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Road vehicles — Design and performance specifications for the WorldSID 50th percentile male side-impact dummy —

Part 1:
Terminology and rationale

Véhicules routiers — Conception et spécifications de performance pour le mannequin mondial (WorldSID), 50e percentile homme, de choc latéral —

Partie 1: Terminologie et raisonnement

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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. 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 15830-1:2005), which has been technically revised. Technical amendments have been incorporated throughout all four parts, resulting from extensive experience with the standard and design changes.

ISO 15830 consists of the following parts, under the general title *Road vehicles — Design and performance specifications for the WorldSID 50th percentile male side-impact dummy*:

— *Part 1: Terminology and rationale*

— *Part 2: Mechanical subsystems*

— *Part 3: Electronic subsystems*

— *Part 4: User's manual*

Introduction

This second edition of ISO 15830 has been prepared on the basis of the existing design, specifications, and performance of the WorldSID 50th percentile adult male side-impact dummy. The purpose of the ISO 15830 series is to document the design and specifications of this side-impact dummy in a form suitable and intended for worldwide regulatory use.

In 1997, ISO/TC 22/SC 12 initiated the WorldSID 50th percentile adult male dummy development, with the aims of defining a global-consensus side-impact dummy, having a wider range of human-like anthropometry, biofidelity, and injury-monitoring capabilities, suitable for regulatory use. Participating in the development were research institutes, dummy and instrumentation manufacturers, governments, and vehicle manufacturers from around the world.

With regard to potential regulatory, consumer information, or research and development use of ISO 15830, users will need to identify which of the permissive (i.e., optional) sensors and other elements defined in ISO 15830-3 are to be used in a given application.

WorldSID drawings in electronic format are being made available. Details are given in ISO 15830-2, Annex B.[14]

In order to apply ISO 15830 properly, it is important that all four parts be used together.

Road vehicles — Design and performance specifications for the WorldSID 50th percentile male side-impact dummy —

Part 1: Terminology and rationale

1 Scope

This part of ISO 15830 provides the definitions, symbols, and rationale used in all parts of this International Standard for the WorldSID 50th percentile side-impact dummy, a standardized anthropomorphic dummy for side-impact testing of road vehicles. It is applicable to impact tests involving

— passenger vehicles of category M_1 and goods vehicles of category N_1,

— impacts to the side of the vehicle structure, and

— impact tests involving use of an anthropomorphic dummy as a human surrogate for the purpose of evaluating compliance with vehicle safety standards.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1207, *Slotted cheese head screws — Product grade A*

ISO 4026, *Hexagon socket set screws with flat point*

ISO 4027, *Hexagon socket set screws with cone point*

ISO 4029, *Hexagon socket set screws with cup point*

ISO 4762, *Hexagon socket head cap screws*

ISO 6487, *Road vehicles — Measurement techniques in impact tests — Instrumentation*

ISO 7379, *Hexagon socket head shoulder screws*

ISO 7380 (all parts), *Button head screws*

ISO/TR 9790:1999, *Road vehicles — Anthropomorphic side impact dummy — Lateral impact response requirements to assess the biofidelity of the dummy*

ISO 10642, *Hexagon socket countersunk head screws*

SAE J211-1:2007, *Instrumentation for impact test — Part 1: Electronic instrumentation*

3 Terms and definitions

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

3.1
1-to-2-G-setting
joint friction setting which will support the weight of a horizontally extended limb segment but will not support twice the limb segment weight

3.2
abdomen rib
lowest two ribs of the six mechanical ribs in the WorldSID dummy

3.3
aluminium honeycomb
manufactured material comprising multi-layered bonded sheets of aluminium bent or corrugated in a rib pattern, in which there is an internal pattern of hexagonal cylindrical spaces, and which is used in this International Standard as an energy-absorbing element in validation tests

3.4
capacity
maximum force or moment which can be measured by a load cell without causing load cell damage

3.5
cheese screw
slotted button head screw, also referred to as a slotted cheese head screw as defined by ISO 1207

3.6
docking station
data recorder connection point inside the dummy which allows the recorder to be conveniently disconnected from the sensors

3.7
full arm
assembly of the WorldSID dummy comprising the articulated upper arm and lower arm, including the hand

3.8
frontal
forward-facing or anterior surfaces of the dummy, when it is in a standing posture

3.9
H-point
point on the outer surface of the dummy on an imaginary line which passes through the left and right hip ball centres

3.10
H-point tool
device which can be inserted into index holes in the dummy pelvis, which provides an external surface for indicating the orientation of the pelvis and an imaginary line connecting the left and right hip ball joint centres

3.11
half arm
assembly of the WorldSID dummy comprising dedicated upper arm components which are different from the components of the full arm

3.12
head form
mechanical device with the same mass and I_{xx} inertia as the WorldSID head, used for lateral neck validation tests

3.13
infrared telescoping rod for assessment of chest compression
IR-TRACC
sensor for deflection measurements

3.14
lower leg
portion of the lower extremity between the knee and the ankle

3.15
mass replacement
non-electronic component which is substituted for a given dummy electronic component, which has the same mass as the given electronic component, and which does not act as a structural component of the dummy (e.g. an accelerometer)

3.16
rigid seat
specialized seat with defined seat bottom and seat back angles used to position the dummy for impact testing

3.17
shoulder rib
upper-most rib of the six mechanical ribs in the WorldSID dummy

3.18
structural replacement
non-electronic component which is substituted for a given dummy electronic component (e.g. a load cell), which has the same mass as the given component, and which also acts as a structural component of the dummy

3.19
thoracic rib
second, third, and fourth upper-most ribs of the six mechanical ribs in the WorldSID dummy

3.20
T1
location corresponding to the first thoracic vertebra in a human

3.21
T4
location corresponding to the fourth thoracic vertebra in a human

3.22
T12
location corresponding to the twelfth thoracic vertebra in a human

3.23
tilt sensor
sensor internal to the dummy which transduces the two orientation angles of the respective body region relative to gravity

3.24
universal
capable of being mounted at several different locations on the dummy

3.25
upper leg
portion of the lower extremity between the knee and the hip ball

3.26
validation
process by which the relevant dummy component or whole dummy is verified and documented to meet the specifications

3.27
W50-
prefix denoting WorldSID 50th percentile adult male dummy part or drawing number

3.28
WorldSID
anthropometric side-impact dummy intended to be used by vehicle manufacturers and all interested parties in the passive safety field to improve occupant protection and in regulatory and consumer information testing in various regions of the world

4 Symbols, subscripts, and abbreviated terms

4.1 Symbols

See Table 1.

Table 1 — Symbols and their meanings

Symbol	Meaning
a	Linear acceleration
F	Force
G	Acceleration due to gravity (9,81 m/s^2)
M	Moment
β	Angular displacement of the head form
δ	Deflection
θ	Angular displacement
φ	Rotation
x	Coordinate in accordance with ISO 6487 or SAE J211-1
y	Coordinate in accordance with ISO 6487 or SAE J211-1
z	Coordinate in accordance with ISO 6487 or SAE J211-1

4.2 Subscripts

See Table 2.

Table 2 — Subscripts and their meanings

Symbol	Meaning
F	Forward
H	Head
R	Rearward
x, y, z	Coordinate system : In the x, y, or z direction; about the x, y, or z axis where x, y, or z are in accordance with ISO 6487 or SAE J211-1

4.3 Abbreviated terms

See Table 3.

Table 3 — Abbreviated terms

Abbreviation	Meaning
AMVO	Anthropometry for Motor Vehicle Occupants dataset (established by UMTRI)
A-P	Anterior-posterior
ASIS	Anterior superior iliac spine
ASPECT	Automotive Seat and Package Evaluation and Comparison Tools (a Society of Automotive Engineers cooperative research program)
ATD	Anthropomorphic test device
BHCS	Button head cap screw, also referred to as a hexagon socket button head screw as defined by ISO 7380
CG	Centre of gravity
CPSS	Cone point set screw, also referred to as a hexagon socket set screw with cone point as defined by ISO 4027
CPSSS	Cone point socket set screw as defined by ISO 4027
CPNT	Cone point nylon tip
DAS	Data acquisition system
FHCS	Flat head cap screw, also referred to as a hexagon socket countersunk head screw as defined by ISO 10642
FTSS	First Technology Safety Systems
IHRA	International Harmonization Research Activities
ISO	International Organization for Standardization
LHSHCS	Low head socket head cap screw
MDB	Movable deformable barrier
NM	Not measured
OC	Occipital condyle
PC	Personal computer
R-L	Right-left

Table 3 *(continued)*

Abbreviation	Meaning
SHCS	Socket head cap screw, also referred to as a hexagon socket head cap screw as defined by ISO 4762
SHSS	Socket head shoulder screw, also referred to as a hexagon socket head shoulder screw as defined by ISO 7379
SI	Sacroiliac
SSCP	Set screw with cup point, also referred to as a hexagon socket set screw with cup point as defined by ISO 4029
SSFP	Set screw with flat point, also referred to as a hexagon socket set crew with flat point as defined by ISO 4026
SSHDP	Set screw with half dog point, as defined by ISO 4026
SSNT	Set screw with nylon tip
UMTRI	University of Michigan Transportation Research Institute

Annex A
(informative)

Rationale regarding background and goals for WorldSID

NOTE All references cited in Annex A are listed in the Bibliography.

A.1 Historical background

A.1.1 General

In November 1997, the WorldSID Task Group was formed under the auspices of the International Organization for Standardization (ISO) TC 22/SC 12/WG 5 — *Anthropomorphic test devices*. Document ISO/TC 22/SC 12/WG 5/N 512 (see Annex C) established the composition and responsibilities of the Task Group. The Task Group's purpose was to develop a unique, technologically advanced side-impact dummy which would have greater biofidelity and which would replace the variety of side-impact dummies used in regulation and in other testings. It was with this double objective of developing an advanced and globally harmonized dummy that the WorldSID Task Group was formed, including a Tri-Chair representing each of the Americas, Europe, and Asia-Pacific regions, and experts from more than 10 countries, including Australia, Canada, France, Germany, Japan, The Netherlands, Sweden, United Kingdom, and United States of America. The members comprised participants from vehicle manufacturers, governmental organizations, research institutes, test laboratories, and dummy and instrumentation manufacturers from around the world.

Worldwide vehicle manufacturers and governmental bodies sponsored the WorldSID's development. A design team of worldwide dummy manufacturers, instrumentation manufacturers, and research organizations was formed to design, develop, and fabricate the prototype. Thirty-seven Task Group meetings were held in order to coordinate the definition, design, development, and evaluation of the dummy, as well as to develop an International Standard which was initially approved in 2005. During the development stage, more than 13 separate organizations from around the world conducted testing and evaluations of the dummy in order to assess its biofidelity, durability, repeatability, reproducibility, and other aspects of performance. Regulation-ready documentation was prepared in the form of ISO 15830, which is available to the relevant regulatory and consumer information bodies worldwide.

Following the release of ISO 15830:2005, testing, evaluation, and development continued. This revised International Standard documents improvements to the WorldSID, including improved rib damping material, improved durability, modified pelvis, new seating procedures, updated biofidelity scores, an updated user manual, and an updated electronic drawing package (available online).

The resulting WorldSID 50th percentile adult male is a new, advanced, global-consensus, side-impact dummy. It has an overall biofidelity classification of 8,0 ("good") using the ISO/TR 9790 biofidelity rating scale. It is planned to be the basis for the future development of a harmonized side-impact dummy family. The WorldSID 50th percentile adult male has a mass of 74,35 kg, a theoretical standing height of 1 753 mm, and a seated height of 911 mm. Almost every body region involves a new, innovative design, setting the WorldSID apart from all existing side-impact dummies. It can accommodate 207 permissible sensor channels (including six tilt sensors) and associated cabling, and up to 192 recording channels with an optional in-dummy data acquisition system (DAS).

A.1.2 Need for an International Standard side-impact dummy

As of December 2008, six other mid-sized male side-impact dummies were available for regulatory, consumer information and development use. These are: the USDOT-SID dummy, which is utilized in the United States side-impact protection regulation[31]; the EuroSID-1 dummy, which is regulated in a European standard[32]; the ES-2 dummy, the ES-2re; the SID/H3 dummy, which is utilized in the United

States side-impact protection regulation FMVSS-201; and the BioSID dummy, which is available for developmental purposes. None of these dummies has “good” biofidelity (i.e. they all have a less than “6,5” rating using the ISO/TR 9790 biofidelity rating scale). The six dummies are structurally different and have different instrumentation capabilities and associated injury assessment criteria. Because of these differences, as well as the differences in the associated test procedures, these dummies typically provide a different design direction in the vehicle development process. This results in substantially different vehicle designs with regard to side-impact protection in the different world regions, despite the similarity in occupant protection needs among the regions.

The existing dummies are less human-like and cannot be instrumented for all the body regions of importance in side-impact protection. This means that they have limited effectiveness as tools for improving occupant protection.

In addition, the total costs to a vehicle manufacturer, and therefore to consumers, of developing different side protection systems for different regions are higher than a harmonized system.

Overall, with the existing diversity of dummies, the benefits in terms of occupant protection are lower, and the costs higher, than what would be the case if a more human-like side-impact dummy was adopted on a worldwide basis.

A.1.3 Benefits and economic impact of an International Standard side-impact dummy

A more human-like side-impact dummy, accepted via consensus among the participating regions by means of an International Standard, along with harmonized vehicle side-impact test procedures, will have significant benefits in terms of more realistic (and therefore more effective) occupant protection as well as reduced costs of side-impact protection system development.

With regard to benefits, it is self-evident that a more advanced, human-like side-impact dummy would result in vehicle side-impact protection systems that would be more effective for human occupants and would be less likely to produce harmful designs, which, in principle, can result from dummies that are either less human-like or unable to monitor for injuries to some body regions.

With regard to costs, it is also self-evident that vehicle manufacturers could eliminate the additional, wasteful efforts needed to develop vehicles to pass different regulatory tests, with different dummies, when they are to be sold in several markets. This process is costly for consumers and has no benefits for passive safety.

For these reasons, most of the major industrial nations, including members of the European Union, Canada, Japan, and the United States, signed the *“Agreement concerning the establishing of global technical regulations for wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles,”* (1998), also referred to as the 1998 Global Agreement. This treaty implemented objectives and methods for proposing and developing within the forum of UN/ECE/TR ANS/WP29 global technical regulations (GTR), which contracting nations or groups of nations would have the option to adopt as part of their domestic rulemaking processes.

In summary, the WorldSID would be expected to have substantial benefits for occupant protection and would reduce total development costs.

A.1.4 Survey of and general differences from previous side-impact dummies

As mentioned in A.1.2, as of December 2008, there were six mid-sized male side-impact dummies, as well as some variations thereto, available for regulatory and development use. The six dummies have different levels of biofidelity. The USDOT-SID, EuroSID-1, ES-2, ES-2re, BioSID dummies have each been rated using the ISO biofidelity scale that provides classifications, as shown in Table A.1. These classifications quantify how closely the dummy dynamic response matches those of a sample of human subjects, for each body region and for all body regions. The USDOT-SID has an ISO biofidelity classification of “unacceptable”, the EuroSID-1 and ES-2re have a classification of “marginal,” and the BioSID and ES-2 have a classification of “fair.”

Table A.1 — ISO biofidelity rating scale

Excellent	**> 8,6 to 10**
Good	> 6,5 to 8,6
Fair	> 4,4 to 6,5
Marginal	> 2,6 to 4,4
Unacceptable	0 to 2,6

As reported by Byrnes, K. et al.[3], the USCAR OSRP (Occupant Safety Research Partnership) conducted a series of ISO/TR 9790 tests in order to compare the biofidelity ratings of the current 50th percentile male side-impact dummies USDOT-SID, EuroSID-1, ES-2, BioSID, and the WorldSID. Even if not all ISO/TR 9790 tests were carried out identically with each dummy (as described in, for example, Appendix G of ISO/TR 9790), the WorldSID was the only dummy to obtain a "good" rating on the ISO biofidelity scale.

As shown in Table A.2,[3] which includes updated WorldSID data and the ES-2re, the WorldSID achieved the best overall dummy rating and also the best single body region ratings for the head, thorax, abdomen, and pelvis.

Table A.2 — Biofidelity comparison of side-impact dummies

	Biofidelity rating						
	Head	**Neck**	**Shoulder**	**Thorax**	**Abdomen**	**Pelvis**	**Overall**
WorldSID production version	10,0	5,3	10,0	8,2	9,3	5,1	8,0
BioSID	6,7	6,7	7,3	6,3	3,8	4,0	5,7
ES-2	5,0	4,4	5,3	5,2	2,6	5,3	4,6
EuroSID-1	5,0	7,8	7,3	5,4	0,9	1,5	4,4
ES-2re	5,0	4,2	4,5	4,0	4,1	3,2	4,2
USDOT-SID	0,0	2,5	0,0	3,1	4,4	2,5	2,3

Independently, the US/NHTSA (National Highway Traffic Safety Administration) evaluated the WorldSID prototype (unrevised version) together with two other side-impact dummies, the ES-2 and the Hybrid III-SID, to a newly developed biofidelity ranking system called Bio Rank System, as reported by Rhule, H. et al.[20]

This Bio Rank System quantifies the ability of a dummy to load a sled wall as a cadaver does (External Biofidelity) and the ability of a dummy to replicate those cadaver responses that best predict injury potential (Internal Biofidelity). The ranking is based on the ratio of the cumulative variance of the dummy response relative to the mean cadaver response and the cumulative variance of the mean cadaver response relative to the mean plus one standard deviation. That ratio expresses how well a dummy duplicates a cadaver response. Contrary to the ISO rating system, the lower the rating value, the better the biofidelity.

Although still under development and not in use by the international community, the data presented by Rhule et al. indicate that this assessment system also showed the WorldSID prototype to have the best ranking out of the three tested dummies.

In summary, compared with other contemporary mid-sized adult male side-impact dummies, the WorldSID overall ratings are better than all others. It achieves by far the best overall rating and is, to date, the only side-impact dummy with an overall biofidelity rating of "good."

A.1.5 Summary of WorldSID development process

The following summarizes some of the milestones in the WorldSID project, in order to describe the international development and consensus process.

— November 1997: WorldSID Task Group (TG) was established by ISO/TC 22/SC 12, reporting to Working Group 5.

— April to October 1998: Draft documents were circulated within the TG as regional contributions to the definition of design and performance requirements for WorldSID.

— February 1999: The WorldSID Task Group and project manager circulated the "Request for Proposals — WorldSID Design and Build" internationally, which included a draft design baseline.

— March 1999: The Task Group made a first selection of WorldSID body region and instrumentation concepts, on the basis of all responses to the Request for Proposal.

— September 1999: The Task Group signed off the WorldSID Design Baseline (document TG N60 Rev 2). This document includes design and performance specifications for the WorldSID as established by consensus of the Task Group during the period October 1998 to September 1999 and defines the guidelines for designing, building, and evaluating the first prototype dummy.

— February 2000: At the 12th TG meeting, the Design Team (DT) presented a first full-assembly 3D WorldSID concept, based on updated body part and instrumentation concepts. The TG was given an illustration of the full-assembly WorldSID (document TG N105, February 2000). Using the Design Brief (TG N60Rev2) as a reference, the Design Team developed as much detail as possible on the specifications for design and performance of the WorldSID. Any deviations from specifications were detailed and rationales for these deviations were provided.

— December 2000: A prototype dummy was completed and sent to Australia for a first round of vehicle and biofidelity tests by the Australian government.

— January 2001 to February 2003: A series of iterative testing and design revisions was conducted on the prototype dummy, resulting in design changes and performance improvements to all body regions of the dummy.

— March 2003 to January 2004: Delivery, testing, and evaluation of 11 pre-production dummies by numerous parties in the three regions. Beginning in March 2003, the pre-production dummies were evaluated in biomechanical tests and also in a multitude of sled, crash, and verification tests throughout the world.

— August 2005: Publication of ISO 15830:2005 and release of production drawings and specifications into the public domain.

Organizationally, at every stage, the TG attempted to include all interested parties involved in the passive safety field, and to this end, three regional groups for Europe, Asia-Pacific, and the Americas were created to facilitate the participation of any interested parties on a worldwide basis. The Task Group brought together delegations from the three regions on a regular basis. The project was financed by contributions from all three of the regions, as further described below. A project manager was contracted to coordinate the development activities and to liaise between the Task Group and the Design Team. The Task Group contracted with Design Team members, comprising dummy manufacturers, instrumentation manufacturers, and members of the European Commission (EC)-sponsored SID-2000 project consortium, to carry out the design and development work.

The vehicle manufacturers in the United States, Japan, and the European Union made large direct contributions to funding through their regional industry organizations: OSRP, JAMA, and ACEA, respectively. The EC also made a significant contribution through the participation in the development of the dummy of the SID-2000 Consortium. Contributions from Transport Canada, the Australian Department of Transport and Regional Services, the US National Highway Transportation and Safety Administration, and the EC-supported SIBER consortium contributed to the funding of the WorldSID prototype evaluation testing. All costs related to the participation of Task Group and Regional Advisory Group members were met by the individual participating organizations.

A.2 Technical targets for the WorldSID

A.2.1 General

The WorldSID Task Group, with inputs from all members as well as the Design Team, developed a comprehensive set of technical targets in the following categories:

- functional description and interface references
  - functional description;
  - interface references;
- loading conditions and interactions;
- anthropometry;
- biofidelity;
- instrumentation;
- repeatability and reproducibility;
- durability;
- sensitivity;
- handling;
- validation;
- miscellaneous.

Detailed targets in each of these areas were identified for the overall dummy and for each of the following body regions:

- head;
- neck;
- shoulder-thorax-abdomen;
- full arms;
- half arms;
- lumbar spine;
- pelvis;
- upper legs;
- lower legs;
- clothing.

In addition, targets for internal electronic measurement components were identified, including those for the following:

- accelerometers;

— load cells;

— displacement transducers;

— tilt sensors, to facilitate dummy positioning;

— in-dummy data acquisition system.

During the development, the highest priority among these targets was given to the goal of matching the biofidelity (i.e., human dynamic response) targets specified in ISO/TR 9790. The target performance was that a rating of "good" to "excellent" be achieved on the biofidelity rating scale contained in ISO/TR 9790, for all segments of the dummy, and for the overall dummy.

The WorldSID Task Group reviewed all of the currently existing side-impact dummies to determine what functions, features, and other needs should be incorporated into the new WorldSID dummy and what improvements were required. The group also reviewed various proposals and ideas from worldwide dummy and instrumentation manufacturers and research organizations. As described in A.1.5, an international Design Team was formed to develop these new concepts and integrate them with existing desirable features into a new, advanced side-impact dummy. The majority of the dummy consists of new design concepts, with the exception of the neck, which is mainly from the ES-2 dummy (all parts except for the neck buffers).

The Task Group also assembled a list of specifications for the WorldSID dummy. This list consisted of general specifications for the full dummy assembly and specific specifications for the various body regions. One of the general targets for the dummy was that it should be a left-right symmetrical design. The Task Group decided that this was necessary, firstly because humans are symmetric and also because future uses of the dummy are unknown. For example, in the future, the dummy may need to measure occupant-to-occupant interaction in a side-impact test. If this were required, the dummy would have to be capable of being instrumented simultaneously on both sides so that it could measure the impact from the striking vehicle and the impact from the adjacent occupant.

In addition, because of the unknown nature of future testing needs, it was desired that the dummy produce reasonable data for ±30° in the horizontal plane and ±10° in the vertical plane. This is to ensure that the dummy does not bind in an off-axis loading situation.

It was also desired that the dummy be capable of using an in-dummy data acquisition system (DAS). This was because of the increasing number of potential channels of interest being specified for injury evaluation purposes. The large number of desirable sensors would produce a large bundle of cables that conventionally would need to be attached to an in-vehicle DAS. This would make it difficult to properly position the dummy. So, the Task Group concluded that it was necessary to offer an optional in-dummy DAS. The WorldSID dummy has up to 192 possible data recording channels. The user, of course, would choose only the appropriate sensor channels for a given test scenario.

A.2.2 Functional description

In general terms, the WorldSID was to be designed for the evaluation of vehicle occupant protection in the event of a lateral collision. In addition, it is expected that because of improved characteristics (e.g. improved biofidelity), the WorldSID will replace existing side-impact dummies. The dummy, therefore, was to accommodate the following:

— Several types of standardized test procedures to assess side-impact car occupant protection in full vehicle collisions. This includes existing procedures as well as future harmonized procedures of regulatory bodies, as well as procedures used by consumer information organizations to compare vehicle performance.

— Development-type testing (standard and non-standard) as conducted by the OEMs and their suppliers to assess and improve performance of restraint systems, vehicle interiors, vehicle structures, etc.

— Research-type testing to enhance the knowledge base of side-impact vehicle and occupant behaviour, through accident reconstructions, component tests, biomechanical tests, etc.

In all these test conditions, the WorldSID was to have improved dynamic behaviour over existing dummies, to have improved measurement capabilities to allow assessment according to most established and evolving injury criteria, and to be easier to handle.

To accommodate the different test conditions, the WorldSID was to be designed in two configurations: one incorporating instrumented full arms and one incorporating non-instrumented half arms. The WorldSID development, therefore, breaks down in the following components (responsible Design Team member is given in parentheses):

— head (SID-2000), representing the human head and designed to exhibit multidirectional biofidelity considering its large variety of contact and non-contact loading conditions;

— neck (SID-2000), representing the human cervical spine and primarily designed to assure proper head kinematics without concern for unrealistic restraint interactions as observed with some existing dummies;

— shoulders/thorax/abdomen assembly (Humanetics, formerly FTSS, SID-2000), representing the human upper torso, with improved biofidelity over existing dummies, and capable of handling off-axis loading without compromising durability, repeatability, and reproducibility;

— full arms (Humanetics, formerly Denton), representing the human upper arms, elbows, lower arms, wrists, and hands, designed primarily for the purpose of airbag interaction assessments;

— half arms (Humanetics, formerly FTSS), representing the human upper arms only, designed for full vehicle testing in which the use of full arms may lead to reduced test-to-test repeatability;

— lumbar spine (Humanetics, formerly FTSS), representing the human lumbar area, designed to better represent the coupling between upper and lower torso and to allow changes in initial (pre-test) posture according to seat and vehicle design;

— pelvis (SID-2000, Humanetics, formerly FTSS), representing the human lower torso, designed with improved biofidelity over existing dummies, and capable of handling off-axis loading without compromising durability, repeatability, and reproducibility;

— upper legs (Humanetics, formerly Denton), representing the human upper legs and knees, designed with integrated instrumentation;

— lower legs (Humanetics, formerly Denton), representing the human lower legs, ankles, and feet (including shoe), designed with integrated instrumentation;

— clothing (Humanetics, formerly FTSS), extending over the complete torso and parts of the extremities to simulate clothing, but also some human skin/flesh;

— in-dummy data acquisition system (DTS), which accommodates at least 64 channels. Integrated wiring throughout the dummy is part of this task;

— accelerometers (Endevco), including linear and angular accelerometers throughout the dummy and dedicated tilt sensors in the head, thorax and pelvis for pre-test positioning;

— load cells (Humanetics, formerly Denton), throughout the dummy and designed as structural components. Structural replacements for all load cells will be provided.

A.2.3 Interface references

The complete WorldSID design and fabrication was contracted to a Design Team that operated not only under mutual confidentiality but also under mutual restriction of design information. This meant that not until approval and release into the public domain of the WorldSID drawings and specifications by the Task Group would a non-generating party within or outside the Design Team have access to design information from a generating party.

This, obviously, was not the case for the interfaces between various components of the dummy, which were generated by Design Team members responsible for components meeting at a specific interface.

Therefore, much emphasis in the design stage was put in the definition of interfaces between various components of the dummy. In addition, good definition of interfaces between the various components was essential to ensure proper assembly and functionality.

Where possible, interface references were based on anthropometry data (anatomical landmarks, joint locations, etc.).

Further details of the specific body region functional requirements and interface reference needs were presented in the Design Brief.[30]

A.2.4 Loading conditions and interaction needs

One requirement for WorldSID was that it function properly within the loading conditions specified by existing and future harmonized test procedures. This was not to be restricted to the test procedures themselves, which include MDB-type side-impact tests, pole tests, and component tests, but also includes tests to enable development of vehicles, vehicle components, and restraints. It was beyond the scope of the Design Brief to attempt to quantify every loading condition the dummy could be subjected to; however, several requirements involved specifications of minimum responses the WorldSID should be able to withstand or attain.

Further details of the specific body region loading conditions and interaction needs were presented in the Design Brief.[30]

A.2.5 Anthropometry needs

A.2.5.1 General

The WorldSID represents a mid-sized adult male vehicle occupant. Several anthropometry data sources were studied and compared with data from studies on anthropometry of different populations around the world. In September 1999, the WorldSID Task Group decided to accept the AMVO dataset for a 50th percentile male (Robbins, D.H. et al.[21]). This dataset describes many anthropometry details of a mid-sized adult male in an automotive posture. Included are a 3D surface description, almost 150 anatomical reference points (including joint centres), definitions of segments (head, neck, etc.), and derivation of inertial properties of these segments. The automotive posture as represented by the AMVO dataset is defined as the design reference posture for the dummy.

Communications with UMTRI revealed that some corrections had to be made since the first release of this dataset, specifically with respect to the H-point definition (yet unpublished information from the ASPECT development). Humanetics (formerly FTSS) corrected the dataset and created a 3D stickman diagram (lines connecting the joint centres) within the outer shell definition and anatomical landmarks. The Design Team used these as references for the WorldSID design. A detailed description of the anthropometry needs is given in Moss, S. et al.[17]

A.2.5.2 Overall landmarks

The anthropometric landmark targets for WorldSID are specified in Table A.3.

Table A.3 — Landmarks

Landmark	Description	*x* mm	*y* mm	*z* mm
	vertebral column			
7	C7	-264	0	499,4
8	T4	-291	0	390,4
10	T12	-244	0	156,4
12	L5	-172	0	23,4

Table A.3 *(continued)*

Landmark	Description	*x* mm	*y* mm	*z* mm
	pelvis			
27	iliocristale	-78	±161	103,4
28	anterior superior illiac spine (l,r)	-23	±116	93,4
29	pubic symphysis	53	0	51,4
31	throchanterion (skeletal reconstruction) (l,r)	22	±203	-9,6
32	H-point	0	±83,5	0
	shoulder			
35	greater tubercle humerus (l,r)	Not specified	±218	Not specified
	joint centres			
54	head/neck	-194	0	598,4
55	c7/t1	-191	0	479,4
58	t12/l1	-175	0	175,4
60	l5/s1	-89	0	39
61	sternoclavicular	-143	±43	443,4
62	claviscapular	-228	±168	437,4
63	glenohumeral	-184	±173	403,4
64	elbow	38	±208	211,4
65	wrist	230	±158	403,4
66	hip (H-point)	0	±83,5	0
67	knee	408	±138	146,4
68	ankle	686	±94	-158,6
	estimated segment centres of gravity			
79	head	-177	0	656,4

A.2.5.3 Ranges of motion

The ranges of motion are based on several sources. Shoulder flexion, extension, abduction, and adduction ranges are based upon estimates of what was to be necessary for initial positioning of the arm and motion without binding as presented in WorldSID Task Group meetings. Shoulder lateral and medial angular displacement ranges are from attachment I of the January 13, 1998 minutes of the SAE Arm-Airbag Interaction Task Group of the Human Biomechanics and Simulation Standards Committee. The elbow flexion and extension ranges match those of the SAE 5th percentile female instrumented arm. The flexion range is the maximum practical mechanical range. The wrist range of motion was provided by the University of Virginia Auto Safety Laboratory, compiled from a variety of sources.

— shoulder flexion: 180° to soft stop

— shoulder extension: 45° to soft stop

— shoulder abduction: 100° to soft stop

— shoulder adduction: 0° to soft stop

— shoulder lateral angular displacement: 31° to soft stop

— shoulder medial angular displacement: 91° to soft stop

— elbow flexion: 135° to soft stop

— elbow extension: -5° to soft stop

— wrist pronation/supination: 80° to soft stop

— wrist flexion/extension: 75° to soft stop

— wrist abduction: 15° to soft stop

— wrist adduction: 25° to soft stop

A.2.5.4 Head

The reference for the head anthropometry was the AMVO data set. The target data are specified in Table A.4. The target for the outer geometry of the head was based on the Hybrid-III geometry (Hubbard R. et al.[43]), since this is a more detailed data set. Facial features from the Hybrid-III (nose, lips, etc.) were to be deleted.

Table A.4 — General head anthropometry reference data (Source: AMVO data set)

Parameter	Target	Reference	Remark
Mass	4,14 kg ± 0,1 kg	AMVO	
Circumference	570,6 mm ± 5 mm	AMVO 1983 Study	
Length	197,4 mm ± 2 mm	AMVO	
Width	158 mm ± 2 mm	AMVO	Hybrid-III: 155 ± 5 mm
CG location	177 mm, 0 mm, 656,4 mm (with respect to mid H-point)	Corrected AMVO	WorldSID-α anthropometry

The location of the head's centre of gravity was to be indicated on the left and right exterior of the head. The tolerance of the indications were to be ± 2,0 mm.

The coordinates (x, y, z in mm), with respect to the H-point for the head CG and OC-joint were to be (–177, 0, 656,4) and (–194, 0, 598,4) respectively.

For packaging reasons, an adjustment to change the orientation of the head depending on the dummy's posture inside a vehicle could be incorporated at the head-neck junction but was incorporated into the neck-thorax bracket. An adjustable lower neck bracket allowed proper orientation of the head. The head reference plane was to be marked on the head and served as a reference to level the head (note that the head reference plane in the reference posture of the occupant as defined by the AMVO data set is at an angle of 3,7° with the horizontal plane).

A.2.5.5 Neck

The neck has similar mass and mass distribution to that of the human, as available from the reference AMVO data set. The target data are specified in Table A.5. Coordinates of the OC-joint and C7/T1-joint were to be (-194, 0, 598,4) and (-191, 0, 479,4). A neck shroud prevented unrealistic airbag interactions.

Table A.5 — General neck anthropometry reference data (Source: AMVO Data Set)

Parameter	Target	Reference	Remark
Mass	0,965 ± 0,2 kg		Production tolerance is tighter.

