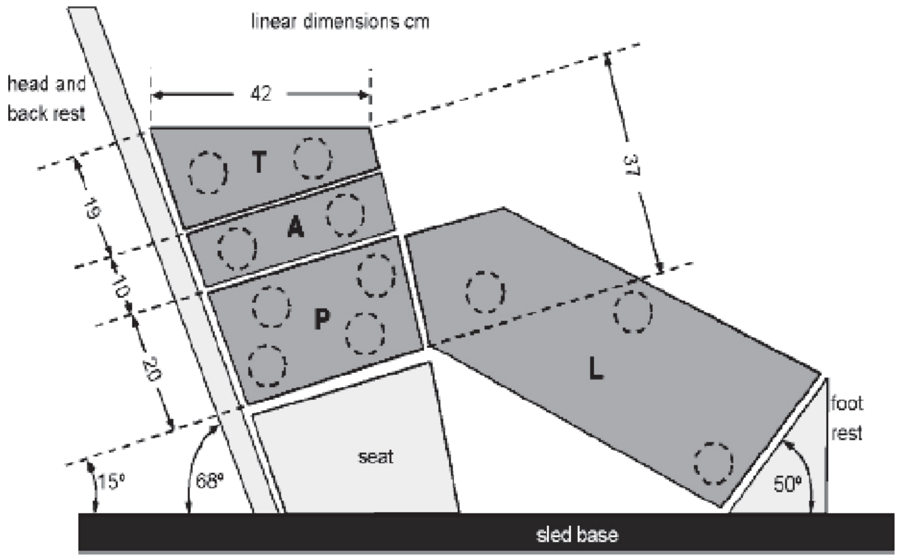


Figure F.2 — Impact wall configuration from the lateral sled tests conducted by MCW and OSU (side view)[39] [40] [28] [27]

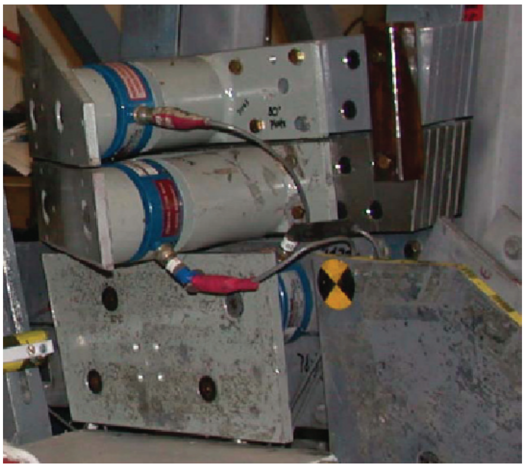


Figure F.3 — Impact wall configuration from the lateral sled tests conducted by MCW for the angled thorax and abdomen plate tests (forward oblique view)[41]

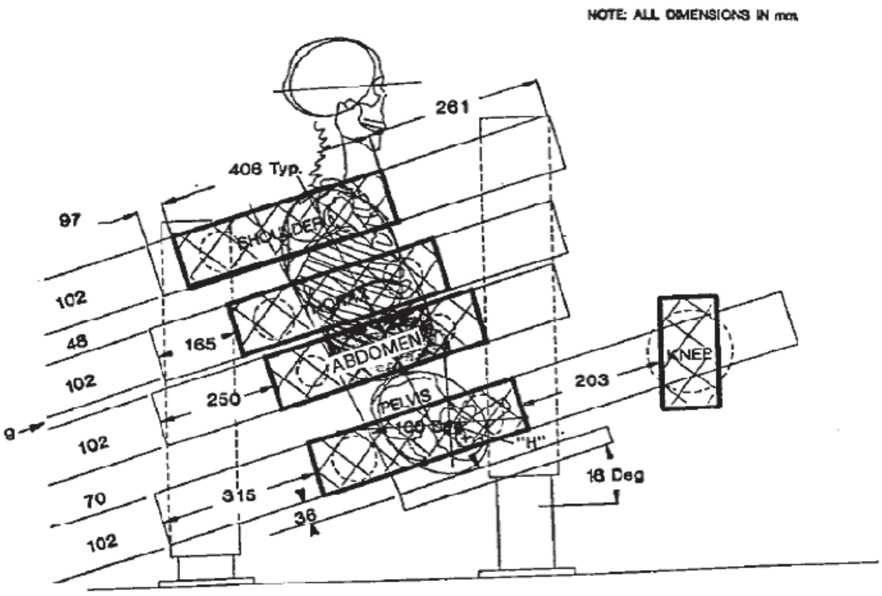


Figure F.4 — Impact wall configuration from the second series of lateral sled tests conducted by WSU (side view)[7] [8] [9] [10] [23]

Table F.1 summarizes the Heidelberg, HSRI, MCW, OSU, and WSU sled tests included in constructing injury risk curves and details all the sled test configurations. They are also provided in the related electronic document RED6. Table F.2 includes the scaled WorldSID results.

Tests selected and for which WorldSID test results are available for the construction of the injury risk curves are in bold.

Table F.1 — PMHS sled tests included in constructing injury risk curves

Test number	PMHS number	PMHS age	PMHS mass kg	PMHS shoulder width cm	PMHS hip width cm	PMHS seating height cm	Test performer	Angle of impact °	Sled wall geometry	Impact surface	Speed level	Shoulder AIS2005	Thorax skeletal AIS2005	Thorax soft tissue AIS2005	Abdomen AIS2005	Pelvis AIS2005
H82016	H82016	21	50	NA	NA		Heid	270	F	R	H	0	3		0	0
SIC-07	**WSU206**	**66**	**75**	**36,5**	**32,5**	**89,5**	**WSU**	**270**	**F**	**R**	**L**	**2**	**4**	**0**	**0**	**0**
SIC-05	**WSU216**	**67**	**44**	**32**	**29,5**	**88,5**	**WSU**	**270**	**F**	**R**	**L**	**0**	**4**	**0**	**0**	**0**
SIC-08[a]	UM12	64	74	31,5	33	83,5	WSU	270	F	R	L	0	2		2	0
SIC-04	WSU215	69	58	31	31,5	88	WSU	270	F	R	H	2	4		2	2
SIC-06	WSU217	60	61	32	31	95,5	WSU	270	F	R	H	2	3		0	2
SIC-01	UM6	67	71	33	34	94,5	WSU	270	OP	R	H	2	4		2	4
SIC-02	WSU187	64	50	30	37,5	83	WSU	270	OP	R	H	2	4		2	4
SIC-03	WSU188	37	70	42,5	33	91,5	WSU	270	OP	R	H	0	4		0	2

L: low speed, approximately 6,7 m/s

H: high speed, approximately 8,9 m/s

Heid: Heidelberg

WSU: Wayne State University

MCW: Medical College of Wisconsin

OSU: Ohio State University

F: flat

OP: offset pelvis 11 cm

OT: offset thorax 11 cm

OA: offset abdomen 11 cm

TAA30: thorax and abdomen plates with a 30° angle relative to the wall

TAA20O1: thorax and abdomen plate with a 20° angle relative to the wall and offset 4,4 cm

R: rigid

PO: 11,4 cm Ethafoam

PP: 10,2 cm Ethafoam

a SIC-08 was not used in the construction of the injury risk curves as the PMHS velocity relative to the wall necessary to correct the WorldSID dummy measurement was not available.

b Test results for the shoulder, thorax, and abdomen body regions are excluded from the construction of the injury risk curves but test results for the pelvis region are included.

Table F.1 *(continued)*

Test number	PMHS number	PMHS age	PMHS mass kg	PMHS shoulder width cm	PMHS hip width cm	PMHS seating height cm	Test performer	Angle of impact °	Sled wall geometry	Impact surface	Speed level	Shoulder AIS2005	Thorax skeletal AIS2005	Thorax soft tissue AIS2005	Abdomen AIS2005	Pelvis AIS2005
SC101	**375**	**73**	**89**	**40**	**33**	**96,5**	**MCW**	**270**	**F**	**R**	**L**	**0**	**3**	**3**	**0**	**0**
SC102	**336**	**27**	**72**	**41,5**	**31,8**	**91,4**	**MCW**	**270**	**F**	**R**	**L**	**0**	**0**	**0**	**0**	**0**
SC120	**453**	**67**	**74**	**41,3**	**38,4**	**95,3**	**MCW**	**270**	**F**	**R**	**L**	**0**	**0**	**0**	**0**	**0**
SC121	**464**	**86**	**67**	**40**	**32,4**	**86,4**	**MCW**	**270**	**F**	**R**	**L**	**0**	**3**	**2**	**0**	**0**
SC124	**HS455**	**45**	**63**	**39,4**	**34,9**	**88,9**	**MCW**	**270**	**F**	**R**	**L**	**0**	**0**	**0**	**0**	**0**
SC135	**HS552**	**56**	**64**	**33**	**30,5**	**94**	**MCW**	**270**	**F**	**R**	**L**	**0**	**3**	**2**	**0**	**0**
SC137[b]	HS561	73	50	30	27,5	76	MCW	270	F	R	L	0	3	0	0	0
SAC 102	**HS484**	**51**	**61**	**34,5**	**29**	**93**	**MCW**	**270**	**F**	**R**	**L**	**0**	**3**	**0**	**0**	**0**
SC108	399	44	83	40,3	32,4	92,7	MCW	270	F	R	H	0	3	0	0	0
SC109	377	49	62	39,4	32,4	86,4	MCW	270	F	R	H	0	3	3	0	3

L: low speed, approximately 6,7 m/s

H: high speed, approximately 8,9 m/s

Heid: Heidelberg

WSU: Wayne State University

MCW: Medical College of Wisconsin

OSU: Ohio State University

F: flat

OP: offset pelvis 11 cm

OT: offset thorax 11 cm

OA: offset abdomen 11 cm

TAA30: thorax and abdomen plates with a 30° angle relative to the wall

TAA20O1: thorax and abdomen plate with a 20° angle relative to the wall and offset 4,4 cm

R: rigid

PO: 11,4 cm Ethafoam

PP: 10,2 cm Ethafoam

a SIC-08 was not used in the construction of the injury risk curves as the PMHS velocity relative to the wall necessary to correct the WorldSID dummy measurement was not available.

b Test results for the shoulder, thorax, and abdomen body regions are excluded from the construction of the injury risk curves but test results for the pelvis region are included.

Table F.1 *(continued)*

Test number	PMHS number	PMHS age	PMHS mass kg	PMHS shoulder width cm	PMHS hip width cm	PMHS seating height cm	Test performer	Angle of impact °	Sled wall geometry	Impact surface	Speed level	Shoulder AIS2005	Thorax skeletal AIS2005	Thorax soft tissue AIS2005	Abdomen AIS2005	Pelvis AIS2005
93LSI32R01	W9301	63	61	NA	29,8	80	OSU	270	F	R	H	0	3	0	2	0
93LSI32R02	W9302	77	75	NA	36,7	90	OSU	270	F	R	H	0	4	0	3	0
94LSI32R05	W9305	73	72	NA	30	91	OSU	270	F	R	H	0	4	0	2	0
LSI32R08[b]	W9308	74	52	36,2	29,5	81	OSU	270	F	R	H	2	5	0	2	2
LSI32R09	W9309	73	51	39,2	34	94	OSU	270	F	R	H	1	4	2	0	2
LSI32R10	W9310	68	98	41,7	36,5	108	OSU	270	F	R	H	0	3	0	2	0
LSI32R13	W9313	72	73	36,6	32,4	93,5	OSU	270	F	R	H	1	4	2	0	0
SC128	HS480	46	69	36	39	84,5	MCW	270	OT	R	L	0	2	0	0	0
SC130	HS489	39	66	37,5	30,5	101,5	MCW	270	OT	R	L	0	3	3	4	0
SC141	HS570	79	74	34	30,5	84,5	MCW	270	OT	R	L	0	4	0	0	0

L: low speed, approximately 6,7 m/s

H: high speed, approximately 8,9 m/s

Heid: Heidelberg

WSU: Wayne State University

MCW: Medical College of Wisconsin

OSU: Ohio State University

F: flat

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TAA20O1: thorax and abdomen plate with a 20° angle relative to the wall and offset 4,4 cm

R: rigid

PO: 11,4 cm Ethafoam

PP: 10,2 cm Ethafoam

[a] SIC-08 was not used in the construction of the injury risk curves as the PMHS velocity relative to the wall necessary to correct the WorldSID dummy measurement was not available.

[b] Test results for the shoulder, thorax, and abdomen body regions are excluded from the construction of the injury risk curves but test results for the pelvis region are included.

Table F.1 *(continued)*

Test number	PMHS number	PMHS age	PMHS mass kg	PMHS shoulder width cm	PMHS hip width cm	PMHS seating height cm	Test performer	Angle of impact °	Sled wall geometry	Impact surface	Speed level	Shoulder AIS2005	Thorax skeletal AIS2005	Thorax soft tissue AIS2005	Abdomen AIS2005	Pelvis AIS2005
SC142	HS564	58	48	33,5	27,5	88	MCW	270	OT	R	L	0	3	0	0	0
SC125	**HS544**	**68**	**81**	**45,5**	**33**	**86,5**	**MCW**	**270**	**OA**	**R**	**L**	**0**	**3**	**0**	**2**	**0**
SC129	**HS483**	**51**	**52**	**34**	**29,5**	**94,5**	**MCW**	**270**	**OA**	**R**	**L**	**0**	**3**	**0**	**0**	**0**
SC144	**HS559**	**76**	**73**	**38**	**31,5**	**87**	**MCW**	**270**	**OP**	**R**	**L**	**0**	**3**	**0**	**0**	**2**
SC139	**HS543**	**56**	**89**	**42**	**29**	**94**	**MCW**	**270**	**OP**	**R**	**L**	**0**	**3**	**2**	**0**	**0**
SC110	**405**	**78**	**90**	**42,2**	**34,9**	**90,2**	**MCW**	**270**	**OP**	**R**	**L**	**2**	**3**	**3**	**0**	**3**
SC111	**434**	**84**	**76**	**38,1**	**33,3**	**94**	**MCW**	**270**	**OP**	**R**	**L**		**4**	**3**	**0**	**0**
SC113	433	74	77	40,6	36,8	91,4	MCW	270	OP	R	H	2	4	3	0	3
SC30A101	HS563	56	57	35	32,5	90	MCW	270	TAA30	R	L	0	3	0	0	0
SC30A102	HS577	74	45	30,5	28,5	81	MCW	270	TAA30	R	L	1	3	0	0	0

L: low speed, approximately 6,7 m/s

H: high speed, approximately 8,9 m/s

Heid: Heidelberg

WSU: Wayne State University

MCW: Medical College of Wisconsin

OSU: Ohio State University

F: flat

OP: offset pelvis 11 cm

OT: offset thorax 11 cm

OA: offset abdomen 11 cm

TAA30: thorax and abdomen plates with a 30° angle relative to the wall

TAA20O1: thorax and abdomen plate with a 20° angle relative to the wall and offset 4,4 cm

R: rigid

PO: 11,4 cm Ethafoam

PP: 10,2 cm Ethafoam

[a] SIC-08 was not used in the construction of the injury risk curves as the PMHS velocity relative to the wall necessary to correct the WorldSID dummy measurement was not available.

