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Summary of Side Impact Response Requirements

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Author(s)
EEVC-WG12 members

Copy
IHRA Biomechanics members
SID-2000 members:
M. Van Ratingen (TNO)
S. Compigne (INRETS)
A. Roberts (TRL)
K. Barnsteiner (BMW)
L. Edlund (Volvo)
T. Kreuzinger (BASt)
M. Burleigh (OTSP)
T. Fairley (DG XII)

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1 INTRODUCTION

This report summarises the main results from the study “Review of Side Impact Response Requirements” [1] performed by INRETS, TRL and TNO as part of the EC project SID-2000 Task 1.1. The basis of this review lies at earlier reviews by ISO/TC22/SC12 Working Group 5 “Anthropomorphic Test Devices” [2] and the European Experimental Safety Committee (EEVC) Working Group 9 [3] which both have established recommended requirements for the biofidelity evaluation of side impact dummies. In addition, the study performed by the SID-2000 consortium [1] reviews data of recent date and gives more general recommendations regarding normalisation techniques to be used, target corridor definition and biofidelity assessment methodology.

This technical document of EEVC WG12 briefly summarises the review of biomechanical data for each body part and lists the response requirements to be used for an enhanced side impact dummy. The last chapter identifies the areas of the body where biomechanical data are still lacking or considered insufficient.

2 SIDE IMPACT RESPONSE REQUIREMENTS

2.1 HEAD

Review - The data bases of HODGSON AND THOMAS [4], APR [27] (drop test), UMTRI [5], and ALLSOP [7] (impactor tests) have been reviewed in relation to their appropriateness for defining side impact dummy biomechanical targets. The following has been concluded :

As none of the PMHS heads were fractured during the HODGSON AND THOMAS tests [4], both test sample size and energy level are appropriate to be used for definition of a side impact head performance requirement.

The requirements for the omni-directional THOR head are based on a combination of UMTRI [5] and HODGSON AND THOMAS data [4]. The THOR head requirement allows assessment of the head performance at low and high impact speed, which would increase the confidence in test results if the head would meet both targets. For these reasons, the THOR requirement could be used as an alternative head requirement. A clear description of the test procedure, including pre-test positioning, instrumentation and filtering, however, was not found, and still has to be identified.

APR padded head impact test data [27] are considered unsuitable as a basis for a side impact head performance requirement for two reasons: 1) removal of the fractured head data leaves a too small test sample and 2) padded tests are found difficult to reproduce, as the surface material is not well specified and not readily available.

The recent circular plate impact results of ALLSOP ET AL.[7] are not appropriate. The impactor is too small and therefore the results give information on response of the human head on microscopic scale instead of macroscopic. As during most impact situations the head contacts large areas, a performance requirement based on these circular plate impacts is not representative for a crash situation.

Biofidelity Requirements – One lateral impact test is proposed for the head. As an alternative to this test (head test 1), a second head test (head test 2) is proposed.

Head test 1 consists of a 200 mm head only drop test based on rigid surface cadaver impacts conducted by HODGSON AND THOMAS [4]. The test procedure, instrumentation, filtering are given in Appendix B. The peak resultant acceleration at the non-impact side of the head should lie between the limits, also given in Appendix B.

In the future, head test 1 may be replaced by head test 2 based on a combination of UMTRI [5] and HODGSON AND THOMAS data [4]. Head test 2 consists of 23.4 kg impactor tests at the head mounted on the neck, at low (2.0 m/s) and high (5.5 m/s) speed. The test procedure, instrumentation, filtering are currently not available. Biofidelity requirements are force-duration windows given in Appendix C.

2.2 NECK

Review - The data bases of Patrick and Chou [8], APR [11] and NBDL [9][10] have been reviewed in relation to their appropriateness for defining side impact dummy biomechanical targets. The following has been concluded:
For reasons of efficiency it is preferable that the biofidelity is assessed in only one condition with one consistent set of response requirements. In this way conflicting requirements for a dummy design can be avoided.
The set of requirements resulting from the NBDL tests appear to be the most complete ones and include detailed information on the T1 response which is not available from the other sources. It is proposed to extent the requirements based on the NBDL tests currently proposed in ISO TR9790.
Since both the Patrick and Chou test [8] as well as the APR [11] test are based on only 1 test with 1 subject, these data are in agreement with earlier recommendations of EEVC-WG9 considered inappropriate.