At the end of the ranges of motion, progressive stiffness was to be built in to prevent overloading.

To allow the head to be oriented over a sufficient range of motion (angular displacement around the y-axis) with the dummy in an automotive position, the neck bracket exhibits an adjustability of at least 10° forward (flexion) and 20° rearward (extension) with respect to the reference posture.

A.2.5.6 Shoulder/thorax/abdomen

The anthropometry landmarks are based on the AMVO and derivative studies. Major design targets are given in Table A.6. The three-dimensional surface of the AMVO model was used as the design target for the outside contours of the dummy.

Table A.6 — Segment masses

Segment masses	Target
Shoulder and thorax	23,763 kg
Abdomen	2,365 kg

A.2.5.7 Full arms

The arm was designed with reference to the AMVO anthropometry data set. This included approximate outside flesh contours, pivot-to-pivot lengths, component masses, and approximate centre of gravity locations.

— Pivot lengths:

  — Shoulder pivot to elbow pivot length: 295,5 mm

  — Elbow pivot to wrist pivot length: 276,1 mm

— Assembly masses: The assembly masses were to be made to match the AMVO data set target of 3,79 kg (1,77 kg upper arm and 2,02 kg lower arm). Precise segmentations were to be established during the design phase.

— Flesh contours:

  — Hand flesh contour was to be new since it is a gripping hand. Basic contour was to be from the AMVO data surface model with simplified geometry with the fingers curved into a gripping position. Left and right hands were to be mirror images of each other.

  — Lower arm flesh contour was to be based on the AMVO data surface model with simplified geometry.

  — Upper arm flesh contour was to be based on the AMVO data surface model with simplified geometry.

  — The shoulder was to be covered with flesh by extending the upper arm flesh up over the shoulder structure. The specific method for covering the shoulder with flesh was to be addressed during the design stage.

A.2.5.8 Half arms

The half arm was to be designed to meet the WorldSID anthropometry specifications, with reference to the source anthropometry data defined by the AMVO data set. The flesh contour is derived from the AMVO shell surface model and approximated to a rectangular section to improve the arm stability during test loading.

The half arm-shoulder joint coincides with that of the full arm and was to be at or very close to the position of the gleno-humeral joint of the anthropometry data set (point 63: -184, ± 173, 403,4).[1)]

1) Coordinates are expressed as x, y, z in mm with respect to the dummy reference position in an orthogonal reference axis system at the H-point (0, 0, 0), unless specifically specified otherwise. The designation "±" refers to

The mass property target of the half arm is specified in Table A.7.

Table A.7 — Mass properties of the WorldSID half arm

Parameter (all identical left and right)	Target
Segment mass (identical left and right)	1,769 kg

A.2.5.9 Lumbar spine

The WorldSID lumbar spine component is defined as the connection between the upper and lower torso and does not specifically simulate the human skeletal lumbar spine. The WorldSID lumbar spine length was to occupy the space between T12/L1 and L5/S1 according to the WorldSID anthropometry specifications in A.2.5.2.

A.2.5.10 Pelvis

A.2.5.10.1 General

The reference for the pelvis anthropometry is the AMVO data set. In order to define the internal geometry of the pelvis, additional data are used from Reynolds et al.[34]

A.2.5.10.2 Overall external dimensions

The external shape of the pelvis is based on the AMVO data set ("shell") but adjusted to obtain a non-compressed buttock flesh. AMVO has defined the pelvis coordinate system at the H-point with the directions of the axes along the vehicle coordinate system. Target data are given in Table A.8.

Table A.8 — Target data for pelvis external dimensions

Parameter	Target
Mass (only pelvis)[a]	11 kg ± 0,2 kg
Mass (pelvis + femur heads)	14,5 kg ± 0,3 kg
Hip breadth	385 mm ± 8 mm

[a] AMVO report refers to McConville, 1980, who considered pelvis as "originates at the centre of the crotch and passes laterally midway between the anterior superior iliac spine and the trochanter landmarks along the lines of the right and left inguinal ligaments."

A.2.5.10.3 Detailed internal dimensions

The internal design of the pelvis was to be primarily based on Reynolds et al.[34] The internal body shape (dummy skeleton) was to not represent the whole human anatomy. Only some important anatomical points were to be represented as well as the overall girdle configuration. Whereas the human pelvis skeleton mass is approximately 1 kg, the dummy uses material with higher density than human bone and was to be instrumented, and hence, was to have a larger mass than the human pelvis. This also results in variation of the pelvic inertia.

Based on Reynolds' data, several bone points have been defined with respect to the (corrected) AMVO H-point definition. To achieve this, Reynolds' coordinate system has been rotated over 54° and the origin of the Reynolds' axis has been moved to the H-point (see definition of Reynolds' coordinate system versus AMVO system in Figure A.1 and Figure A.2). Reynolds' bone markers and AMVO surface markers are shown on Figure A.3, Figure A.4, and Figure A.5.

left and right side.

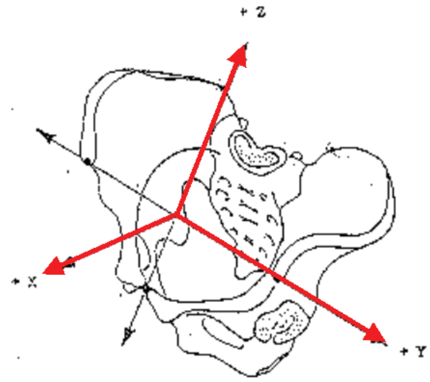


Figure A.1 — Reynolds' pelvis coordinate system

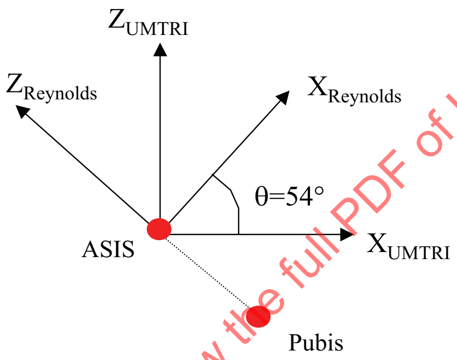


Figure A.2 — Angular shift from AMVO to Reynolds' coordinate system

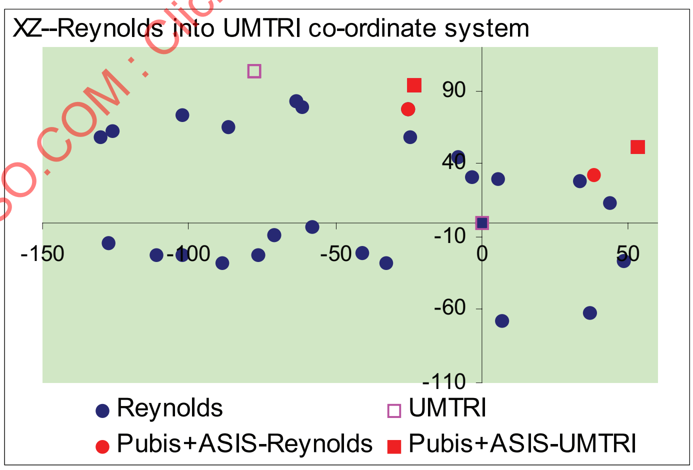


Figure A.3 — Bone and surface landmark coordinates given by Reynolds and AMVO projected on XY plane

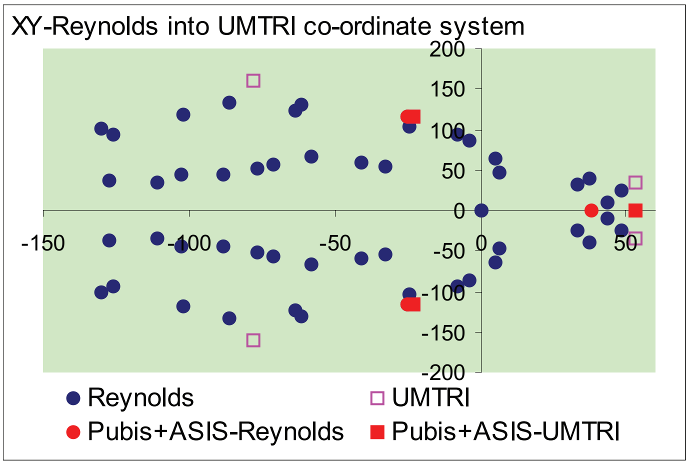


Figure A.4 — Bone and surface landmark coordinates given by Reynolds and AMVO projected on XZ plane

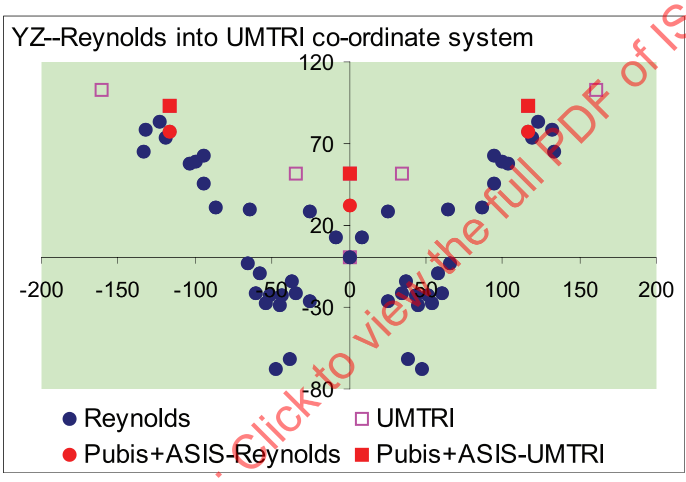


Figure A.5 — Bone and surface landmark coordinates given by Reynolds and AMVO projected on YZ plane

As the difference between the Reynolds bone markers and the AMVO surface markers is surprising, other data have been searched that could give further confirmation on the pelvic bone geometry. The European Project HUMOS[2)] has produced a 3D model of a 50th percentile male (175 cm and 80 kg) in the AMVO seated posture. The 3D reconstruction is based on several cross sections obtained from the frozen cadaver subject. The dimensions of the HUMOS male cannot be considered statistically representative of the population but can be used to further select the appropriate pelvic bone dimensions.

Figure A.6, Figure A.7, and Figure A.8 include a comparison between the HUMOS and Reynolds bone dimensions, which appear rather similar.

2) Human Model for Safety — Project Programme BE 97-4169.

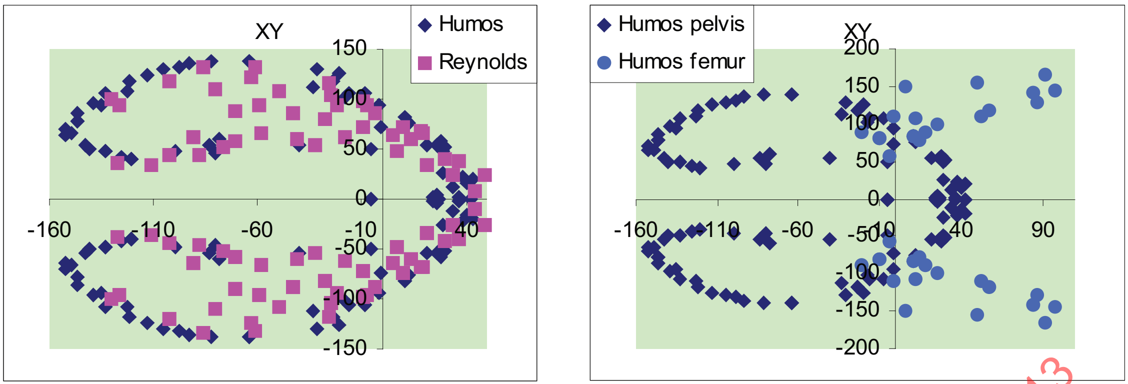


Figure A.6 — HUMOS and Reynolds bone markers projected on XY plane

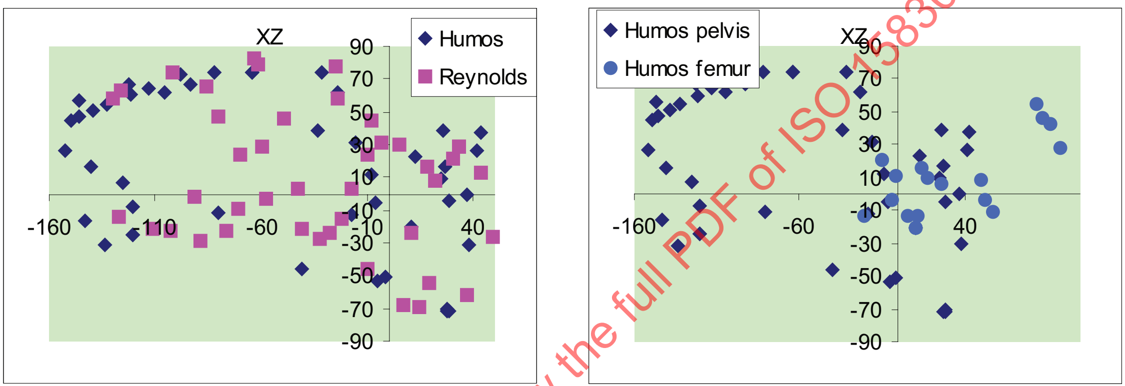


Figure A.7 — HUMOS and Reynolds bone markers projected on XZ plane

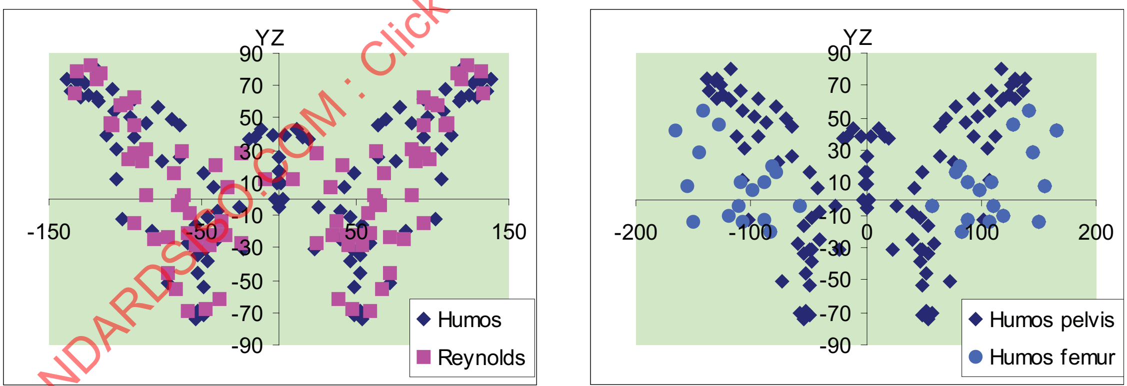


Figure A.8 — HUMOS and Reynolds bone markers projected on YZ plane

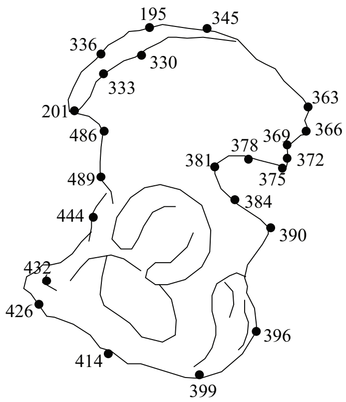


Figure A.9 — Location of Reynolds' pelvis landmarks (Reynolds et al.[34])

Table A.9 — Other pelvis bony landmarks (Reynolds et al.[34])

Points on left side contour	XRU-H pt	YRU-H pt	ZRU-H pt
330	-86	133	65
333	-61	132	79
336	-63	123	83
342	-130	100	59
345	-126	95	63
363	-127	37	-14
366	-111	35	-22
369	-102	44	-22
372	-89	45	-28
378	-71	58	-9
381	-58	66	-4
384	-41	60	-21
390	-33	54	-28
414	49	25	-27
444	5	64	29
486	-24	104	58
489	-8	95	45
492	-4	87	31
189-H point	0	0	0
195-ilocristale summum	-102	119	74
201-ASIS	-25	117	78
204-pubis	38	0	32
375-post-inf iliac spine	-77	52	-22
396-medial tuberosity point	7	48	-68
399-inf. tuberosity point	37	39	-61
426-ant. symphysis pole	44	9	13
432-pubotubercule	33	25	29
Trochanter	22	165	-9,6

The iliac crest points (for example, point number 336 as shown in Figure A.9 and Table A.9) are the highest points in the seated position and their coordinates are important for defining potential interaction with the abdominal ribs.

A.2.5.10.4 Detailed pelvis shape

The ischium shape and position have to be human-like to have a proper pressure mapping on the seat cushion (see Figure A.10). The WorldSID-α pressure map was to be similar to that shown below; no pressure values are specified in TG-N60 Rev 2.

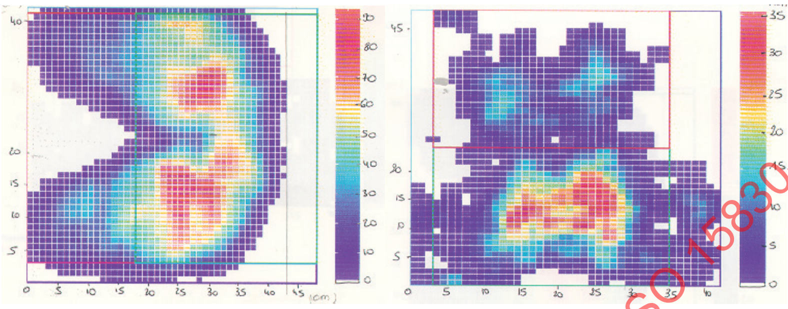


Figure A.10 — An example of a mean seat pressure distribution obtained from five different subjects seated in a truck seat (Seat angle: 4°, back seat angle: 18°; pressure mapping of buttock on left and pressure mapping of back on right[3])

The HUMOS study gives the flesh thickness at different heights where horizontal cutting planes were chosen. The data given here cannot be considered statistically representative of the 50th percentile male but constitute a first indication (Figure A.11).

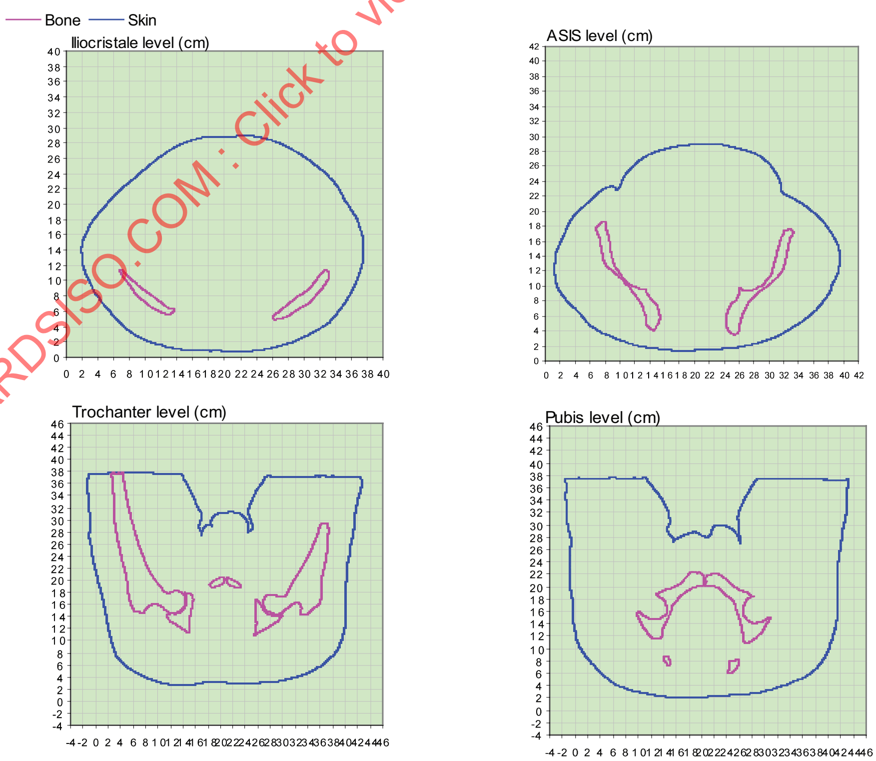


Figure A.11 — Cross sections of pelvis area at iliocristale, ASIS, greater trochanter, and pubis level (from HUMOS)

3) Personal communication — RENAULT-RVI.

The average horizontal flesh thicknesses found in the HUMOS subject are as follows:

— at iliocristale: 40 to 45 mm (each side, in lateral direction);

— at ASIS: 40 mm (each side, in lateral direction);

— at trochanter level: 40 to 45 mm (each side, in lateral direction);

— at pubis: 60 mm (in front of the pubic bone).

In conclusion:

— The Reynolds[34] pelvic bone dimension was to be considered for the main bony points of the dummy pelvis.

— The AMVO shape was to give exterior dimensions of the pelvis.

— The flesh thickness was to be derived from the AMVO and Reynolds[34] markers distance (40 mm on the iliocristale and 30 mm at the trochanter).

A.2.5.10.5 Pelvis ranges of motion

Hip ranges of motion depend on knee position. The WorldSID was to be the seated dummy; therefore, the focus was on the range of motion in seated position.

The flesh should not reduce the femur joint range of motion by more than 5°. The hip joint can be tuned by friction setting.

A.2.5.10.6 Posture

The dummy should be able to be seated in the rear of a small car. Hip ranges of motion and flesh design have to allow 53° of flexion in the upward direction. The position of the dummy pelvis (H-point location) should be measurable with an H-point tool. The measurement should be precise at ± 2,5 mm. The design of the WorldSID pelvis was to include a tilt sensor to measure pelvis angle ± 1°.

A.2.5.11 Upper leg

The AMVO data set was taken as reference for the anthropometry specifications. The knee pivot position and orientation were to be maintained at the AMVO coordinates (x, y, z) of (408 mm, 138 mm, 146,4 mm) and (408 mm, -138 mm, 146,4 mm) relative to the H-point. The segmentation locations were to be defined during the design stage. Once the segmentation is defined, the mass target was to be defined based upon the AMVO data, correcting for the segmentation. The basic flesh shape was to be based upon a simplification of the AMVO flesh surface shell adjusted to an uncompressed state. The knee range of motion design target was to be 144° forced, based on Webb.[33]

A.2.5.12 Lower leg

The lower leg was to be designed to represent the mid-sized male as represented by the AMVO data set. Major anthropometry specifications that were to be considered in the design of the lower leg are

— the knee joint centres (points 67: 408 mm, ± 138 mm, 146,4 mm), and

— the ankle joint centres (points 68: 686 mm, ± 94 mm, -158,6 mm).

The flesh system was to have a continuous outer surface when the lower leg is at or close to its reference position (according to the AMVO data set). Continuous surfaces cannot be guaranteed over the full range of motion of the ankle and knee joints.

A.2.5.13 Clothing

The suit was to be tailored to be snug-fitting to the exterior surfaces of the dummy, with additional material added around joints to allow full range of motion. If necessary, a soft shoulder pad was to be sewn into the suit to improve the shape of the jacket. The foam pad was not to affect the response of the dummy.

A.2.6 Biofidelity

A.2.6.1 General

ISO/TR 9790:1999 describes laboratory test procedures and impact response requirements suitable for assessing the lateral impact biofidelity of the head, neck, shoulder, thorax, abdomen, and pelvis of crash test dummies, subcomponent test devices, and math models that are used to represent a 50th percentile adult male.

A.2.6.2 Head

Two lateral head impact tests are defined in ISO/TR 9790. Head test 1 is based on the rigid surface cadaver impacts conducted by Hodgson and Thomas.[12] Head test 2 is based on the padded surface cadaver impacts of the Association Peugeot-Renault (APR).[35] Note that test 2 was not conducted since the padding specified for the test is no longer available.

An additional requirement was placed on the head design requiring the head to meet the frontal head biofidelity as specified by Hodgson and Thomas.[12] This test is not included in ISO/TR 9790 and is therefore not included in the biofidelity rating.

A.2.6.3 Neck

Three lateral neck bending tests are defined. Neck test 1 is based on the human volunteer data of Ewing et al.,[10] and the requirements are based on the analysis of Wismans et al.[29] Neck test 2 is based on the human volunteer data of Patrick and Chou.[19] Neck test 3 is based on the cadaver tests of the APR.[35] To evaluate if the biofidelity requirements are met for the neck, the respective sled test environments that were used to obtain the human volunteer and/or cadaver data were to be duplicated.

A.2.6.4 Shoulder

Four lateral impact test conditions are defined for the shoulder. Shoulder test 1 is based on impactor tests conducted by the APR using unembalmed cadavers.[2] Shoulder test 2 is based on the Ewing et al.[10] volunteer sled tests. Shoulder test 3 is based on the cadaver sled tests of Tarriere.[37] Shoulder test 4 is based on the cadaver sled tests of Wayne State University (WSU) as described by Irwin.[38],[15]

The exact padding used in shoulder test 4 is no longer available. The WorldSID was tested in this configuration by multiple labs using "similar" but different paddings, but careful review of the resulting data indicated that differences in the padding resulted in significant data anomalies. The data issues related to the padding differences were discussed in detail with WG 5 where it was agreed that shoulder test 4 not be included in the biofidelity rating.

A.2.6.5 Thorax

Six lateral thoracic impact test conditions are defined. Thorax tests 1 and 2 are based on cadaver impactor tests conducted by the Highway Safety Research Institute (HSRI) described by Eppinger et al.[9] and WSU described by Viano.[28] Thorax tests 3 and 4 are based on the cadaver drop tests of the APR as described by Stalnaker et al. and Walfisch et al.[24],[39],[40] Thorax test 5 is based on cadaver sled tests of the University of Heidelberg described by Marcus et al.[16] Thorax test 6 is based on cadaver sled tests of WSU described by Irwin et al.[38],[15] Note that thorax test 4 and test 6 were not conducted because the padding is no longer available (see A.2.6.4 for details).

A.2.6.6 Abdomen

Five lateral abdominal impact test conditions are defined. Abdomen tests 1 and 2 are based on the lateral cadaver drop tests conducted by the APR.[40],[2] Abdomen tests 3 to 5 are based on cadaver sled tests of WSU.[15] Three abdomen tests were not included in the biofidelity rating. Abdomen test 2, a 2-metre drop, and test 4, a high-speed rigid wall sled test, were not included because it was deemed that the test energies were excessive. In addition, test 5 was excluded because the padding is not available (see A.2.6.4 for details).

A.2.6.7 Pelvis

Thirteen lateral pelvic impact test conditions are defined. Pelvis tests 1 and 2 are based on impactor tests of ONSER described by Cesari[41],[5],[7]). Pelvis tests 3 to 6 are based on free fall cadaver tests of the APR described by Tarriere.[25] Pelvis tests 7 to 9 are based on cadaver sled tests of the University of Heidelberg described by Marcus et al.[16] Pelvis tests 11 to 13 are based on cadaver sled tests of WSU described by Irwin.[15] Note that pelvis tests 5, 6, 9, 12, and 13 were not conducted because the padding is no longer available. In addition, tests 8 and 11 were not conducted due to their excessive energy levels (see A.2.6.4 and A.2.6.6 for details).

A.2.7 Instrumentation needs

Overall design targets for measurement capability of the WorldSID were that:

— The instrumentation would support the assessment of injury risk using existing criteria as described in existing standard side-impact test procedures. This follows the recommendations from ISO/TC 22/SC 12/WG 6.

— The instrumentation would support the assessment and optimization of vehicle components and restraint systems.

— The instrumentation would support assessment of occupant behaviour in reconstructed accidents.

— Instrumentation would be designed as integral parts of the dummy.

— Instrumentation would conform to ISO 6487 or SAE J211-1.

— Instrumentation would be designed such that an in-dummy data acquisition system can be used.

— Instrumentation would support ease of use. Sensor identification should be incorporated with or without an in-dummy data acquisition system.

Specific component instrumentation targets are shown in Table A.10.

Table A.10 — Target WorldSID instrumentation listing

Component	Instrumentation	Channels	Subtotal
Head	Head CG linear acceleration ($a_{x,y,z}$)	3	8
	Rotational acceleration ($\alpha_{x,y,z}$)	3	
	Head tilt ($\theta_{x,y}$)	2	
Neck	OC joint (upper neck) loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	12
	C7/T1 (lower neck) loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	
Shoulders (each side)	Shoulder rib linear acceleration ($a_{x,y,z}$)	3	7 each side 14 total
	Shoulder rib displacement (δ_y)	1	
	Shoulder joint forces ($F_{x,y,z}$)	3	

Table A.10 *(continued)*

Component	Instrumentation	Channels	Subtotal
Full arm (each side)	Upper arm loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	21 each side
	Lower arm loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	42 total
	Elbow moments ($M_{x,y}$)	2	
	Elbow angular displacement (φ_y)	1	
	Elbow linear acceleration ($a_{x,y,z}$)	3	
	Wrist linear acceleration ($a_{x,y,z}$)	3	
Half arm (each side)	None		0
Thorax (each side)	Upper thorax rib linear acceleration ($a_{x,y,z}$)	3	12 each side
	Upper thorax rib deflection (δ_y)	1	24 total
	Middle thorax rib linear acceleration ($a_{x,y,z}$)	3	
	Middle thorax rib deflection (δ_y)	1	
	Lower thorax rib linear acceleration ($a_{x,y,z}$)	3	
	Lower thorax rib deflection (δ_y)	1	
Spine	T1 acceleration ($a_{x,y,z}$)	3	13
	T4 (centre spine box) linear acceleration ($a_{x,y,z}$)	3	
	T12 (lower spine box) linear acceleration ($a_{x,y,z}$)	3	
	Thorax (spine box) rotational acceleration ($\alpha_{x,z}$)	2	
	Thorax tilt ($\theta_{x,y}$)	2	
Abdomen (each side)	Upper abdomen rib linear acceleration ($a_{x,y,z}$)	3	8 each side
	Upper abdomen rib deflection (δ_y)	1	16 total
	Lower abdomen rib linear acceleration ($a_{x,y,z}$)	3	
	Lower abdomen rib deflection (δ_y)	1	
Lumbar spine	Lower lumbar spine loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	6
Pelvis	Pelvis CG linear acceleration ($a_{x,y,z}$)	3	18
	Pubic symphysis loads (F_y)	1	
	Sacroiliac loads (left and right) ($F_{x,y,z}$, $M_{x,y,z}$)	12	
	Pelvis tilt ($\theta_{x,y}$)	2	
Upper Leg (each side)	Femur neck forces ($F_{x,y,z}$)	3	12 each side
	Mid-femur loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	24 total
	Outboard knee force (F_y)	1	
	Inboard knee force (F_y)	1	
	Knee angular displacement (φ_y)	1	
Lower Leg (each side)	Upper tibia loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	15 each side
	Lower tibia loads ($F_{x,y,z}$, $M_{x,y,z}$)	6	30 total
	Ankle angular displacement ($\varphi_{x,y,z}$)	3	

The targets for the WorldSID total channel count differed with the various configurations of the dummy.

— Total number of channels for WorldSID with two full arms and instrumented on struck and non-struck side (shoulder-thorax-abdomen ribs not instrumented on non-struck side) was to be 180.

— Total number of channels for WorldSID with full arms and instrumented on the struck side only (for extremities) was to be 132.

— Total number of channels for WorldSID with half arms and instrumented on struck side only (for extremities) was to be 111.

The WorldSID was to be designed with an optional in-dummy data acquisition system, capable of recording a minimum of 64 channels on-board (power and set-up external).

All sensors were to be orientated in accordance with ISO 6487 or SAE J211-1 and local coordinate systems were to be defined for all components listed in Table A.10.

A high level of integration of the instrumentation with WorldSID parts was to be achieved through an integrated wiring concept (i.e. the mass of cables internal to the dummy were to be designated as part of the dummy). In addition, for all sensors, structural or mass replacements were to be provided and the mass characteristics of the sensors were to be accounted for at body part level. All load sensors were to be structural components of the dummy.

Further details of the specific body region instrumentation needs were presented in the Design Brief.[30]

A.2.8 Repeatability and reproducibility needs

Repeatability of the WorldSID could only be assessed once the actual design is completed and built. Assessment of reproducibility requires multiple dummies. At the design level, low mass, low dimensional tolerances, selection of strong materials, and good symmetry (where applicable) were to help ensure that the dummy would meet overall repeatability requirements. In addition, validation procedures were to be developed that would consider body part responses relevant to the expected test conditions.

General repeatability requirements for the WorldSID were to be that the cumulative variance (CV) on injury assessment and calibration signals would be less than or equal to 7 % in both validation and in general use.

Further details of the specific body region repeatability and reproducibility needs were presented in the Design Brief.[30]

A.2.9 Durability needs

Provided the loads on the components remain below 150 % of the injury assessment values (IARV, e.g. Mertz[42]), the components were to remain functional for at least 10 tests. Since injury tolerance levels (e.g. probability of AIS ≥ 3) for each body region of WorldSID did not yet exist at the time when WorldSID performance targets were being established, the injury assessment reference values (IARV) developed by Mertz[42] were used in the subsequent WorldSID durability evaluation phase.

Further details of the specific body region durability needs were presented in the Design Brief.[30]

A.2.10 Sensitivity needs

The design of the WorldSID was to include continuous surfaces, integrated shoes, clothing, and targetable surfaces. In addition, the dummy was to have a non-binding design for oblique impacts up to +/- 30° from lateral and +/- 10° from horizontal.

The WorldSID was to be compatible with a 16 °C to 20 °C soaking environment and a 16 °C to 26 °C operating temperature.

A.2.11 Handling needs

The WorldSID was to be developed using a design-for-assembly approach, was to have a high level of integration with required and desired instrumentation, and was to be provided with a detailed user manual. Features for dummy storage and positioning were to be integrated in order to further enhance dummy handling.

Further details of the specific body region handling needs were presented in the Design Brief.[30]

A.2.12 Verification, calibration, and validation needs

As much as possible, existing dummy calibration fixtures and procedures were to be used for WorldSID. The WorldSID delivery was to include calibration specifications for the extremities, which had not been done for other side-impact dummies.

Further details of the specific body region verification, calibration, and validation needs were presented in the Design Brief.[30]

A.2.13 Other needs

The Design Team established a drawing and part coding system according to ISO standards (i.e. involving adoption of ANSI standard Y14.5M 1994). The coding system consists of an eight-digit character code. The first three digits represent the dummy type: "W50" for the 50th percentile male WorldSID. The following five digits represent the body region (one digit), body sub-region (one digit), and the part ID (three digits). Fasteners are the exception to this rule and are coded upward of W50-6000000. Table A.11 gives the designated codes for WorldSID assembly, subassemblies, and components for reference.