[b] Test results for the shoulder, thorax, and abdomen body regions are excluded from the construction of the injury risk curves but test results for the pelvis region are included.

Table F.1 *(continued)*

Test number	PMHS number	PMHS age	PMHS mass kg	PMHS shoulder width cm	PMHS hip width cm	PMHS seating height cm	Test performer	Angle of impact °	Sled wall geometry	Impact surface	Speed level	Shoulder AIS2005	Thorax skeletal AIS2005	Thorax soft tissue AIS2005	Abdomen AIS2005	Pelvis AIS2005
SC20A102[b]	HS572	46	74	43	33	98	MCW	270	TAA20O1	R	L	0	3	3	0	0
SC115[b]	**402**	**72**	**66**	**42,5**	**31,1**	**87,6**	**MCW**	**270**	**F**	**PO**	**L**	**0**	**3**	**2**	**0**	**0**
SC136[b]	**HS539**	**54**	**61**	**35,5**	**30**	**91**	**MCW**	**270**	**F**	**PP**	**L**	**0**	**3**	**0**	**0**	**0**
SC138[b]	HS551	58	48	31	27	81	MCW	270	F	PP	L	0	3	0	0	0
SC119[b]	486	75	42	35,6	30,5	81,3	MCW	270	F	PO	L	0	3	2	0	0
SC107	**394**	**50**	**93**	**41,6**	**36,2**	**95,3**	**MCW**	**270**	**F**	**PO**	**H**	**0**	**3**	**0**	**0**	**0**
SC133	**HS558**	**73**	**74**	**34,5**	**31,5**	**93**	**MCW**	**270**	**F**	**PP**	**H**	**0**	**4**	**3**	**2**	**0**
SC116	**444**	**67**	**76**	**41,3**	**36,8**	**94**	**MCW**	**270**	**F**	**PO**	**H**	**0**	**3**	**0**	**0**	**0**
SC134	**HS537**	**58**	**62**	**31,5**	**29,5**	**83,5**	**MCW**	**270**	**F**	**PP**	**H**	**0**	**3**	**0**	**0**	**0**
94LSI32P03	**W9303**	**59**	**81**	**NA**	**37,4**	**86,5**	**OSU**	**270**	**F**	**PP**	**H**	**0**	**3**	**0**	**2**	**0**

L: low speed, approximately 6,7 m/s

H: high speed, approximately 8,9 m/s

Heid: Heidelberg

WSU: Wayne State University

MCW: Medical College of Wisconsin

OSU: Ohio State University

F: flat

OP: offset pelvis 11 cm

OT: offset thorax 11 cm

OA: offset abdomen 11 cm

TAA30: thorax and abdomen plates with a 30° angle relative to the wall

TAA20O1: thorax and abdomen plate with a 20° angle relative to the wall and offset 4,4 cm

R: rigid

PO: 11,4 cm Ethafoam

PP: 10,2 cm Ethafoam

[a] SIC-08 was not used in the construction of the injury risk curves as the PMHS velocity relative to the wall necessary to correct the WorldSID dummy measurement was not available.

[b] Test results for the shoulder, thorax, and abdomen body regions are excluded from the construction of the injury risk curves but test results for the pelvis region are included.

Table F.1 *(continued)*

Test number	PMHS number	PMHS age	PMHS mass kg	PMHS shoulder width cm	PMHS hip width cm	PMHS seating height cm	Test performer	Angle of impact °	Sled wall geometry	Impact surface	Speed level	Shoulder AIS2005	Thorax skeletal AIS2005	Thorax soft tissue AIS2005	Abdomen AIS2005	Pelvis AIS2005
94LSI32P04[b]	W9304	75	42	NA	28	81	OSU	270	F	PP	H	2	3	0	4	2
95LSI32P06	**W9306**	**82**	**74**	**NA**	**32**	**89**	**OSU**	**270**	**F**	**PP**	**H**	**1**	**5**	**0**	**2**	**0**
LSI32P12	**W9312**	**80**	**45**	**34**	**29,9**	**84**	**OSU**	**270**	**F**	**PP**	**H**	**1**	**3**	**0**	**2**	**0**
LSI32P14	**W9314**	**79**	**67**	**30,6**	**31,4**	**91**	**OSU**	**270**	**F**	**PP**	**H**	**0**	**3**	**0**	**2**	**0**
LSI32P15	**W9315**	**68**	**54**	**30,4**	**31,8**	**90,3**	**OSU**	**270**	**F**	**PP**	**H**	**0**	**4**	**0**	**0**	**0**
LSI32P16	**W9316**	**77**	**48**	**28,7**	**29,5**	**85**	**OSU**	**270**	**F**	**PP**	**H**	**0**	**4**	**0**	**4**	**2**
SC117	468	59	73	41,9	32,1	95,3	MCW	270	OP	PO	L	0	3	0	0	0
SC118	473	74	51	41,9	31,8	91,4	MCW	270	OP	PO	L	0	3	0	0	0
SC143	HS557	57	70	37	30	88	MCW	270	OP	PP	L	0	1	0	0	0
SC140	HS571	62	77	40,5	31,5	95	MCW	270	OP	PP	H	0	0	0	0	0

L: low speed, approximately 6,7 m/s

H: high speed, approximately 8,9 m/s

Heid: Heidelberg

WSU: Wayne State University

MCW: Medical College of Wisconsin

OSU: Ohio State University

F: flat

OP: offset pelvis 11 cm

OT: offset thorax 11 cm

OA: offset abdomen 11 cm

TAA30: thorax and abdomen plates with a 30° angle relative to the wall

TAA20O1: thorax and abdomen plate with a 20° angle relative to the wall and offset 4,4 cm

R: rigid

PO: 11,4 cm Ethafoam

PP: 10,2 cm Ethafoam

a SIC-08 was not used in the construction of the injury risk curves as the PMHS velocity relative to the wall necessary to correct the WorldSID dummy measurement was not available.

b Test results for the shoulder, thorax, and abdomen body regions are excluded from the construction of the injury risk curves but test results for the pelvis region are included.

Table F.2 — Scaled WorldSID data included in constructing injury risk curves

Test number	Scaled peak shoulder rib deflection mm (CFC600)	Scaled peak shoulder force Y N (CFC1000)	Scaled peak thoracic rib deflection mm (CFC600)	Scaled peak thoracic rib VC m/s (deflection CFC180)	Scaled peak abdomen rib deflection mm (CFC600)	Scaled peak abdomen rib VC m/s (deflection CFC180)	Scaled lower spine acceleration 3 ms m/s² (CFC180)	Scaled peak pubic force N (CFC1000)	Scaled pelvis acceleration 3 ms m/s² (CFC1000)
H82016	NA	NA	NA	NA	NA	NA	NA	NA	NA
SIC-07	**NA**	**2 325**	**59,7**	**0,81**	**26,4**	**0,38**	**490**	**1 536**	**558**
SIC-05	**NA**	**2 481**	**63,7**	**0,92**	**28,2**	**0,43**	**523**	**1 638**	**595**
SIC-08[a]									
SIC-04									
SIC-06									
SIC-01									
SIC-02									
SIC-03									
SC101	**NA**	**1 600**	**60,1**	**0,92**	**31,8**	**0,31**	**342**	**1 458**	**533**
SC102	**NA**	**1 608**	**60,3**	**0,93**	**31,9**	**0,31**	**344**	**1 465**	**536**
SC120	**NA**	**1 573**	**59,0**	**0,89**	**31,2**	**0,30**	**337**	**1 434**	**524**
SC121	**NA**	**1 495**	**56,1**	**0,80**	**29,7**	**0,27**	**320**	**1 362**	**498**
SC124	**NA**	**1 661**	**62,3**	**0,99**	**33,0**	**0,33**	**355**	**1 514**	**553**
SC135	**NA**	**1 690**	**63,4**	**1,03**	**33,5**	**0,34**	**362**	**1 540**	**563**
SC137[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	1 609	588
SAC 102	**NA**	**1 840**	**69,0**	**1,22**	**36,5**	**0,41**	**394**	**1 677**	**613**
SC108									
SC109									
93LSI32R01									
93LSI32R02									
94LSI32R05									
LSI32R08[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]		
LSI32R09									

[a] SIC-08 was not used in the construction of the injury risk curves as the PMHS velocity relative to the wall necessary to correct the WorldSID dummy measurement was not available.

[b] Test results for the shoulder, thorax, and abdomen body regions are excluded from the construction of the injury risk curves but test results for the pelvis region are included.

Table F.2 *(continued)*

Test number	Scaled peak shoulder rib deflection mm (CFC600)	Scaled peak shoulder force Y N (CFC1000)	Scaled peak thoracic rib deflection mm (CFC600)	Scaled peak thoracic rib VC m/s (deflection CFC180)	Scaled peak abdomen rib deflection mm (CFC600)	Scaled peak abdomen rib VC m/s (deflection CFC180)	Scaled lower spine acceleration 3 ms m/s^2 (CFC180)	Scaled peak pubic force N (CFC1000)	Scaled pelvis acceleration 3 ms m/s^2 (CFC1000)
LSI32R10									
LSI32R13									
SC128									
SC130									
SC141									
SC142									
SC125	**NA**	**915**	**50,1**	**0,57**	**68,1**	**1,11**	**375**	**1 558**	**617**
SC129	**NA**	**879**	**48,2**	**0,53**	**65,4**	**1,02**	**360**	**1 497**	**593**
SC144	**NA**	**2 052**	**55,5**	**0,84**	**19,3**	**0,23**	**500**	**2 137**	**592**
SC139	**NA**	**2 159**	**58,4**	**0,93**	**20,3**	**0,25**	**526**	**2 248**	**623**
SC110	**NA**	**1 940**	**52,4**	**0,75**	**18,3**	**0,20**	**473**	**2 020**	**560**
SC111	**NA**	**1 804**	**48,8**	**0,65**	**17,0**	**0,17**	**440**	**1 879**	**521**
SC113									
SC30A101									
SC30A102									
SC20A102									
SC115	**NA**	**1 108**	**43,3**	**0,36**	**23,4**	**0,13**	**293**	**1 049**	**330**
SC136	**NA**	**1 155**	**45,1**	**0,39**	**24,4**	**0,14**	**305**	**1 094**	**344**
SC138[b]	b	b	b	b	b	b	b	1 158	364
SC119[b]	b	b	b	b	b	b	b	783	246
SC107	**NA**	**1 359**	**64,6**	**1,00**	**42,7**	**0,51**	**464**	**1 600**	**530**
SC133	**NA**	**1 499**	**71,3**	**1,22**	**47,1**	**0,62**	**512**	**1 765**	**584**
SC116	**NA**	**1 368**	**65,0**	**1,01**	**43,0**	**0,51**	**467**	**1 610**	**533**
SC134	**NA**	**1 436**	**68,3**	**1,12**	**45,1**	**0,57**	**490**	**1 690**	**560**

a SIC-08 was not used in the construction of the injury risk curves as the PMHS velocity relative to the wall necessary to correct the WorldSID dummy measurement was not available.

b Test results for the shoulder, thorax, and abdomen body regions are excluded from the construction of the injury risk curves but test results for the pelvis region are included.

Table F.2 *(continued)*

Test number	Scaled peak shoulder rib deflection mm (CFC600)	Scaled peak shoulder force Y N (CFC1000)	Scaled peak thoracic rib deflection mm (CFC600)	Scaled peak thoracic rib VC m/s (deflection CFC180)	Scaled peak abdomen rib deflection mm (CFC600)	Scaled peak abdomen rib VC m/s (deflection CFC180)	Scaled lower spine acceleration 3 ms m/s^2 (CFC180)	Scaled peak pubic force N (CFC1000)	Scaled pelvis acceleration 3 ms m/s^2 (CFC1000)
94LSI32P03	**NA**	**1 520**	**72,3**	**1,25**	**47,8**	**0,63**	**519**	**1 789**	**592**
94LSI32P04[b]	b	b	b	b	b	b	b	1 647	545
95LSI32P06	NA	1 505	71,6	1,23	47,3	0,62	514	1 772	587
LSI32P12	NA	1 506	71,6	1,23	47,3	0,62	514	1 773	587
LSI32P14	NA	1 505	71,6	1,22	47,3	0,62	514	1 771	586
LSI32P15	**NA**	**1 599**	**76,1**	**1,38**	**50,3**	**0,70**	**546**	**1 882**	**623**
LSI32P16	**NA**	**1 550**	**73,7**	**1,30**	**48,7**	**0,66**	**529**	**1 825**	**604**
SC117									
SC118									
SC143									
SC140									

a SIC-08 was not used in the construction of the injury risk curves as the PMHS velocity relative to the wall necessary to correct the WorldSID dummy measurement was not available.

b Test results for the shoulder, thorax, and abdomen body regions are excluded from the construction of the injury risk curves but test results for the pelvis region are included.

Annex G
(informative)

Assessment of the quality of the sled test results

Annex G details the description of analyses used to assess the quality of sled test results.

G.1 Momentum

Nusholtz et al.[38] proposed to use momentum for a data quality check. For a given test condition, the momentum for different PMHS should be consistent. Inconsistency in the momentum can be an indication of an instrumentation malfunction or improper calibration.

$$Momentum = \int_0^T F_{total\_norm} dt \quad (G.1)$$

where F_{total_norm} are the force measurements on the individual impact plates, normalized to a mid-size[19].

The integral is calculated from the time that the PMHS contact the first impact plate until the time that the PMHS is no longer contacting any of the impact plates.

The momentum for each test, with given impact wall configuration and impact velocity, should be consistent with all similar tests.

Momentum is also reported to a single sled velocity for a given test configuration to be able to compare momentum.

G.2 PMHS velocity at impact

For many tests, acceleration was measured at the PMHS (upper spine, lower spine, and pelvis). It is possible to calculate the velocity at each of these locations on the PMHS relative to the wall. If the PMHS is vertical when it strikes the impact wall, the velocity at these locations will be similar. If not, the PMHS was leaning, possibly due to friction of the pelvis on the bench.