Biofidelity Requirements – One lateral neck bending tests is defined based on the NBDL sled tests by EWING at al. [9], and analysis by WISMANS et al. [10].

<u>Neck test 1</u> is a 7.2 G lateral sled test. The test procedure, instrumentation, filtering are given in Appendix D. Requirements are:

1. horizontal acceleration-time history and horizontal displacement time history of T1 relative to the sled, plus minus standard deviation (shoulder requirement);

2. peak horizontal and vertical displacement of head c.g. relative to (non-rotating) T1 as well as time of peak head excursion;

3. peak lateral and vertical (downward) acceleration time histories of the head cg plus minus standard deviation;

4. peak lateral flexion and peak twist angles and occipital and twist torques.

Specific targets are given in Appendix D. Note that the T1 acceleration time history can also be used as input in an isolated head-neck assembly test which would allow the neck response to be assessed independent from the dummy response.

2.3 SHOULDER

Review - The data bases of APR [12] [28] (impactor and drop tests), HSRI/HEIDELBERG [30] [31] (sled), WSU/GMRL [32] (sled) have been reviewed in relation to their appropriateness for defining side impact dummy biomechanical targets. The following has been concluded:
The APR impactor test series [12] is the only series of discrete shoulder impact tests, performed to examine specifically the lateral dynamic behaviour of the shoulder complex. However, since these tests are limited in number it is felt that the EEVC analysis and associated targets and detailed test procedures are to be preferred to the ISO proposals, as only the EEVC analysis was based on the original raw data. It is recommended that a quasi static design target be added ensuring that the shoulder complex is not able to transmit unrealistic forces from a range of different directions.
Since the arm has such an influence on the shoulder kinematics it is felt that the sled-based tests (e.g. the Heidelberg tests given for the thorax) should be used to evaluate ‘upper body’ responses rather than the performance of individual body parts and therefore should not be recommended to specify discrete body part biofidelity targets such as the shoulder. Furthermore, it is recommended that no biofidelity design targets are made based on the APR drop test procedure due to the perceived difficulty in suspending a PMHS, in a repeatable manner and the resulting change in shape and mass distribution, coupled with the lack of precision in controlling the point of impact.

Biofidelity Requirements – One dynamic lateral shoulder test is proposed based on the impactor tests by APR [12]. In addition, a quasi-static target is proposed to be used as a design guideline for the shoulder.

<u>Shoulder test 1</u> is a 4.5 m/s lateral linearly guided impactor test using the standard, 23.4 kg – 150 mm diameter, dummy certification impactor, performed at angles of 90° (perpendicular to the shoulder) to 15° forward of the perpendicular, in the horizontal plane. The test procedure, instrumentation, filtering are given in Appendix E. The requirement is a force-time corridor also given in Appendix E.

The lateral displacement of the shoulder, relative to the spine, should be 55 mm under a lateral <u>quasi-static loading</u> of 200 N.

Quasi static targets for ranges of movement are included in Appendix E.

2.4 THORAX

Review - The impactor test data bases of HSRI [13], ONSER [14] and WSU/ GMRL [15], the drop test database of APR [28] and sled test data bases of HSRI/HEIDELBERG [30] [31] and WSU [32] have been reviewed. The following conclusions were made: The HSRI tests at 90° at an impact velocity of 4.3 m/s and the WSU/GMRL tests at 60° oblique at an impact velocity of 4.3 and 6.7 m/s data both can be used to assess biofidelity. However, review of these requirements clearly exposed inconsistencies in filtering, injury level and impactor systems between the HSRI and WSU tests. It is therefore proposed to have separate requirements on the basis of the two databases, instead of combining both sets as defined by ISO. The drop tests should not be used as biofidelity targets for reasons mentioned earlier. Three of the HEIDELBERG sled test configurations can be used to evaluate the biofidelity of the integrated dummy and appropriate proposals for target corridors have been made by EEVC WG9 and ISO. It is proposed that the EEVC test velocities should be used as the impact velocities were corrected for the sled rebound velocity.

Biofidelity Requirements – Three thorax tests are proposed based on the HSRI [13] and WSU/GM [15] impactor tests, and the HEIDELBERG [31] sled tests.

<u>Thorax test 1</u> is a 4.3 m/s lateral impactor test using the standard, 23.4 kg – 150 mm diameter, dummy certification impactor, performed at 90° (perpendicular to the thorax on the horizontal plane. The test procedure, instrumentation, filtering are given in Appendix F. Requirements are impactor deceleration and dummy T1 acceleration corridors also given Appendix F.