Table A.11 — WorldSID part coding system

Dummy ID	Component number	Body region/other
W50	0	Top level assembly
W50	10000	Head
W50	20000	Neck
W50	30000	Torso — shoulders/thorax/abdomen
W50	40000	Pelvis/lumbar
	41000	Lumbar spine
	42000	Pelvis
W50	50000	Legs
	51000	Femur
	52000	Knee
	53000	Tibia
	54000	Ankle
	55000	Foot
W50	60000	Arms — full/half
	61000	Full arm
	62000	Half arm
W50	70000	Data acquisition system and instrumentation
	71000	Load cells
	72000	Accelerometers
	73000	Deflection sensors
	74000	Data acquisition system and signal conditioning
W50	80000	Clothing, test equipment, miscellaneous
W50	6000000	Fasteners

Further details of other needs in the specific body regions were presented in the Design Brief.[30]

Annex B
(informative)

Rationale regarding performance of the WorldSID

B.1 Performance basis of the WorldSID

NOTE The performance of the WorldSID is described subsequently, based on the test data, design drawings, and CAD files available up through late 2010.

B.2 Anthropometry performance

B.2.1 Overall dummy landmarks

Table B.1 — Actual dummy versus design target landmarks

Landmark	Description	Design target			Actual[a]		
		x mm	*y* mm	*z* mm	*x* mm	*y* mm	*z* mm
	vertebral column						
7	C7	-264	0	499,4	-264	0	499,4
8	T4	-291	0	390,4	-291	0	390,4
10	T12	-244	0	156,4	-244	0	156,4
12	L5	-172	0	23,4	-172	0	23,4
	pelvis						
27	iliocristale	-78	±161	103,4	-78	±161	103,4
28	anterior superior iliac spine (l,r)[b]	-23	±116	93,4	Not available	Not available	Not available
29	pubic symphysis[c]	53	0	51,4	Not available	Not available	Not available
31	throchanterion (skeletal reconstruction) (l,r)	22	±203	-9,6	Not available	Not available	Not available
32	H-point	0	±83,5	0	0	±83,5	0
	shoulder						
35	greater tubercle humerus (l,r) (half arm)		±218			±218	
35	greater tubercle humerus (l,r) (full arm)		±218			±222,6	
	joint centres						
54	head/neck	-194	0	598,4	-194	0	598,4
55	c7/t1	-191	0	479,4	-191	0	479,4
58	t12/l1	-175	0	175,4	-175	0	175,4
60	l5/s1	-89	0	39	-89	0	39

Table B.1 *(continued)*

Landmark	Description	Design target			Actual[a]		
		x mm	*y* mm	*z* mm	*x* mm	*y* mm	*z* mm
61	sternoclavicular	-143	±43	443,4	-143	±43	443,4
62	claviscapular	-228	±168	437,4	-228	±168	437,4
63	glenohumeral[d]	-184	±173	403,4	-169	±173	404,4
64	elbow[d]	38	±208	211,4	53,4	±211,6	212,2
65	wrist[d]	230	±158	403,4	244,2	±162,5	403,3
66	hip (H-point)	0	±83,5	0	0	±83,5	0
67	knee	408	±138	146,4	408	±138	146,3
68	ankle	686	±94	-158,6	680	±94	-158,6
	estimated segment centres of gravity						
79	head	-177	0	656,4	-177	0	656,4

a Some of the actual reference locations listed are very difficult or impossible to measure directly, and therefore, the computer-aided design (CAD) values for all points are listed as actual and are believed to be accurate.

b The dummy pelvis was designed with a single curvature shape to avoid a structural buckling mode that would occur with a more human-like shape.

c Packaging of the pubic load cell required a deviation from the target location.

d The actual shoulder joint had to be 15 mm forward of the target to accommodate the shoulder rib design.

B.2.2 Range of motion

Table B.2 — Actual dummy range of motion vs. design target

Motion	Design target	Actual
Shoulder flexion	180° to soft stop	172° to contact, 190° forced
Shoulder extension	45° to soft stop	40° contact, 50° forced
Shoulder abduction	100° to soft stop	101, 50°
Shoulder adduction	0° to soft stop	-1°
Shoulder lateral angular displacement	31° to soft stop	31°
Shoulder medial angular displacement	91° to soft stop	91,8°
Elbow flexion	135° to soft stop	137,1°
Elbow extension	-5° to soft stop	-3,9°
Wrist pronation	80° to soft stop	81,7°
Wrist supination	80° to soft stop	82°
Wrist flexion	75° to soft stop	75°
Wrist extension	75° to soft stop	55° to flesh contact, 77° forced
Wrist abduction	15° to soft stop	15°
Wrist adduction	25° to soft stop	28,5°

B.2.3 Head

The actual WorldSID head anthropometry is given in Table B.3 and is compared with the original design target.

Table B.3 — Actual dummy head anthropometry vs. design target

Parameter	Target	Actual
Mass	4,14 kg ± 0,1 kg	4,23 kg
Circumference	570,6 mm ± 5 mm	568 kg
Height	230,9 mm	231 mm
Length	197,4 mm ± 2 mm	199 mm
Width	158 mm ± 2 mm	159 mm
CG location	177mm, 0mm, 656,4mm (with respect to mid H-point)	177 mm, 0 mm, 656 mm

B.2.4 Neck anthropometry

The neck is designed according to AMVO corrected anthropometry. The length of the neck design complies with the AMVO requirement; however, in order to meet the biofidelity performance requirement, the diameter of the neck itself is reduced. A neck shield is designed to simulate the skin contour of the AMVO shell. Due to the limit of the mechanical design packaging, the dummy design can not have the same split location as defined in the AMVO for a 50th percentile human. Therefore, the weight of the neck design is 1,038 kg, which is within the AMVO requirement of 0,966 kg ± 0,200 kg.

B.2.5 Shoulder/thorax/abdomen anthropometry

The shoulder is designed with an outer and an inner rib for each side. The inner rib has damping material attached to the metal rib. The shoulder rib is tilted 10° upward at the front to simulate arm joint motion during an impact test. The arm-to-shoulder joint is designed to provide range of motion for the arm.

Three thorax ribs are designed to represent the human thorax. The ribs are horizontal in reference to the AMVO sitting posture except for the first thorax rib, which is tilted 5° upward at the front to cover the space between the shoulder rib and the first thorax rib.

The abdomen is represented by two abdomen ribs. The mechanical design is similar to the thorax except for the damping material, which is thicker to meet the performance requirements.

Since the mechanical interface between the upper torso and the lower torso differs from the AMVO body segment locations, the total weight of 22,74 kg for the shoulder/thorax/abdomen, including the lower neck bracket assembly, is different from the specifications in AMVO.

B.2.6 Full arms

The pivot lengths were first priority. The target for shoulder pivot to elbow pivot was 295,5 mm, whereas the design measured 295,0 mm in CAD. The target for elbow-to-wrist pivot was 276,1 mm, and the design measured 276,1 mm in CAD. The second priority for the arm design was measurement capability and strength. The strength of the arm bone was designed to exceed the capacities of the load cells. The third priority was range of motion (ROM). The measured ROMs on one arm are shown in Table B.2.

The fourth priority was the external shape of the arm flesh. The upper arm flesh shape was derived by taking slices of the AMVO surface shell and drawing ellipses through the sections to approximate the area of the section. The resulting surface was smoothed and simplified somewhat, and the left and right upper arm fleshes were made as mirror images. The lower arm flesh shape was derived in a similar fashion by taking slices of the AMVO surface shell and drawing ellipses through the sections to approximate the area of the section. This surface was smoothed, simplified, and made symmetrical so that one arm flesh part could be used for the left and right arms. The hand shape was derived in a slightly different fashion. The hand was made by taking one of the Hybrid III 50th male hand shapes, bending the fingers, and mirroring it for the other side. This gave a more reasonable shape for a dummy hand than trying to use the AMVO surface data directly.

Matching the mass distributions of the arm could only be an approximation. The AMVO anthropometry data set splits body segments by defining planes through the joint centres. In a dummy, these planes pass through multiple parts. The arm was designed by grouping parts that would be cut by the split planes into one of the body segments. Then, the mass targets of the flesh components were adjusted to have the dummy segments match the AMVO body segment mass targets. The final check of this process was to measure the entire arm mass of one of the arms and compare it to the full arm mass target from the AMVO data set. The actual full arm mass was 3,72 kg as compared to the target mass from the AMVO study of 3,79 kg.

Due to the many other requirements for the arm, there was no possibility to adjust the centre of gravity locations of the arm segments.

B.2.7 Half arms

The half arm was designed to match the AMVO upper arm weight and geometry. The actual weight is 1,768 kg. The performance of the half arm is not tested independently but is tested in combination with the shoulder and the thorax.

B.2.8 Lumbar spine

The lumbar design was limited by space constraints and was designed to fit within 50 mm between the thorax and the pelvis. The lumbar flexibility provides shear flexibility between the upper and lower torso to simulate human response. The lumbar is approximately aligned with L5/S1 but not with T12/L1.

B.2.9 Pelvis

The actual pelvis breadth is 384,6 mm. The actual dummy pelvis mass is difficult to compare to the target mass because the dummy mechanical split lines are different than those used for determining the target masses; however, the overall dummy mass and mass distributions match the general mass targets.

B.2.10 Upper leg

The AMVO data set was taken as reference for the anthropometry specifications for the upper leg segment. The hip and joint centres were matched to the locations specified in the AMVO data (see Table B.1). The flesh shape was split from the pelvis and is a smoothed simplified shaped derived from an approximation of what the un-deformed surface shell would be. In the knee area, the outer flesh shape was made with spherical radii on both sides and the front to give uniform surfaces to transfer load to the knee contact load cells and the front of the knee. The front knee surface radius approximated the forward location of the surface shell.

The mass segmentation between the AMVO data set and the upper leg was an approximation. The split planes in the AMVO data set pass through the hip socket and the knee centre. In the dummy, the pelvis flesh is split in a plane perpendicular to the bone well below the hip ball. The bone from the hip ball to the split above the upper tibia load cell is part of the upper leg assembly in the dummy. Due to these major differences in the splits in the dummy versus the AMVO study, the masses were adjusted by taking a portion of the mass from the AMVO study and transferring it from the upper leg to the pelvis. This made the dummy upper leg mass several kilograms light. The human mass of bone structure and flesh from the knee pivot to the top of the upper tibia load cell should be part of the lower leg but is included in the upper leg in the dummy. This adds to the dummy upper leg mass. As a result of such mass distributions, the average measured upper leg mass of the dummies was 6,7 kg while the target mass was 8,6 kg.

B.2.11 Lower leg

The AMVO data set was taken as reference for the anthropometry specifications for the lower leg segment. The knee joint centre location is shown in Table B.1. The AMVO data set specifies one joint centre for the ankle, but the dummy was designed with a split distance between the inversion/eversion and dorsiflexion/plantarflexion pivots. The dorsiflexion/plantarflexion pivot was located at the AMVO pivot shown in Table B.1.

The external flesh shape was designed based on the surface shell by taking vertical slices through surface shell. At each slice, an ellipse was drawn approximating the area of the cross section. These ellipses were made symmetric about the centre of the bone so that one flesh could be used on both the left and right legs. The resulting surface was smoothed. At the knee end, a spherical cut was made to mate to the upper leg flesh.

The mass segmentation between the AMVO data set and the lower leg was an approximation. The split planes in the AMVO data set pass through the knee and ankle joint centres. The dummy segmentation is very different. The split between the upper and lower legs is at the top of the upper tibia load cell. The split between the lower leg and ankle/foot is at the bottom of the lower tibia load cell for the bone structure, which is well above the ankle pivot. In addition, the foot and shoe are combined in the dummy into one moulded component.

These major segmentation differences make a comparison of dummy and AMVO mass targets difficult. For the dummy, the average lower leg mass was measured at 2,8 kg, whereas the AMVO target was 3,6 kg. For the dummy ankle/foot assembly, the average measured mass was 2,3 kg versus a target of 1,0 kg. These differences are partly due to the segmentation differences, partly due to the inclusion of the shoe in the dummy, and partly due to the dummy ankle assembly being somewhat heavier than the AMVO mass target.

B.2.12 Clothing

The clothing is fabricated from 5 mm thick neoprene and is tailored to fit the dummy according to the AMVO shell. The clothing provides smooth external contours for the dummy skin surface and does not adversely affect the joint motions. Two shoulder pads, which are not an integral part of the suit, provide human-like shoulder contours.

B.3 Biofidelity performance

B.3.1 ISO/TR 9790 ratings procedures

As found in ISO/TR 9790, ISO has defined the biofidelity rating for the six WorldSID body regions as follows:

$$B_i = \frac{\sum j\left(V_{i,j}\left(\sum W_{i,j,k} R_{i,j,k}\right)\right) / \sum W_k}{\sum j V_{i,j}} \quad (1)$$

where

B_i is the body region biofidelity rating;

$V_{i,j}$ is the weighting factor for each test condition for a given body region;

$W_{i,j,k}$ is the weighting factor for each response measurement for which a requirement is given;

$R_{i,j,k}$ is the rating of how well a given response meets its requirement ($R_{i,j,k}$ is equal to 10 if the response meets the requirement, 5 if the response is outside but lies within one corridor width of the requirement, and 0 if neither of the previous is met). Note that when a rating was determined by the WorldSID Task Group, particular emphasis was placed on the loading and peak phase of the data being considered. It is the WorldSID Task Group's understanding that this is common practice and that this procedure has been used in the determination of ratings for other dummies;

i represents the body region;

j represents the test condition for a given body region i;

k represents the response measurement for a given test condition j and a body region i.

Values for the weighting factors for the various test conditions, $V_{i,j}$, and response measurements, $W_{i,j,k}$, were determined by averaging the results of a poll of the ISO/TC 22/SC 12/WG 5 experts and are given in tables S.2 through S.7 of Annex S of ISO/TR 9790.

The experts agreed on the following method for assigning values to $R_{i,j,k}$.

$R_{i,j,k}$ = 10 if response meets requirement.

$R_{i,j,k}$ = 5 if response is outside requirement but lies within one corridor width of the requirement.

$R_{i,j,k}$ = 0 if neither of the above is met.

Using this method, the overall biofidelity rating, B, was to have a design target value between 0 and 10. Five classifications indicating the degree of biofidelity were established for the overall biofidelity rating. These are,

— Excellent biofidelity: $8,6 \leq B \leq 10,0$

— Good biofidelity: $6,5 \leq B \leq 8,6$

— Fair biofidelity: $4,4 \leq B \leq 6,5$

— Marginal biofidelity: $2,6 \leq B \leq 4,4$

— Unacceptable biofidelity: $0,0 \leq B \leq 2,6$

Further, the WG 5 experts stipulated that the overall biofidelity value, B, of a side-impact dummy (or math model) had to be greater than 2,6 to be acceptable for assessing side-impact occupant protection.

As described in A.2, the objective for the WorldSID was that it would have "good" to "excellent" biofidelity.

B.3.2 Head

One of the two head tests specified in ISO/TR 9790 was carried out with the WorldSID for lateral assessment. Head test 2 was not conducted because the required padding for the test is no longer available.

Head test 1, defined in ISO/TR 9790 and according to Hodgson and Thomas,[12] is a 200-mm drop test onto a rigid surface with the head only. Targets are given for head resultant accelerations. As only test 1 could be carried out, the overall head biofidelity rating is the same as that of test 1. Head test 1 data are given in Annex D.

The biofidelity rating of the head is 10,0.

B.3.3 Neck

B.3.3.1 General

Three different sled tests were conducted to determine the lateral biofidelity of the dummy neck assembly. Neck test 2 data are from the WorldSID revised prototype. As recommended by the WorldSID Task Group, neck tests 1 and 3 were performed with the arm at 45° with respect to the ground. Neck test 2 was performed with the arm at 45° with respect to the torso. All neck tests were conducted without the neck shield since it was previously determined by Cesari et al.[6] that the neck shield had no influence on the neck biofidelity performance. Neck tests 1 through 3 data are given in Annex D.

B.3.3.2 Neck test 1

Neck test 1, defined in ISO/TR 9790, is a sled test based on the volunteer tests conducted by Ewing et al.[10] The requirements derived from these tests originate from the analysis performed by Wismans et al.[29] The mean sled velocity was 6,9 m/s and average sled deceleration was 7,2 G. Boundaries were given for lateral acceleration and displacement at T1, lateral and vertical head CG displacement relative to T1, the time of peak head excursion, lateral and vertical peak head acceleration, the peak lateral flexion angle, and the peak twist angle.

The biofidelity rating for neck test 1 is 7,4.

B.3.3.3 Neck test 2

Neck test 2, defined in ISO/TR 9790, is a sled test configuration referring to the tests of Patrick and Chou.[19] The sled velocity was 5,8 m/s and the constant deceleration level was 6,7 G. From this test, boundaries for peak flexion angle, peak forces and moments at the occipital condyles, and peak head resultant acceleration were given.

The biofidelity rating for neck test 2 is 2,0.

B.3.3.4 Neck test 3

Neck test 3, defined in ISO/TR 9790, is the configuration established by Tarriere et al.,[25] based on a single cadaveric test with an initial velocity of 6 m/s and sled deceleration of 12,2 G. Boundaries are given for peak lateral T1 acceleration, peak lateral head CG acceleration, peak horizontal displacement of the head CG relative to the sled, peak flexion angle, and peak twist angle.

The biofidelity rating for neck test 3 is 7,2.

B.3.3.5 Overall neck biofidelity rating

The overall neck biofidelity ratings are given in Table B.4.

Table B.4 — Overall neck biofidelity

	j	$V_{2,j}$	$R_{2,j}$
Neck test 1	1	7	7,4
Neck test 2	2	6	2,0
Neck test 3	3	3	7,2
Neck biofidelity rating		5,3	

B.3.4 Shoulder

B.3.4.1 General

Three of four ISO/TR 9790 shoulder tests were conducted on the WorldSID. Shoulder test 4 was excluded because the padding is not available. Tests run included one pendulum impact and two sled tests. As recommended by the WorldSID Task Group, shoulder tests 2 and 3 were performed with the arm at 45° with respect to the ground. The shoulder tests 1 through 3 data are given in Annex D.

B.3.4.2 Shoulder test 1

Shoulder test 1, defined in ISO/TR 9790, involves APR-type pendulum impacts using a 23,4 kg pendulum with a 150-mm cylindrical impact face at 4,5 m/s (Bendjellal et al.[2]). Targets are given for the impactor force/time history and the maximum shoulder deflection.

The biofidelity rating for shoulder test 1 is 10,0.

B.3.4.3 Shoulder test 2

Shoulder test 2, defined in ISO/TR 9790, is the 7,2 G sled test configuration described under neck test 1. targets are given for peak horizontal T1 acceleration and peak horizontal T1 displacement.

The biofidelity rating for shoulder test 2 is 10,0.

B.3.4.4 Shoulder test 3

Shoulder test 3, defined in ISO/TR 9790, is the 12,2 G sled test configuration described under neck test 3. Targets are given for T1 accelerations.

The biofidelity rating for shoulder test 3 is 10,0.

B.3.4.5 Overall shoulder biofidelity rating

The overall biofidelity ratings of the WorldSID shoulder are given in Table B.5.

Table B.5 — Overall shoulder biofidelity

	j	$V_{3,j}$	$R_{3,j}$
Shoulder test 1	1	6	10,0
Shoulder test 2	2	5	10,0
Shoulder test 3	3	3	10,0
Shoulder biofidelity rating B3		10,0	

B.3.5 Thorax

B.3.5.1 General

Four different tests were performed on the WorldSID thorax to determine the thorax biofidelity rating. These tests included two pendulum tests, a drop test, and one sled test. Thorax tests 4 and 6 were not conducted because the required padding is no longer available. As recommended by the WorldSID Task Group, 10 of the 13 thorax test 5 runs were performed with the arm at 45° with respect to the ground while the remaining three runs were inadvertently performed with the arm at 45° with respect to the torso. The measurement data are given in Annex D.

B.3.5.2 Thorax test 1

Thorax test 1, defined in ISO/TR 9790, is a pendulum test in which a 23,4 kg, rigid impactor with a diameter of 150 mm impacts onto the thoracic ribs, with the arms in a horizontal position, at 4,3 m/s (Eppinger, R.H. et al.[9]). Targets are given for the pendulum force and upper spine lateral acceleration.

The biofidelity rating for thorax test 1 is 7,8.

B.3.5.3 Thorax test 2

Thorax test 2 is the same configuration as thorax test 1 except that the impact speed is 6,7 m/s (Viano[28]). Targets are only given for the pendulum impact force.

The biofidelity rating for thorax test 2 is 10,0.

B.3.5.4 Thorax test 3

Thorax test 3, defined in ISO/TR 9790, consists of dropping the dummy laterally from a height of 1 m onto a continuous, rigid plate which spans the shoulder, thorax, and abdomen regions, with a separate plate for the pelvis region. The arm is rotated 20° forward of the dummy's thoracic spine (Stalnaker[24]). Targets are given for the thoracic plate force and peak rib deflection.

The biofidelity rating for thorax test 3 is 8,3.

B.3.5.5 Thorax test 5

Thorax test 5, defined in ISO/TR 9790, requires a Heidelberg-type rigid wall sled impact at 6,8 m/s (Marcus[16]). Targets are given for the thorax plate force, peak lateral upper spine acceleration, peak lateral lower spine acceleration, and peak lateral acceleration of the impacted rib.

The biofidelity rating for thorax test 5 is 6,4.

B.3.5.6 Overall thorax biofidelity rating

The overall biofidelity ratings of the WorldSID thorax are given in Table B.6.

Table B.6 — Summary of thorax biofidelity ratings

	j	$V_{4,j}$	$R_{4,j}$
Thorax test 1	1	9	7,8
Thorax test 2	2	9	10,0
Thorax test 3	3	6	8,3
Thorax test 5	5	7	6,4
Thorax biofidelity rating B4		8,2	

B.3.6 Abdomen

B.3.6.1 General

To determine the overall abdomen biofidelity of the WorldSID, two different abdominal tests were performed. These tests consist of one drop test and one sled test. Abdomen tests 2 and 4 were not conducted due to the severity of the tests which caused the dummy's ribs to bottom out and invalidated the required data. Abdomen test 5 was not conducted because the padding is not available. As recommended by the WorldSID Task Group, six of the nine abdomen test 3 runs were performed with the arm at 45° with respect to the ground while the remaining three runs were inadvertently performed with the arm at 45° with respect to the torso. The data are given in Annex D.

B.3.6.2 Abdomen test 1

Abdomen test 1, defined in ISO/TR 9790, is a lateral drop test from a height of 1 m onto a simulated armrest, which protrudes 41 mm above a continuous, rigid plate (Bendjellal[2]). The plate spans the shoulder and thorax regions, with a separate plate for the pelvis region. Targets are given for the armrest force, peak lower spine acceleration, peak impacted rib acceleration, and peak abdominal penetration.

The biofidelity rating for abdomen test 1 is 9,0.

B.3.6.3 Abdomen test 3

Abdomen test 3, defined in ISO/TR 9790, is a WSU-type rigid wall sled test where the sled is accelerated until it reaches a velocity of 6,8 m/s. The brakes are then applied and the dummy slides into the rigid wall (Cavanaugh[4]). The dummy is seated on the sled with its arm at 45° forward from the vertical. A target is given for the abdominal plate force.

The biofidelity rating for abdomen test 3 is 10,0.

B.3.6.4 Overall abdomen biofidelity rating

The overall biofidelity ratings of the WorldSID abdomen are given in Table B.7.

Table B.7 — Summary of abdomen biofidelity ratings

	j	$V_{5,j}$	$R_{3,j}$
Abdomen test 1	1	7	9,0
Abdomen test 3	3	3	10,0
Abdomen biofidelity rating B5		9,3	

B.3.7 Pelvis

B.3.7.1 General

Six out of thirteen ISO/TR 9790 pelvis tests were conducted with the WorldSID. Pelvis tests 5, 6, 9, 12, and 13 were not conducted, as the padding was unavailable. Pelvis tests 8 and 11 were not included due to the severity of the tests. As recommended by the WorldSID Task Group, 10 of the 13 pelvis test 7 runs and six of the pelvis test 10 runs were performed with the arm at 45° with respect to the ground while the remaining runs were inadvertently performed with the arm at 45° with respect to the torso. The measurement data are given in Annex D.

B.3.7.2 Pelvis test 1

Pelvis test 1, defined in ISO/TR 9790, involves a rigid pendulum impact at 6 m/s. The impactor is defined as a 17,3 kg rigid impactor with a 600 mm radius of curvature and an outer diameter of 127 mm (Cesari et al.[41]; Cesari and Ramet[5]; Cesari[7]). A target is given for the pendulum force.

The biofidelity rating for pelvis test 1 is 10,0.

B.3.7.3 Pelvis test 2

Pelvis test 2 configuration is equivalent to pelvis test 1, but with an impact speed of 10 m/s (Cesari et al.[41]; Cesari and Ramet[5]; Cesari et al.[7]). A target is given for the pendulum force.

The biofidelity rating for pelvis test 2 is 5,0.

B.3.7.4 Pelvis test 3

Pelvis test 3, defined in ISO/TR 9790, consists of dropping the dummy laterally from a height of 0,5 m onto a continuous, rigid plate which spans the shoulder, thorax, and abdomen regions, with a separate plate for the pelvis region. The arm is rotated 20° forward of the dummy's thoracic spine (Tarriere[25]). A target is given for the peak pelvic acceleration.

The biofidelity rating for pelvis test 3 is 5,0.

B.3.7.5 Pelvis test 4

Pelvis test 4 is the same as pelvis test 3, but with a drop height of 1 m. (Tarriere et al.[25]). A target is given for the peak pelvis acceleration.

The biofidelity rating for pelvis test 4 is 0,0.

B.3.7.6 Pelvis test 7

Pelvis test 7, defined in ISO/TR 9790, requires a Heidelberg-type rigid wall sled impact at 6,8 m/s (Stalnaker et al.[24]). Targets are given for the peak pelvic force and the peak pelvic acceleration.

The biofidelity rating for pelvis test 7 is 3,9.

B.3.7.7 Pelvis test 10

Pelvis test 10, defined in ISO/TR 9790, requires a WSU-type rigid wall sled impact at 6,8 m/s (Cavanaugh et al.[4]). Targets are given for the pelvic plate force and the peak lateral pelvic acceleration.

The biofidelity rating for pelvis test 10 is 3,1.

B.3.7.8 Overall pelvis biofidelity rating

The overall biofidelity ratings of the WorldSID pelvis are given in Table B.8.

Table B.8 — Overall pelvis biofidelity

	j	$V_{6,j}$	$R_{6,j}$
Pelvis test 1	1	8	10,
Pelvis test 2	2	9	5,0
Pelvis test 3	3	4	5,0
Pelvis test 4	4	4	0,0
Pelvis test 7	7	8	3,9
Pelvis test 10	10	3	3,1
Pelvis biofidelity rating B6		5,1	

B.3.8 Overall dummy

Table B.9 — Overall WorldSID biofidelity ratings

Region	Weighting	Rating
Head	7	10,0
Neck	6	5,3
Shoulder	5	10,0
Thorax	10	8,2
Abdomen	8	9,3
Pelvis	8	5,1
Overall		8,0

B.4 Available instrumentation

B.4.1 General

The instrumentation that is compatible with the WorldSID and that was available at the time of its launch in 2004 is described by Scherer,[23] Page,[18] and the WorldSID-α Design Brief.[30] All sensors are specified as being “permissible” in ISO 15830-3 in order to allow for variations as may be required by different regulatory, consumer information, test facility, laboratory, and research applications. The permissible and compatible sensors are described subsequently by body region. Detailed normative specifications for all permissible sensors are given in ISO 15830-3.

A general summary of permissible instrumentation units for the various body regions is given in Table B.10.

In addition, a permissible, modular data acquisition system comprising up to six 32-channel digital recording units (i.e. up to 192 recorder channels) was available and can be housed at various specified locations in the dummy, as described in ISO 15830-2 and ISO 15830-3.

Since all WorldSID sensors and the DAS are “permissible” (i.e. optional), the baseline configuration of the WorldSID is specified with either a “mass replacement” or a “structural replacement” for each of these units, the latter being provided for load bearing sensors. This was done so that the specified mass and structural continuity of the overall dummy and all dummy subassemblies are maintained regardless of which sensors are selected for a given application. The sole exception to this rule are the two permissible DAS units for the full arm configuration, which can be placed in the dummy’s suit pockets, which have no mass replacement or structural replacement, and their masses are not included in the baseline WorldSID mass or channel count mentioned in the preceding paragraph.

Table B.10 — General summary of WorldSID permissible instrumentation units

Body region	Number	Instrumentation units
Head	2	Tilt sensors
	1	Tri-axial linear accelerometer at CG
	3	Angular accelerometers
	1	Upper neck load cell
Neck	1	Lower neck load cell
	1	T1 tri-axial accelerometer

Table B.10 *(continued)*

Body region	Number	Instrumentation units
Upper torso	6	IR-TRACC modules
	6	Tri-axial rib accelerometers
	1	Shoulder load cell
	2	Angular accelerometers
	1	T4 tri-axial linear accelerometer
	1	T12 tri-axial linear accelerometer
	1	Temperature sensor
	2	Tilt sensors
	2	DAS modules
Full arm (per full arm)	1	Arm load cell
	1	Forearm load cell
	1	Tri-axial elbow linear accelerometer
	1	Tri-axial wrist accelerometer
	1	Elbow rotation sensor
	1	Elbow load cell
Lower torso	1	Lower lumbar spine load cell
	1	Sacroiliac load cell module
	1	Pubic symphysis load cell
	1	Tri-axial linear accelerometer
	2	Tilt sensors
	1	DAS module
Lower extremities	1	Femur load cell
(per lower extremity)	1	Femur neck load cell
	2	Knee load cells
	1	Knee rotation sensor
	2	DAS modules
	1	Upper tibia load cell
	1	Lower tibia load cell
	3	Ankle rotation sensors

B.4.2 Head

The head instrumentation core inserts from the base of the head and is secured by a bolt that is inserted through the top of the head. This method of instrumentation mounting and access avoids a vertical seam in the skull element, which could confound interactions with vehicle interior surfaces and airbags. The head instrumentation, mounted on the core, consists of a tri-axial accelerometer located at the head centre of gravity, three rotational accelerometers, also located at the head centre of gravity, and two tilt sensors. The tilt sensors are static devices and are intended to be used for proper positioning of the head prior to testing. A six-axis load cell mounts between the base of the head and the upper neck.

B.4.3 Neck

The neck instrumentation consists of one six-axis load cell and a tri-axial accelerometer at T1. The lower neck load cell mounts to the neck adjustment bracket.

B.4.4 Upper torso

B.4.4.1 Shoulder

The shoulder rib is instrumented with an InfraRed Telescoping Rod for Assessment of Chest Compression (IR-TRACC)[22] to measure deflection and a tri-axial accelerometer. A shoulder load cell is located on the impacted side of the dummy where it can measure loads along three axes: F_x, F_y, and F_z.

B.4.4.2 Ribs

Each thoracic and abdominal rib is instrumented with tri-axial accelerometers on the inside of the outboard ends of the rib units. Each rib can also be equipped with an IR-TRACC unit to measure deflection. The IR-TRACC measurement devices are gimbal-mounted to the spine box and connected at the outboard end of the rib unit with a rose joint.

B.4.4.3 Thoracic spine

Tri-axial accelerometers are located in the proximity of the T4 and T12 locations along the spine box. Two rotational accelerometers are mounted on the spine box, measuring about the x and z axes. Two tilt sensors are mounted to the spine box to measure pre-test orientations of the spine box about the x and y axes. One internal temperature sensor is mounted via a spacer adjacent to the auxiliary battery on the non-impact side of the spine box. In addition, two 32-channel DAS units are mounted in the spine box of the WorldSID upper torso.

B.4.5 Arm

The full arm has six axis upper and lower arm load cells, a two axis elbow load cell (M_x, M_y), an elbow rotation potentiometer, and tri-axial accelerometers adjacent to the elbow and wrist joints.

B.4.6 Lower torso

B.4.6.1 Lumbar spine

The lumbar spine mounts directly onto a six channel lumbar spine load cell. In order to meet packaging constraints, this six channel lumbar load cell also incorporates the left and right six channel sacroiliac load cells.

B.4.6.2 Pelvis

The pelvis has a tri-axial accelerometer mounted at its centre of gravity. A single-channel pubic symphysis load cell connects both sides of the pubic bone. The pelvis also contains an 18-channel lumbar/sacroiliac load cell and one left and one right three-channel femoral neck load cell. The pelvis also includes two tilt sensors that are to be used for pre-test pelvis positioning. In addition, one 32-channel DAS unit is packaged in the pelvis.

B.4.7 Lower extremities

Each leg is instrumented with “universal” six-axis leg load cells. “Universal” denotes that each load cell was designed to be mounted at various different locations within the leg assembly. These load cells can be located in the femur, upper tibia, and lower tibia. The knees also have single-axis load cells located at the inboard and outboard side of each knee measuring lateral loads. The inversion-eversion and flexion rotations of the ankle are also measured by potentiometers. In addition, one 32-channel DAS system is included in each leg.

B.5 Repeatability and reproducibility performance

B.5.1 General

A series of tests was performed for the purpose of assessing the repeatability of the WorldSID dummy. Analysis was performed using the coefficient of variation (CV) as a figure of merit. The CV is defined as the standard deviation of the samples divided by the sample mean and is expressed as a percentage. Responses which have a CV of 3 % or less, are commonly considered as having an excellent level of repeatability, whilst a value of 10 % and above is considered to have a poor level of repeatability.

Production dummy test results which follow include a combination of repeat tests performed on the same part (repeatability) and tests performed on different parts (reproducibility). The CV values from these tests should be considered as general indications of the WorldSID repeatability and reproducibility.

B.5.2 Head

The validation tests performed on WorldSID production dummy heads are described in ISO 15830-2, 5.1. The data from these tests are given Annex E. The results are given in Table B.11.