The velocity at all locations of the spine and sacrum are compared at the time of contact with the first impact plate, regardless of the impact plate configuration.

G.3 PMHS leaning distance

Given the anthropometry of each PMHS, it is possible to calculate a theoretical distance that it is leaning at the time of contact with the impact wall. A theoretical difference between the time that the thorax plate is contacted and the time that the pelvis plate is contacted can be calculated.

[(pelvis breadth − shoulder breadth)/PMHS velocity relative to the wall]

The actual difference of time of contact with the thorax and pelvis plates can also be calculated. The time of contact was calculated, by using a modification of SAE J2052-Test Device Head Contact Duration Analysis (1997) (first time at which 5 % of the maximum plate force is reached, stepping backward in time from the time of maximum plate force).

The actual difference of contact time is then compared to the theoretical difference. The difference between the two contact times can be multiplied by the PMHS velocity relative to the wall to estimate the distance of leaning of the PMHS.

G.4 Transmissibility

The actual difference of contact time on the plate forces can also be compared to the transmissibility, the transmissibility being the time of maximum cross-correlation between two plate force measurements.

The cross-correlation consists in finding the time shift allowing the maximization of the sum of the product of the two signals considered on the whole time history.

$$C_{\text{ab}} = \sum_{t}^{t'} \text{a}_i \cdot \text{b}_i \tag{G.2}$$

where

a_i is the standard alignment signal at the i^{th} time step;

b_i is the signal to be aligned at the i^{th} time step;

t is the beginning of the loading;

t' is the end of the loading.

The signals over the whole time history were used to calculate the time when the cross-correlation is maximum.

The comparison was performed between the thorax and pelvis load plates. If the transmissibility is not consistent with the actual difference of contact times, it means the considered test presents some irregularities.

G.5 Seating height

The MCW sled wall geometry was designed in order not to load the shoulder of the surrogate. The check for the shoulder interaction could have been done for all the tests looking at the high-speed videos. Unfortunately, all the films were not available. The use of the anthropometric measurements taken prior to the test was then chosen. The seated height of the occupant (SEATHT) was taken prior to the test with the test occupant sitting erect, looking straight ahead. It corresponded to the vertical distance from the sitting surface to the top of the head (see Figure G.1).

Figure G.1 — Illustration of the seated height (SEATHT), as defined in the MCW test reports

Schneider et al. (1985)[48] provided some reference points specifying the anthropometry of the 50th and 95th male occupant. The top of the head was not included as a specific point. They also provided some drawings illustrating the anthropometry. The seating height were measured based on these drawings. The seating heights measured on the UMTRI drawings were 888 mm for the 50th male and 950 mm for the 95th male. The difference between the 50th and 95th seating height was 62 mm. The seating height of a 5th percentile male was then calculated by subtracting 62 mm from the seating height of the 50th male, hypothesizing a normal distribution of this parameter. The seating height of a 5th percentile male was then found to be 826 mm.

It was proposed to exclude the PMHS with a seating height lower than 826 mm unless it was clear from the films that the shoulder did not interact with the wall, from the construction of the injury risk curves for the shoulder, thorax, and abdomen. These PMHS were not excluded from the construction of the pelvis injury risk curves because there was no evidence of the influence of the shoulder contact on the pelvis effective mass.

Annex H
(informative)

WorldSID results

Annex H presents the WorldSID 50th test results corresponding to the PMHS configurations listed in Annex A to Annex F.

H.1 WorldSID head impactor test results

Table H.1 describes the dummy data available for head impactor tests.

Table H.1 — Dummy head impactor test results used for the construction of the injury risk curve

PMHS test condition	Actual WorldSID impact speed m/s	WorldSID test number	WorldSID HIC
Calspan 25,3 kg rigid impactor at 4 m/s (203 mm × 254 mm rectangular impact face)	NA	NA	NA
Calspan 23,4 kg rigid impactor at 4 m/s (152-mm-diameter circular impact face)	NA	NA	NA
Calspan 24,4 kg rigid impactor at 3 m/s (171,5 mm × 203 mm rectangular impact face)	NA	NA	NA
Calspan 24,4 kg impactor at 4 m/s (171,5mm × 203 mm rectangular impact face covered with 51 mm pad)	NA	NA	NA

H.2 WorldSID head drop test results

Table H.2 describes the dummy data available for head drop tests.

Table H.2 — Dummy head drop test results used for the construction of the injury risk curve

PMHS test condition	Actual World-SID drop height	WorldSID test number	WorldSID HIC
APR lateral drop from 1,83 m onto flat, rigid surface	NA	NA	NA
APR lateral drop from 2,5 m onto flat, rigid surface	NA	NA	NA
WSU lateral drop from 0,46 m onto flat, rigid surface	NA	NA	NA
MCW lateral drop from 0,6 m onto flat surface covered with X mm thick rubber (40 durometer)	NA	NA	NA

Table H.2 *(continued)*

PMHS test condition	Actual World-SID drop height	WorldSID test number	WorldSID HIC
MCW lateral drop from 0,9 m onto flat surface covered with 50-mm-thick rubber (40 durometer)	NA	NA	NA
MCW lateral drop from 1,2 m onto flat surface covered with 50-mm-thick rubber (40 durometer)	NA	NA	NA
MCW lateral drop from 1,5 m onto flat surface covered with 50-mm-thick rubber (40 durometer)	NA	NA	NA
MCW lateral drop from 1,8 m onto flat surface covered with 50-mm-thick rubber (40 durometer)	NA	NA	NA
MCW lateral drop from 2,1 m onto flat surface covered with 50-mm-thick rubber (40 durometer)	NA	NA	NA
MCW lateral drop from 2,4 m onto flat surface covered with 50-mm-thick rubber (40 durometer)	NA	NA	NA
MCW lateral drop from 2,7 m onto flat surface covered with 50-mm-thick rubber (40 durometer)	NA	NA	NA
MCW lateral drop from 3 m onto flat surface covered with 50-mm-thick rubber (40 durometer)	NA	NA	NA
MCW lateral drop from 3,3 m onto flat surface covered with 50-mm-thick rubber (40 durometer)	NA	NA	NA
MCW oblique drop from 0,3 m onto flat surface covered with 50-mm-thick rubber (90 durometer)	NA	NA	NA
MCW oblique drop from 0,6 m onto flat surface covered with 50-mm-thick rubber (90 durometer)	NA	NA	NA
MCW oblique drop from 0,9 m onto flat surface covered with 50-mm-thick rubber (90 durometer)	NA	NA	NA
MCW oblique drop from 1,2 m onto flat surface covered with 50-mm-thick rubber (90 durometer)	NA	NA	NA
MCW oblique drop from 1,5 m onto flat surface covered with 50-mm-thick rubber (90 durometer)	NA	NA	NA
MCW oblique drop from 1,8 m onto flat surface covered with 50-mm-thick rubber (90 durometer)	NA	NA	NA
MCW oblique drop from 2,1 m onto flat surface covered with 50-mm-thick rubber (90 durometer)	NA	NA	NA

Table H.2 *(continued)*

PMHS test condition	Actual WorldSID drop height	WorldSID test number	WorldSID HIC
MCW oblique drop from 0,3 m onto 25,4 mm radius cylinder covered with 50-mm-thick rubber (90 durometer)	NA	NA	NA
MCW oblique drop from 0,6 m onto 25,4 mm radius cylinder covered with 50-mm-thick rubber (90 durometer)	NA	NA	NA
MCW oblique drop from 0,9 m onto 25,4 mm radius cylinder covered with 50-mm-thick rubber (90 durometer)	NA	NA	NA
MCW oblique drop from 1,2 m onto 25,4 mm radius cylinder covered with 50-mm-thick rubber (90 durometer)	NA	NA	NA
MCW oblique drop from 1,5 m onto 25,4 mm radius cylinder covered with 50-mm-thick rubber (90 durometer)	NA	NA	NA
MCW oblique drop from 1,8 m onto 25,4 mm radius cylinder covered with 50-mm-thick rubber (90 durometer)	NA	NA	NA

H.3 WorldSID shoulder impactor results

Table H.3 describes the dummy data available for shoulder impactor tests.

Table H.3 — Dummy shoulder impactor test results used for the construction of the injury risk curve

PMHS test condition	WorldSID test number	Actual WorldSID impact speed m/s	WorldSID peak shoulder deflection mm (CFC600)	WorldSID peak shoulder force Y N (CFC1000)
APR lateral impact by 23 kg rigid impactor at 4,5 m/s (150-mm-diameter circular impact face)	WS009-PRSH-1	4,51	46,1	1 544
	WS009-PRSH-2	4,51	39,5	1 566
	WS009-PRSH-3	4,50	37	1 491
	WS009-PRSH-4	4,50	40,1	1 557
	Mean at 4,5 m/s	4,50	40,7	1 540
APR 15° forward of lateral impact by 23 kg rigid impactor at 4,5 m/s (150-mm-diameter circular impact face)	NA	NA	NA	NA
INRETS lateral impact by 23,4 kg rigid impactor at 1,5 m/s (150 mm × 80 mm rectangular impact face)	NA	NA	NA	NA
NOTE: For oblique loading, IR-TRACC measurements are used.				

Table H.3 *(continued)*

PMHS test condition	WorldSID test number	Actual WorldSID impact speed m/s	WorldSID peak shoulder deflection mm (CFC600)	WorldSID peak shoulder force Y N (CFC1000)
INRETS 15° rearward of lateral impact by 23,4 kg rigid impactor at 1,5 m/s (150 mm × 80 mm rectangular impact face)	NA	NA	NA	NA
INRETS 15° forward of lateral impact by 23,4 kg rigid impactor at 1,5 m/s (150 mm × 80 mm rectangular impact face)	NA	NA	NA	NA
INRETS lateral impact by 23,4 kg rigid impactor at 6 m/s (150 mm × 80 mm rectangular impact face)	NA	NA	NA	NA
INRETS lateral impact by 23,4 kg rigid impactor at 3,5 m/s (150 mm × 80 mm rectangular impact face)	NA	NA	NA	NA
OSU lateral impact by 23 kg impactor at 4,5 m/s (203,2 mm × 152,4 mm rectangular impact face covered by Arcel 310 foam 26,4 kg/m^3 density)	NA	NA	NA	NA
OSU lateral impact by 23 kg impactor at 6 m/s (203,2 mm × 152,4 mm rectangular impact face covered by Arcel 310 foam 26,4 kg/m^3 density)	NA	NA	NA	NA
OSU lateral impact by 23 kg impactor at 4,5 m/s (200 mm × 150 mm rectangular impact face covered by Arcel 310 foam 26,4 kg/m^3 density)	VRTC WorldSID Bolte lateral shoulder test 1	4,4	36,2	NA
	VRTC WorldSID Bolte lateral shoulder test 2	4,4	36,2	NA
	Mean at 4,4 m/s	4,4	36,2	NA
WSU lateral impact by 23 kg rigid impactor at 4,5 m/s (152,4-mm-diameter circular impact face)	WS009-PRSH-1	4,51	46,1	1544
	WS009-PRSH-2	4,51	39,5	1566
	WS009-PRSH-3	4,50	37	1491
	WS009-PRSH-4	4,50	40,1	1557
	Mean at 4,5 m/s	4,50	40,7	1540
NOTE: For oblique loading, IR-TRACC measurements are used.				

H.4 WorldSID thorax impactor results

Table H.4 describes the dummy data available for thorax impactor tests.

Table H.4 — Dummy thorax impactor test results used for the construction of the injury risk curve

PMHS test condition	WorldSID test number	Actual WorldSID impact speed m/s	World-SID peak thoracic rib deflection mm (CFC600)	WorldSID peak thoracic rib VC m/s (deflection CFC180)
WSU 30° forward of lateral impact by 23,4 kg rigid impactor at 6 m/s (152,4-mm-diameter circular impact face)	NA	NA	NA	NA
WSU 30° forward of lateral impact by 23,4 kg rigid impactor at 8,7 m/s (152,4-mm-diameter circular impact face)	NA	NA	NA	NA
HSRI lateral impact by 23,4 kg rigid impactor at 4,3 m/s (152,4-mm-diameter circular impact face)	TC-WS009-PRTLS9	4,36	39,5	0,46
	TC-WS009-PRTLS10	4,76	37,0	0,43
	TC-WS009-PRTLS11	4,36	37,4	0,43
	Mean at 4,3 m/s	4,3	36,4	0,48
UMTRI lateral impact by 25 kg impactor at 2 m/s (152,4-mm-diameter circular impact face covered without pad)	NA	NA	NA	NA
UMTRI lateral impact by 25 kg impactor at 2 m/s (152,4-mm-diameter circular impact face covered with 0,5-cm-thick Ensolite pad)	NA	NA	NA	NA
UMTRI lateral impact by 25 kg impactor at 2 m/s (152,4-mm-diameter circular impact face covered with 10-cm-thick Ensolite pad)	NA	NA	NA	NA
UMTRI lateral impact by 25 kg impactor at 8,5 m/s (152,4-mm-diameter circular impact face covered with 0,5-cm-thick Ensolite pad)	NA	NA	NA	NA
UMTRI lateral impact by 25 kg impactor at 8,5 m/s (152,4-mm-diameter circular impact face covered with 10-cm-thick Ensolite pad)	NA	NA	NA	NA
OSU lateral impact by 23 kg rigid impactor at 2,5 m/s (152,4-mm-diameter circular impact face)	VRTC-Lateral Test 2	2,5	24,1	0,17
	VRTC-Lateral Test 3	2,5	23,5	0,16
	VRTC-Lateral Test 4	2,5	23,8	0,17
	Mean at 2,5 m/s	2,5	23,8	0,17
OSU 30° forward of lateral impact by 23 kg rigid impactor at 2,5 m/s (152,4-mm-diameter circular impact face)	VRTC-30° Oblique Test 1	2,5	NA	NA
	VRTC-30° Oblique Test 2	2,5	NA	NA
	VRTC-30° Oblique Test 3	2,5	NA	NA

H.5 WorldSID abdomen impactor test results

Table H.5 describes the dummy data available for abdomen impactor tests.