<u>Thorax test 2</u> are 4.3 and 6.7 m/s lateral impactor tests using the standard, 23.4 kg – 150 mm diameter, dummy certification impactor, performed at an angle of 60° on the horizontal plane.

<u>Thorax test 3</u> are 7.6 m/s rigid wall and 7.6 and 10.3 m/s rigid and padded wall sled tests in the HEIDELBERG test conditions. Appendix G gives the test procedure and details. Requirements are shoulders and thorax force/time corridors also given in Appendix G.

For the future, it is recommended to develop separate oblique targets based on the displacement limited impactor data by WSU/GM [15], adopting EEVC WG9 techniques. It is also felt that the WSU tests could be used to increase the sled test biofidelity target database, but that they need to be much better specified in alignment with the original test procedures, in particular with respect to the specification of the paper honeycomb material. If a new in-depth review of the WSU/GMRL 8.9 m/s padded wall data recommends that it is a good thoracic biofidelity test procedure with good targets, then consideration should be given to removing the HEIDELBERG 10.3 m/s rigid wall test from the list of design targets and adding in the WSU tests.

2.5 ABDOMEN

Review - The full body test data bases of APR [28] (drop test) and WSU [32][33] (sled test) and impactor test data bases of WSU/GMRL [15] and TALANTIKITE [16] have been reviewed in relation to their appropriateness for defining side impact dummy biomechanical targets. The following conclusions were made:
Sled tests only will provide information on the global behaviour of the dummy. Of the WSU sled tests only the padded tests are considered to be valid as there are not enough data on rigid- wall sled tests. Tests on the abdomen area are necessary to develop dummy abdomen. WSU/GMRL and TALANTIKITE performed tests in approximately the same conditions using impactor or pendulum, but in different initial positions. To avoid defining two different test procedures (one with a seated dummy, based on TALANTIKITE tests and another with an upright dummy, based on WSU/GMRL tests) it is proposed to only use the WSU tests. Drop tests were considered inappropriate for reasons mentioned earlier.

Biofidelity Requirements – Two tests are proposed for the abdomen based on the WSU sled tests [32][33] and WSU/GM [15] impactor tests, respectively.

Abdomen test 1 is a 8.9 m/s padded wall sled test in WSU test condition. The test procedure, instrumentation, filtering are given in Appendix H. Requirements are abdomen force/time corridors also given in Appendix H.

Note: these tests are only valid if thorax biofidelity is met.

Abdomen test 2 are 4.8, 6.8 and 9.4 m/s oblique impactor tests using the standard, 23.4 kg – 150 mm diameter, dummy certification impactor, performed at 60° off-axis. The test procedure, instrumentation, filtering are given in Appendix I.
Requirements are force-time and force-deflection corridors also given in Appendix I.

2.6 PELVIS

Review - The test data bases of APR [29] (drop test), ONSER [17], NUSHOLTZ [18], WSU/GMRL [15], CHAMOUARD [19], LAB & INRETS [20][21] (impactor tests) and HEIDELBERG [30] [31]and WSU [32][33] (sled tests) have been reviewed in relation to their appropriateness for defining side impact dummy biomechanical targets. The following conclusions were made:
WSU and HEIDELBERG sled tests are both realistic simulators of car tests and they are therefore useful in the determination of the global behaviour. It is recommended to assign greater weight to rigid-wall sled tests as the cadaver response in padded wall tests is too dependent on the padding characteristics.
ONSER, WSU/GMRL, LAB & INRETS, CHAMOUARD and NUSHOLTZ tests are all impactor tests with different masses, different shapes and performed at various speeds. CHAMOUARD and NUSHOLTZ were not found to be suitable as either the impactor mass used or injuries sustained were not representative of a car door impact. ONSER, LAB & INRETS and WSU/GMRL data were compared and an attempt has been made to put forward one requirement on the basis of all databases. The APR drop tests have a poor repeatability and which are not representative of occupant position in a car and are therefore not proposed.

Biofidelity Requirements – Three tests are proposed for the pelvis based on the HEIDELBERG [30] [31] sled tests, the WSU [32][33] sled tests and one requirement based on ONSER[17], LAB & INRETS [20][21] and WSU/GMRL [15] impactor tests.

<u>Pelvis test 1</u> are 3.4, 6.6 m/s impactor tests using the standard, 23.4 kg – 150 mm diameter, dummy certification impactor, performed at 90° lateral. The test procedure, instrumentation, filtering are given in Appendix J. Requirements are force, the peak acceleration and deflection corridors also given in Appendix J.