Table B.11 — Head test results

Response measurements	CV (%)
Lateral drop peak resultant CG acceleration	5,6
Frontal drop peak resultant CG acceleration	4,3

B.5.3 Neck

The validation tests performed on WorldSID production dummy necks are described in ISO 15830-2, 5.2. The data from these tests are given in Annex E. The results are given in Table B.12.

Table B.12 — Neck test results

Response measurements	CV (%)
Peak flexion angle	4,1
Peak M_x	4,7

B.5.4 Shoulder

The validation tests performed on the production dummy shoulder are described in ISO 15830-2, 5.3. The data from these tests are given in Annex E. The results are given in Table B.13.

Table B.13 — Shoulder results

Response measurements	CV (%)
Pendulum force	4,2
Peak shoulder deflection	4,9

B.5.5 Thorax

B.5.5.1 General

The validation tests performed on the production dummy thorax are described in ISO 15830-2, 5.3. The data from these tests are given in Annex E. The results are given in Table B.14 and Table B.15.

B.5.5.2 Thorax with arm

Table B.14 — Thorax with arm results

Response measurements	CV (%)
Pendulum force	4,1
Upper spine T4 lateral acceleration	6,7
Lower spine T12 lateral acceleration	5,6
Thorax rib 1 deflection	7,0
Thorax rib 2 deflection	4,3
Thorax rib 3 deflection	4,0

B.5.5.3 Thorax no arm

Table B.15 — Thorax no arm results

Response measurements	CV (%)
Pendulum force	4,7
Upper spine T4 lateral acceleration	8,1
Lower spine T12 lateral acceleration	10,7
Thorax rib 1 deflection	6,4
Thorax rib 2 deflection	4,6
Thorax rib 3 deflection	5,5

B.5.6 Abdomen

The validation tests performed on the production dummy abdomen are described in ISO 15830-2, 5.3. The data from these tests are given in Annex E. The results are given in Table B.16.

Table B.16 — Abdomen results

Response measurements	CV (%)
Pendulum force	3,9
Peak acceleration of the lower spine T12	6,3
Abdomen rib 1 deflection	3,9
Abdomen rib 2 deflection	4,4

B.5.7 Pelvis

The validation tests performed on the production dummy pelvis are described in ISO 15830-2, 5.3.6. The data from these tests are given in Annex E. The results are given in Table B.17.

Table B.17 — Pelvis results

Response measurements	CV (%)
Pendulum force	5,5
Pelvis acceleration	6,5

B.6 Durability performance

The WorldSID durability was evaluated by means of detailed inspections of components following prescribed biofidelity and verification tests. The head, neck, thorax, and pelvis were each subjected to a minimum of 10 tests over the full range of severity not exceeding 150 % of the IARVs (i.e. as given in Mertz[42]). No damage was observed to any of the components or the associated instrumentation.

Permanent deformation of the shoulder rib and accompanying IR-TRACC damage was observed as a result of the 8,9 m/s rigid wall sled test and the 2-meter body drop test. These test conditions are extremely severe and caused excessive stroking (bottoming out) of several ribs and the IR-TRACCs. While these conditions were considered to be in excess of 150 % of the IARVs, structural reinforcement in the form of a rib doubler was added to the outer shoulder rib to further improve durability. Subsequent sled tests conducted at 8,9 m/s confirmed that durability had been improved as no permanent deformation or IR-TRACC damage was observed.

Numerous full-scale pole and MDB tests were carried out with WorldSID in the driver and/or rear passenger struck-side position. Dummy responses ranged from below the IARVs to three times the IARVs or the maximum measurement range. No damage was observed during visual inspections of the head, neck, thorax, pelvis, or legs, indicating excellent durability.

Some rib damping material cracks and debonding were reported in 2007. Analysis linked the problems to a particular batch of damping material. This problem prompted the Task Group to locate a new supplier of damping material and review the overall design. New material was purchased, small design changes were implemented to reduce stress concentrations, new ribs were fabricated, and extensive testing was conducted. The results of numerous single-rib bending tests, followed by full dummy biofidelity and vehicle tests, indicate that the new damping material and rib design have good durability.

B.7 Sensitivity performance

As required, the WorldSID production design consists of continuous surfaces, including a neck shroud, integrated shoes, and clothing. No targeting problems were reported by any test labs.

The WorldSID was subjected to a wide variety of test types including oblique sled impacts up to 30° from lateral and no binding of ribs or other flexible dummy components was observed. In addition, overall good repeatability in sled testing was observed indicating that the dummy is not overly sensitive to the small changes in impact angles which are a part of test-to-test setup variability. Overall, the dummy is not overly sensitive to small changes in impact angles but the responses do change in response to gradually increasing changes in impact angles.

A temperature sensitivity study was conducted to assess the influence of temperature variations on the performance of the shoulder, thorax, abdomen, and pelvis. The results indicated that the rib deflection measurements were insensitive to temperature in the temperature range from 20,6 °C to 22,2 °C. Thus, the use of the WorldSID in a temperature range from 20,6 °C to 22,2 °C is recommended.

B.8 Handling performance

WorldSID was designed with ease of handling being a key requirement. WorldSID was designed to have a high level of integration with both the required and permissible instrumentation, which enhances its overall handling. It is also provided with user manuals, which provide detailed instructions for disassembling and assembling the dummy. A lifting bar which is used for dummy transfer, positioning, and storage is included in the dummy design. This feature provides further enhancement of dummy handling.

The handling performance of the dummy was investigated by numerous test laboratories worldwide over several years in diverse situations, including biofidelity tests, validation tests, and full-scale tests. Various additional design refinements with regard to handling were identified and implemented during the prototype, pre-production, and production stages as a result of user feedback. The substantial experience accumulated during this test and refinement process confirmed that WorldSID has good handling performance in terms of assembly-disassembly, positioning, and storage.

B.9 Verification, calibration, and validation performance

Validation requirements are described in ISO 15830-2, Clause 4. Validation test procedures for the head, neck, thorax, and pelvis are described in ISO 15830-2, Clause 5. The procedures were developed so as to harmonize to the extent possible with existing dummy validation procedures.

Test fixtures required for the validation procedures are predominantly universal and common to other ATDs. Equipment unique to WorldSID is listed in ISO 15830-2, Table A.1. The validation bench, which was originally unique to WorldSID, was designed to facilitate and improve the repeatability of dummy positioning. The bench has since been adopted for use in validation testing of the SID-IIs.

Annex C
(informative)

Resolution establishing WorldSID task group

ISO/TC 22/SC 12/WG 5 agrees[36] that the harmonized side-impact dummy work item shall be done by a task group with the following composition and responsibilities:

1) The task group will report to WG 5 and will be a joint three-way chairpersonship consisting of the Americas, Europe, and Asia/Pacific. The meeting chair will rotate between these three individuals, with the sitting chair providing secretariat support.

2) The members of the task group will be comprised of four representatives from each region and one regional chairperson. The representatives from the region will not include dummy and instrumentation manufacturers. Each country may have one governmental representative on the task group. Decision making within the task group shall be by consensus.

3) The task group shall develop specifications, achieve consensus, and obtain the approval of WG 5 prior to design and beginning fabrication of prototype segments. Once WG 5 approval is obtained, the task group will delegate the prototype build among the participating dummy and instrumentation manufacturers. The task group shall review and reach consensus on the prototype dummy hardware and obtain WG5 approval.

4) Design requirements shall be based on the revised ISO/TR 9790 (WG 5 Document N455 - Revision 4). No basic research shall be conducted. The biofidelity of all body regions, instrumentation capability, and dummy repeatability shall be rated good or excellent. Initially, the design units shall be metric.

5) Dummy and instrumentation manufacturers are encouraged to participate because they are an integral part of the dummy development process. Dummy manufacturers shall work toward a common design and common interfaces of the prototype. Instrumentation manufacturers shall work together toward common fit and function. The final dummy design shall be public domain to aid adoption in any future regulatory activity. Manufacturing processes may be proprietary but not the specifications and dummy drawings. The same dummy shall be able to be fabricated anywhere.

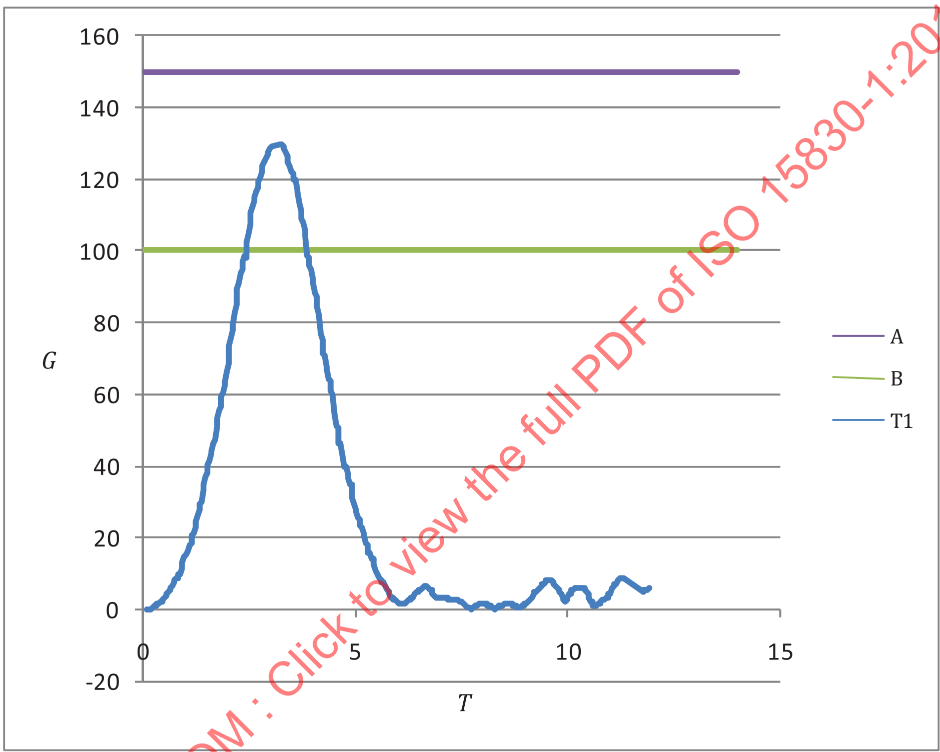
6) One-third of the total design cost will be funded per region. Total design cost and budget will be determined and agreed upon by the task group. Prototype evaluation and technical expertise will be in kind contributions.

7) Ms. Scherer will be the regional chair for the Americas, Mr. Cesari will be the regional chair for Europe, and Mr. Uchimura will be the regional chair for Asia/Pacific.

Annex D
(informative)

Biofidelity test data

D.1 Head



Rating 10

Key

T time (ms)

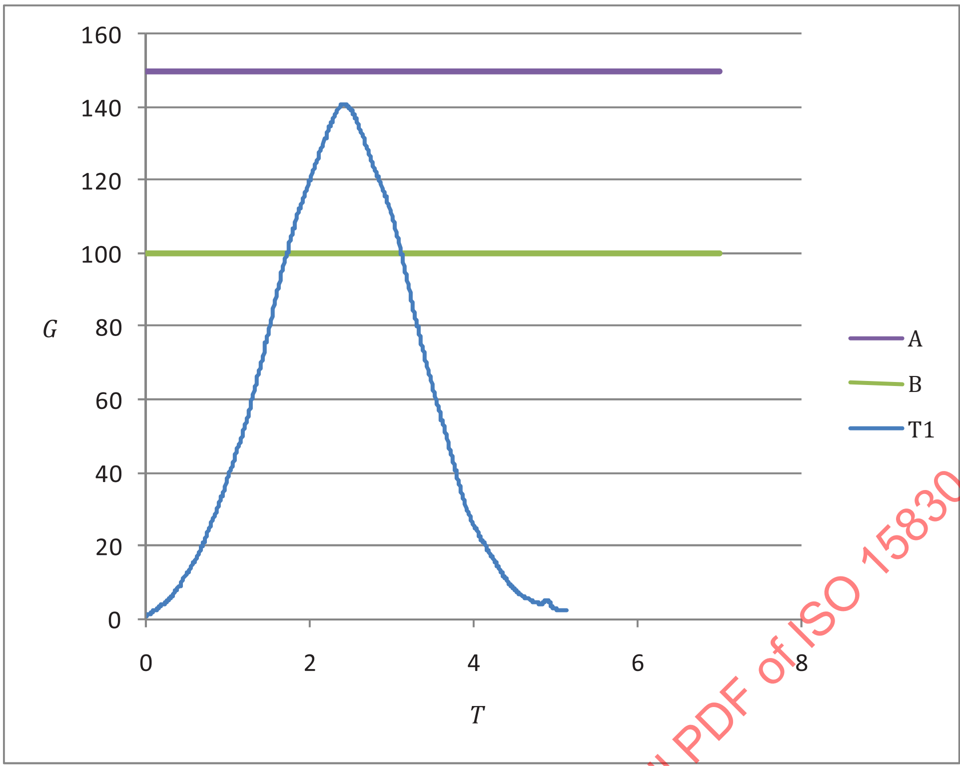
G acceleration of non-impact side of head (g)

A ISO/TR 9790 upper corridor

B ISO/TR 9790 lower corridor

T1 test number W009-PRSH-2

Figure D.1 — Head test 1 - 200 mm lateral head drop (right side) - resultant acceleration



Rating 10

Key

T time (ms)

G acceleration of non-impact side of head (g)

A ISO/TR 9790 upper corridor

B ISO/TR 9790 lower corridor

T1 left side impact

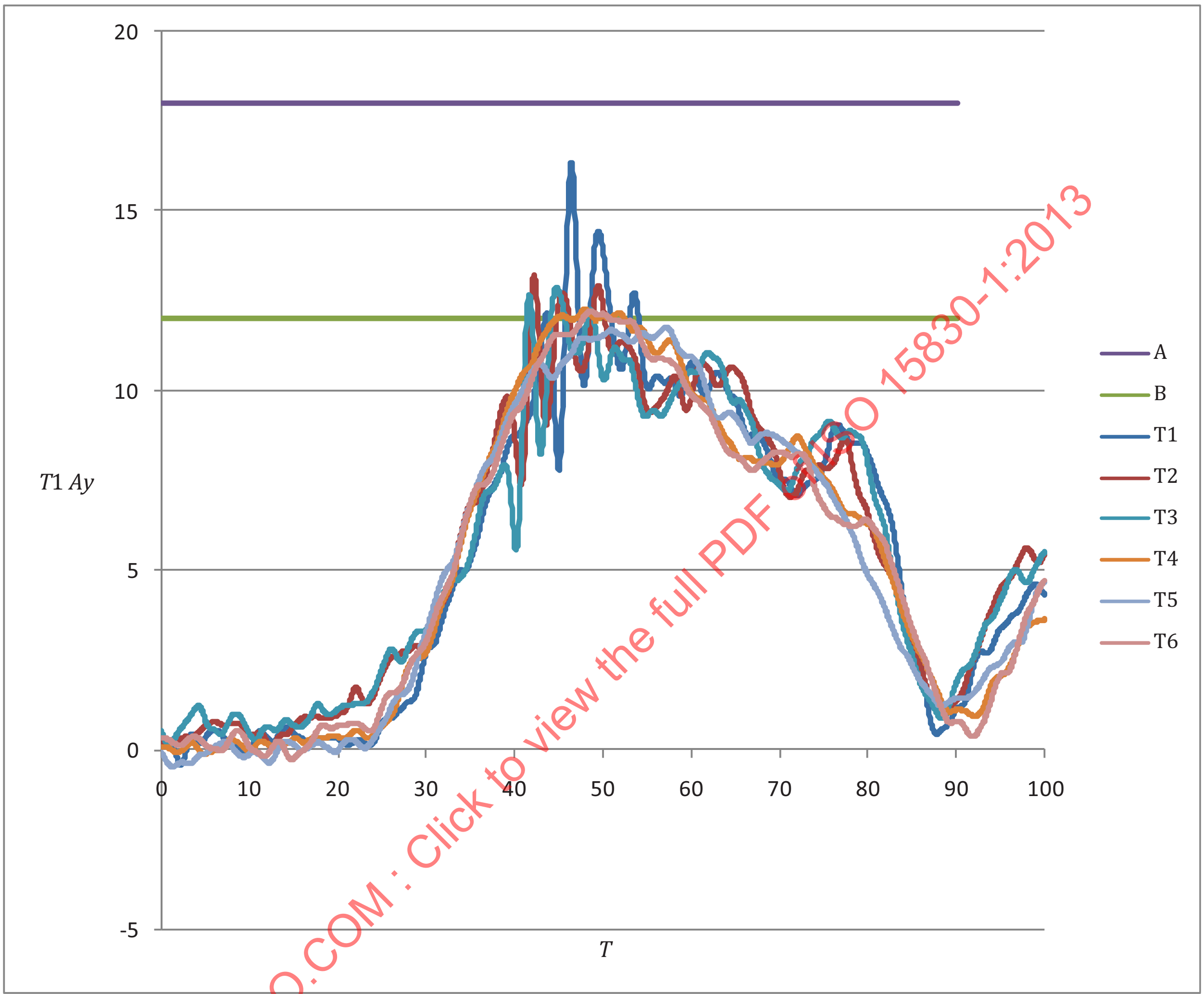
Figure D.2 — Head test 1 - 200 mm lateral head drop (left side) - resultant acceleration

Table D.1 — Head test 1 - 200 mm rigid lateral test results

<table>
<tr><th rowspan="2">Measure</th><th rowspan="2">Lower bound</th><th rowspan="2">Upper bound</th><th>Run</th><th>Weight factor</th><th>Rating</th></tr>
<tr><th>#1</th><th></th><th></th></tr>
<tr><td>Peak resultant acceleration at a point on the non-impacted side of the head, left impact</td><td>100</td><td>150</td><td>141</td><td rowspan="2">9</td><td rowspan="4">10,0</td></tr>
<tr><td>Rating</td><td></td><td></td><td>10</td></tr>
<tr><td>Peak resultant acceleration at a point on the non-impacted side of the head, right impact</td><td>100</td><td>150</td><td>129</td><td rowspan="2">9</td></tr>
<tr><td>Rating</td><td></td><td></td><td>10</td></tr>
</table>

D.2 Neck

D.2.1 Neck test 1 – 7,2 G sled test



Ratings: 10 for all tests

Key

T time (ms)

T1 A_y T1 lateral acceleration (g)

A ISO/TR 9790 upper corridor

B ISO/TR 9790 lower corridor

T1 test number WSID1-70423-1

T2 test number WSID1-70424-1

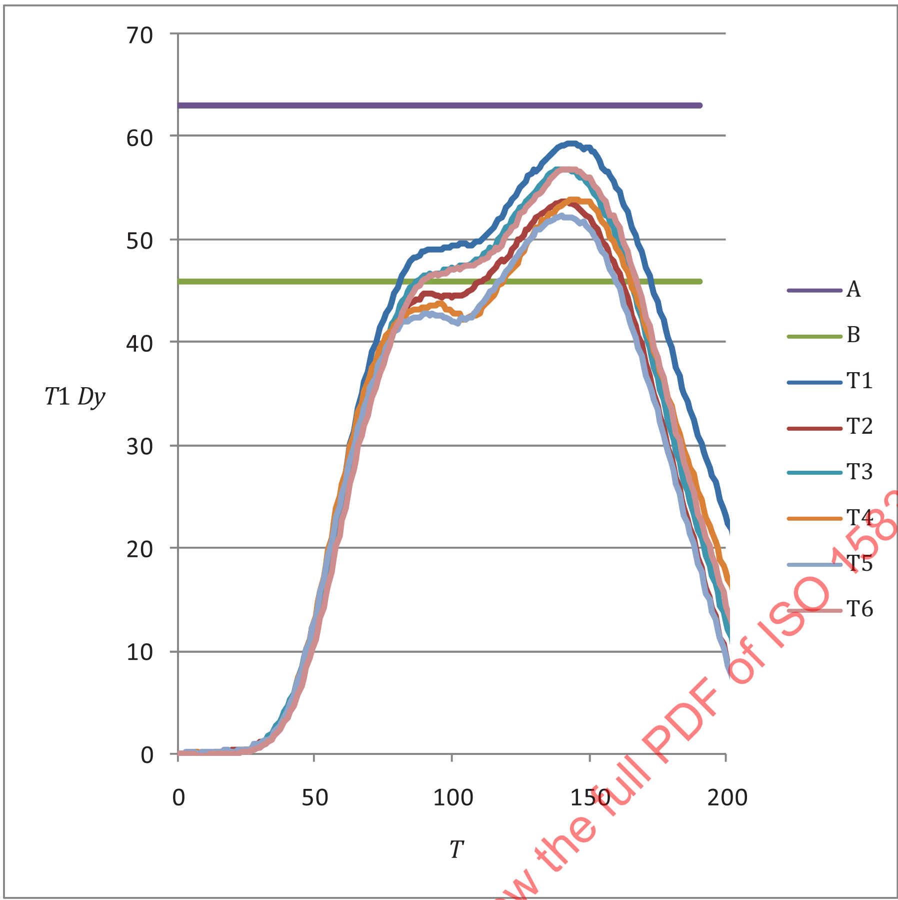
T3 test number WSID1-70424-2

T4 test number WSID2-70423-1

T5 test number WSID2-70424-1

T6 test number WSID2-70424-2

Figure D.3 — Neck test 1 - 7,2 G sled - peak lateral T1 acceleration

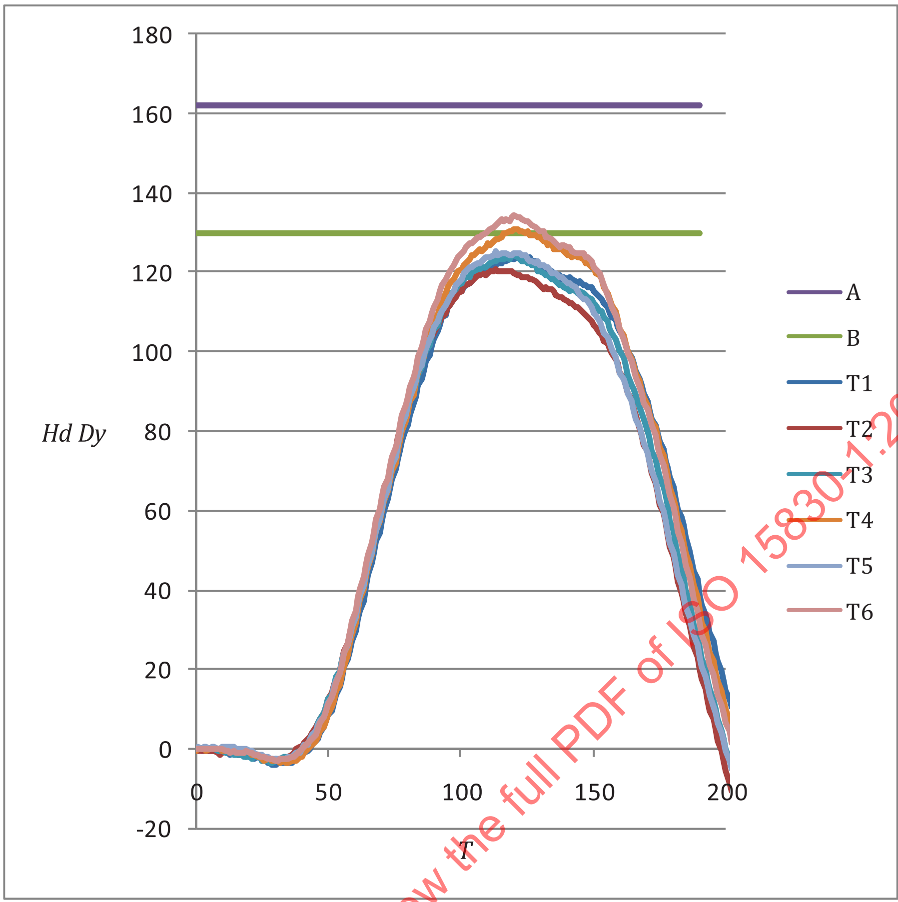


Ratings: 10 for all tests

Key

T	time (ms)
T1 *Dy*	T1 lateral displacement with respect to sled (mm)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70423-1
T2	test number WSID1-70424-1
T3	test number WSID1-70424-2
T4	test number WSID2-70423-1
T5	test number WSID2-70424-1
T6	test number WSID2-70424-2

Figure D.4 — Neck test 1 - 7,2 G sled - peak lateral T1 displacement relative to sled

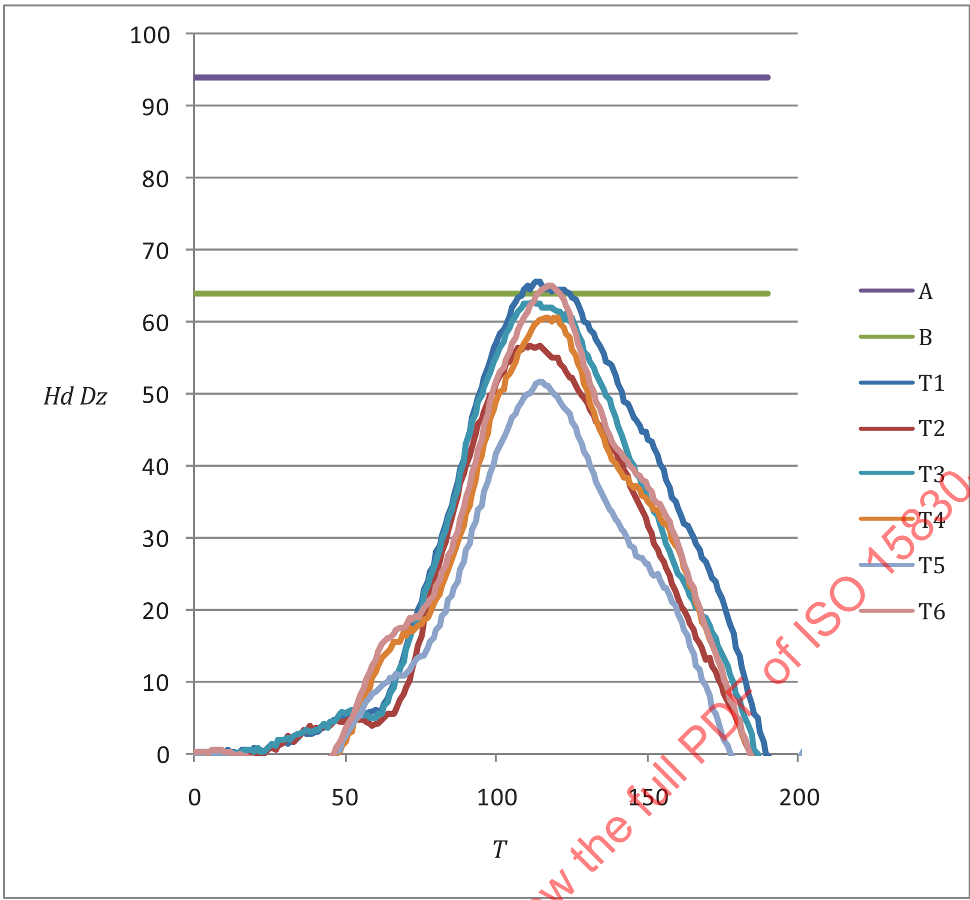


Ratings: 5,5,5,10,5,10

Key

T	time (ms)
Hd Dy	head lateral displacement with respect to T1 (mm)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70423-1
T2	test number WSID1-70424-1
T3	test number WSID1-70424-2
T4	test number WSID2-70423-1
T5	test number WSID2-70424-1
T6	test number WSID2-70424-2

Figure D.5 — Neck test 1 - 7,2 G sled - peak lateral head cg displacement relative to T1

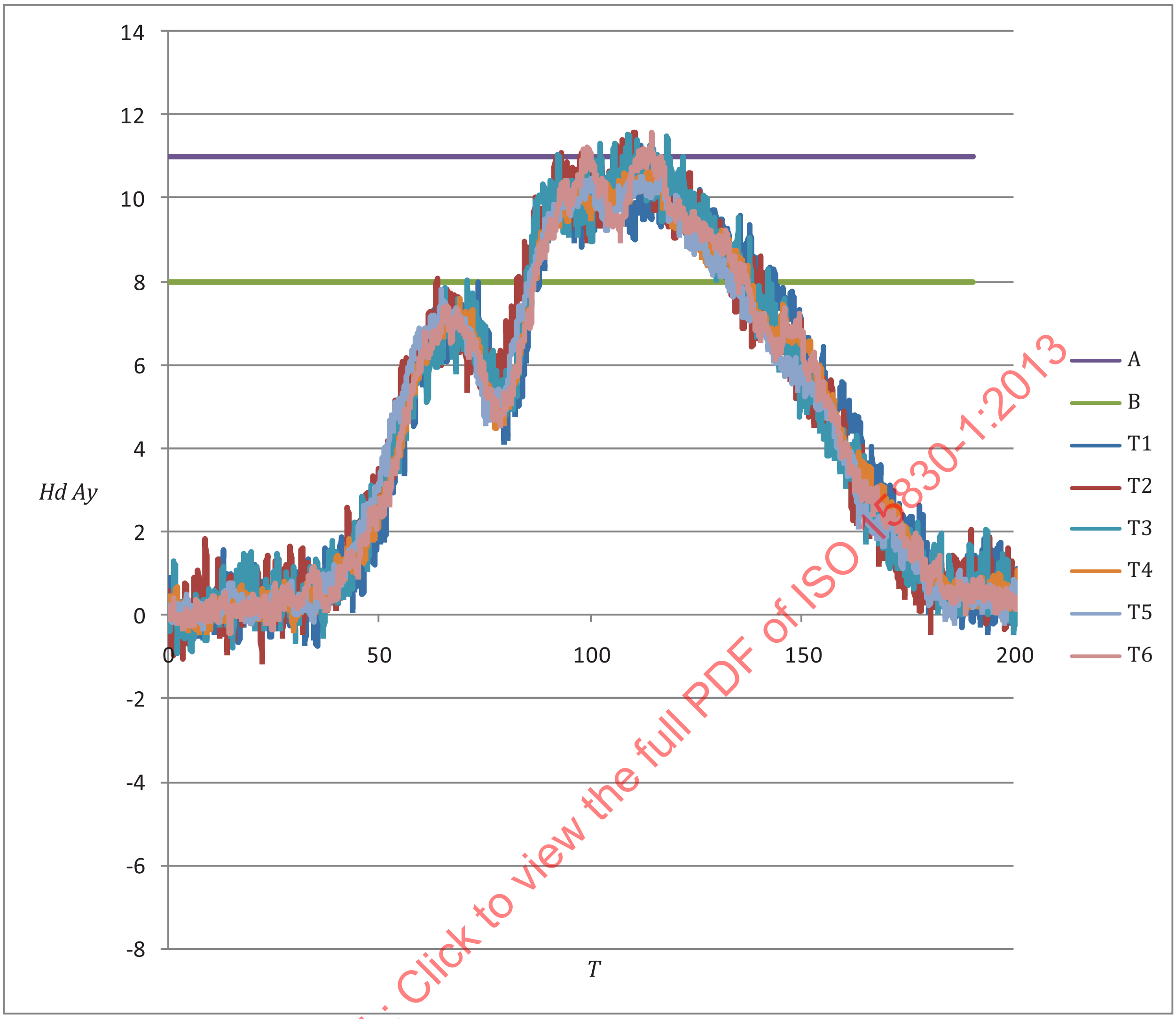


Ratings: 10,5,5,5,5,10

Key

T	time (ms)
Hd Dz	head vertical displacement with respect to T1 (mm)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70423-1
T2	test number WSID1-70424-1
T3	test number WSID1-70424-2
T4	test number WSID2-70423-1
T5	test number WSID2-70424-1
T6	test number WSID2-70424-2

Figure D.6 — Neck test 1 - 7,2 G sled - peak vertical head cg displacement relative to T1

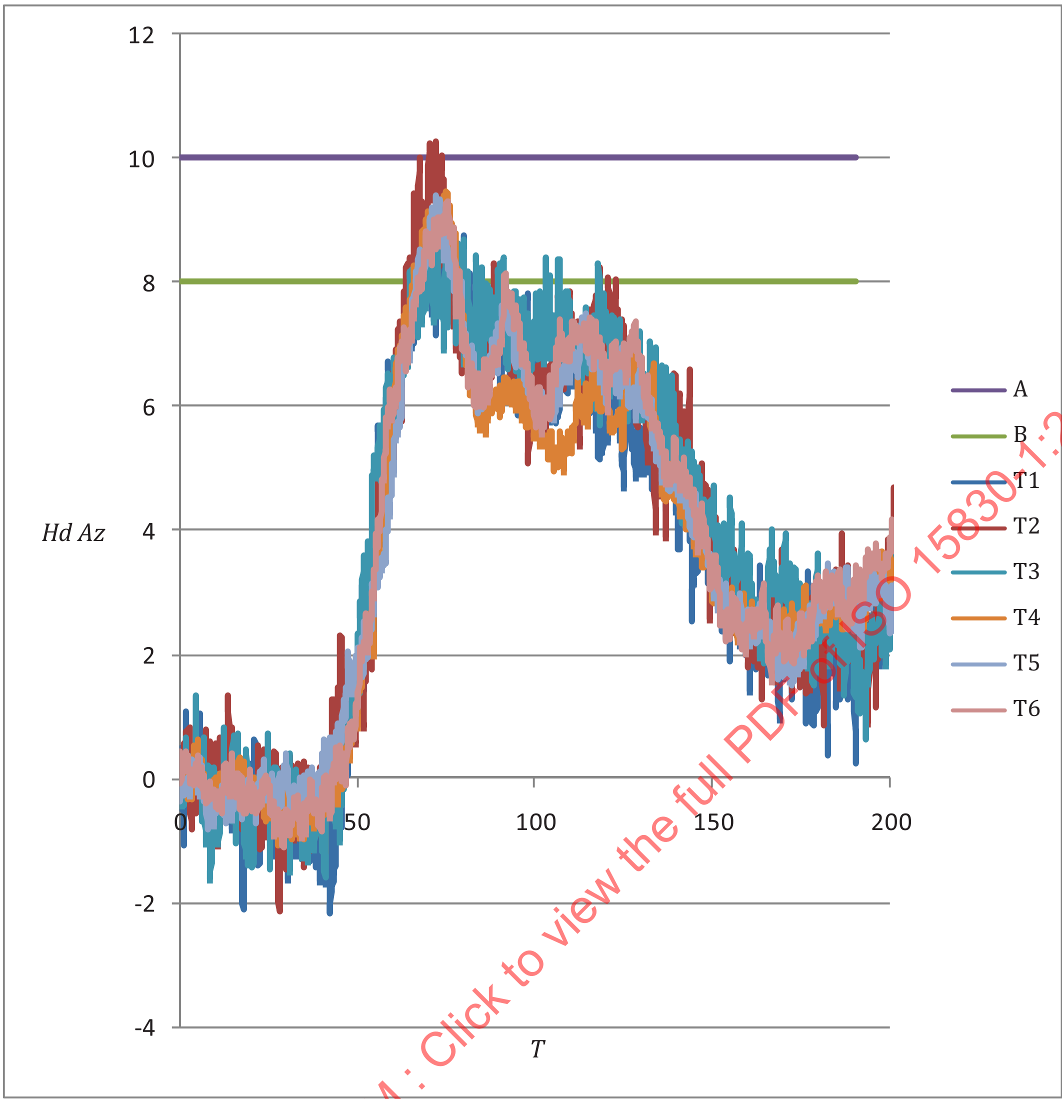


Ratings: 10,5,5,10,10,5

Key

T	time (ms)
Hd Ay	head lateral acceleration (g)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70423-1
T2	test number WSID1-70424-1
T3	test number WSID1-70424-2
T4	test number WSID2-70423-1
T5	test number WSID2-70424-1
T6	test number WSID2-70424-2