Table H.5 — Dummy abdomen impactor test results used for the construction of the injury risk curve

PMHS test condition	**WorldSID test number**	**Actual WorldSID impact speed** m/s	**WorldSID lower spine acceleration 3 ms** m/s^2 **(CFC180)**	**Maximum WorldSID abdomen rib peak deflection** mm **(CFC600)**	**Maximum WorldSID abdomen rib VC** m/s **(deflection CFC180)**
OSU lateral impact by 9,1 kg impactor at 6,3 m/s (200 mm × 150 mm rectangular impact face covered with Arcel 310 1,5 lb/f^3 foam pad)	NA	NA	NA	NA	NA
OSU lateral impact by 9,1 kg impactor at 9,7 m/s (200 mm × 150 mm rectangular impact face covered with Arcel 310 1,5 lb/f^3 foam pad)	NA	NA	NA	NA	NA
OSU lateral impact by 9,1 kg impactor at 9 m/s (200 mm × 150 mm rectangular impact face covered with Arcel 310 3 lb/f^3 foam pad)	NA	NA	NA	NA	NA
OSU lateral impact by 9,1 kg impactor at 6 m/s (200 mm × 150 mm rectangular impact face covered with Ethafoam LC-200 pad)	NA	NA	NA	NA	NA
OSU lateral impact by 9,1 kg impactor at 11 m/s (200 mm × 150 mm rectangular impact face covered with Ethafoam LC-200 pad)	NA	NA	NA	NA	NA
WSU 30° forward of lateral impact by 23,4 kg rigid impactor at 10 m/s (152,4-mm-diameter circular impact face)	NA	NA	NA	NA	NA

H.6 WorldSID pelvis impactor test results

Table H.6 describes the dummy data available for pelvis impactor tests.

Table H.6 — Dummy pelvis impactor test results used for the construction of the injury risk curve

PMHS test condition	**WorldSID test number**	**Actual WorldSID impact speed** m/s	**WorldSID pelvis acceleration 3 ms** m/s^2 **(CFC1000)**	**WorldSID peak pubis force** N **(CFC1000)**
WSU lateral impact by 23,4 kg rigid impactor at 6 m/s and 10 m/s (152,4-mm-diameter circular impact face)	140487	6,68	388	NA
	140498	6,68	398	NA
	140500	6,68	373	NA
	140507	6,68	385	NA
	140514	6,68	514	NA
	140885	6,68	390	NA
	140890,01	6,77	415	NA
	140896	6,77	420	NA
	140904,01	6,74	422	NA
	140920	6,74	406	NA
	140929,01	6,77	406	NA
	141062	6,77	439	NA
	141067	6,68	466	NA
	141073	6,77	446	NA
	141075	6,68	410	NA
	141082	6,68	419	NA
	141086	6,68	416	NA
	146537	6,63	485	NA
	146563	6,68	447	NA
	146577	6,68	475	NA
	146581	6,68	438	NA
	147758	6,63	481	NA
	147759	6,63	475	NA
	147760	6,68	477	NA
	147761	6,68	422	NA
	156237	6,68	481	NA
	156249	6,68	416	NA
	156253	6,63	470	NA
	156256	6,74	457	NA
	162704,01	6,74	427	NA
	162712,01	6,69	448	NA
	162895	6,68	456	NA
	162899	6,68	440	NA
	Mean at 6,7 m/s	6,7	437	NA
ONSER lateral impact by 17,3 kg rigid impactor at 6 m/s (impact face is segment of a sphere R=175 mm, r=60 mm)	WS009-PRPLS1	6,0	264	1 053
	WS009-PRPLS2	6,0	254	1 107
	WS009-PRPLS3	6,0	260	1 096
	Mean at 6 m/s	6,0	259	1 086

Table H.6 *(continued)*

PMHS test condition	WorldSID test number	Actual WorldSID impact speed m/s	WorldSID pelvis acceleration 3 ms m/s^2 (CFC1000)	WorldSID peak pubis force N (CFC1000)
ONSER lateral impact by 17,3 kg rigid impactor at 10 m/s (impact face is segment of a sphere R=175 mm, r=60 mm)	WS009-PRPHS1	10,0	474	1 926
	WS009-PRPHS2	10,0	439	1 895
	WS009-PRPHS3	10,1	472	1 845
	Mean at 10 m/s	10,0	462	1 889
INRETS lateral impact by 23,4 kg rigid impactor at 3,5 m/s (200 mm × 100 mm rectangular impact face)	NA	NA	NA	NA
INRETS lateral impact by 23,4 kg rigid impactor at 6 m/s (200 mm × 100 mm rectangular impact face)	NA	NA	NA	NA
INRETS lateral impact by 12 kg rigid impactor at 11 m/s (200 mm × 200 mm rectangular impact face)	NA	NA	NA	NA
INRETS lateral impact by 16 kg rigid impactor at 11 m/s (200 mm × 200 mm rectangular impact face)	NA	NA	NA	NA

H.7 WorldSID sled test results

Table H.7 describes the dummy data available for sled tests.

Table H.7 — Dummy sled test results used for the construction of the injury risk curve

PMHS test condition	**WorldSID test number**	**Actual WorldSID impact speed** m/s	**Peak WorldSID shoulder rib deflection** mm **(CFC600)**	**Peak WorldSID shoulder Y force** N **(CFC1000)**	**Peak WorldSID thorax rib deflection** mm **(CFC600)**	**Peak WorldSID thoracic rib deflection (extrapolated)** mm **(CFC600)**	**Peak WorldSID thoracic rib VC** m/s **(deflection CFC180)**	**Peak WorldSID thoracic rib VC (deflection extrapolated** m/s **(deflection CFC180)**	**Peak WorldSID abdomen rib deflection** mm **(CFC600)**	**Peak WorldSID abdomen rib deflection (extrapolated** mm **(CFC600)**	**Peak WorldSID abdomen rib VC** m/s **(deflection CFC180)**	**Peak WorldSID abdomen rib VC (deflection extrapolated** m/s **(deflection CFC180)**	**WorldSID lower spine acceleration 3 ms** m/s^2 **(CFC180)**	**WorldSID pelvis acceleration 3 ms** m/s^2 **(CFC1000)**	**Peak WorldSID pubis force** N **(CFC1000)**
Heidelberg rigid, flat wall test at 8,9 m/s	NA	8,9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
WSU rigid, flat wall sled test at 6,3 m/s	070409-1 WS1	6,5	NA	2 783	66,2	68,9	/	1,14	28,4	/	0,45	/	586	623	1 723
	070409-1 WS2	6,5	NA	2 513	65,3	66,2	/	0,91	26,5	/	0,40	/	552	640	1 655
	070410-2 WS1	6,6	NA	2 696	65,3	65,8	/	1,12	32,5	/	0,49	/	590	610	1 682
	070410-2 WS2	6,3	NA	2 520	65,3	68,0	/	0,99	26,0	/	0,40	/	536	673	1 620
	070410-3 WS1	6,5	NA	2 667	66,1	67,8	/	1,13	32,5	/	0,50	/	575	645	1 686
	070410-3 WS2	6,5	NA	2 483	65,3	67,4	/	1,00	24,2	/	0,43	/	522	633	1 658
	H28774	6,1	NA	2 504	57,1	62,5	/	0,89	31,1	/	0,48	/	525	582	1 803
	H28775	6,0	NA	2 473	57,4	64,9	/	0,89	31,5	/	0,44	/	489	582	1 657
	H28776	5,9	NA	2 498	57,2	62,0	/	0,89	29,8	/	0,56	/	507	570	1 777
	Mean at 6,3 m/s	6,3	NA	2 568	65,9		0,99		29,2		0,46		541	616	1 696
WSU rigid, flat wall sled test at 8,9 m/s	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NOTE 1 NA means that the test was not performed. For the non-extrapolated values, / means that the value to be used is the extrapolated one. For the extrapolated values, / means that the non-extrapolated value should be used.

NOTE 2 Rib deflections were extrapolated because measurements showed flat topping either due to a measurement problem or due to a maximum range of motion.

Table H.7 *(continued)*

PMHS test condition	**WorldSID test number**	**Actual WorldSID impact speed** m/s	**Peak WorldSID shoulder rib deflection** mm **(CFC600)**	**Peak WorldSID shoulder Y force** N **(CFC1000)**	**Peak WorldSID thorax rib deflection** mm **(CFC600)**	**Peak WorldSID thoracic rib deflection (extrapolated)** mm **(CFC600)**	**Peak WorldSID thoracic rib VC** m/s **(deflection CFC180)**	**Peak WorldSID thoracic rib VC (deflection extrapolated** m/s **(deflection CFC180)**	**Peak WorldSID abdomen rib deflection** mm **(CFC600)**	**Peak WorldSID abdomen rib deflection (extrapolated** mm **(CFC600)**	**Peak WorldSID abdomen rib VC** m/s **(deflection CFC180)**	**Peak WorldSID abdomen rib VC (deflection extrapolated** m/s **(deflection CFC180)**	**WorldSID lower spine acceleration 3 ms** m/s² **(CFC180)**	**WorldSID pelvis acceleration 3 ms** m/s² **(CFC1000)**	**Peak WorldSID pubis force** N **(CFC1000)**
WSU rigid, pelvis offset sled test at 8,9 m/s	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MCW and OSU rigid, flat wall sled test at 6,7 m/s	070411-1 WS1	6,4	NA	1 789	68,9	/	1,22	/	37	/	0,39	/	402	624	1 652
	070411-1 WS2	6,5	NA	1 871	65,6	/	1,11	/	34	/	0,34	/	367	591	1 643
	070412-1 WS1	6,4	NA	1 723	67,5	70,6	1,25	1,25	37	/	0,47	/	422	605	1 668
	070412-1 WS2	6,3	NA	1 851	64,8	/	1,10	/	35	/	0,34	/	368	588	1 646
	070412-2 WS1	6,4	NA	1 715	68,4	69,3	1,18	1,18	38	/	0,44	/	394	597	1 603
	070412-2 WS2	6,3	NA	1 845	66,0	/	1,12	/	34	/	0,33	/	356	594	1 628
	Mean at 6,4 m/s	6,4	NA	1 804	67,7		1,17		35,8		0,39		386	601	1 644
MCW and OSU rigid, flat wall sled test at 8,9 m/s	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NOTE 1 NA means that the test was not performed. For the non-extrapolated values, / means that the value to be used is the extrapolated one. For the extrapolated values, / means that the non-extrapolated value should be used.

NOTE 2 Rib deflections were extrapolated because measurements showed flat topping either due to a measurement problem or due to a maximum range of motion.

Table H.7 *(continued)*

PMHS test condition	WorldSID test number	Actual WorldSID impact speed m/s	Peak WorldSID shoulder rib deflection mm (CFC600)	Peak WorldSID shoulder Y force N (CFC1000)	Peak WorldSID thorax rib deflection mm (CFC600)	Peak WorldSID thoracic rib deflection (extrapolated) mm (CFC600)	Peak WorldSID thoracic rib VC m/s (deflection CFC180)	Peak WorldSID thoracic rib VC (deflection extrapolated m/s (deflection CFC180)	Peak WorldSID abdomen rib deflection mm (CFC600)	Peak WorldSID abdomen rib deflection (extrapolated mm (CFC600)	Peak WorldSID abdomen rib VC m/s (deflection CFC180)	Peak WorldSID abdomen rib VC (deflection extrapolated m/s (deflection CFC180)	WorldSID lower spine acceleration 3 ms m/s² (CFC180)	WorldSID pelvis acceleration 3 ms m/s² (CFC1000)	Peak WorldSID pubis force N (CFC1000)
MCW and OSU rigid, thorax offset sled test at 6,7 m/s	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MCW and OSU rigid, abdomen offset sled test at 6,7 m/s	070413-3 WS1	6,4	NA	728	54,1	/	0,67	/	67,7	68,9	1,18	/	357	614	1 544
	070413-3 WS2	6,3	NA	1 041	43,3	/	0,41	/	63,1	/	0,90	/	369	611	1 474
	Mean at 6,3 m/s	6,3	NA	882	48,3		0,53		65,6		1,03		361	595	1 501
MCW and OSU rigid, pelvis offset sled test at 6,7 m/s	070416-1 WS1	6,3	NA	2 070	57,6	/	0,88	/	22,6	/	0,26	/	508	580	2 118
	070416-1 WS2	6,3	NA	1 971	51,6	/	0,76	/	15,4	/	0,18	/	477	586	2 090
	Mean at 6,3 m/s	6,3	NA	2 027	54,8		0,82		19,1		0,22		494	585	2 111
MCW and OSU rigid, pelvis offset sled test at 8,9 m/s	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NOTE 1 NA means that the test was not performed. For the non-extrapolated values, / means that the value to be used is the extrapolated one. For the extrapolated values, / means that the non-extrapolated value should be used.

NOTE 2 Rib deflections were extrapolated because measurements showed flat topping either due to a measurement problem or due to a maximum range of motion.

Table H.7 *(continued)*

PMHS test condition	**WorldSID test number**	**Actual WorldSID impact speed** m/s	**Peak WorldSID shoulder rib deflection** mm **(CFC600)**	**Peak WorldSID shoulder Y force** N **(CFC1000)**	**Peak WorldSID thorax rib deflection** mm **(CFC600)**	**Peak WorldSID thoracic rib deflection (extrapolated)** mm **(CFC600)**	**Peak WorldSID thoracic rib VC** m/s **(deflection CFC180)**	**Peak WorldSID thoracic rib VC (deflection extrapolated** m/s **(deflection CFC180)**	**Peak WorldSID abdomen rib deflection** mm **(CFC600)**	**Peak WorldSID abdomen rib deflection (extrapolated** mm **(CFC600)**	**Peak WorldSID abdomen rib VC** m/s **(deflection CFC180)**	**Peak WorldSID abdomen rib VC (deflection extrapolated** m/s **(deflection CFC180)**	**WorldSID lower spine acceleration 3 ms** m/s² **(CFC180)**	**WorldSID pelvis acceleration 3 ms** m/s² **(CFC1000)**	**Peak WorldSID pubis force** N **(CFC1000)**
MCW and OSU padded, flat wall sled test at 6,7 m/s	070412-3 WS1	6,2	NA	1 117	50,4	/	0,48	/	28,0	/	0,17	/	303	373	1 162
	070412-3 WS2	6,3	NA	1 249	45,2	/	0,39	/	26,3	/	0,16	/	346	367	1 179
	070413-1 WS1	6,2	NA	1 113	49,7	/	0,49	/	28,6	/	0,18	/	306	364	1 204
	070413-1 WS2	6,3	NA	1 222	45,0	/	0,40	/	25,1	/	0,15	/	333	360	1 026
	070413-2 WS1	6,3	NA	1 305	50,6	/	0,49	/	28,3	/	0,17	/	319	362	1 163
	070413-2 WS2	6,2	NA	1 339	46,4	/	0,42	/	18,5	/	0,11	/	338	362	1 223
	Mean at 6,3 m/s	6,3	NA	1 233	48,2		0,45		26,0		0,16		326	367	1 168
MCW and OSU padded, flat wall sled test at 8,9 m/s	070416-2 WS1	8,5	NA	1 191	67,8	73,1	/	1,30	48,6	/	0,63	/	515	597	1 643
	070416-2 WS2	8,6	NA	1 826	66,3	70,0	/	1,16	46,0	/	0,63	/	514	577	1 903
	Mean at 8,6 m/s	8,6	NA	1 514	72,0		1,24		47,6		0,63		517	590	1 782
MCW and OSU padded, pelvis offset sled test at 6,7 m/s	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NOTE 1 NA means that the test was not performed. For the non-extrapolated values, / means that the value to be used is the extrapolated one. For the extrapolated values, / means that the non-extrapolated value should be used.