<u>Pelvis test 2</u> are 7.6 m/s rigid wall and 7.6 and 10.3 m/s rigid and padded wall sled tests in the HEIDELBERG test conditions. Appendix K gives the test procedure and details. Requirements are peak pelvis impact forces corridors also given in Appendix K.

<u>Pelvis test 3</u> are 6.7 rigid wall and 6.7 and 8.9 m/s rigid and padded wall sled test in WSU test condition. The test procedure, instrumentation, filtering are given in Appendix L. Requirements are pelvic force/time and compression/time corridors defined as plus or minus average standard deviation force/time corridors given in Appendix L.

2.7 FEMUR

Review - The test data bases of MATHER [22], PRITZ [23], MELVIN [24], PORTA ET AL. [25] and KRESS ET AL [26]. have been reviewed in relation to their appropriateness for defining side impact dummy biomechanical targets. The following conclusions were made:
Through these articles, tolerance levels of femur bone are described, in lateral impact, under static and dynamic loading. Unfortunately, none reports data such as force/time response of isolated femur or global response of lower extremities. Current dummies allow to measure forces and momentum at upper extremities level. It could be useful to perform tests on cadavers to determine forces and momentum at dummy load cell position. The little data available are Porta average force results and Pritz bumper force and peak pelvic acceleration results. Unfortunately, the results of these studies are not well detailed. This is not sufficient to derive requirements for the lower extremities.

Biofidelity Requirements – No side impact requirement has been defined for the femur.

3 DISCUSSION

In this report side impact biofidelity response requirements have been recommended for head, neck, shoulder, thorax, abdomen and pelvis. Overall, the following remarks can be made:

Head – the biomechanical data available on the head are generally considered sufficient to develop a head for a side impact dummy. However, the data set could be extended in the future as indicated in section 2.1. Fact is that the data available are not of recent date and only limited measurements were taken. The design of the head could greatly benefit from future research work that would address more realistic impact conditions and the various injury types seen in real-world crashes.

Neck – the way neck may be loaded in a movable deformable barrier or pole test suggests the neck of a side impact dummy should be biofidelic for more than side impacts only. Currently, separate requirements, based on different test conditions, hold for side impact and frontal flexion/extension, while compatibility between these targets is not assured. The NBDL tests have been carried out for side, oblique and frontal flexion/extension. Further analysis of NBDL data could lead to a set of omni-directional neck biofidelity targets.

Shoulder – The shoulder is a complex body part/joint with many degrees of freedom. The data currently available are generally considered insufficient for dummy design purposes. Future design work should more specifically address the shoulder in realistic automotive loading conditions.

Thorax, abdomen and pelvis – Current design targets based on impactor as well as sled test data rightly reflect the conditions in which these body parts may be loaded in side impact crashes. The biofidelity data base could be extended in the future as indicated in section 2.4. However, virtually no data exist to assess the high velocity-low mass type loading associated with a deploying airbag. Future research work should address this issue as well as oblique loading conditions of upper and lower torso.

Other body parts - No suitable data were presented or found for lumbar spine and upper extremities. The lumbar spine dynamic performance greatly influences the load transfer between upper and lower torso, however, no biomechanical data are known today to support the design of this dummy part. The legs, although not frequently and/or severely injured in side impact crashes, affect the body kinematics and, if incorrectly designed in a dummy, may cause unrealistic load paths. No biomechanical data are available to design a dummy leg for side impact.

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Appendix A Cadaver and Volunteer Data Bases

This Appendix summarises the biomechanical data bases that have been looked at in the report "SID 2000 Task 1.1: Review Of Side Impact Response Requirements". The following includes response data for head, neck, shoulder, thorax, abdomen, pelvis and for the full body.

Head Response

Hodgson and Thomas (1975) [4]
A series of non-fracture, cadaver head omni-directional impact tests conducted on 7 embalmed cadavers. In these tests the cadavers were strapped on their side to a pallet that was free to pivot about one end. The cadaver's head and neck were allowed to extend over the free end of the pallet. The pallet was rotated upwards to achieve a prescribed distance between the head and the impact surface. Then the pallet was released producing the desired head impact. Impact velocities measured were in the range of 1.65-1.92 m/s. Results were presented in terms of peak resultant accelerations (96-135 g) and peak impact force as function of drop height/impact velocity.