Figure D.7 — Neck test 1 - 7,2 G sled - peak head lateral acceleration

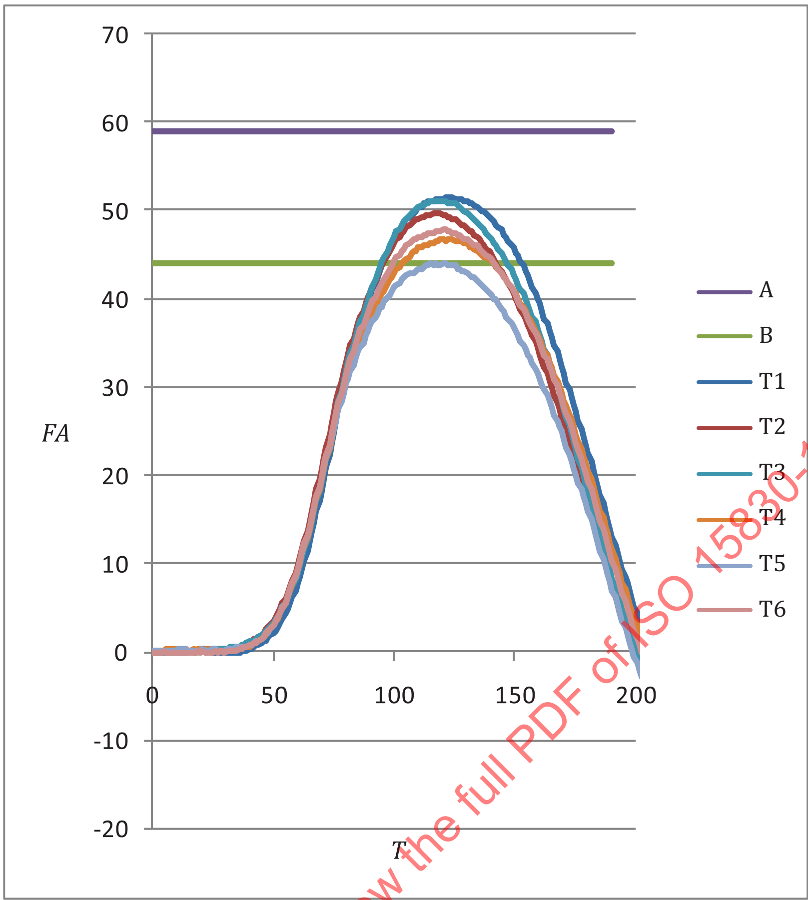


Ratings: 10 for all tests

Key

T	time (ms)
Hd Az	head vertical acceleration (g)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70423-1
T2	test number WSID1-70424-1
T3	test number WSID1-70424-2
T4	test number WSID2-70423-1
T5	test number WSID2-70424-1
T6	test number WSID2-70424-2

Figure D.8 — Neck test 1 - 7,2 G sled - peak head vertical acceleration



Ratings: 10 for all tests

Key

T time (ms)

FA flexion angle (degree)

A ISO/TR 9790 upper corridor

B ISO/TR 9790 lower corridor

T1 test number WSID1-70423-1

T2 test number WSID1-70424-1

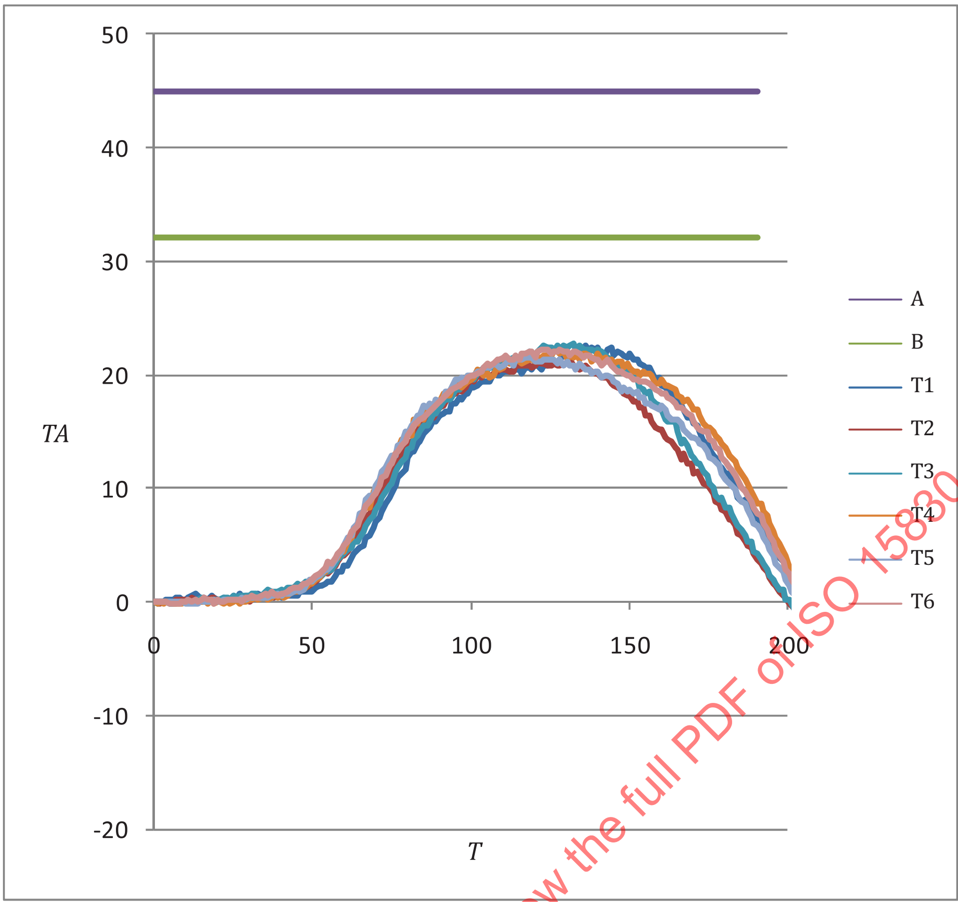
T3 test number WSID1-70424-2

T4 test number WSID2-70423-1

T5 test number WSID2-70424-1

T6 test number WSID2-70424-2

Figure D.9 — Neck test 1 - 7,2 G sled - peak flexion angle



Ratings: 5 for all tests

Key

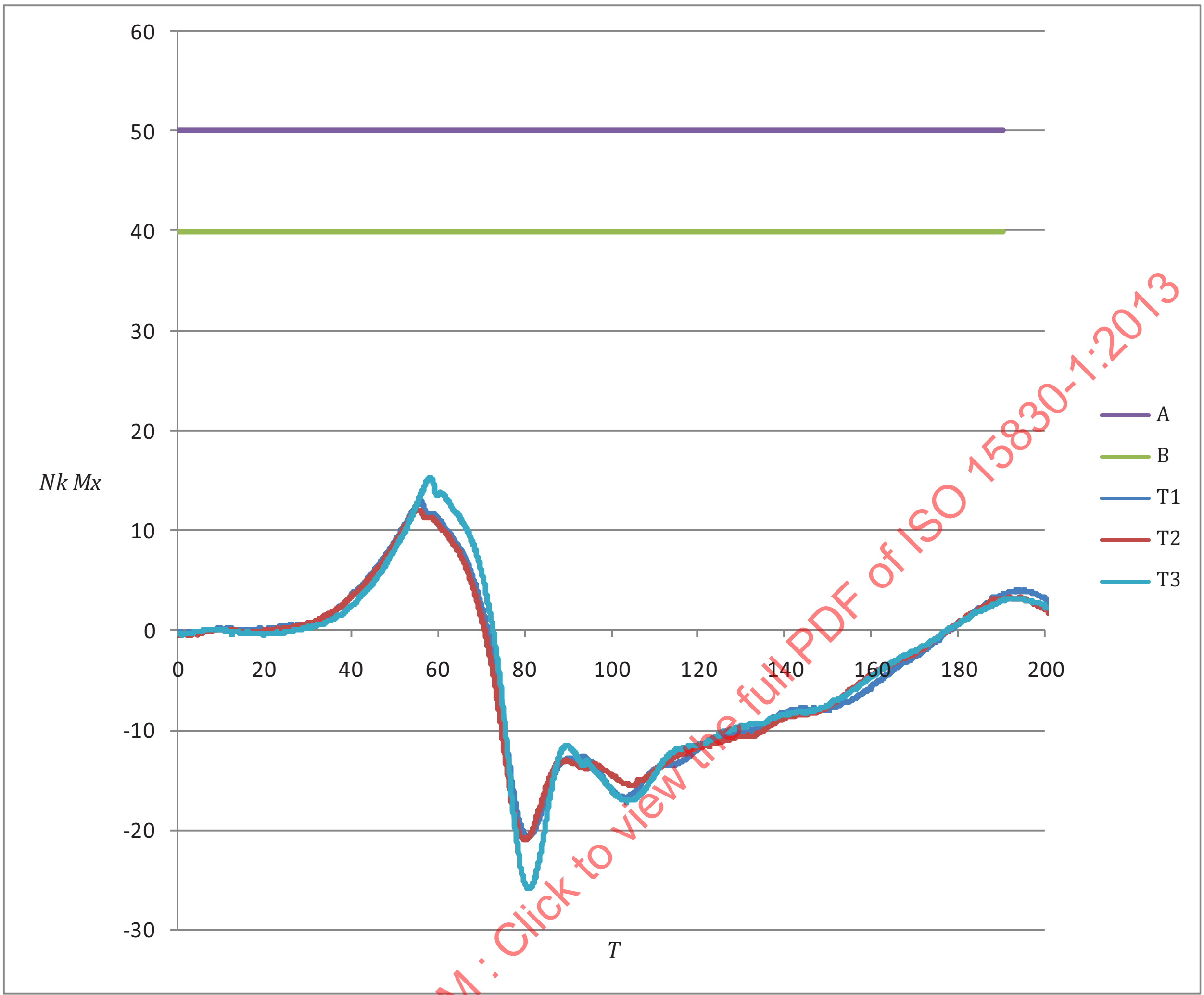
T time (ms)
TA twist angle (degree)
A ISO/TR 9790 upper corridor
B ISO/TR 9790 lower corridor
T1 test number WSID1-70423-1
T2 test number WSID1-70424-1
T3 test number WSID1-70424-2
T4 test number WSID2-70423-1
T5 test number WSID2-70424-1
T6 test number WSID2-70424-2

Figure D.10 — Neck test 1 - 7,2 G sled - peak twist angle

Table D.2 — Neck test 1 - 7,2 G sled test results

Measure	Lower bound	Upper bound	Run							Weight factor	Rating
			#1	#2	#3	#4	#5	#6	Avg		
Horizontal acceleration of T1 (G) CFC180	12	18	16	13	13	12	12	12	13	5	7,4
Rating			10	10	10	10	10	10	10		
Horizontal displacement of T1 relative to sled (mm)	46	63	59	54	57	54	52	57	55,5	5	
Rating			10	10	10	10	10	10	10		
Horizontal displacement of head CG relative to T1 (mm)	130	162	124	121	124	131	125	134	126,5	8	
Rating			5	5	5	10	5	10	6,7		
Vertical displacement of head CG relative to T1 (mm)	64	94	66	57	63	61	52	65	60,7	6	
Rating			10	5	5	5	5	10	6,7		
Time of peak head excursion (sec)	0,159	0,175	0,122	0,113	0,120	0,120	0,113	0,120	0,118	5	
Rating			0	0	0	0	0	0	0		
Lateral acceleration of head CG (G) CFC1000	8	11	11	12	12	11	11	12	11,5	5	
Rating			10	5	5	10	10	5	7,5		
Vertical acceleration of head CG (G) CFC1000	8	10	9	10	9	9	9	9	9,2	5	
Rating			10	10	10	10	10	10	10		
Head flexion angle (degrees)	44	59	51	50	51	47	44	48	48,5	7	
Rating			10	10	10	10	10	10	10		
Head twist angle (degrees)	32	45	22	21	23	22	22	22	22,0	4	
Rating			5	5	5	5	5	5	5		

D.2.2 Neck test 2 – 6,7 G sled test

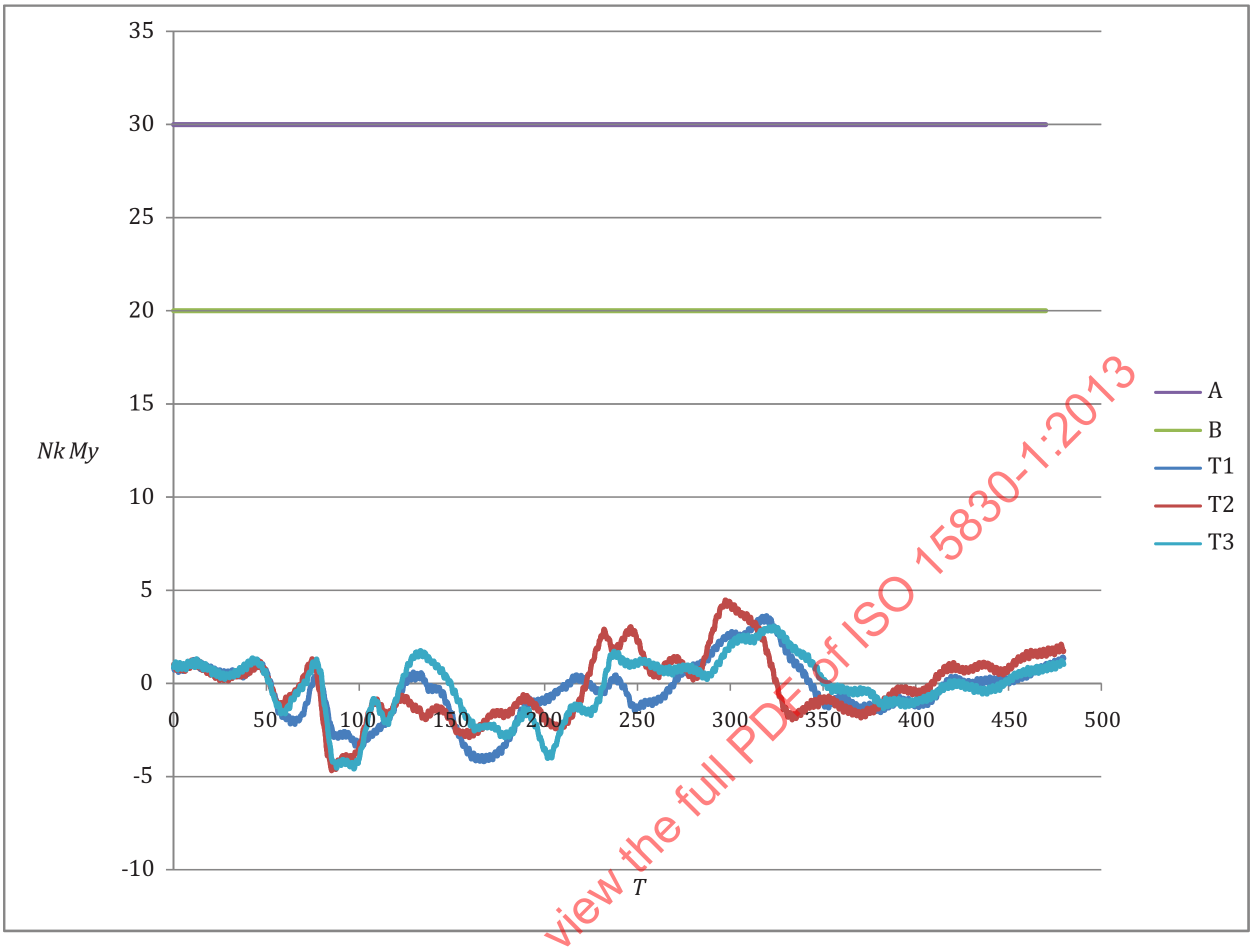


Ratings: 0,0,0

Key

T	time (ms)
Nk Mx	neck OC M_x (Nm)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number H28626
T2	test number H28627
T3	test number H28628

Figure D.11 — Neck test 2 - 6,7 G sled - peak bending moment about A-P (M_x) at occipital condyles

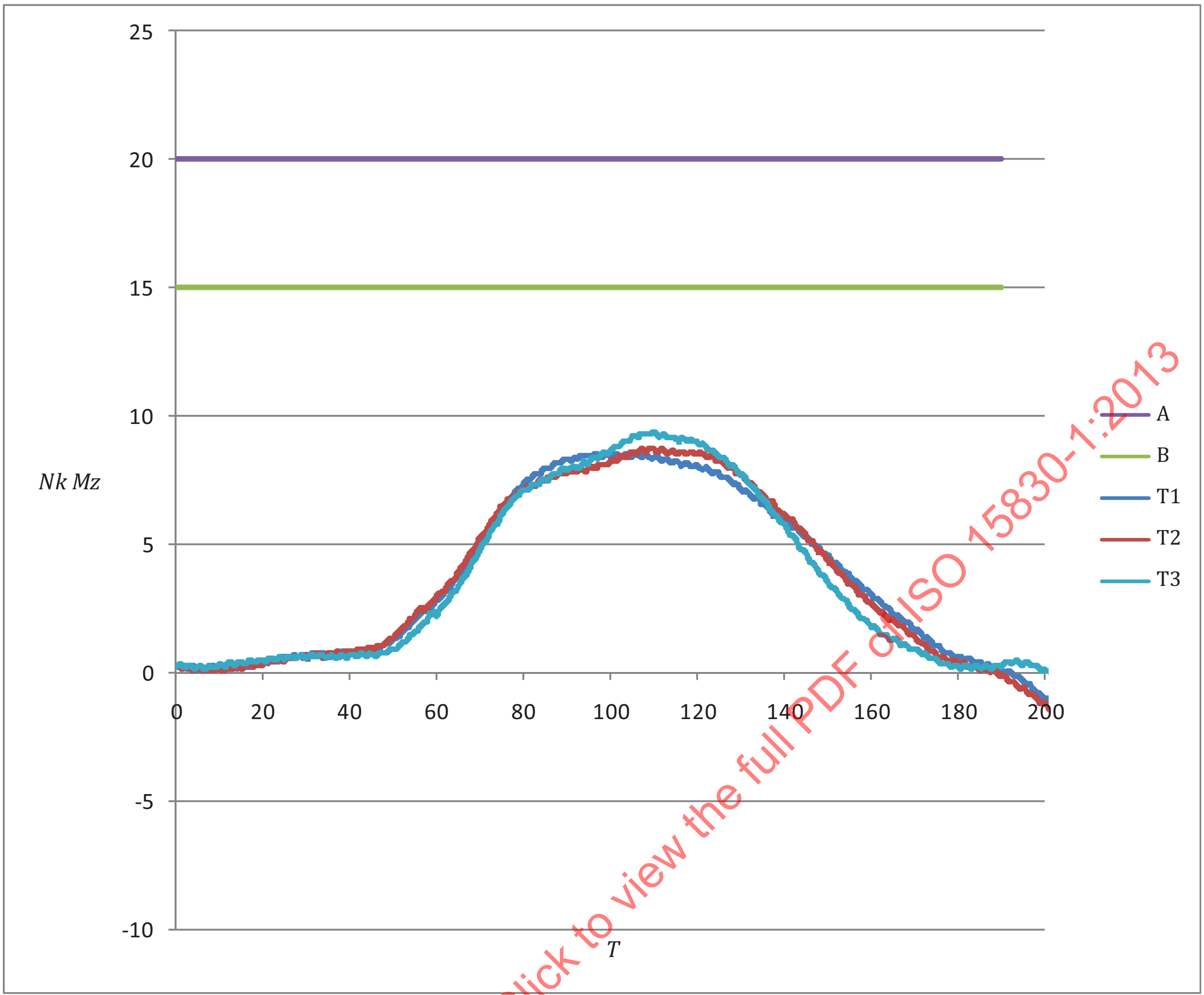


Ratings: 0,0,0

Key

T	time (ms)
Nk My	neck OC *My* (Nm)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number H28626
T2	test number H28627
T3	test number H28628

Figure D.12 — Neck test 2 - 6,7 G sled - peak bending moment about R-L (M_y) at occipital condyles

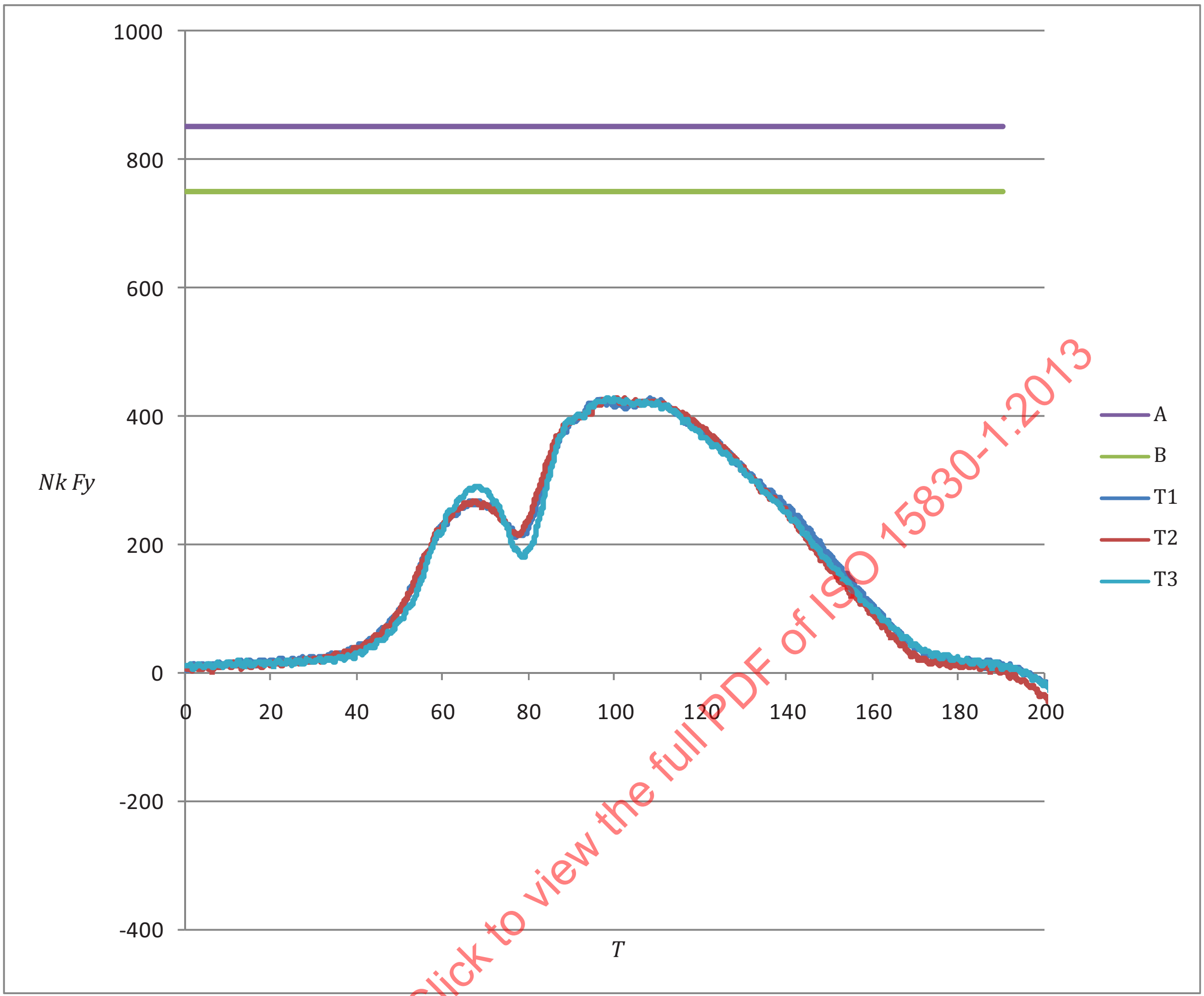


Ratings: 0,0,0

Key

T	time (ms)
Nk Mz	upper neck *Mz* (Nm)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number H28626
T2	test number H28627
T3	test number H28628

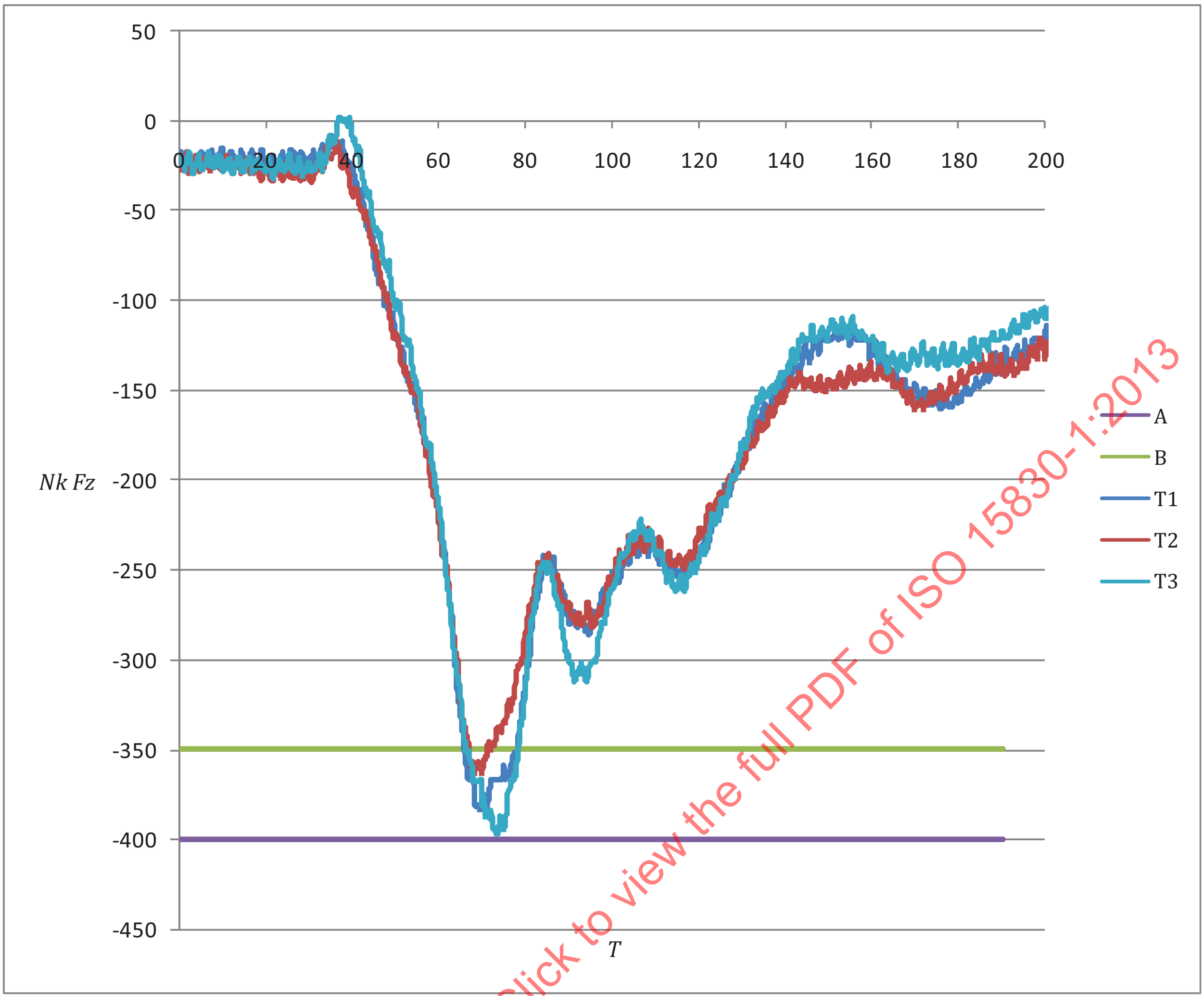
Figure D.13 — Neck test 2 - 6,7 G sled - peak twist moment (M_z)



Key

T	time (ms)
Nk Fy	upper neck *Fy* (N)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number H28626
T2	test number H28627
T3	test number H28628

Figure D.14 — Neck test 2 - 6,7 G sled - peak F_y shear force



Ratings: 10,10,10

Key

T time (ms)

Nk Fz upper neck *Fz* (N)

A ISO/TR 9790 upper corridor

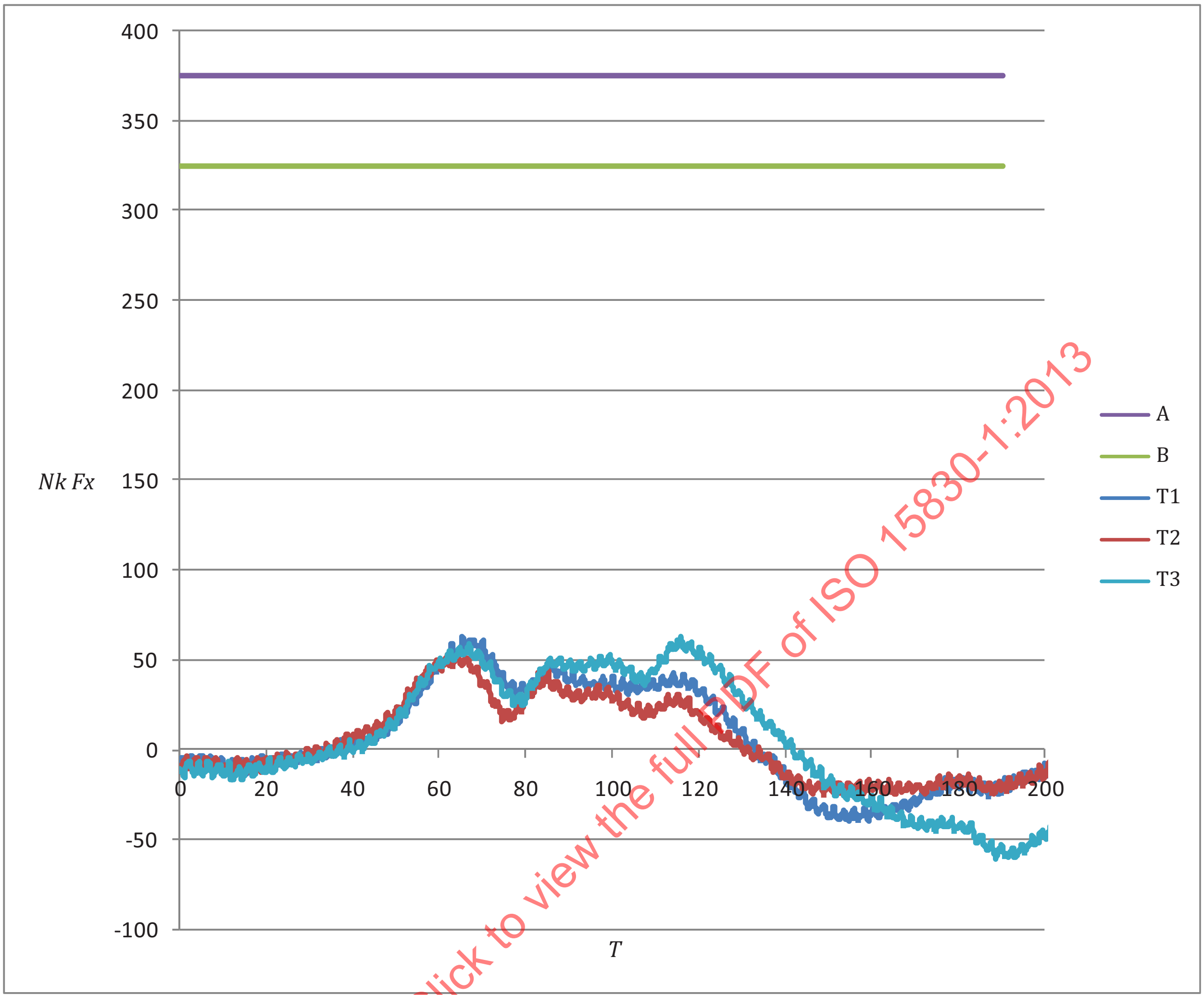
B ISO/TR 9790 lower corridor

T1 test number H28626

T2 test number H28627

T3 test number H28628

Figure D.15 — Neck test 2 - 6,7 G sled - peak F_Z tension force

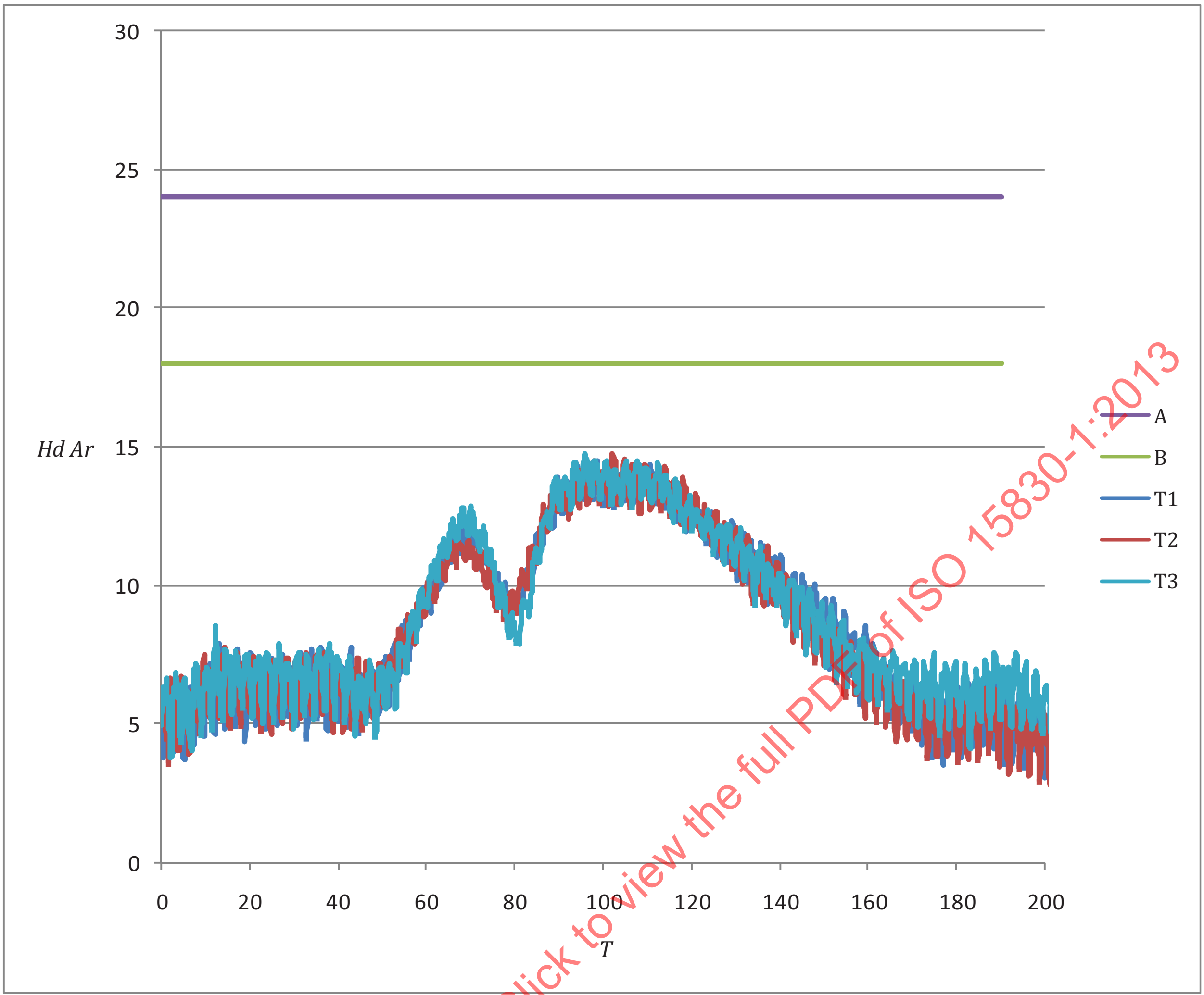


Ratings: 0,0,0

Key

T	time (ms)
Nk Fx	upper neck *Fx* (N)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number H28626
T2	test number H28627
T3	test number H28628