NOTE 2 Rib deflections were extrapolated because measurements showed flat topping either due to a measurement problem or due to a maximum range of motion.

Table H.7 *(continued)*

PMHS test condition	**WorldSID test number**	**Actual WorldSID impact speed** m/s	**Peak WorldSID shoulder rib deflection** mm **(CFC600)**	**Peak WorldSID shoulder Y force** N **(CFC1000)**	**Peak WorldSID thorax rib deflection** mm **(CFC600)**	**Peak WorldSID thoracic rib deflection (extrapolated)** mm **(CFC600)**	**Peak WorldSID thoracic rib VC** m/s **(deflection CFC180)**	**Peak WorldSID thoracic rib VC (deflection extrapolated** m/s **(deflection CFC180)**	**Peak WorldSID abdomen rib deflection** mm **(CFC600)**	**Peak WorldSID abdomen rib deflection (extrapolated** mm **(CFC600)**	**Peak WorldSID abdomen rib VC** m/s **(deflection CFC180)**	**Peak WorldSID abdomen rib VC (deflection extrapolated** m/s **(deflection CFC180)**	**WorldSID lower spine acceleration 3 ms** m/s² **(CFC180)**	**WorldSID pelvis acceleration 3 ms** m/s² **(CFC1000)**	**Peak WorldSID pubis force** N **(CFC1000)**
MCW and OSU padded, pelvis offset sled test at 8,9 m/s	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NOTE 1 NA means that the test was not performed. For the non-extrapolated values, / means that the value to be used is the extrapolated one. For the extrapolated values, / means that the non-extrapolated value should be used.

NOTE 2 Rib deflections were extrapolated because measurements showed flat topping either due to a measurement problem or due to a maximum range of motion.

Annex I
(informative)

Data scaling

Annex I describes the method used to scale the data before constructing the injury risk curves.

PMHS included in biomechanical studies present different characteristics (e.g. height, mass, mass distribution, bone strength) than an average mid-size adult male. It is therefore not correct to directly correlate the response of a mid-size male dummy to the injuries of a PMHS that is not a mid-size male. Each PMHS represents a different percentile. Each PMHS percentile is called "*xxth* percentile".

Scaling methods were developed in order to define injury risk curves for subjects of a given percentile using the injury risk curves of a different percentile. For example, the injury risk curves for a 5th percentile female or for a 95th male could be derived from injury risk curves defined for a 50th percentile male. Scaling factors were defined for each criterion in Reference[32] and are presented for some criteria in Formula (I.1).

$$\lambda_d = \lambda_L \tag{I.1}$$

where λ_d is the ratio of deflection and λ_L is the ratio of a characteristic length of the PMHS.

The matter being only to scale each subject to a different size, their bone characteristics were kept constant ($\lambda_{\sigma f}$ =1 and λ_E =1, with $\lambda_{\sigma f}$ being the failure strength ratio and λ_E the Young's modulus ratio). Formula (I. 1) is then equivalent to Formula (I.2).

$$\lambda_\varepsilon = 1 \tag{I.2}$$

where λ_ε is the ratio of strain.

Strain can be defined in terms of deflection (d) and length (L) for each body region, therefore:

$$\frac{\lambda_d}{\lambda_L} = 1 \tag{I.3}$$

Formula (I.3) means that an *xxth* percentile PMHS will sustain the same injuries as a 50th percentile PMHS if each is compressed in proportion to the characteristic length, as written in Formula (I.4).

$$\frac{d_{xxth\_PMHS}}{L_{xxth\_PMHS}} = \frac{d_{50\text{th}\_PMHS}}{L_{50\text{th}\_PMHS}} \tag{I.4}$$

The use of a mass-spring-mass model, like in the normalization process,[24] allows for the calculation of a subject deflection as a function of the impactor mass and initial velocity, the subject mass, and the subject stiffness. By rearranging Formula (I.4), it is possible to calculate the impact velocity necessary to induce the same injuries on the 50th percentile PMHS as on the *xxth* percentile PMHS. This velocity is named $V_{0\_50th\_PMHS}$.

This impact velocity $V_{0\_50th\_PMHS}$, however, does not correspond exactly to the impact velocity from the actual 50th percentile dummy tests. That is the reason why the actual 50th percentile dummy data responses need to be scaled to account for velocity differences relative to the target impact speed scaled for a 50th percentile PMHS $V_{0\_50th\_PMHS}$.

The principle of the scaling method is the same for the force, the acceleration, and the viscous criterion.

The following paragraphs explain in detail the calculation process done, first, to scale *xxth* percentile PMHS data to 50th percentile PMHS data, and second, to scale the dummy data to the relevant velocity $V_{0\_50th\_PMHS}$.

A mass-spring-mass model is considered. The impacting mass was equal to the impactor mass in the impactor tests and infinite in both the drop and sled tests. It can be noted that no scaling was necessary for the sled test configuration except the adjustment due to differences between the dummy impact speed and each PMHS impact speed.

I.1 Scaling factor for impactor test

I.1.1 Deflection

Since $\frac{\lambda_d}{\lambda_L} = 1$, the invariant parameter is compression.

In the data sample selected in the analysis, each PMHS represents a different percentile. Each PMHS percentile is called "*xxth* percentile".

Given the mass-spring-mass model in Reference[24],the deflection and the compression for the *xxth* percentile PMHS are:

$$deflection_{xxth\_PMHS} = V_{0\_xxth\_PMHS} \times \sqrt{\frac{m_{xxth\_PMHS} \times m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}} \times \frac{1}{k_{xxth\_PMHS}}} \quad \text{(I.5)}$$

$$compression_{xxth\_PMHS} = \frac{V_{0\_xxth\_PMHS}}{L_{xxth\_PMHS}} \times \sqrt{\frac{m_{xxth\_PMHS} \times m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}} \times \frac{1}{k_{xxth\_PMHS}}} \quad \text{(I.6)}$$

where

$V_{0\_xxth\_PMHS}$ is the impact speed for the *xxth* percentile PMHS test;

k_{xxth_PMHS} is the stiffness of the body region considered of an *xxth* percentile PMHS;

m_{imp_PMHS} is the impactor mass (the same impactor mass is used for the *xxth* and the 50th percentile PMHS);

m_{xxth_PMHS} is the effective mass of the body region considered of the *xxth* percentile PMHS;

L_{xxth_PMHS} is a characteristic length for the *xxth* PMHS.

For a 50th percentile PMHS, the deflection and the compression are:

$$deflection_{50th\_PMHS} = V_{0\_50th\_PMHS} \times \sqrt{\frac{m_{50th\_PMHS} \times m_{imp\_PMHS}}{m_{50th\_PMHS} + m_{imp\_PMHS}} \times \frac{1}{k_{50th\_PMHS}}} \quad \text{(I.7)}$$

$$compression_{50th\_PMHS} = \frac{V_{0\_50th\_PMHS}}{L_{50th\_PMHS}} \times \sqrt{\frac{m_{50th\_PMHS} \times m_{imp\_PMHS}}{m_{50th\_PMHS} + m_{imp\_PMHS}} \times \frac{1}{k_{50th\_PMHS}}} \tag{I.8}$$

where

$V_{0\_50th\_PMHS}$ is the impact speed for the 50th percentile PMHS test;

k_{50th_PMHS} is the stiffness of the body region considered of a 50th percentile PMHS;

m_{50th_PMHS} is the effective mass of the body region considered of the 50th percentile PMHS (see Table I.1);

L_{50th_PMHS} is a characteristic length for the 50th PMHS.

Since the invariant parameter is compression: $compression_{xxth\_PMHS} = compression_{50th\_PMHS}$, for a given injury assessment.

$$\frac{V_{0\_xxth\_PMHS}}{L_{xxth\_PMHS}} \times \sqrt{\frac{m_{xxth\_PMHS} \times m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}} \times \frac{1}{k_{xxth\_PMHS}}} = \frac{V_{0\_50th\_PMHS}}{L_{50th\_PMHS}} \times \sqrt{\frac{m_{50th\_PMHS} \times m_{imp\_PMHS}}{m_{50th\_PMHS} + m_{imp\_PMHS}} \times \frac{1}{k_{50th\_PMHS}}}$$
(I.9)

If the same impactor mass is considered for the *xxth* percentile PMHS and the 50th percentile PMHS, the impact velocity for a 50th percentile PMHS allowing the same compression can be defined as follows:

$$V_{0\_50th\_PMHS} = \frac{V_{0\_xxth\_PMHS} \times L_{50th\_PMHS}}{L_{xxth\_PMHS}} \times \sqrt{\frac{m_{xxth\_PMHS} \times m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}} \times \frac{m_{50th\_PMHS} + m_{imp\_PMHS}}{m_{50th\_PMHS} \times m_{imp\_PMHS}} \times \frac{k_{50th\_PMHS}}{k_{xxth\_PMHS}}}$$
(I.10)

Making the hypothesis of geometric similarity of the PMHS:

$$\lambda_k = \frac{k_{xxth\_PMHS}}{k_{50th\_PMHS}} = \lambda_m^{1/3} \tag{I.11}$$

$$\lambda_L = \frac{L_{xxth\_PMHS}}{L_{50th\_PMHS}} = \lambda_m^{1/3} \tag{I.12}$$

$$\lambda_m = \frac{m_{xxth\_PMHS}}{m_{50th\_PMHS}} \tag{I.13}$$

$$V_{0\_50th\_PMHS} = \frac{V_{0\_xxth\_PMHS}}{\lambda_m^{1/3}} \times \sqrt{\frac{\lambda_m}{\lambda_m^{1/3}} \times \frac{m_{50th\_PMHS} + m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}}} \tag{I.14}$$

$$V_{0\_50th\_PMHS} = V_{0\_xxth\_PMHS} \times \sqrt{\frac{m_{50th\_PMHS} + m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}}} \tag{I.15}$$

It means that a 50th percentile PMHS should be impacted at $V_{0\_50th\_PMHS}$ in order to have the same compression as the *xxth* percentile PMHS and that the injury assessments for the 50th and *xxth* percentile PMHS will be the same.

Consequently, the 50th percentile dummy measurement to be associated with the PMHS injury assessment is the dummy measurement that would be found for an impact speed of $V_{0\_50th\_PMHS}$.

However, dummy tests were only conducted at reference velocities, $V_{REF\_0\_50th\_dummy}$. If $d_{REF\_50th\_dummmy}$ is the deflection measured on the dummy at this reference velocity, then the dummy deflection at $V_{0\_50th\_PMHS}$, named $d_{scaled\_50th\_dummmy}$, would be the following:

$$d_{scaled\_50th\_dummmy} = d_{REF\_50th\_dummmy} \times \frac{V_{0\_50th\_PMHS}}{V_{REF\_0\_50th\_dummmy}} \quad \text{(I.16)}$$

since for a given subject, deflection and impact velocity are proportional with the spring-mass model considered here.

Finally, it gives:

$$d_{scaled\_50th\_dummmy} = \frac{d_{REF\_50th\_dummmy}}{V_{REF\_0\_50th\_dummmy}} \times V_{0\_xxth\_PMHS} \times \sqrt{\frac{m_{50th\_PMHS} + m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}}} \quad \text{(I.17)}$$

Table I.1 — PMHS effective mass used for data scaling

50th male dummy	PMHS used to determine the mean % effective mass/total body mass	mean % effective mass/total body mass	m_{50th_PMHS} kg
For shoulder impactor tests	LCE01, LCE02, LCE03, LCE04, LCE07, LCE08, LCE09, LCE10, LCE11, LCE12, LCE13, LCE14, LCE15, LCE16, LCE17, LCE18, LCE20, LCE21, LCE22, LCE23, LCE24, LCE25, LCE26, LCE27, LCE28, LCE29, LCE30, LCE31, LCE32, LCE33, LCE34, LCE35, LCE36, 02-UM29899, 04-UM29850, 05-UM29852, 06-UM29851, 07-WSU025, 09-WSU170, 10-WSU091, 11-WSU164, 12-UM30436	20,4	15,6
For thorax impactor tests	76T061, 76T062, 76T064, 76T065, 77T066, 77T070, 77T071, 77T073, 77T074, 77T076, 77T077, 77T081, 77T084, 77T088, 77T090, 77T091, 77T094, 77T097, 0503OTH25L01, 0503LTH25R01, 0504LTH25L01, 0504OTH25R02, 0507LTH25R01, 0507OTH25L01, 0602LTH25R01, 0602OTH25L01	39,6	30,4
For abdomen impactor tests	93VRTAB01, 93VRTAB02, 93VRTAB03, 93VRTAB04, 93VRTAB05, 93VRTAB06, 93VRTAB07	50,4	38,4
For pelvis impactor test	D1, D2, E1, H3, I1, I2, I3, I4, I5, J1, L1, L2, L3, L4, T2, V2, W2, MRB02, MRB03, MRB04, MRB06, MRB07, MRB08, MRB11, MRB12, MRB15, MRB16, MRB17, MRB18, MRB19	31,2	23,9

For each of the PMHS for which the effective mass was not available, the mean ratio of the effective mass out of the total body mass was multiplied by the total body mass of the PMHS considering a similar body posture, similar impact location on the body, similar impactor, similar impact angle, similar test velocity, etc. as those included in the PMHS sample used to compute the mean effective mass.

I.1.2 Force

Since $\frac{\lambda_F}{\lambda_S} = 1$, stress is the invariant parameter where λ_F is the ratio of force and λ_S is the ratio of surface.

In the data sample selected in the analysis, each PMHS represents a different percentile. Each PMHS percentile is called "*xxth* percentile".