Figure D.16 — Neck test 2 - 6,7 G sled - peak F_x shear force



Ratings: 5,5,5

Key

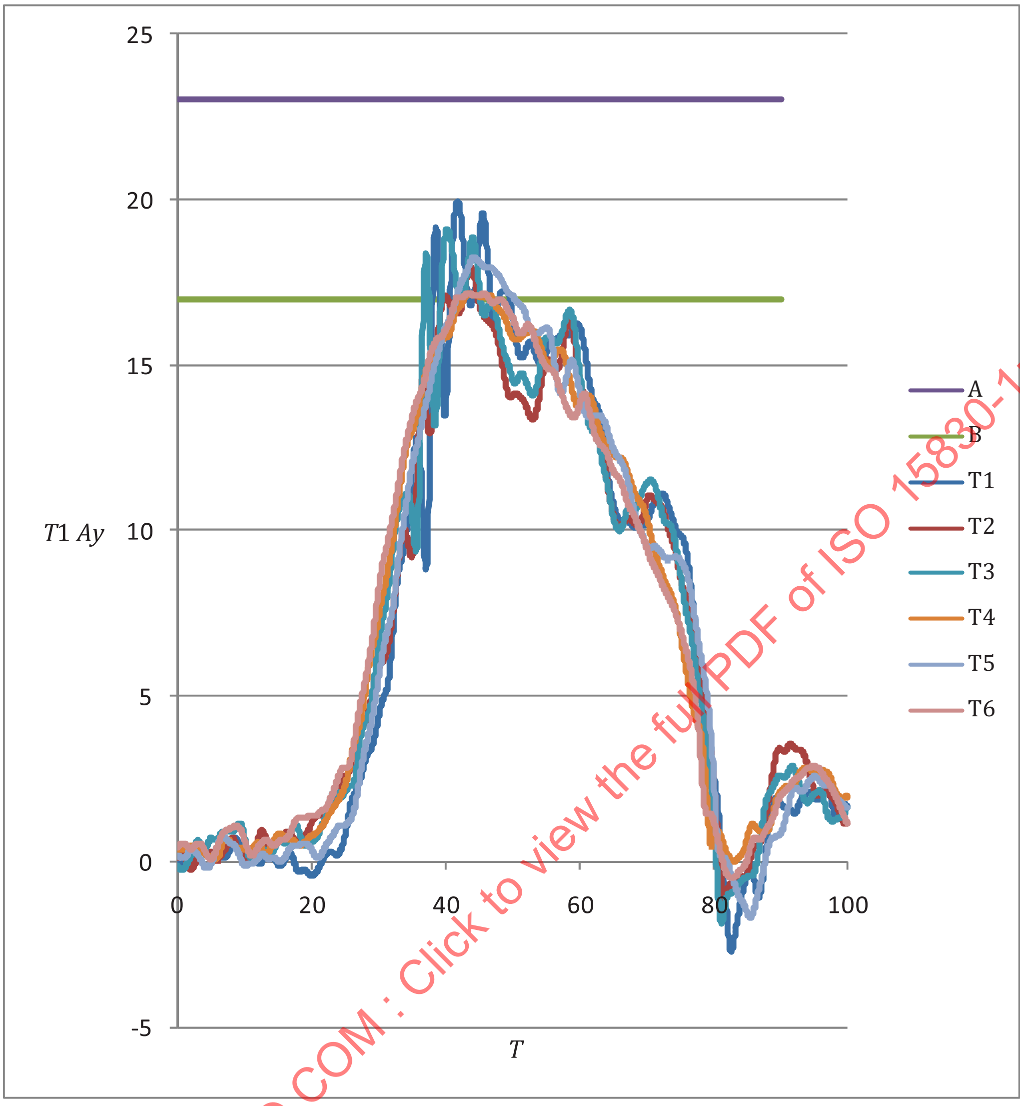
T	time (ms)
Hd Ar	head resultant acceleration (g)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number H28626
T2	test number H28627
T3	test number H28628

Figure D.17 — Neck test 2 - 6,7 G sled - peak head resultant acceleration

Table D.3 — Neck test 2 - 6,7 G sled test results

Measure	Lower bound	Upper bound	Run				Weight factor	Rating
			#1	#2	#3	Avg		
Head flexion angle (degrees)	40	50	NM	NM	NM		7	2,0
Rating			0	0	0	0		
Peak moment A-P axis at OC, M_x (Nm)	40	50	13	13	15	13,7	7	
Rating			0	0	0	0		
Peak moment R-L axis OC, M_y (Nm)	20	30	4	4	3	3,7	3	
Rating			0	0	0	0		
Peak twist moment, M_z (Nm)	15	20	8	9	9	8,7	4	
Rating			0	0	0	0		
Peak shear force OC, F_y (N)	750	850	427	428	428	427,7	7	
Rating			0	0	0	0,0		
Peak tension force OC, F_z (N)	350	400	384	363	397	381,3	6	
Rating			10	10	10	10		
Peak A-P shear force, F_x (N)	325	375	63	55	63	60,3	3	
Rating			0	0	0	0,0		
Peak resultant head acceleration (G)	18	24	14	15	15	14,7	4	
Rating			5	5	5	5,0		

D.2.3 Neck test 3 – 12,2 G sled test

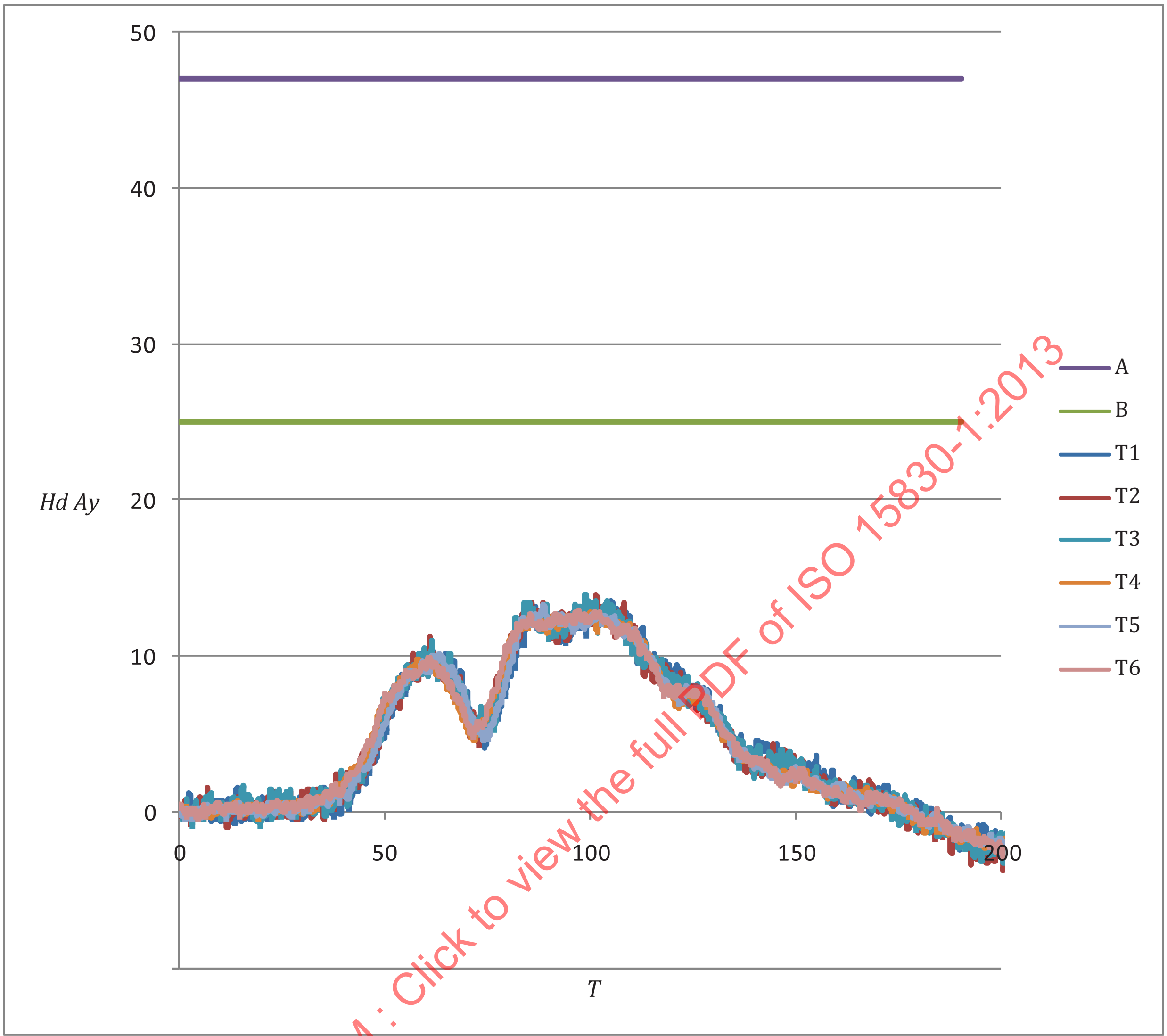


Ratings: 10 for all tests

Key

T	time (ms)
T1 Ay	T1 lateral acceleration (g)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70425-1
T2	test number WSID1-70424-3
T3	test number WSID1-70424-4
T4	test number WSID2-70425-1
T5	test number WSID2-70424-3
T6	test number WSID2-70424-4

Figure D.18 — Neck test 3 - 12,2 G sled - T1 lateral acceleration

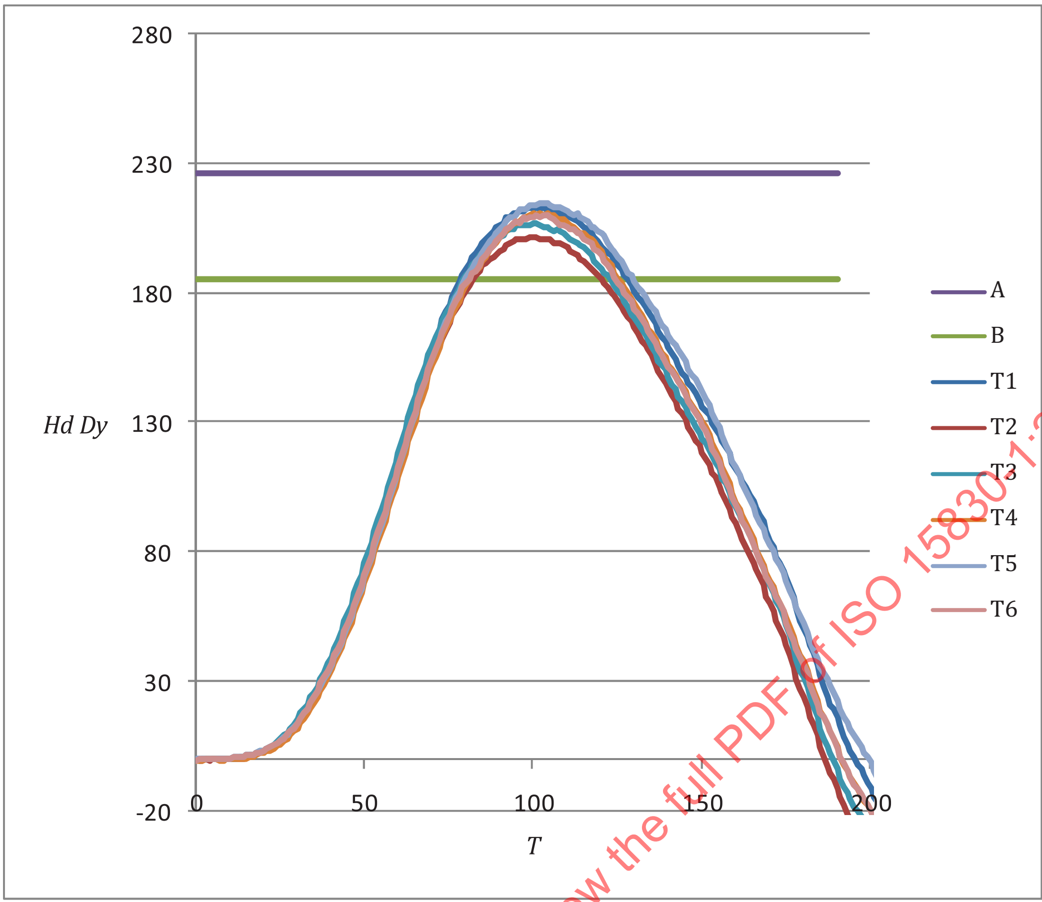


Ratings: 5 for all tests

Key

T	time (ms)
Hd Ay	head lateral acceleration (g)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70425-1
T2	test number WSID1-70424-3
T3	test number WSID1-70424-4
T4	test number WSID2-70425-1
T5	test number WSID2-70424-3
T6	test number WSID2-70424-4

Figure D.19 — Neck test 3 - 12,2 G sled - head lateral acceleration

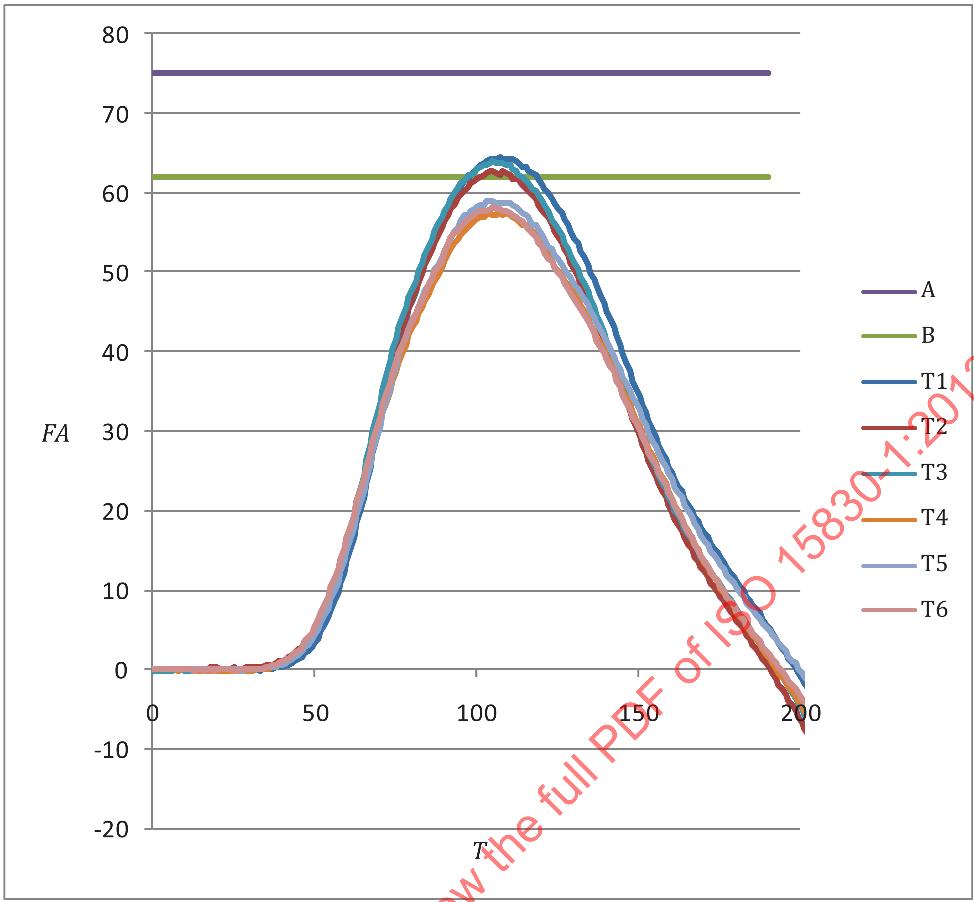


Ratings: 10 for all tests

Key

T	time (ms)
Hd Dy	head lateral displacement with respect to sled (mm)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70425-1
T2	test number WSID1-70424-3
T3	test number WSID1-70424-4
T4	test number WSID2-70425-1
T5	test number WSID2-70424-3
T6	test number WSID2-70424-4

Figure D.20 — Neck test 3 - 12,2 G sled - head lateral displacement relative to sled



Ratings: 10,10,10,5,5,5

Key

T time (ms)

FA flexion angle (degree)

A ISO/TR 9790 upper corridor

B ISO/TR 9790 lower corridor

T1 test number WSID1-70425-1

T2 test number WSID1-70424-3

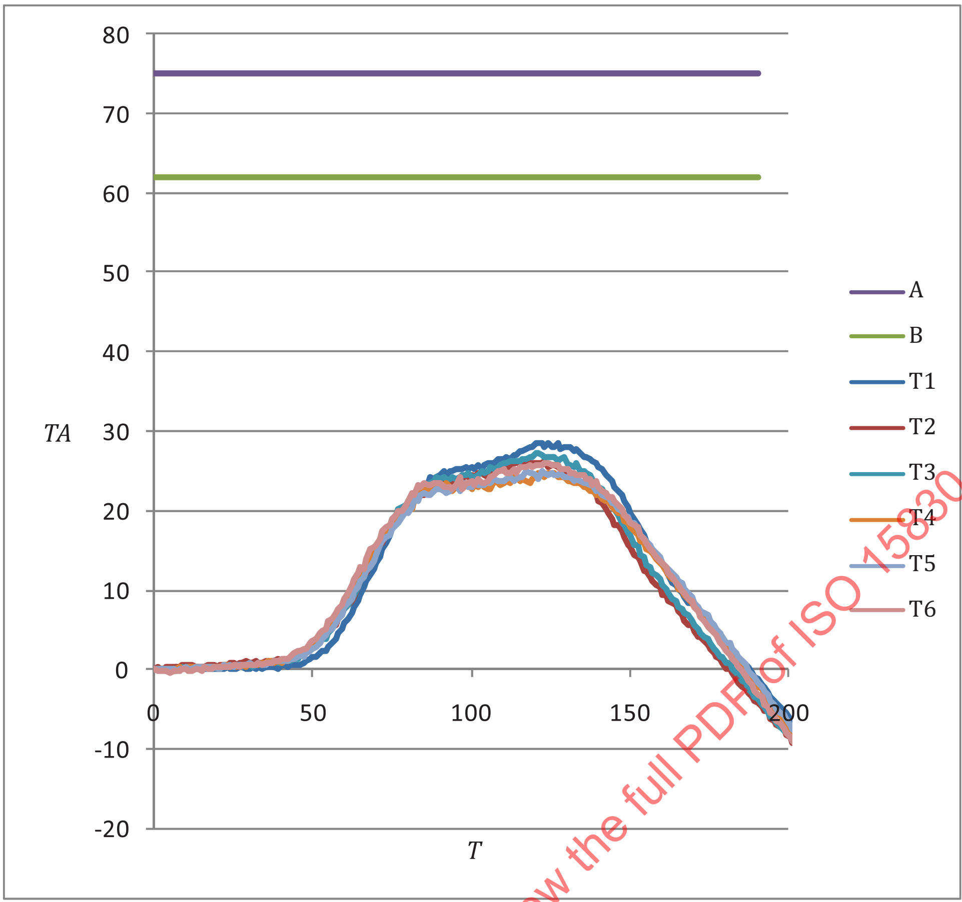
T3 test number WSID1-70424-4

T4 test number WSID2-70425-1

T5 test number WSID2-70424-3

T6 test number WSID2-70424-4

Figure D.21 — Neck test 3 - 12,2 G sled - flexion angle



Ratings: 0 for all tests

Key

T	time (ms)
TA	twist angle (degree)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70425-1
T2	test number WSID1-70424-3
T3	test number WSID1-70424-4
T4	test number WSID2-70425-1
T5	test number WSID2-70424-3
T6	test number WSID2-70424-4

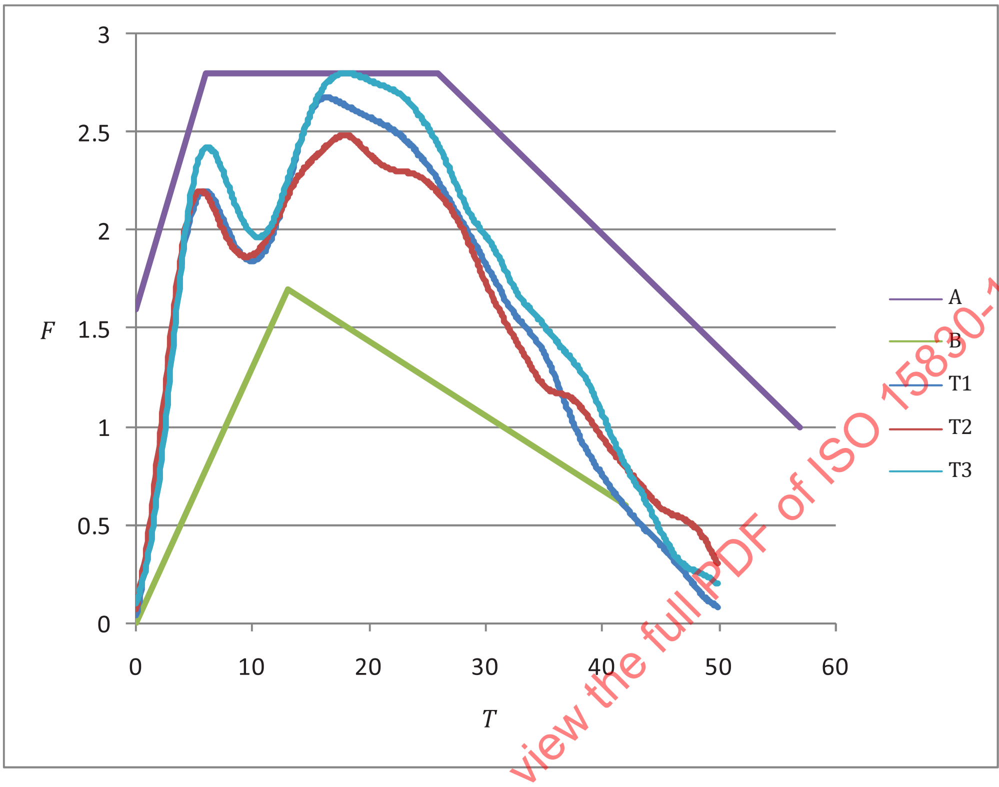
Figure D.22 — Neck test 3 - 12,2 G sled - twist angle

Table D.4 — Neck test 3 - 12,2 G sled test results

Measure	Lower bound	Upper bound	Run							Weight factor	Rating
			#1	#2	#3	#4	#5	#6	Avg		
Peak lateral acceleration of T1 (G)	17	23	20	18	19	17	18	17	18,2	5	7,2
Rating			10	10	10	10	10	10	10,0		
Peak lateral acceleration of head CG (G)	25	47	14	14	14	13	13	13	13,5	5	
Rating			5	5	5	5	5	5	5,0		
Peak horizontal displacement of head CG relative to sled (G)	185	226	213	202	207	211	214	210	209,5	8	
Rating			10	10	10	10	10	10	10,0		
Peak flexion angle (degrees)	62	75	64	63	64	58	59	58	61,0	7	
Rating			10	10	10	5	5	5	7,5		
Peak twist angle (degrees)	62	75	28	26	27	25	25	26	26,2	4	
Rating			0	0	0	0	0	0	0,0		

D.3 Shoulder

D.3.1 Shoulder test 1 – 4,5 m/s pendulum test



Ratings: 10,10,10

Key

T time (ms)

F pendulum force (kN)

A ISO/TR 9790 upper corridor

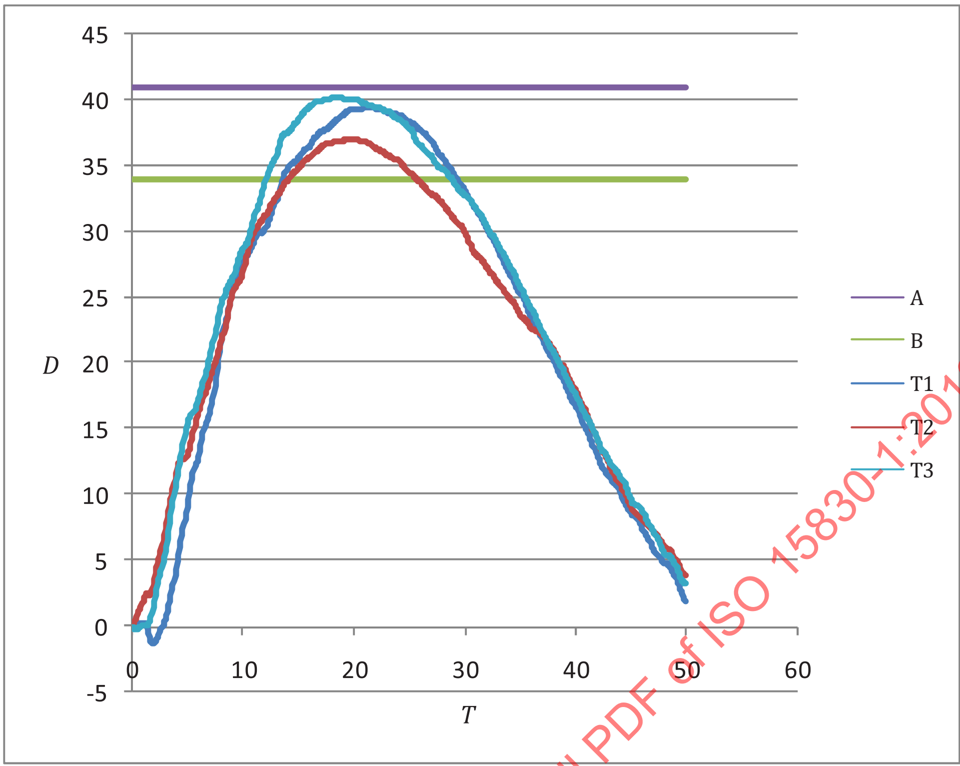
B ISO/TR 9790 lower corridor

T1 test number W009-PRSH-2

T2 test number W009-PRSH-3

T3 test number W009-PRSH-4

Figure D.23 — Shoulder test 1 - pendulum force



Ratings: 10,10,10

Key

T time (ms)

D shoulder deflection (mm)

A ISO/TR 9790 upper corridor

B ISO/TR 9790 lower corridor

T1 test number W009-PRSH-2

T2 test number W009-PRSH-3

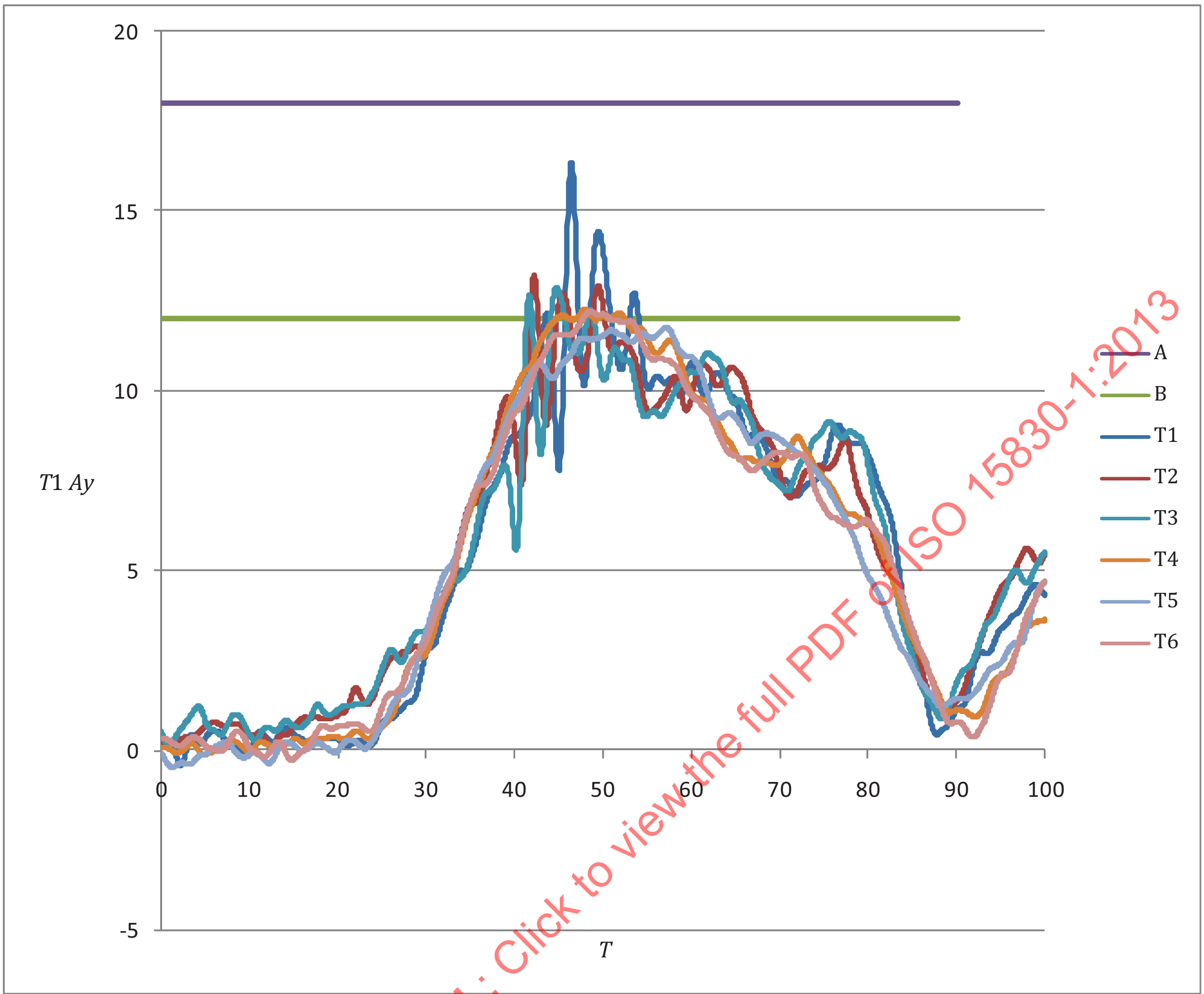
T3 test number W009-PRSH-4

Figure D.24 — Shoulder test 1 - shoulder rib deflection

Table D.5 — Shoulder test 1 – 4,5 m/s pendulum test results

Measure	**Lower bound**	**Upper bound**	**Run**				**Weight factor**	**Rating**
			#1	#2	#3	Avg		
Shoulder pendulum force (N)	Plot	Plot	Plot	Plot	Plot	Plot	8	10
Rating			10	10	10	10		
Peak shoulder deflection (mm)	34	41	39	37	40	39	6	
Rating			10	10	10	10,0		

D.3.2 Shoulder test 2 – 7,2 G sled test

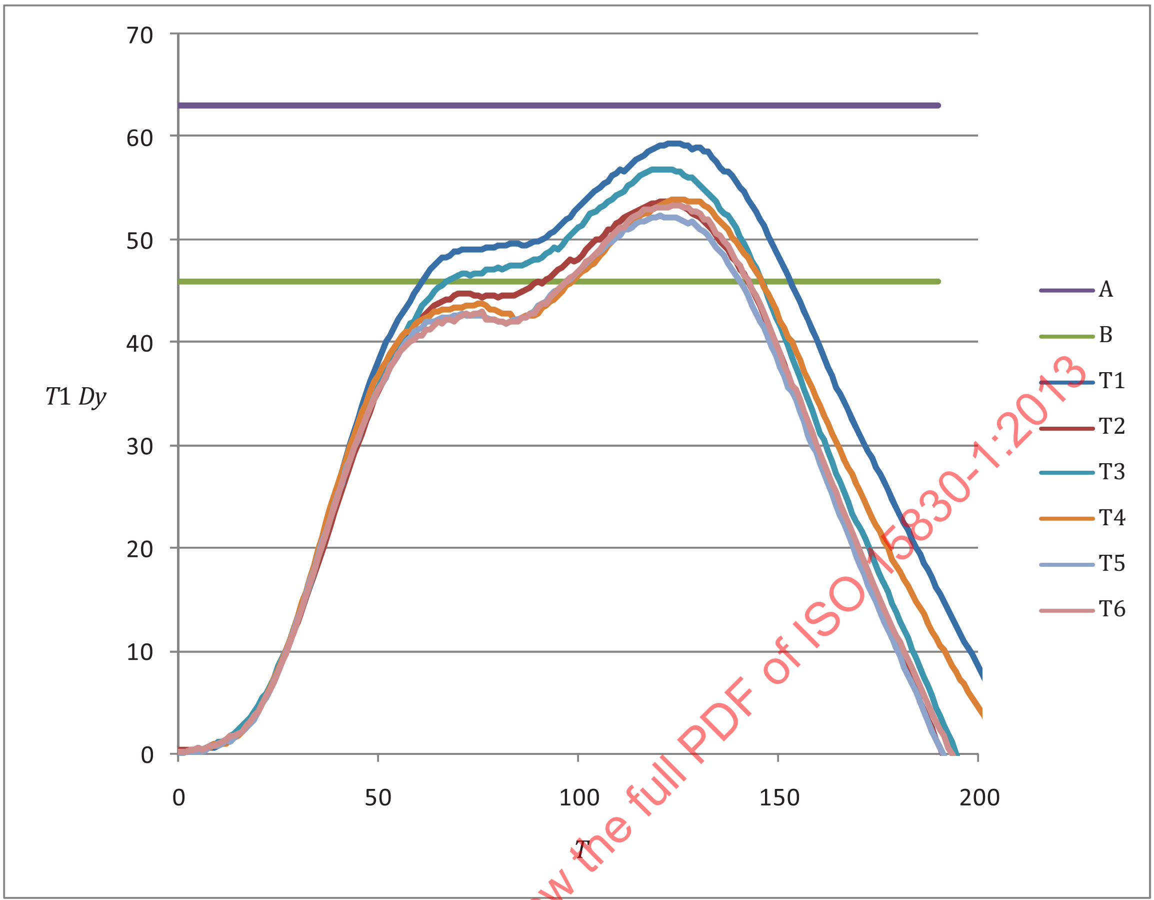


Ratings: 10 for all tests

Key

T	time (ms)
T1 Ay	T1 lateral acceleration (g)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70423-1
T2	test number WSID1-70424-1
T3	test number WSID1-70424-2
T4	test number WSID2-70423-1
T5	test number WSID2-70424-1
T6	test number WSID2-70424-2

Figure D.25 — Shoulder test 2 - 7,2 G sled - peak lateral T1 acceleration



Ratings: 10 for all tests

Key

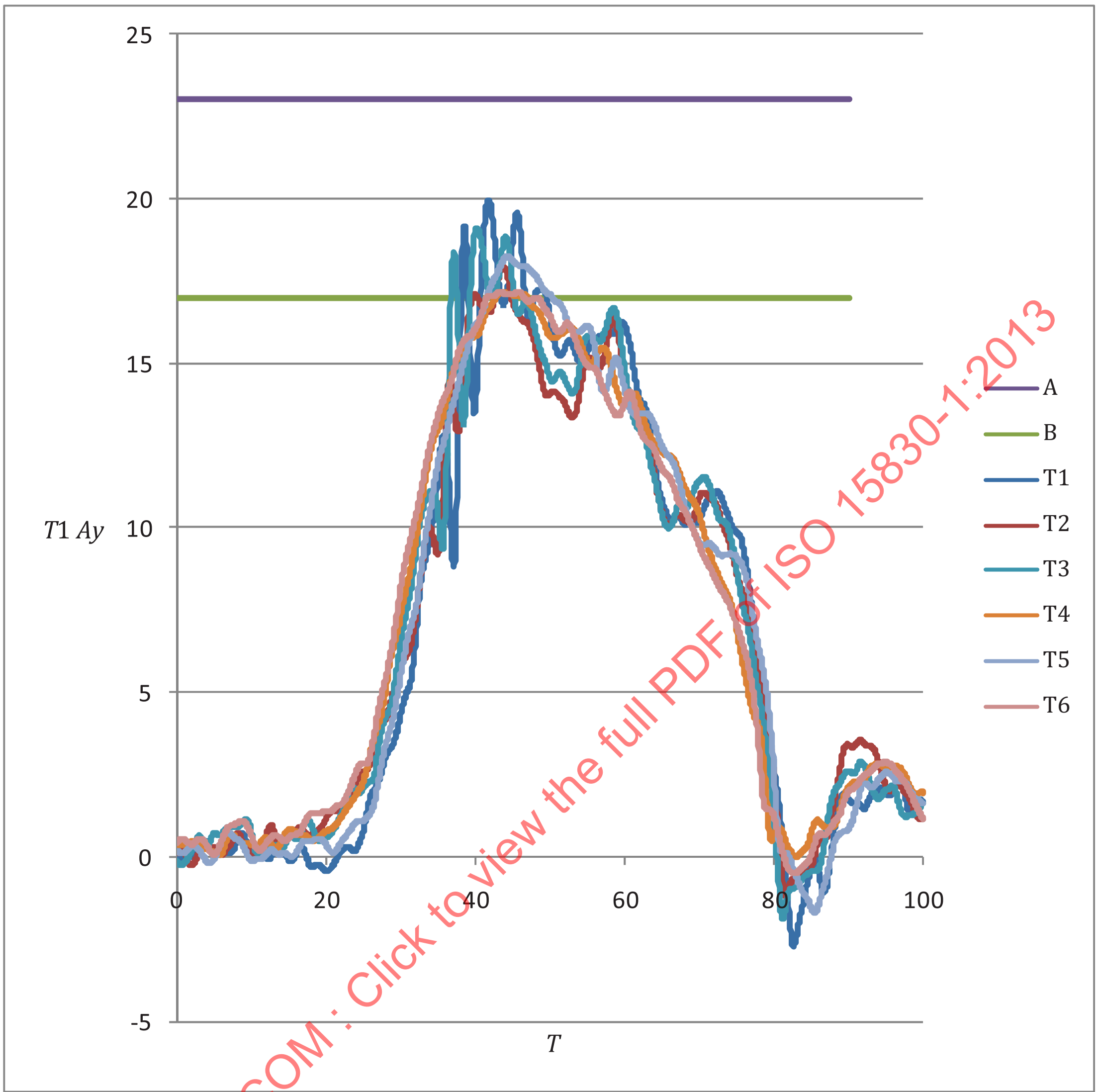
T	time (ms)
T1 Ay	T1 lateral displacement with respect to head (mm)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70423-1
T2	test number WSID1-70424-1
T3	test number WSID1-70424-2
T4	test number WSID2-70423-1
T5	test number WSID2-70424-1
T6	test number WSID2-70424-2

Figure D.26 — Shoulder test 2 - 7,2 G sled - peak lateral T1 displacement relative to sled

Table D.6 — Shoulder test 2 - 7,2 G sled test results

Measure	Lower bound	Upper bound	Run							Weight factor	Rating
			#1	#2	#3	#4	#5	#6	Avg		
Horizontal acceleration T1 (G)	12	18	16	13	13	12	12	12	13,0	6	10,0
Rating			10	10	10	10	10	10	10		
Horizontal displacement T1 relative to sled (mm)	46	63	59	54	57	54	52	53	54,8	6	
Rating			10	10	10	10	10	10	10		

D.3.3 Shoulder test 3 – 12,2 G sled test



Ratings: 10 for all tests

Key

T	time (ms)
T1 Ay	T1 lateral acceleration (g)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WSID1-70425-1
T2	test number WSID1-70424-3
T3	test number WSID1-70424-4
T4	test number WSID2-70425-1
T5	test number WSID2-70424-3
T6	test number WSID2-70424-4

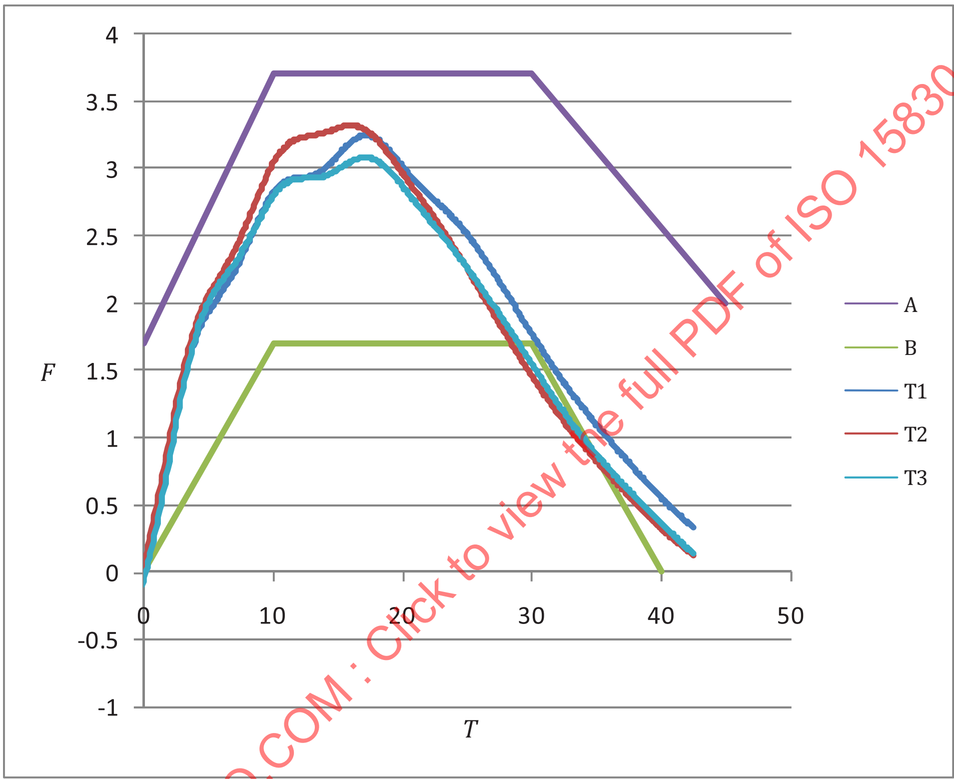
Figure D.27 — Shoulder test 3 - 12,2 G sled peak lateral T1 acceleration

Table D.7 — Shoulder test 3 - 12,2 G sled test results

Measure	Lower bound	Upper bound	Run							Weight factor	Rating
			#1	#2	#3	#4	#5	#6	Avg		
Peak lateral acceleration T1 (G)	17	23	20	18	19	17	18	17	18,2	6	10,0
Rating			10	10	10	10	10	10	10,0		

D.4 Thorax

D.4.1 Thorax test 1 – 4,3 m/s pendulum test

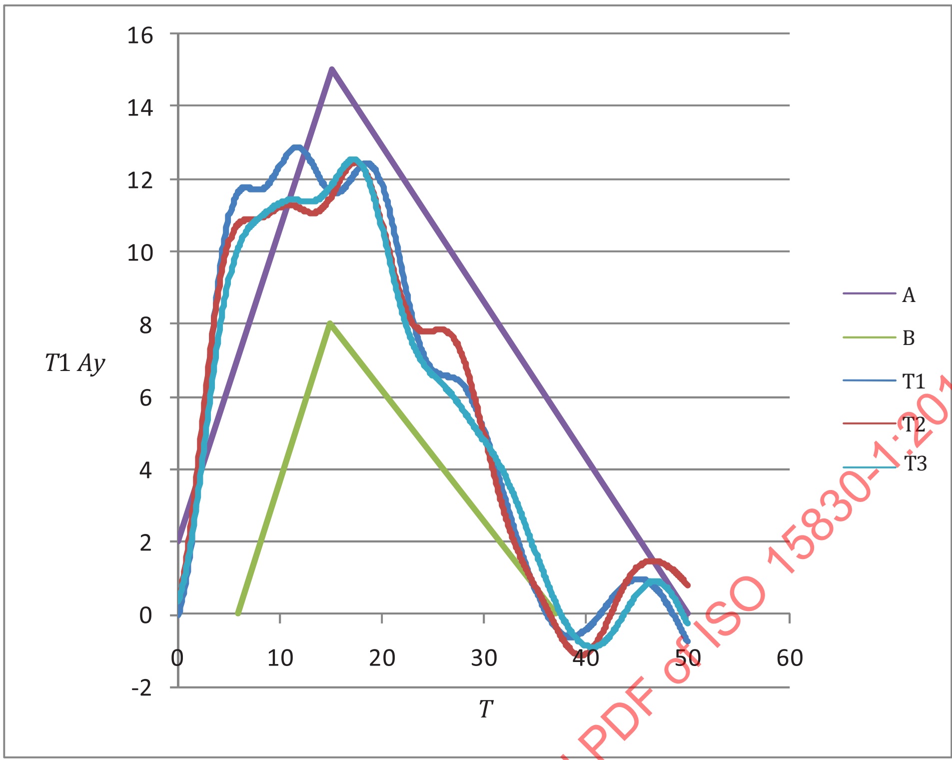


Ratings: 10,10,10

Key

T time (ms)
F pendulum force (kN)
A ISO/TR 9790 upper corridor
B ISO/TR 9790 lower corridor
T1 test number W009-BDRPH-9
T2 test number W009-BDRPH-10
T3 test number W009-BDRPH-11

Figure D.28 — Thorax test 1 - pendulum force



Ratings: 5,5,5

Key

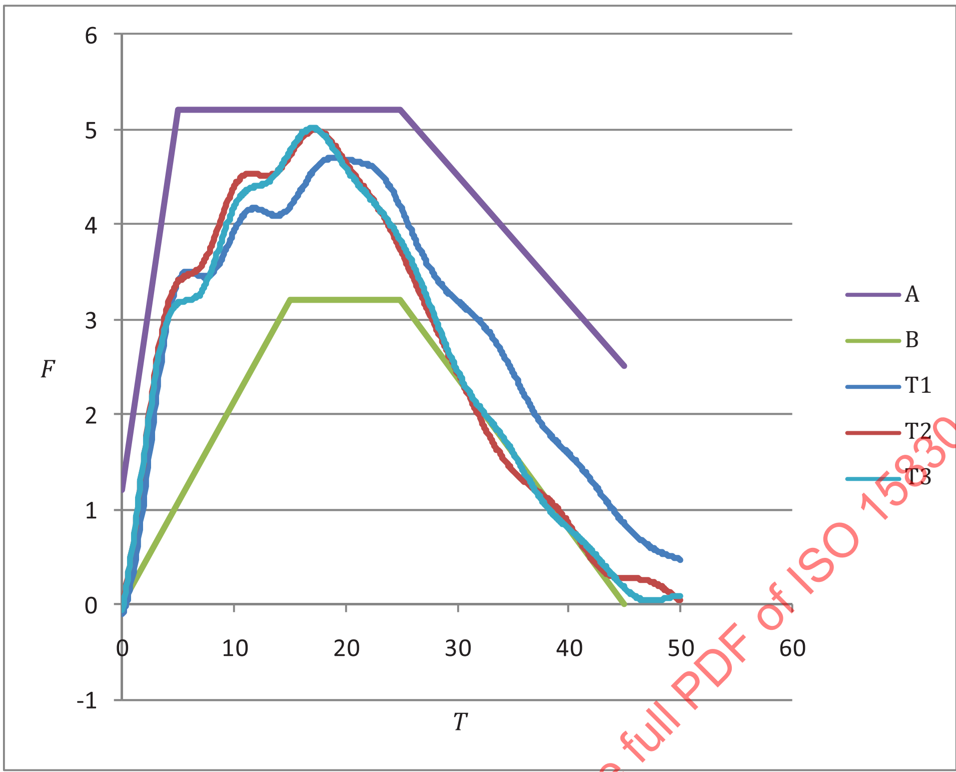
T	time (ms)
T1 Ay	upper spine lateral acceleration (g)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number W009-BDRPH-9
T2	test number W009-BDRPH-10
T3	test number W009-BDRPH-11

Figure D.29 — Thorax test 1 - T1 lateral acceleration

Table D.8 — Thorax test 1 - test results

Measure	Lower bound	Upper bound	Run				Weight factor	Rating
			#1	#2	#3	Avg		
Pendulum force (kN)	Plot	Plot	Plot	Plot	Plot	Plot	9	7,8
Rating			10	10	10	10,0		
T1 lateral acceleration (G)	Plot	Plot	Plot	Plot	Plot	Plot	7	
Rating			5	5	5	5		

D.4.2 Thorax test 2 – 6,7 m/s pendulum test



Ratings: 10,10,10

Key

T time (ms)

F pendulum force (kN)

A ISO/TR 9790 upper corridor

B ISO/TR 9790 lower corridor

T1 test number W009-PRTHS1

T2 test number W009-PRTHS2

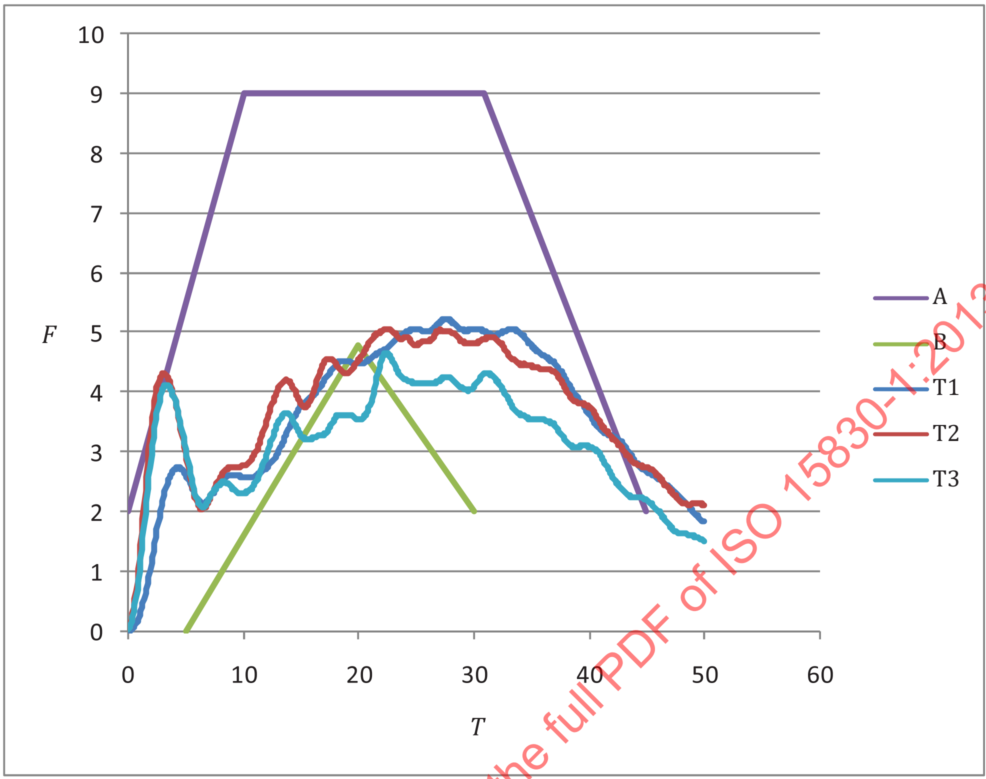
T3 test number W009-PRTHS3

Figure D.30 — Thorax test 2 - pendulum force

Table D.9 — Thorax test 2 – 6,7 m/s test results

Measure	Lower bound	Upper bound	Run				Weight factor	Rating
			#1	#2	#3	Avg		
Pendulum force (kN)	Plot	Plot	Plot	Plot	Plot	Plot	9	10,0
Rating			10	10	10	10,0		

D.4.3 Thorax test 3 – 1 m rigid drop test



Ratings: 10,10,10

Key

T time (ms)

F plate force (kN)

A ISO/TR 9790 upper corridor

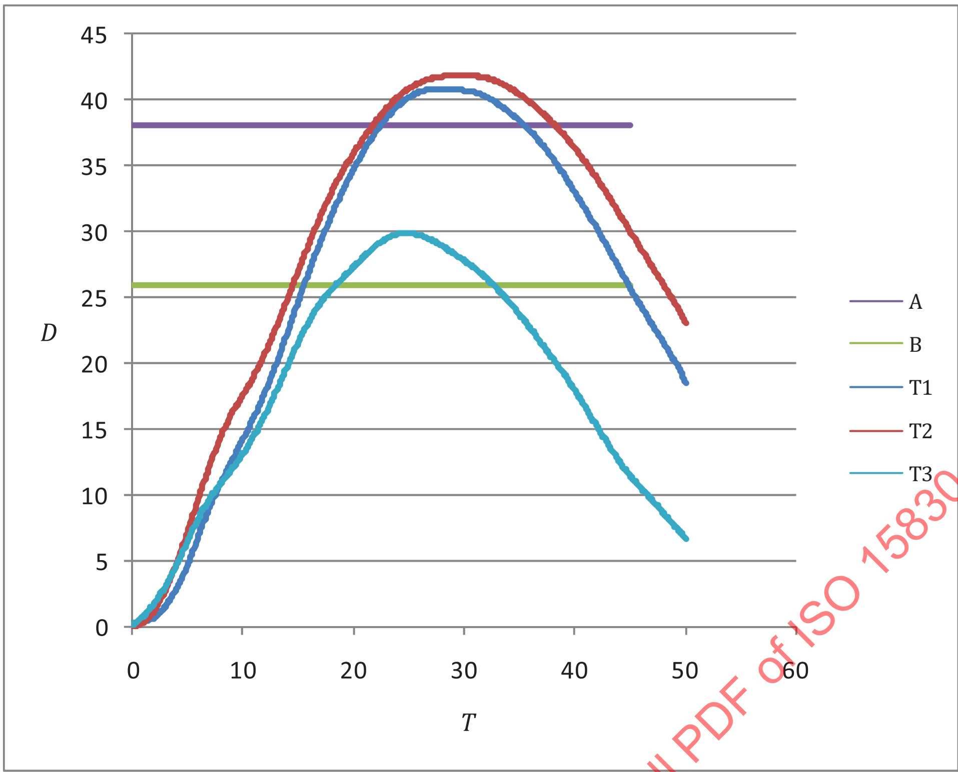
B ISO/TR 9790 lower corridor

T1 test number W009-BDRPH-1

T2 test number W009-BDRPH-2

T3 test number W009-BDRPH-3

Figure D.31 — Thorax test 3 - plate force



Ratings: 5,5,10

Key

T time (ms)

D rib 2 deflection (mm)

A ISO/TR 9790 upper corridor

B ISO/TR 9790 lower corridor

T1 test number W009-BDRPH-1

T2 test number W009-BDRPH-2

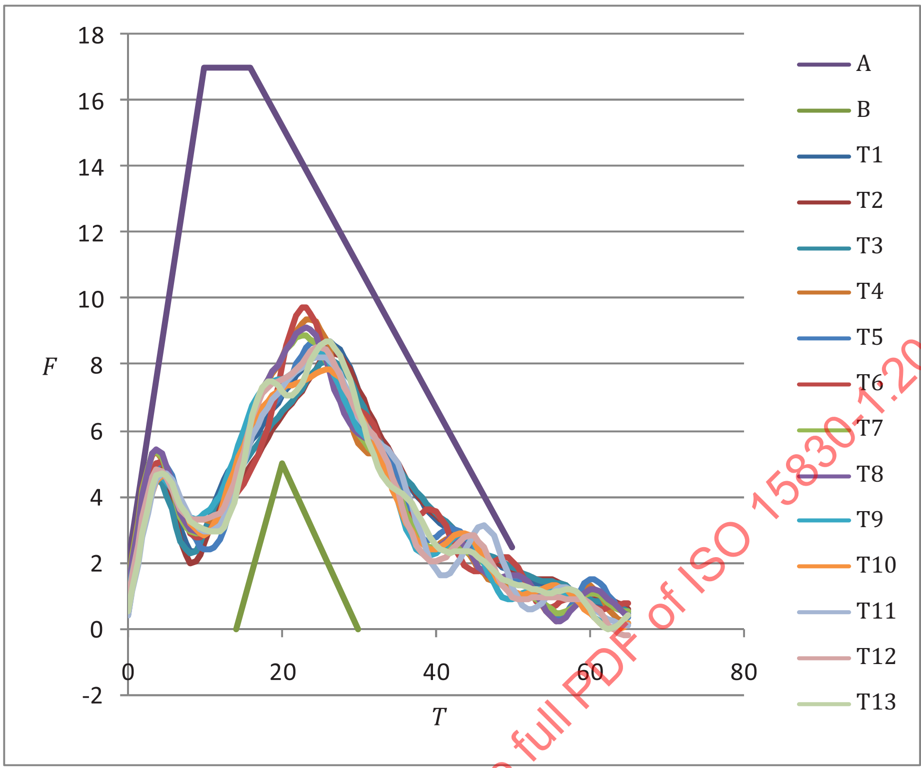
T3 test number W009-BDRPH-3

Figure D.32 — Thorax test 3 – rib deflection

Table D.10 — Thorax test 3 - 1 m rigid drop test results

Measure	Lower bound	Upper bound	Run				Weight factor	Rating
			#1	#2	#3	Avg		
Thorax plate force (kN)	Plot	Plot	Plot	Plot	Plot	Plot	8	8,3
Rating			10	10	10	10,0		
Peak deflection impacted rib (mm)	26	38	41	42	30	37	8	
Rating			5	5	10	6,7		

D.4.4 Thorax test 5 – 6,8 m/s rigid sled test

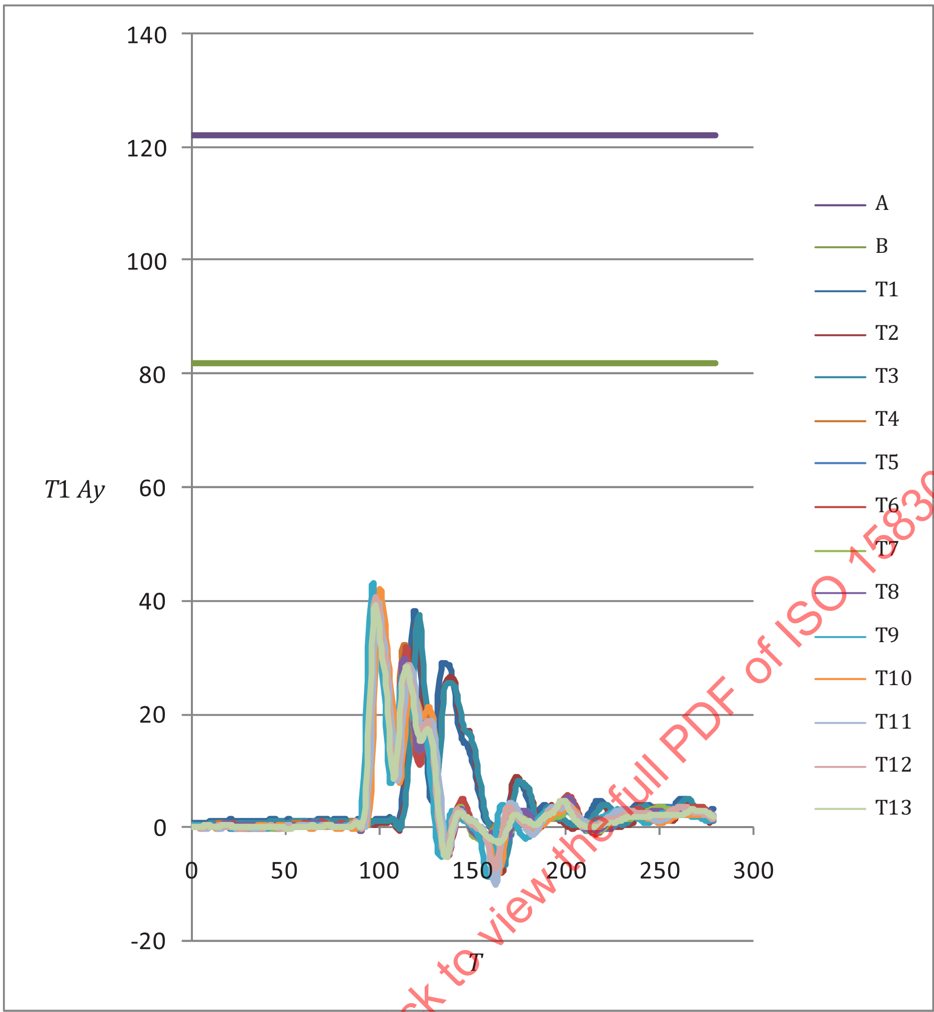


Ratings: 10 for all 13 tests

Key

T time (ms)
F plate force (kN)
A ISO/TR 9790 upper corridor
B ISO/TR 9790 lower corridor
T1 test number H28642
T2 test number H28643
T3 test number H28644
T4 test number 070215-1 WS1
T5 test number 070215-2 WS1
T6 test number 070215-3 WS1
T7 test number 070216-1 WS1
T8 test number 070216-2 WS1
T9 test number 070215-1 WS2
T10 test number 070215-2 WS2
T11 test number 070215-3 WS2
T12 test number 070216-1 WS2
T13 test number 070216-2 WS2

Figure D.33 — Thorax test 5 – plate force

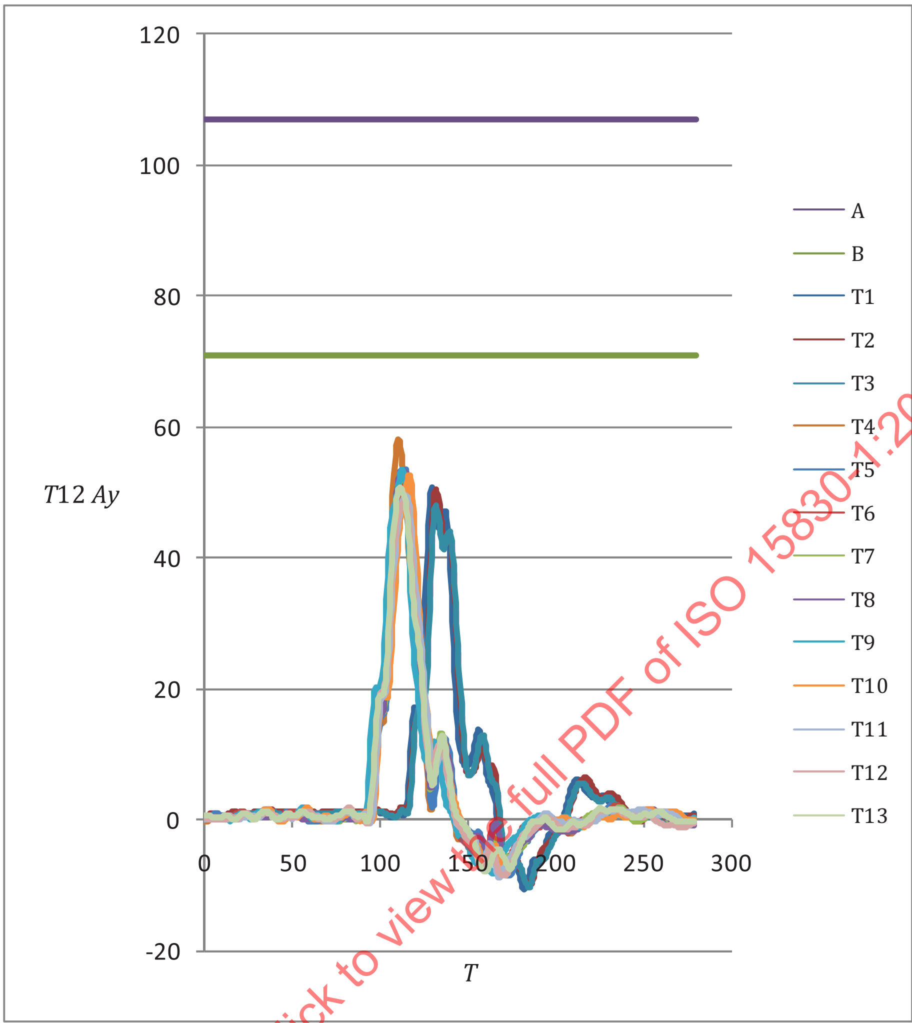


Ratings: 5 for 2 tests, 0 for 11 tests

Key

T	time (ms)
T1 Ay	upper spine lateral acceleration (g)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number H28642
T2	test number H28643
T3	test number H28644
T4	test number 070215-1 WS1
T5	test number 070215-2 WS1
T6	test number 070215-3 WS1
T7	test number 070216-1 WS1
T8	test number 070216-2 WS1
T9	test number 070215-1 WS2
T10	test number 070215-2 WS2
T11	test number 070215-3 WS2
T12	test number 070216-1 WS2
T13	test number 070216-2 WS2