Given the mass-spring-mass model in Reference[24],the force and the stress for the *xxth* percentile PMHS are:

$$Force_{xxth\_PMHS} = V_{0\_xxth\_PMHS} \times \sqrt{\frac{m_{xxth\_PMHS} \times m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}} \times k_{xxth\_PMHS}} \quad \text{(I.18)}$$

$$stress_{xxth\_PMHS} = \frac{V_{0\_xxth\_PMHS}}{S_{xxth\_PMHS}} \times \sqrt{\frac{m_{xxth\_PMHS} \times m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}} \times k_{xxth\_PMHS}} \qquad (I.19)$$

where

$V_{0\_xxth\_PMHS}$ is the impact speed for the *xxth* percentile PMHS test;

k_{xxth_PMHS} is the stiffness of the body region considered of a *xxth* percentile PMHS;

m_{imp_PMHS} is the impactor mass (the same impactor mass is used for the *xxth* and the 50th percentile PMHS);

m_{xxth_PMHS} is the effective mass of the body region considered of the *xxth* percentile PMHS;

S_{xxth_PMHS} is a characteristic section for the *xxth* PMHS (a characteristic section could be the area of a section of the ischio-ilio pubic ramus).

For a 50th percentile PMHS, the force and the stress are:

$$Force_{50th\_PMHS} = V_{0\_50th\_PMHS} \times \sqrt{\frac{m_{50th\_PMHS} \times m_{imp\_PMHS}}{m_{50th\_PMHS} + m_{imp\_PMHS}} \times k_{50th\_PMHS}} \qquad (I.20)$$

$$stress_{50th\_PMHS} = \frac{V_{0\_50th\_PMHS}}{S_{50th\_PMHS}} \times \sqrt{\frac{m_{50th\_PMHS} \times m_{imp\_PMHS}}{m_{50th\_PMHS} + m_{imp\_PMHS}} \times k_{50th\_PMHS}} \qquad (I.21)$$

where

$V_{0\_50th\_PMHS}$ is the impact speed for the 50th percentile PMHS test;

k_{50th_PMHS} is the stiffness of the thorax of a 50th percentile PMHS;

m_{50th_PMHS} is the effective mass of the body region considered of the 50th percentile PMHS (see Table I.1);

S_{50th_PMHS} is the characteristic section for the 50th PMHS.

Since the invariant parameter is stress: $stress_{xxth\_PMHS} = stress_{50th\_PMHS}$, for a given injury assessment.

$$\frac{V_{0\_50th\_PMHS}}{S_{50th\_PMHS}} \times \sqrt{\frac{m_{50th\_PMHS} \times m_{imp\_PMHS}}{m_{50th\_PMHS} + m_{imp\_PMHS}} \times k_{50th\_PMHS}} = \frac{V_{0\_xxth\_PMHS}}{S_{xxth\_PMHS}} \times \sqrt{\frac{m_{xxth\_PMHS} \times m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}} \times k_{xxth\_PMHS}}$$
(I.22)

If the same impactor mass is considered for the *xxth* percentile PMHS and the 50th percentile PMHS, the impact velocity for a 50th percentile allowing the same stress can be defined as follows:

$$V_{0\_50th\_PMHS} = V_{0\_xxth\_PMHS} \times \frac{S_{50th\_PMHS}}{S_{xxth\_PMHS}} \times \sqrt{\frac{m_{xxth\_PMHS} \times m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}} \times \frac{k_{xxth\_PMHS}}{k_{50th\_PMHS}} \times \frac{m_{50th\_PMHS} + m_{imp\_PMHS}}{m_{50th\_PMHS} \times m_{imp\_PMHS}}}$$
(I.23)

Making the hypothesis of geometric similarity of the PMHS:

$$\lambda_k = \frac{k_{xxth\_PMHS}}{k_{50th\_PMHS}} = \lambda_m^{1/3} \qquad (I.24)$$

$$\lambda_S = \frac{S_{xxth\_PMHS}}{S_{50th\_PMHS}} = \lambda_m^{2/3} \tag{I.25}$$

$$\lambda_m = \frac{m_{xxth\_PMHS}}{m_{50th\_PMHS}} \tag{I.26}$$

$$V_{0\_50th\_PMHS} = \frac{V_{0\_xxth\_PMHS} \times L_{50th\_PMHS}}{L_{xxth\_PMHS}} \times \sqrt{\frac{m_{xxth\_PMHS} \times m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}} \times \frac{m_{50th\_PMHS} + m_{imp\_PMHS}}{m_{50th\_PMHS} \times m_{imp\_PMHS}} \times \frac{k_{50th\_PMHS}}{k_{xxth\_PMHS}}}$$
(I.27)

$$V_{0\_50th\_PMHS} = V_{0\_xxth\_PMHS} \times \frac{1}{\lambda_m^{2/3}} \times \sqrt{\frac{m_{50th\_PMHS} + m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}} \times \lambda_m^{4/3}} \tag{I.28}$$

$$V_{0\_50th\_PMHS} = V_{0\_xxth\_PMHS} \times \sqrt{\frac{m_{50th\_PMHS} + m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}}} \tag{I.29}$$

It means that a 50th percentile PMHS should be impacted at $V_{0\_50th\_PMHS}$ in order to have the same stress as the *xxth* percentile PMHS and that the injury assessments for the 50th and *xxth* percentile PMHS will be the same.

Consequently, the 50th percentile dummy measurement to be associated with the PMHS injury assessment is the dummy measurement that would be found for an impact speed of $V_{0\_50th\_PMHS}$.

However, dummy tests were only conducted at reference velocities, $V_{REF\_0\_50th\_dummy}$. If $F_{REF\_50th\_dummmy}$ is the force measured on the dummy at this reference velocity, then the dummy force at $V_{0\_50th\_PMHS}$, named $F_{scaled\_50th\_dummmy}$, would be the following:

$$F_{scaled\_50th\_dummmy} = F_{REF\_50th\_dummmy} \times \frac{V_{0\_50th\_PMHS}}{V_{REF\_0\_50th\_dummmy}} \tag{I.30}$$

since for a given subject, force and impact velocity are proportional with the spring-mass model considered here.

$$F_{scaled\_50th\_dummmy} = \frac{F_{REF\_50th\_dummmy}}{V_{REF\_0\_50th\_dummmy}} \times V_{0\_xxth\_PMHS} \times \sqrt{\frac{m_{50th\_PMHS} + m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}}} \tag{I.31}$$

I.1.3 Acceleration

Since $\lambda_a \times \lambda_L = 1$, the invariant parameter is stress where λ_a is the ratio of acceleration.

In the data sample selected in the analysis, each PMHS represents a different percentile. Each PMHS percentile is called "*xxth* percentile".

Given the spring-mass model in Reference[24],the acceleration and stress for the *xxth* percentile PMHS are:

$$Acc_{xxth\_PMHS} = \frac{V_{0\_xxth\_PMHS}}{m_{xxth\_PMHS}} \times \sqrt{\frac{m_{xxth\_PMHS} \times m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}} \times k_{xxth\_PMHS}} \tag{I.32}$$

$$Stress_{xxth\_PMHS} = \frac{V_{0\_xxth\_PMHS}}{m_{xxth\_PMHS}} \times \sqrt{\frac{m_{xxth\_PMHS} \times m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}} \times k_{xxth\_PMHS}} \times \frac{m_{xxth\_PMHS}}{S_{xxth\_PMHS}} \quad (I.33)$$

where

$V_{0\_xxth\_PMHS}$ is the impact speed for the *xxth* percentile PMHS test;

k_{xxth_PMHS} is the stiffness of the body region considered of a *xxth* percentile PMHS;

m_{imp_PMHS} is the impactor mass (the same impactor mass is used for the *xxth* and the 50th percentile PMHS);

m_{xxth_PMHS} is the effective mass of the body region considered of the *xxth* percentile PMHS;

S_{xxth_PMHS} is a characteristic section for the *xxth* PMHS.

For a 50th percentile PMHS, the acceleration and stress are:

$$Acc_{50th\_PMHS} = \frac{V_{0\_50th\_PMHS}}{m_{50th\_PMHS}} \times \sqrt{\frac{m_{50th\_PMHS} \times m_{imp\_PMHS}}{m_{50th\_PMHS} + m_{imp\_PMHS}} \times k_{50th\_PMHS}} \quad (I.34)$$

$$Stress_{50th\_PMHS} = \frac{V_{0\_50th\_PMHS}}{m_{50th\_PMHS}} \times \sqrt{\frac{m_{50th\_PMHS} \times m_{imp\_PMHS}}{m_{50th\_PMHS} + m_{imp\_PMHS}} \times k_{50th\_PMHS}} \times \frac{m_{50th\_PMHS}}{S_{50th\_PMHS}} \quad (I.35)$$

where

$V_{0\_50th\_PMHS}$ is the impact speed for the 50th percentile PMHS test;

k_{50th_PMHS} is the stiffness of the body region considered of a 50th percentile PMHS;

m_{50th_PMHS} is the effective mass of the body region considered of the 50th percentile PMHS (see Table I.1);

S_{50th_PMHS} is a characteristic section for the 50th PMHS.

Since the invariant parameter is stress: $stress_{xxth\_PMHS} = stress_{50th\_PMHS}$, for a given injury assessment.

$$\frac{V_{0\_50th\_PMHS}}{m_{50th\_PMHS}} \times \sqrt{\frac{m_{50th\_PMHS} \times m_{imp\_PMHS}}{m_{50th\_PMHS} + m_{imp\_PMHS}} \times k_{50th\_PMHS}} \times \frac{m_{50th\_PMHS}}{S_{50th\_PMHS}} = \frac{V_{0\_xxth\_PMHS}}{m_{xxth\_PMHS}} \times \sqrt{\frac{m_{xxth\_PMHS} \times m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}} \times k_{xxth\_PMHS}} \times \frac{m_{xxth\_PMHS}}{S_{xxth\_PMHS}}$$

(I.36)

If the same impactor mass is considered for the *xxth* percentile PMHS and the 50th percentile PMHS, the impact velocity for a 50th percentile PMHS allowing the same stress can be defined.

Making the hypothesis of geometric similarity of the PMHS:

$$\lambda_k = \frac{k_{xxth\_PMHS}}{k_{50th\_PMHS}} = \lambda_m^{1/3} \quad (I.37)$$

$$\lambda_S = \frac{S_{xxth\_PMHS}}{S_{50th\_PMHS}} = \lambda_m^{2/3} \quad (I.38)$$

$$\lambda_m = \frac{m_{xxth\_PMHS}}{m_{50th\_PMHS}} \quad \text{(I. 11, I. 12, I. 13)} \tag{I.39}$$

$$V_{0\_50th\_PMHS} = V_{0\_xxth\_PMHS} \times \sqrt{\frac{m_{50th\_PMHS} + m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}}} \tag{I.40}$$

It means that a 50th percentile PMHS should be impacted at $V_{0\_50th\_PMHS}$ in order to have the same stress as the *xxth* percentile PMHS and that the injury assessments for the 50th and *xxth* percentile PMHS will be the same.

Consequently, the 50th percentile dummy measurement to be associated with the PMHS injury assessment is the dummy measurement that would be found for an impact speed of $V_{0\_50th\_PMHS}$.

However, dummy tests were only conducted at reference velocities, $V_{REF\_0\_50th\_dummy}$. If $Acc_{REF\_50th\_dummmy}$ is the acceleration measured on the dummy at this reference velocity, then the dummy acceleration at $V_{0\_50th\_PMHS}$, named $Acc_{scaled\_50th\_dummmy}$, would be the following:

$$Acc_{scaled\_50th\_dummmy} = Acc_{REF\_50th\_dummmy} \times \frac{V_{0\_50th\_PMHS}}{V_{REF\_0\_50th\_dummmy}} \tag{I.41}$$

since for a given subject, acceleration and impact velocity are proportional with the spring-mass model considered here.

$$Acc_{scaled\_50th\_dummmy} = \frac{Acc_{REF\_50th\_dummmy}}{V_{REF\_0\_50th\_dummmy}} \times V_{0\_xxth\_PMHS} \times \sqrt{\frac{m_{50th\_PMHS} + m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}}} \tag{I.42}$$

I.1.4 Viscous criterion

Since $\lambda_V = 1$, the invariant parameter is PMHS velocity where λ_V is the ratio of velocity.

In the data sample selected in the analysis, each PMHS represents a different percentile. Each PMHS percentile is called "*xxth* percentile".

The deflection, deflection speed, and compression for the *xxth* percentile PMHS are:

$$deflection_{xxth\_PMHS} = \frac{V_{0\_xxth\_PMHS}}{\omega} \times \sin(\omega t) \tag{I.43}$$

$$V_{xxth\_PMHS} = V_{0\_xxth\_PMHS} \times \cos(\omega t) \tag{I.44}$$

$$C_{xxth\_PMHS} = \frac{V_{0\_xxth\_PMHS}}{\omega} \times \sin(\omega t) \times \frac{1}{L_{xxth\_PMHS}} \tag{I.45}$$

where

$V_{0\_xxth\_PMHS}$ is the impact speed for the *xxth* percentile PMHS test;

ω is pulsation;

L_{xxth_PMHS} is the length for the *xxth* PMHS.

The VC for the *xxth* percentile PMHS is:

$$VC_{xxth\_PMHS} = V_{0\_xxth\_PMHS} \times \cos(\omega t) \times \frac{V_{0\_xxth\_PMHS}}{\omega} \times \sin(\omega t) \times \frac{1}{L_{xxth\_PMHS}} \quad (I.46)$$

$$VC_{xxth\_PMHS} = V^2_{0\_xxth\_PMHS} \times \cos(\omega t) \times \frac{1}{\omega} \times \sin(\omega t) \times \frac{1}{L_{xxth\_PMHS}} \quad (I.47)$$

$$VC_{xxth\_PMHS} = \sin(2\omega t) \times \frac{V^2_{0\_xxth\_PMHS}}{2 \times \omega \times L_{xxth\_PMHS}} \quad (I.48)$$

The maximum for VC for the *xxth* percentile PMHS is:

$$VC_{xxth\_PMHS\_\max} = \frac{V^2_{0\_xxth\_PMHS}}{2 \times L_{xxth\_PMHS} \times \omega} \quad (I.49)$$

$$VC_{xxth\_PMHS\_\max} = \frac{V^2_{0\_xxth\_PMHS}}{2L_{xxth\_PMHS}} \times \sqrt{\frac{m_{xxth\_PMHS} \times m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}} \times \frac{1}{k_{xxth\_PMHS}}} \quad (I.50)$$

The maximum for VC for the 50th percentile PMHS is:

$$VC_{50th\_PMHS\_\max} = \frac{V^2_{0\_50th\_PMHS}}{2L_{50th\_PMHS}} \times \sqrt{\frac{m_{50th\_PMHS} \times m_{imp\_PMHS}}{m_{50th\_PMHS} + m_{imp\_PMHS}} \times \frac{1}{k_{50th\_PMHS}}} \quad (I.51)$$

Since the invariant parameter is velocity: $V_{xxth\_PMHS} = V_{50th\_PMHS}$, for a given injury assessment.

$$\frac{V^2_{0\_50th\_PMHS}}{2L_{50th\_PMHS}} \times \sqrt{\frac{m_{50th\_PMHS} \times m_{imp\_PMHS}}{m_{50th\_PMHS} + m_{imp\_PMHS}} \times \frac{1}{k_{50th\_PMHS}}} = \frac{V^2_{0\_xxth\_PMHS}}{2L_{xxth\_PMHS}} \times \sqrt{\frac{m_{xxth\_PMHS} \times m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}} \times \frac{1}{k_{xxth\_PMHS}}}$$
(I.52)

If the same impactor mass is considered for the *xxth* percentile PMHS and the 50th percentile PMHS, the impact velocity for a 50th percentile PMHS allowing the same velocity can be defined.