Figure D.34 — Thorax test 5 - T1 acceleration

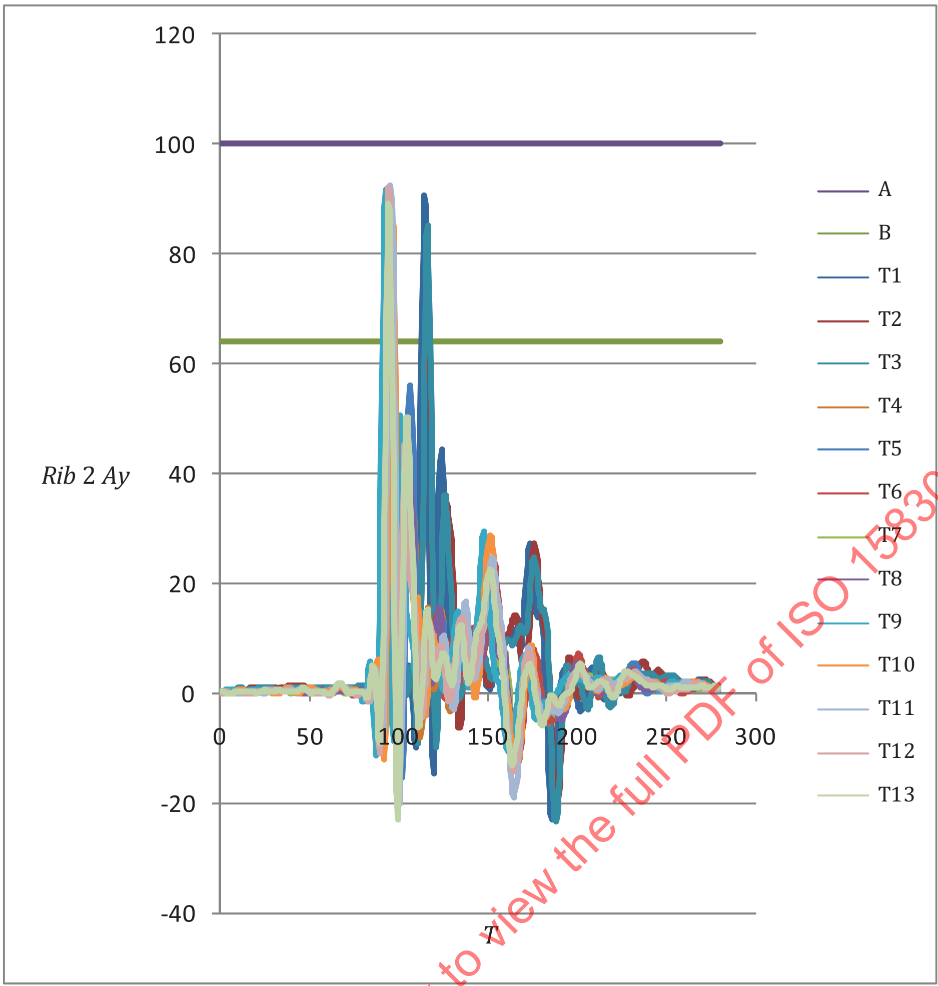


Ratings: 5 for all 13 tests

Key

T time (ms)
T12 Ay lower spine lateral acceleration (g)
A ISO/TR 9790 upper corridor
B ISO/TR 9790 lower corridor
T1 test number H28642
T2 test number H28643
T3 test number H28644
T4 test number 070215-1 WS1
T5 test number 070215-2 WS1
T6 test number 070215-3 WS1
T7 test number 070216-1 WS1
T8 test number 070216-2 WS1
T9 test number 070215-1 WS2
T10 test number 070215-2 WS2
T11 test number 070215-3 WS2
T12 test number 070216-1 WS2
T13 test number 070216-2 WS2

Figure D.35 — Thorax test 5 - T12 acceleration



Ratings: 10 for all tests

Key

T	time (ms)
Rib2 Ay	rib 2 lateral acceleration (g)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number H28642
T2	test number H28643
T3	test number H28644
T4	test number 070215-1 WS1
T5	test number 070215-2 WS1
T6	test number 070215-3 WS1
T7	test number 070216-1 WS1
T8	test number 070216-2 WS1
T9	test number 070215-1 WS2
T10	test number 070215-2 WS2
T11	test number 070215-3 WS2
T12	test number 070216-1 WS2
T13	test number 070216-2 WS2

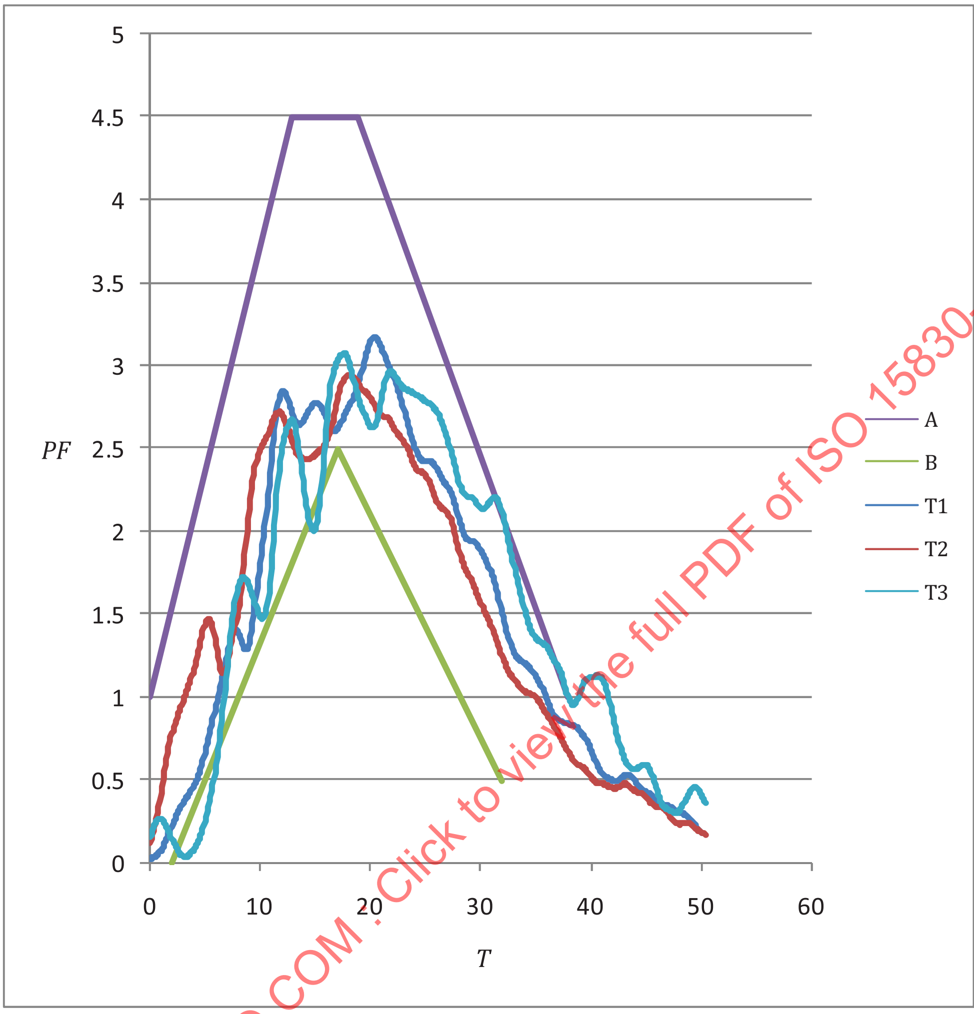
Figure D.36 — Thorax test 5 - rib acceleration

Table D.11 — Thorax test 5 - 6,8 m/s sled test results

<table>
<tr><th rowspan="2">Measure</th><th rowspan="2">Lower bound</th><th rowspan="2">Upper bound</th><th colspan="2">Run</th><th rowspan="2">Weight factor</th><th rowspan="2">Rating</th></tr>
<tr><th></th><th>Avg</th></tr>
<tr><td>Thorax plate force (kN)</td><td>Plot</td><td>Plot</td><td>Plot</td><td>Plot</td><td rowspan="2">8</td><td rowspan="8">6,4</td></tr>
<tr><td>Rating</td><td></td><td></td><td>All tests 10</td><td>10,0</td></tr>
<tr><td>Peak upper spine lateral acceleration (G)</td><td>82</td><td>122</td><td></td><td>39</td><td rowspan="2">7</td></tr>
<tr><td>Rating</td><td></td><td></td><td>Two tests 5,
11 tests 0</td><td>0,8</td></tr>
<tr><td>Peak lower spine lateral acceleration (G)</td><td>71</td><td>107</td><td></td><td>52,0</td><td rowspan="2">7</td></tr>
<tr><td>Rating</td><td></td><td></td><td>All tests 5</td><td>5,0</td></tr>
<tr><td>Peak lateral acceleration impacted rib (G)</td><td>64</td><td>100</td><td></td><td>86</td><td rowspan="2">6</td></tr>
<tr><td>Rating</td><td></td><td></td><td>All tests 10</td><td>10</td></tr>
</table>

D.5 Abdomen

D.5.1 Abdomen test 1 – 1,0 m drop onto rigid armrest test



Ratings: 10,10,10

Key

T time (ms)

PF plate force (kN)

A ISO/TR 9790 upper corridor

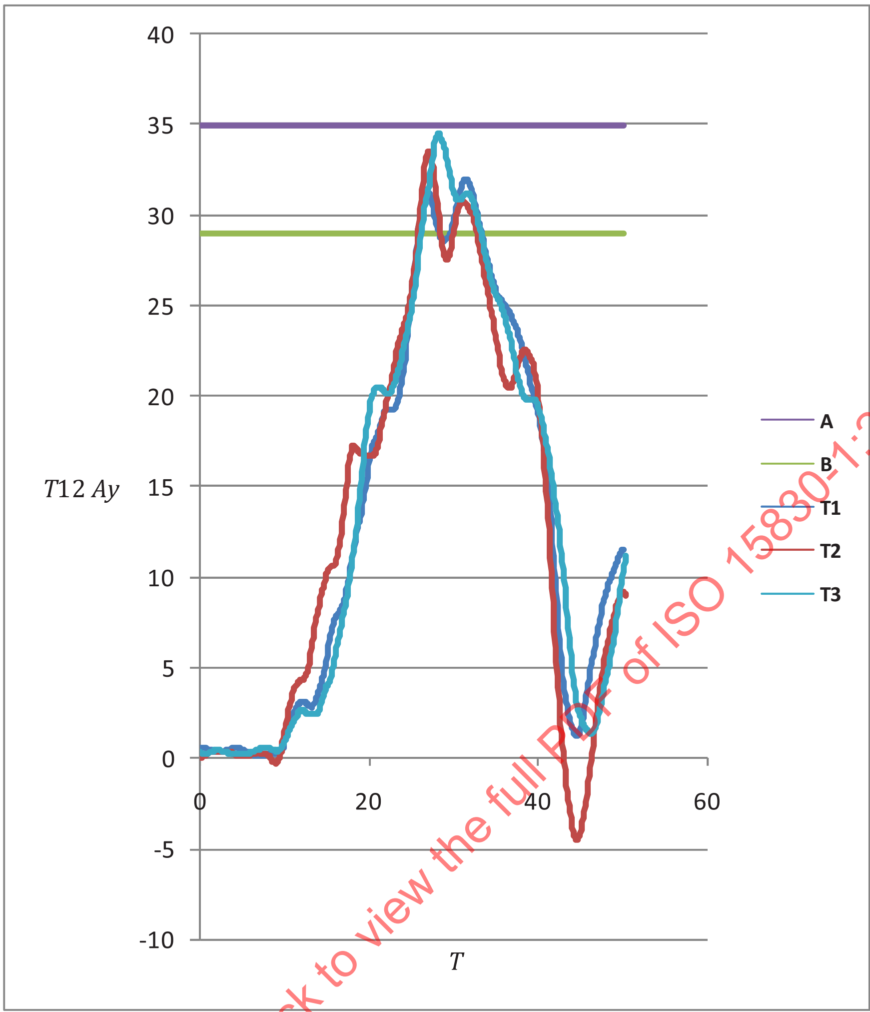
B ISO/TR 9790 lower corridor

T1 test number WS009-BDRAL-1

T2 test number WS009-BDRAL-2

T3 test number WS009-BDRAL-3

Figure D.37 — Abdomen test 1 – armrest force

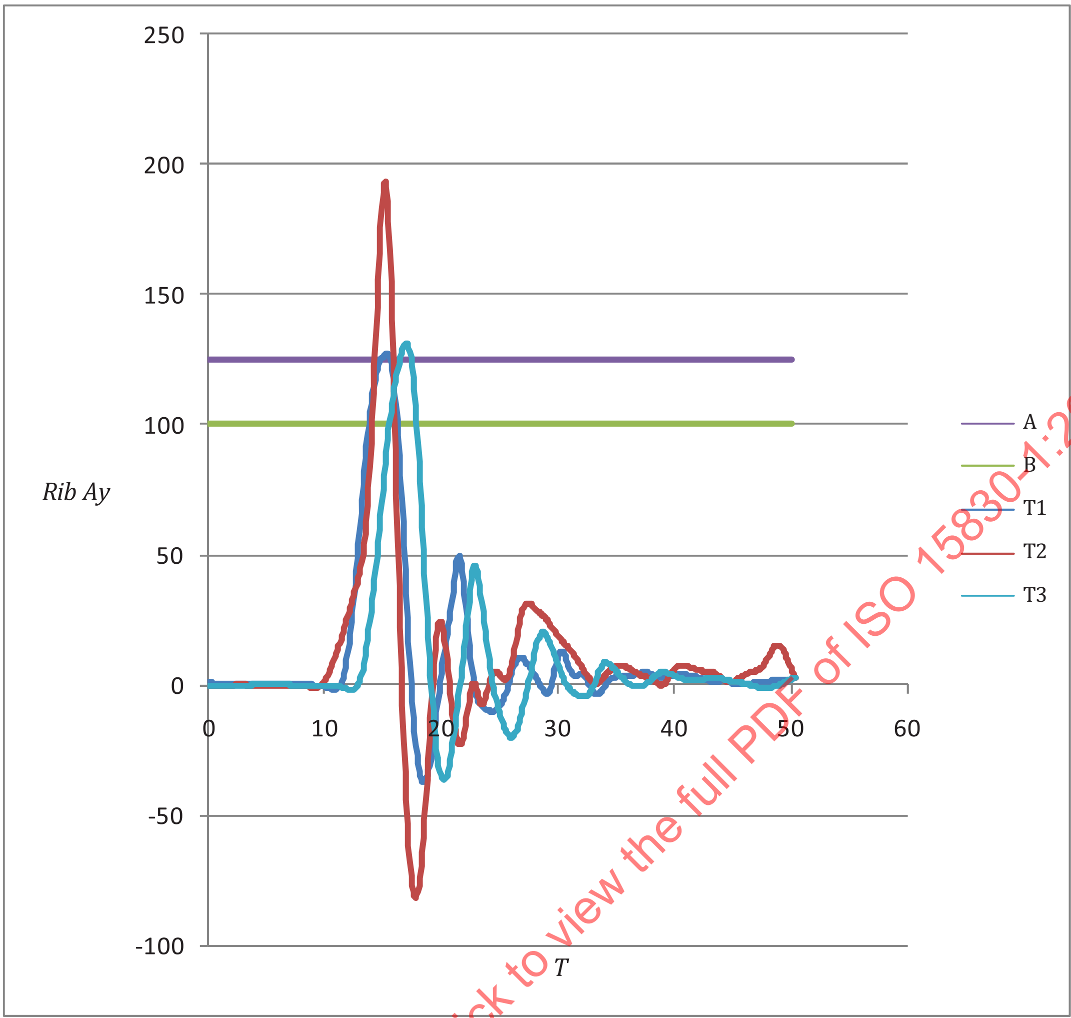


Ratings: 10,10,10

Key

T	time (ms)
T12 Ay	lower spine lateral acceleration (g)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WS009-BDRAL-1
T2	test number WS009-BDRAL-2
T3	test number WS009-BDRAL-3

Figure D.38 — Abdomen test 1 - T12 lateral acceleration

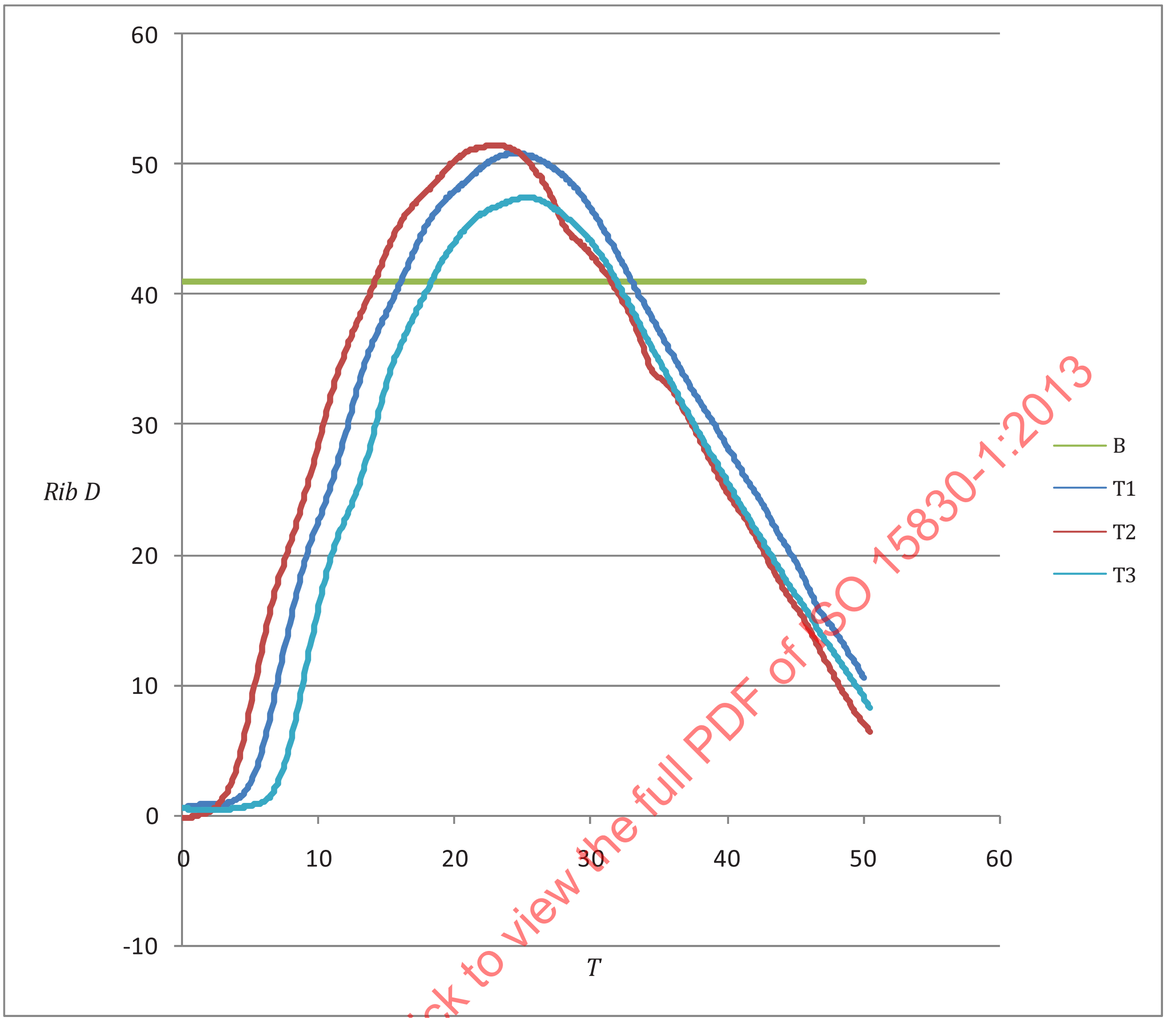


Ratings: 5,0,5

Key

T	time (ms)
Rib Ay	impacted rib lateral acceleration (g)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1	test number WS009-BDRAL-1
T2	test number WS009-BDRAL-2
T3	test number WS009-BDRAL-3

Figure D.39 — Abdoment test 1 - rib acceleration



Ratings: 10,10,10

Key

T time (ms)

Rib D impact rib lateral deflection (g)

B ISO/TR 9790 lower corridor

T1 test number WS009-BDRAL-1

T2 test number WS009-BDRAL-2

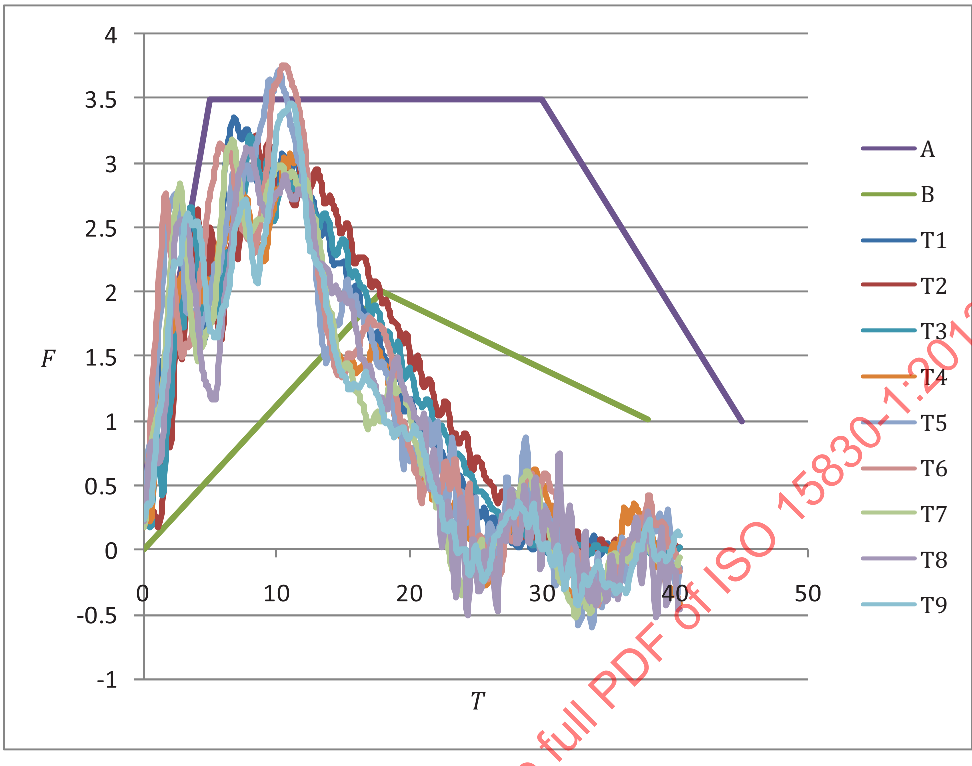
T3 test number WS009-BDRAL-3

Figure D.40 — Abdomen test 1 - rib deflection

Table D.12 — Abdomen test 1 - 1 m rigid armrest test results

Measure	Lower bound	Upper bound	Run				Weight factor	Rating
			#1	#2	#3	Avg		
Armrest force (kN)			See plot	See plot	See plot		9	9,0
Rating			10	10	10	10,0		
T12 lateral acceleration (G)	29	35	32	34	35	34	6	
Rating			10	10	10	10,0		
Peak acceleration of impacted rib (mm)	100	125	127	193	130	150	4	
Rating			5	0	5	3,3		
Abdomen rib deflection (mm)	41		51	51	47	50	9	
Rating			10	10	10	10,0		

D.5.2 Abdomen test 3 – 6,8 m/s rigid sled test



Ratings: 10 for all tests

Key

T time (ms)
F plate force (kN)
A ISO/TR 9790 upper corridor
B ISO/TR 9790 lower corridor
T1 test number H28774
T2 test number H28775
T3 test number H28776
T4 test number 070410-1 WS1
T5 test number 070410-2 WS1
T6 test number 070410-3 WS1
T7 test number 070410-1 WS1
T8 test number 070410-2 WS1
T9 test number 070410-1 WS2

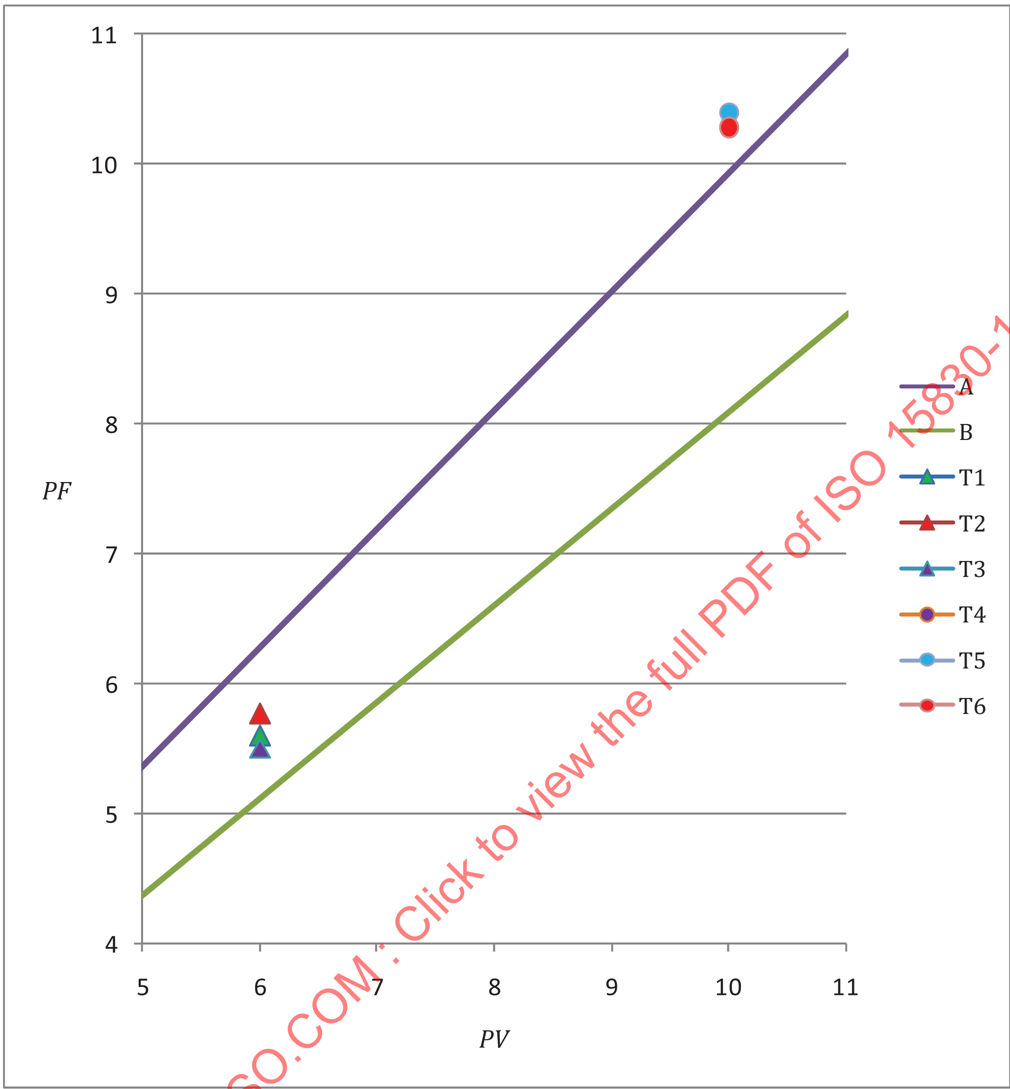
Figure D.41 — Abdomen test 3 - plate force

Table D.13 — Abdomen test 3 - 6,8 m/s plate force sled test results

Measure	Lower bound	Upper bound	Run		Weight factor	Rating
				Avg		
Abdomen plate force (kN)			See plot		9	10,0
Rating			10	10,0		

D.6 Pelvis

D.6.1 Pelvis test 1 – 6,0 m/s pendulum test



Test 1 ratings: 10,10,10; Test 2 ratings: 5,5,5

Key

PV	pendulum velocity (m/s)
PF	pendulum force (kN)
A	ISO/TR 9790 upper corridor
B	ISO/TR 9790 lower corridor
T1 Pelvis test 1	test number WS009-PRPLS1
T2 Pelvis test 1	test number WS009-PRPLS2
T3 Pelvis test 1	test number WS009-PRPLS3
T4 Pelvis test 2	test number WS009-PRPHS1
T5 Pelvis test 2	test number WS009-PRPHS2
T6 Pelvis test 2	test number WS009-PRPHS3

Figure D.42 — Pelvis test 1 and 2 - pendulum force

Table D.14 — Pelvis test 1 – 6,0 m/s pendulum test results

Measure	Lower bound	Upper bound	Run				Weight factor	Rating
			#1	#2	#3	Avg		
Pendulum force (kN)	Plot	Plot	Plot	Plot	Plot	Plot	9	10,0
Rating			10	10	10	10,0		

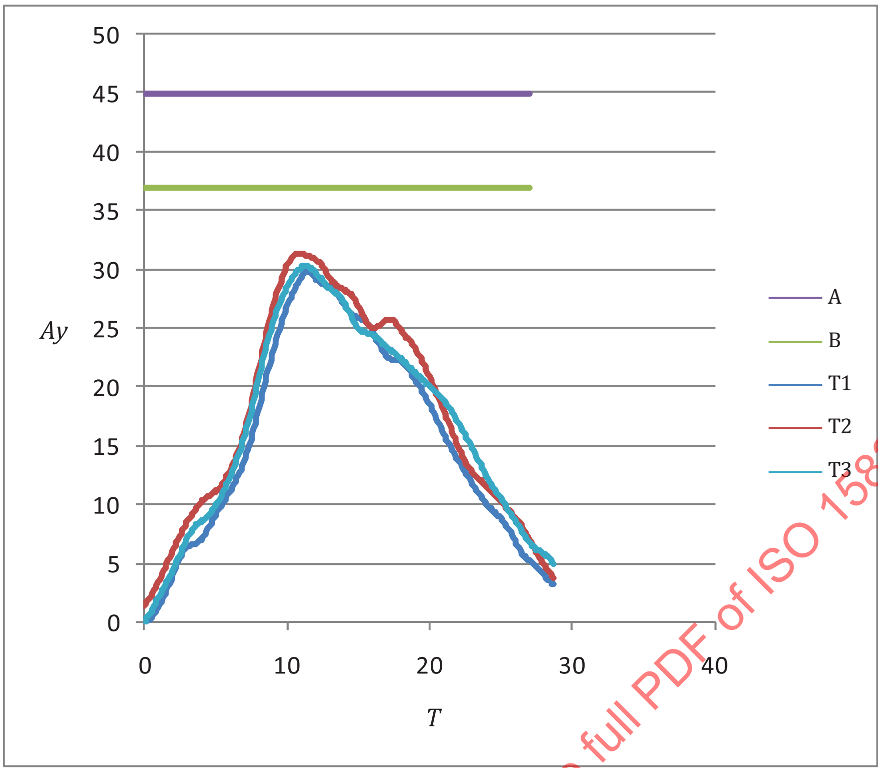
D.6.2 Pelvis test 2 – 10,0 m/s pendulum test

See Figure D.19.

Table D.15 — Pelvis test 2 - 10,0 m/s pendulum test results

Measure	Lower bound	Upper bound	Run				Weight factor	Rating
			#1	#2	#3	Avg		
Pendulum force (kN)	Plot	Plot	Plot	Plot	Plot	Plot	9	5,0
Rating			5	5	5	5,0		

D.6.3 Pelvis test 3 – 0,5 m rigid drop test



Ratings: 5,5,5

Key

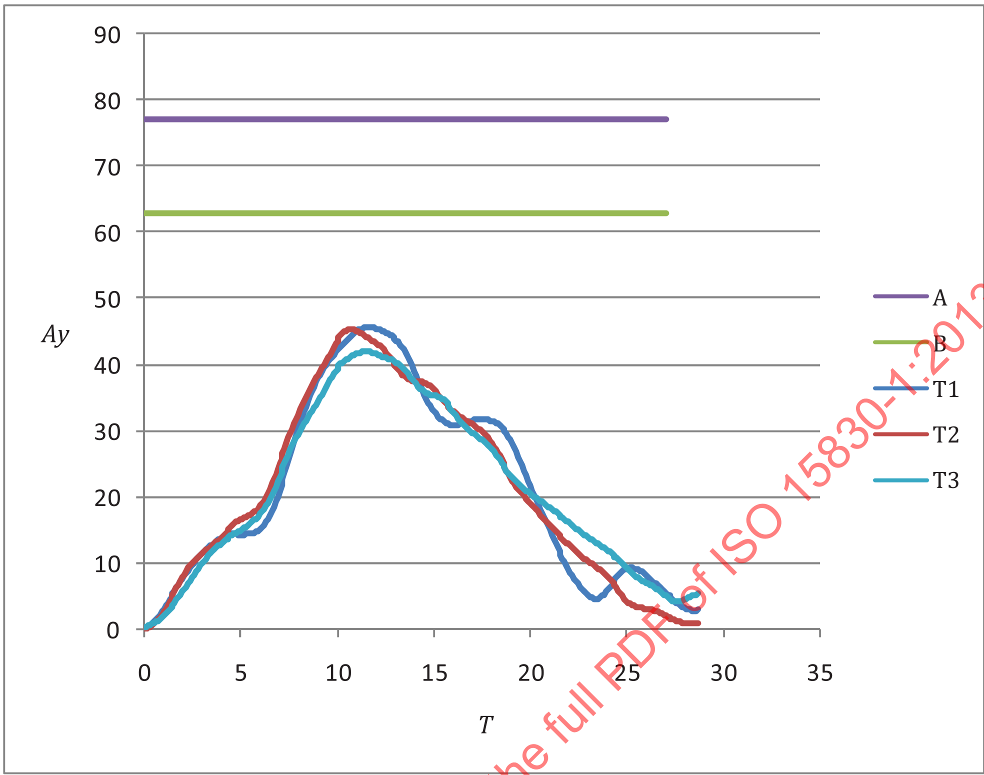
T time (ms)
Ay lateral acceleration (g)
A ISO/TR 9790 upper corridor
B ISO/TR 9790 lower corridor
T1 test number WS009-BDRPL1
T2 test number WS009-BDPRL2
T3 test number WS009-BDRPL3

Figure D.43 — Pelvis test 3 - pelvis acceleration

Table D.16 — Pelvis test 3 - 0,5 m acceleration drop test results

Measure	Lower bound	Upper bound	Run				Weight factor	Rating
			#1	#2	#3	Avg		
Peak pelvis acceleration (G)	37	45	30	31	30	30	7	5,0
Rating			5	5	5	5,0		

D.6.4 Pelvis test 4 – 1,0 m rigid drop test



Ratings: 0,0,0

Key

T time (ms)

Ay lateral acceleration (g)

A ISO/TR 9790 upper corridor

B ISO/TR 9790 lower corridor

T1 test number WS009-BDRPL1

T2 test number WS009-BDPRL2

T3 test number WS009-BDRPL3

Figure D.44 — Pelvis test 4 - pelvis acceleration

Table D.17 — Pelvis test 4 – 1,0 m rigid drop test results

Measure	Lower bound	Upper bound	Run				Weight factor	Rating
			#1	#2	#3	Avg		
Peak pelvis acceleration (G)	63	77	46	45	42	44	7	0,0
Rating			0	0	0	0		