Making the hypothesis of geometric similarity of the PMHS:

$$\lambda_k = \frac{k_{xxth\_PMHS}}{k_{50th\_PMHS}} = \lambda_m^{1/3} \quad (I.53)$$

$$\lambda_L = \frac{L_{xxth\_PMHS}}{L_{50th\_PMHS}} = \lambda_m^{1/3} \quad (I.54)$$

$$\lambda_m = \frac{m_{xxth\_PMHS}}{m_{50th\_PMHS}} \quad (I.55)$$

$$V_{0\_50th\_PMHS} = V_{0\_xxth\_PMHS} \times \left(\frac{m_{50th\_PMHS} + m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}}\right)^{1/4} \quad (I.56)$$

It means that a 50th percentile PMHS should be impacted at $V_{0\_50th\_PMHS}$ in order to have the same maximum of VC as the *xxth* percentile PMHS and that the injury assessments for the 50th and *xxth* percentile PMHS will be the same.

Consequently, the 50th percentile dummy measurement to be associated with the PMHS injury assessment is the dummy measurement that would be found for an impact speed of $V_{0\_50th\_PMHS}$.

However, dummy tests were only conducted at reference velocities, $V_{REF\_0\_50th\_dummy}$. If $VC_{REF\_\max\_50th\_dummmy}$ is the maximum VC measured on the dummy at this reference velocity, then the dummy maximum VC at $V_{0\_50th\_PMHS}$, named $VC_{\max\_scaled\_50th\_dummmy}$, would be the following:

$$VC_{\max\_scaled\_50th\_dummmy} = VC_{REF\_\max\_50th\_dummmy} \times \left(\frac{V_{0\_50th\_PMHS}}{V_{REF\_0\_50th\_dummmy}}\right)^2 \qquad (I.57)$$

since for a given subject, VC and impact velocity are square proportional with the spring-mass model considered here.

$$VC_{\max\_scaled\_50th\_dummmy} = VC_{REF\_\max\_50th\_dummmy} \times \left(\frac{V_{0\_xxth\_PMHS}}{V_{REF\_0\_50th\_dummmy}}\right)^2 \times \sqrt{\frac{m_{50th\_PMHS} + m_{imp\_PMHS}}{m_{xxth\_PMHS} + m_{imp\_PMHS}}}$$

(I.58)

I.2 Scaling factor for sled and drop test

The same process is used as the one described above, replacing impactor mass by an infinite mass.

I.2.1 Deflection

$$d_{scaled\_50th\_dummmy} = d_{REF\_50th\_dummmy} \times \frac{V_{0\_xxth\_PMHS}}{V_{REF\_0\_50th\_dummmy}} \quad \text{(I.59)}$$

I.2.2 Force

$$F_{scaled\_50th\_dummmy} = F_{REF\_50th\_dummmy} \times \frac{V_{0\_xxth\_PMHS}}{V_{REF\_0\_50th\_dummmy}} \quad \text{(I.60)}$$

I.2.3 Acceleration

$$Acc_{scaled\_50th\_dummmy} = \frac{Acc_{REF\_50th\_dummmy}}{V_{REF\_0\_50th\_dummmy}} \times V_{0\_xxth\_PMHS} \quad \text{(I.61)}$$

I.2.4 For viscous criterion

$$VC_{\max\_scaled\_50th\_dummmy} = VC_{REF\_\max\_50th\_dummmy} \times \left(\frac{V_{0\_xxth\_PMHS}}{V_{REF\_0\_50th\_dummmy}}\right)^2 \quad \text{(I.62)}$$

I.3 Hypothesis of geometric similarity

The hypothesis of geometric similarity was made in the scaling process. The characteristic dimensions were indeed not available for the major part of the different series of PMHS tests. For example, the pelvis width was not available for the ONSER pelvis impactor tests. The ONSER pelvis impactor test sample represents half of the pelvis impactor tests used in this study (45 tests). Excluding these tests based on the fact that the characteristic dimension was not available would mean constructing the injury risk curves with small sample sizes and reduce the confidence in the results. Finally, it was preferred to keep a consistent way to calculate the stiffness and length ratio within the PMHS test samples. All the tests, including those for which the characteristic dimensions were available, were then analysed making the hypothesis of geometric similarity. Making the hypothesis of geometric similarity when no characteristic dimensions are available is a method that was already used in ISO/TR 9790.

Annex J
(informative)

Steps to build injury risk curves dedicated to the WorldSID 50th

Annex J describes the different steps to be followed to build the injury risk curves for the WorldSID 50th dummy.

J.1 Estimation of the parameters

The risk according to the Weibull distribution is

$$Risk(\%) = 1 - \exp\left[-\left(\frac{Dummy\_measurement}{\exp(\text{int} + PMHS\_age \times coef\_age} \right)^{\frac{1}{\exp(\log\_scale)}} \right] \tag{J.1}$$

The risk according to the log-normal distribution is

$$Risk(\%) = \log\_normal\_distribution\left[mean = \text{int} + age \times coef\_age, std = \exp(\log\_scale) \right] \tag{J.2}$$

The risk according to the log-logistic distribution is

$$Risk(\%) = \frac{1}{1 + \exp\left\{ -\left[\ln(Dummy\_measurement) - (\text{int} + age \times coef\_age) \right] / \exp(\log\_scale) \right\}} \tag{J.3}$$

when Dummy_measurement corresponds to the dummy measurement and PMHS_age corresponds to the PMHS age.

Table J.1 — Estimated parameters for the Weibull, log-normal, and log-logistic distributions for the survival analysis

Injury risk	Dummy measurement	Distribution	int	Coef_age	Log_scale	AIC
Shoulder AIS2+	Maximum shoulder rib deflection (mm)	Weibull	4,802 901 10	−0,010 876 66	−1,526 854 06	22,702 7
	Maximum shoulder rib **Y** force (N)	Weibull	8,143 520 261	−0,005 505 064	−2,002 759 491	28,680 4
Skeletal thoracic AIS3+	Maximum thoracic rib deflection (mm)	Log-logistic	4,669 947 91	−0,014 571 79	−2,094 495 85	24,883 7
	Maximum thoracic rib VC (m/s)	Log-normal	0,981 639 78	−0,027 385 26	−0,682 914 85	29,691 1
Skeletal thoracic AIS4+	Maximum thoracic rib deflection (mm)	Log-normal	5,463 324 33	−0,016 541 52	−1,239 534 59	29,735 4
	Maximum thoracic rib VC (m/s)	Log-normal	2,635 478 73	−0,033 129 79	−0,507 249 49	30,650 7

Table J.1 *(continued)*

Injury risk	Dummy measurement	Distribution	int	Coef_age	Log_scale	AIC
Soft tissue thoracic AIS2+	Maximum thoracic rib VC (m/s)	Log-normal	21,522 029 6	−0,249 326 8	2,190 178 2	45,789 2
Soft tissue thoracic AIS3+	Maximum thoracic rib VC (m/s)	Log-normal	55,427 821 8	−0,589 543 4	2,773 955 6	35,607 2
Abdomen soft tissue AIS2+	Maximum abdomen rib deflection (mm)	Weibull	5,367 785 71	−0,021 028 76	−2,153 073 24	14,988 9
	Maximum abdomen rib VC (m/s)	Weibull	1,990 103 19	−0,034 274 53	−1,678 603 32	14,977 7
	Lower spine acceleration **Y** 3 ms (m/s^2)	Weibull	7,226 378 56	−0,012 791 82	−1,860 358 41	27,576 8
Abdomen soft tissue AIS3+	Maximum abdomen rib deflection (mm)	Log-normal	6,865 650 56	−0,033 380 33	−1,010 341 17	11,959 1
	Maximum abdomen rib VC (m/s)	Log-normal	4,229 733 29	−0,052 732 82	−0,629 770 80	11,869 6
	Lower spine acceleration **Y** 3 ms (m/s^2)					/
Pelvis AIS2+	Maximum pubic force (N)	Weibull	8,774 827 06	−0,013 855 68	−1,525 878 36	64,005 2
	Pelvis acceleration **Y** 3 ms (m/s^2)	Weibull	7,848 665 45	−0,017 648 48	−1,271 622 71	81,179 1
Pelvis AIS3+	Maximum pubic force (N)	Weibull	8,704 064 39	−0,011 639 87	−1,827 378 27	44,204 8
	Pelvis acceleration Y 3 ms (m/s^2)	Weibull	8,776 559 53	−0,027 097 67	−1,317 818 37	54,890 5

J.2 Identification of the overly influential observations

The overly influential observations for the WorldSID 50th injury risk curves are specified in Tables J.2 to J.7.

Table J.2 — Overly influential observations for the shoulder AIS2+ risk as a function of the maximum shoulder rib deflection

Shoulder AIS2+	Maximum shoulder rib deflection mm
Survival distribution with the lowest AIC	Weibull
lat01	
lat02	
lat03	x
lat04	

Table J.2 *(continued)*

Shoulder AIS2+	Maximum shoulder rib deflection mm
01-UM29840	
02-UM29899	
03-UM29844	
04-UM29850	x
05-UM29852	
06-UM29851	x
07-WSU025	
08-UM30356	
09-WSU170	
10-WSU091	
11-WSU164	
12-UM30436	x
MS201	
MS202	
MS203	

Table J.3 — Overly influential observations for the shoulder AIS2+ risk as a function of the maximum shoulder Y force

Shoulder AIS2+	Maximum shoulder rib Y force N
Survival distribution with the lowest AIC	Weibull
SC101	
SC102	
SC120	
SC121	
SC124	
SC135	
SAC 102	
SIC-07	
SIC-05	x
SC125	
SC129	
SC144	
SC139	
SC110	
SC111	
SC115	
SC136	
SC107	

Table J.3 *(continued)*

Shoulder AIS2+	**Maximum shoulder rib Y force** N
SC133	
SC116	
SC134	
94LSI32P03	
95LSI32P06	
LSI32P12	
LSI32P14	
LSI32P15	
LSI32P16	
01-UM29840	
02-UM29899	
03-UM29844	
04-UM29850	x
05-UM29852	
06-UM29851	x
07-WSU025	
08-UM30356	
09-WSU170	
10-WSU091	
11-WSU164	
12-UM30436	x
MS201	
MS202	
MS203	

Table J.4 — Overly influential observations for the skeletal thoracic AIS3+ and AIS4+ risk as a function of the maximum thoracic rib deflection and VC

Skeletal thoracic AIS3+	Maximum thoracic rib deflection mm	Maximum thoracic rib VC m/s	Skeletal thoracic AIS4+	Maximum thoracic rib deflection mm	Maximum thoracic rib VC m/s	Soft tissue thoracic AIS2+	Maximum thoracic rib VC m/s	Soft tissue thoracic AIS3+	Maximum thoracic rib VC m/s
Survival distribution with the lowest AIC	**Log-logistic**	**Log-normal**	**Survival distribution with the lowest AIC**	**Log-normal**	**Log-normal**	**Survival distribution with the lowest AIC**	**Log-normal**	**Survival distribution with the lowest AIC**	**Log-normal**
SC101			SC101			SC101		SC101	
SC102	x	x	SC102			SC102		SC102	
SC120	x	x	SC120			SC120		SC120	
SC121			SC121	x	x	SC121		SC121	
SC124	x	x	SC124			SC124		SC124	
SC135			SC135			SC135		SC135	
SAC 102			SAC 102			SAC 102		SAC 102	
SIC-07			SIC-07			SIC-07		SIC-07	
SIC-05			SIC-05			SIC-05		SIC-05	
SC125			SC125			SC125		SC125	
SC129	x	x	SC129			SC129		SC129	
SC144			SC144			SC144		SC144	
SC139			SC139			SC139		SC139	
SC110			SC110			SC110		SC110	
SC111			SC111	x	x	SC111		SC111	
SC115			SC115			SC115	x	SC115	
SC136		x	SC136			SC136		SC136	
SC107			SC107			SC107		SC107	
SC133			SC133			SC133		SC133	x
SC116			SC116			SC116		SC116	
SC134			SC134			SC134		SC134	
94LSI32P03			94LSI32P03			94LSI32P03		94LSI32P03	
95LSI32P06			95LSI32P06			95LSI32P06		95LSI32P06	
LSI32P12			LSI32P12	x		LSI32P12		LSI32P12	
LSI32P14			LSI32P14	x		LSI32P14		LSI32P14	
LSI32P15			LSI32P15		x	LSI32P15		LSI32P15	
LSI32P16			LSI32P16			LSI32P16		LSI32P16	
76T062			76T062			76T062		76T062	
76T065			76T065			76T065		76T065	
77T071			77T071			77T071		77T071	x
77T074			77T074			77T074		77T074	
0503LTH25R01			0503LTH25R01			0503LTH25R01		0503LTH25R01	
0504LTH25L01			0504LTH25L01			0504LTH25L01	x	0504LTH25L01	
0507LTH25R01			0507LTH25R01			0507LTH25R01		0507LTH25R01	
0602LTH25R01			0602LTH25R01			0602LTH25R01	x	0602LTH25R01	

Table J.5 — Overly influential observations for the abdomen AIS2+ and AIS3+ risk as a function of the maximum abdomen rib deflection and VC and as a function of the lower spine Y acceleration 3 ms

Abdomen AIS2+	Maximum abdomen rib deflection mm	Maximum abdomen rib VC m/s	Lower spine acceleration Y 3 ms m/s^2	Abdomen AIS3+	Maximum abdomen rib deflection mm	Maximum abdomen rib VC m/s	Lower spine acceleration Y 3 ms m/s^2
Survival distribution with the lowest AIC	**Weibull**	**Weibull**	**Weibull**	**Survival distribution with the lowest AIC**	**Log-normal**	**Log-normal**	**Log-normal**
SC101				SC101			
SC102				SC102			
SC120				SC120			
SC121	x			SC121			
SC124				SC124			
SC135				SC135			
SAC 102				SAC 102			
SIC-07				SIC-07			
SIC-05				SIC-05			
SC125			x	SC125	x	x	
SC129	x	x		SC129			
SC144				SC144			
SC139				SC139			
SC110				SC110			
SC111			x	SC111			
SC115				SC115			
SC136				SC136			
SC107				SC107			
SC133				SC133			
SC116				SC116			
SC134				SC134			
94LSI32P03	x	x	x	94LSI32P03			
95LSI32P06				95LSI32P06			
LSI32P12				LSI32P12			
LSI32P14				LSI32P14			
LSI32P15			x	LSI32P15			
LSI32P16				LSI32P16			

Table J.6 — Overly influential observations for the pelvis AIS2+ and AIS3+ risk as a function of the maximum pubic force

Pelvis AIS2+	Maximum pubic force N	Pelvis AIS3+	Maximum pubic force N
Survival distribution with the lowest AIC	**Weibull**	**Survival distribution with the lowest AIC**	**Weibull**
SC101		SC101	
SC102		SC102	
SC120		SC120	
SC121		SC121	
SC124		SC124	
SC135		SC135	
SC137		SC137	
SAC 102		SAC 102	
SIC-07		SIC-07	
SIC-05		SIC-05	
SC125		SC125	
SC129		SC129	
SC144		SC144	
SC139		SC139	
SC110		SC110	
SC111		SC111	
SC115		SC115	
SC136		SC136	
SC138		SC138	
SC119		SC119	
SC107		SC107	
SC133		SC133	
SC116		SC116	
SC134		SC134	
94LSI32P03		94LSI32P03	
94LSI32P04		94LSI32P04	
95LSI32P06		95LSI32P06	
LSI32P12		LSI32P12	
LSI32P14		LSI32P14	
LSI32P15		LSI32P15	
LSI32P16		LSI32P16	
A4		A4	x
B2		B2	
C2		C2	
D2		D2	
E1		E1	

Table J.6 *(continued)*

Pelvis AIS2+	**Maximum pubic force** N	**Pelvis AIS3+**	**Maximum pubic force** N
Survival distribution with the lowest AIC	**Weibull**	**Survival distribution with the lowest AIC**	**Weibull**
F1		F1	
H3		H3	
I5		I5	
J1		J1	
K3		K3	
L4	x	L4	x
M3	x	M3	
N6		N6	
O6		O6	x
R5		R5	x
S1		S1	
T2		T2	
V2	x	V2	x
W2	x	W2	x

Table J.7 — Overly influential observations for the pelvis AIS2+ and AIS3+ risk as a function of the pelvis acceleration Y 3 ms

Pelvis AIS2+	Pelvis acceleration Y 3 ms m/s^2	Pelvis AIS3+	Pelvis acceleration Y 3 ms m/s^2
Survival distribution with the lowest AIC	**Weibull**	**Survival distribution with the lowest AIC**	**Weibull**
SC101			
SC102			
SC120			
SC121			
SC124			
SC135			
SC137			
SAC 102			
SIC-07			
SIC-05			
SC125			
SC129			
SC144			
SC139			
SC110			
SC111			
SC115			
SC136			
SC138			
SC119			
SC107			
SC133			
SC116			
SC134			
94LSI32P03			
94LSI32P04			
95LSI32P06			
LSI32P12			
LSI32P14			
LSI32P15			
LSI32P16			
WSU956-13			
WSU993-16			
WSU986-21			
WSU986-22			
WSU047-26			

Table J.7 *(continued)*

Pelvis AIS2+	Pelvis acceleration Y 3 ms m/s^2	Pelvis AIS3+	Pelvis acceleration Y 3 ms m/s^2
Survival distribution with the lowest AIC	**Weibull**	**Survival distribution with the lowest AIC**	**Weibull**
WSU047-27			
WSU008-31			
WSU008-32	x		
WSU063-35			
WSUUOMI-38			
WSUUOMI-39			
WSUUOM2-44			
WSUUOM2-45			
A4	x		x
B2	x		x
C2			
D2			
E1			
F1			
H3			
I5	x		
J1			
K3			
L4			
M3	x		
N6			
O6			x
R5	x		
S1			
T2			
V2	x		x
W2	x		x

J.3 Calculation of the 95 % confidence intervals of the relative confidence interval (CI) size and corresponding quality index

Table J.8 — 95 % confidence intervals of the relative confidence interval (CI) size and corresponding quality index

Injury risk	Dummy measurement	Distribution			Measurement value	Lower 95 % CI	Upper 95 % CI	Relative CI size	Quality index
Shoulder AIS2+	Maximum shoulder rib deflection (mm)	Weibull (AIC=22,702 7)	45 yo	5 %	39,18	21,67	70,84	1,255	marginal
				25 %	56,99	35,45	91,62	0,986	fair
				50 %	68,98	42,29	112,52	1,018	marginal
			67 yo	5 %	30,85	19,00	50,07	1,007	marginal
				25 %	44,86	35,58	56,56	0,468	good
				50 %	54,30	44,54	66,20	0,399	good
Shoulder AIS2+	Maximum shoulder rib **Y** force (N)	Weibull (AIC=28,680 4)	45 yo	5 %	1 798,90	1 341,4	2 412,5	0,595	fair
				25 %	2 270,25	1 765,2	2 919,9	0,509	fair
				50 %	2 556,33	1 974,6	3 309,5	0,522	fair
			67 yo	5 %	1 593,7	1 281,8	1 981,5	0,439	good
				25 %	2 011,3	1 789,1	2 261,1	0,235	good
				50 %	2 264,7	2 034,6	2 520,9	0,215	good
Skeletal thoracic AIS3+	Maximum thoracic rib deflection (mm)	Log-logistic (AIC=24,883 7)	45 yo	5 %	38,54	27,72	53,58	0,671	fair
				25 %	48,37	38,00	61,58	0,488	good
				50 %	55,38	44,43	69,04	0,444	good
			67 yo	5 %	27,97	20,68	37,83	0,613	fair
				25 %	35,11	28,92	42,62	0,390	good
				50 %	40,19	34,22	47,21	0,323	good
Skeletal thoracic AIS3+	Maximum thoracic rib VC (m/s)	Log-normal (AIC=29,691 1)	45 yo	5 %	0,339	0,164	0,700	1,580	unacceptable
				25 %	0,554	0,323	0,949	1,132	marginal
				50 %	0,778	0,481	1,261	1,002	marginal
			67 yo	5 %	0,186	0,091	0,378	1,548	unacceptable
				25 %	0,303	0,190	0,482	0,962	fair
				50 %	0,426	0,302	0,600	0,699	fair
Skeletal thoracic AIS4+	Maximum thoracic rib deflection (mm)	Log-normal (AIC=29,735 4)	45 yo	5 %	69,60	42,97	112,73	1,002	fair
				25 %	92,17	50,97	166,70	1,256	marginal
				50 %	112,05	53,64	234,05	1,610	unacceptable
			67 yo	5 %	48,37	34,29	68,23	0,702	fair
				25 %	64,06	53,33	76,93	0,368	good
				50 %	77,87	58,30	104,01	0,587	fair

Table J.8 *(continued)*

Injury risk	Dummy measurement	Distribution			Measurement value	Lower 95 % CI	Upper 95 % CI	Relative CI size	Quality index
Skeletal thoracic AIS4+	Maximum thoracic rib VC (m/s)	Log-normal (AIC=30,650 7)	45 yo	5 %	1,167	0,440	3,097	2,277	unacceptable
				25 %	2,092	0,593	7,383	3,244	unacceptable
				50 %	3,141	0,636	15,515	4,737	unacceptable
			67 yo	5 %	0,562	0,276	1,148	1,550	unacceptable
				25 %	1,010	0,696	1,466	0,762	fair
				50 %	1,516	0,804	2,856	1,353	marginal
Soft tissue thoracic AIS2+	Maximum thoracic rib VC (m/s)	Log-normal (AIC=45,789 2)	45 yo	5 %	0,012	6e-16	3e+11	2e+13	unacceptable
				25 %	71,847	3e-13	2e+16	2e+14	unacceptable
				50 %	29 801,85	1e-28	8e+36	3e+32	unacceptable
			67 yo	5 %	1e-04	3e-34	8e+24	1e+29	unacceptable
				25 %	0,298	2e-04	4521	1518	unacceptable
				50 %	123,61	2e-14	9e+17	7e+15	unacceptable
Soft tissue thoracic AIS3+	Maximum thoracic rib VC (m/s)	Log-normal (AIC=35,607 2)	45 yo	5 %	12,740	1e-19	1e+21	1e+20	unacceptable
				25 %	71 971 026	3e-106	2e+121	3e+113	unacceptable
				50 %	4e+12	9e-168	1e+192	4e+179	unacceptable
			67 yo	5 %	0	4e-67	2e+57	8e+61	unacceptable
				25 %	167	2e-32	1e+36	7e+33	unacceptable
				50 %	8 272 250	7e-94	9e+106	1e+100	unacceptable
Abdomen soft tissue AIS2+	Maximum abdomen rib deflection (mm)	Weibull (AIC=14,988 9)	45 yo	5 %	58,94	39,80	87,29	0,806	fair
				25 %	72,01	49,70	104,33	0,759	fair
				50 %	79,75	53,55	118,77	0,818	fair
			67 yo	5 %	37,11	26,86	51,27	0,658	fair
				25 %	45,34	38,30	53,68	0,339	good
				50 %	50,21	43,696	57,71	0,279	good
Abdomen soft tissue AIS2+	Maximum abdomen rib VC (m/s)	Weibull (AIC=14,977 7)	45 yo	5 %	0,899	0,467	1,729	1,404	marginal
				25 %	1,240	0,649	2,368	1,386	marginal
				50 %	1,461	0,731	2,919	1,497	marginal
			67 yo	5 %	0,423	0,261	0,684	0,999	fair
				25 %	0,583	0,449	0,759	0,532	fair
				50 %	0,688	0,548	0,863	0,458	good
Abdomen soft tissue AIS2+	Lower spine Y acceleration 3 ms (m/s^2)	Weibull (AIC=27,576 8)	45 yo	5 %	487,13	310,55	764,12	0,931	fair
				25 %	637,06	390,59	1 039,05	1,018	marginal
				50 %	730,49	408,92	1 304,93	1,227	marginal
			67 yo	5 %	367,64	246,82	547,62	0,818	fair
				25 %	480,80	409,07	565,10	0,325	good
				50 %	551,31	454,77	668,34	0,387	good

Table J.8 *(continued)*

Injury risk	Dummy measurement	Distribution			Measurement value	Lower 95 % CI	Upper 95 % CI	Relative CI size	Quality index
Abdomen soft tissue AIS3+	Maximum abdomen rib deflection (mm)	Log-normal (AIC=11,959 1)	45 yo	5 %	117,29	11,68	1 178,11	9,945	unacceptable
				25 %	166,99	10,15	2 747,89	16,394	unacceptable
				50 %	213,48	8,11	5 622,74	26,301	unacceptable
			67 yo	5 %	56,28	26,37	120,12	1,666	unacceptable
				25 %	80,13	24,60	260,99	2,950	unacceptable
				50 %	102,43	17,77	590,36	5,590	unacceptable
Abdomen soft tissue AIS3+	Maximum abdomen rib VC (m/s)	Log-normal (AIC=11,869 6)	45 yo	5 %	2,666	0,0799	89,000	33,356	unacceptable
				25 %	4,470	0,077	259,290	57,986	unacceptable
				50 %	6,403	0,063	645,798	100,850	unacceptable
			67 yo	5 %	0,836	0,260	2,690	2,909	unacceptable
				25 %	1,401	0,271	7,246	4,978	unacceptable
				50 %	2,007	0,192	21,029	10,383	unacceptable
Abdomen soft tissue AIS3+	Lower spine Y acceleration 3 ms (m/s^2)	Log-normal (AIC=6)	45 yo	5 %	605,425 1	0	infinite	/	unacceptable
				25 %	605,545 2	0	infinite	/	unacceptable
				50 %	605,628 8	0	infinite	/	unacceptable
			67 yo	5 %	550,950 1	0	infinite	/	unacceptable
				25 %	551,059 5	0	infinite	/	unacceptable
				50 %	551,135 5	0	infinite	/	unacceptable
Pelvis AIS2+	Maximum pubic force (N)	Weibull (AIC=64,005 2)	45 yo	5 %	1 818,0	1 133,9	2 915,0	0,980	fair
				25 %	2 644,0	1603,9	4 362,0	1,043	marginal
				50 %	3 202,3	1 861,4	5 509,3	1,139	marginal
			67 yo	5 %	1 340,4	1 027,2	1 748,9	0,538	fair
				25 %	1 950,0	1 652,0	2 301,9	0,333	good
				50 %	2 360,9	1 954,9	2 851,2	0,380	good
Pelvis AIS2+	Pelvis Y acceleration 3 ms (m/s^2)	Weibull (AIC=81,179 1)	45 yo	5 %	503,56	330,15	768,07	0,870	fair
				25 %	816,61	512,08	1 302,26	0,968	fair
				50 %	1 044,95	595,07	1 834,95	1,187	marginal
			67 yo	5 %	341,53	236,91	492,36	0,748	fair
				25 %	553,85	471,45	650,66	0,324	good
				50 %	708,72	566,71	886,30	0,451	good
Pelvis AIS3+	Maximum pubic force (N)	Weibull (AIC=44,204 8)	45 yo	5 %	2 214,0	1 275,5	3 843,2	1,160	marginal
				25 %	2 921,6	1 630,0	5 236,8	1,235	marginal
				50 %	3 365,5	1 816,6	6 235,1	1,313	marginal
			67 yo	5 %	1 713,8	1 363,6	2 154,0	0,461	good
				25 %	2 261,6	1 861,1	2 748,2	0,392	good
				50 %	2 605,1	2 074,8	3 271	0,459	good

Table J.8 *(continued)*

Injury risk	Dummy measurement	Distribution			Measurement value	Lower 95 % CI	Upper 95 % CI	Relative CI size	Quality index
Pelvis AIS3+	Pelvis Y acceleration 3 ms (m/s^2)	Weibull (AIC=54,980 5)	45 yo	5 %	864,36	379,14	1 970,55	1,841	unacceptable
				25 %	1 371,44	495,20	3 798,12	2,408	unacceptable
				50 %	1 735,49	546,64	5 509,86	2,860	unacceptable
			67 yo	5 %	476,20	343,25	660,64	0,667	fair
				25 %	755,56	523,30	1 090,92	0,751	fair
				50 %	956,13	572,43	1 597,03	1,072	marginal

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