UMTRI (1985) [5]
Frontal and lateral non-fracture head impact tests were performed at UMTRI. In these tests, unembalmed cadavers were seated before a pneumatic impactor. A 10 kg rigid flat circular impactor impacted the head in frontal and lateral direction. During the lateral impact tests, the lateral plane of the head was normal to the impactor axis. The impactor axis passed just above the external auditory meatus of the cadaver head. In total 6 tests were performed, including one by Stalnaker et al. (1977, [6]). Four out of six tests were side impact, with impact velocities varying between 5.7 and 7.4 m.s-1 (equivalent to 4.7-6.0 m.s-1 drop test velocities) . For these tests, the peak resultant forces were measured between 13.4 and 18.0 kN (3.8-4.9 kN after normalising) with a duration of between 3.8 and 4.9 ms.

Allsop et al. (1991) [7]
Allsop et al. used 31 unembalmed cadaver heads to document the lateral stiffness and fracture characteristics of the human skull. They used new techniques, in which the cadaver head is impacted with enough energy to cause fracture. The force-time history is recorded during impact and the moment of fracture (and thus the fracture force) is identified by a discontinuity in the measured acoustic emissions characteristic. The human specimen head were placed in plaster of paris (depth was 40% - 50% of the head width). The orientation depended on the impactor used for the test: for a rectangular plate impactor (5 cm * 10 cm, 12 kg) the head was 45 degrees rotated to the impactor plane of travel, for the flat circular impactor (2.54 cm diameter, 10.6 kg), the sagittal plane was at a right angle to the impactor plane of travel. Drop heights were 102 cm for the rectangular plate impactor and 38 cm for the circular plate impactor. For a rectangular plate, the

average fracture force was 12.5 kN and the stiffness was 4200 N/mm. For a circular plate, the average fracture force was 5 kN and the stiffness was 1800 N/mm.

Neck Response

Patrick and Chou (1976) [8]
The first data on dynamical neck performance in side impact have been published by Patrick and Chou. The authors conducted a series of lateral neck bending tests on a single volunteer using a decelerator sled. A rigid seat with a 15° seat back angle was attached to the sled, sideways to the direction of travel. One side of the seat had a rigid, vertically-oriented, side support which restricted upper torso rotation and supported the torso during sled translation. The volunteer was seated in the chair with his shoulder and hip against the side board. A belt restraint system consisting of cross chest shoulder straps, lap strap, crotch strap and a horizontal chest strap was used to secure the volunteer to the seat. The sled was accelerated gently over a 60 foot distance and then abruptly decelerated at a prescribed constant deceleration level with a hydraulic shock absorber. The data were first published in 1976.

Ewing (1977) [9]
Ewing et al. conducted a series of lateral neck bending tests with volunteers at the Naval Biodynamics Laboratory (NBDL), US. The volunteers were seated upright on a sled fixture that was mounted sideways to the direction of travel of a HYGE sled. They were positioned snugly against a lightly padded wooden board, which restricted upper torso rotation and supported the torso during sled translation. Both shoulders were restrained by straps. Their pelvis were restrained by a lap belt and an inverted-V pelvis strap that was tied to the lap belt. They held their heads upright prior to sled acceleration. In 1986, Wismans et al. [10] analysed and published the results of 9 tests with 9 subjects performed between 1981 and 1985 at the NBDL.

APR (1984) [11]
Tarrière and Bendjellal conducted four high-G cadaver tests to obtain data that could be used to define lateral neck bending response in a test environment of greater severity than used for volunteer testing. Unfortunately, each test had an abnormality. Tarrière selected one test as being the most appropriate test to use for defining a set of high-G response requirements. Based on ratios of cadaver response compared to volunteer response obtained for low-G sled tests, the cadaver data for maximum horizontal and vertical head displacement and peak head flexion and torsion angles were modified by Tarrière to reflect human response. Bendjellal et al [ ] have extended the human specimen tests of Tarrière [27] with two new tests. The same test set-up and instrumentation has been used, but results from these tests are reliable in contrary to earlier test results. The velocity change during the tests was 6.3 m.s-1 and the peak sled acceleration was 14.7 G resp. 12.2 G.

Autopsy results of the subjects revealed no injuries either to brain or cervical region.

Shoulder Response

APR (1984) [12]
Association Peugeot Renault have performed four shoulder tests. This is the only series of discrete shoulder impact tests, performed to examine specifically the lateral dynamic behaviour of the shoulder complex. These tests used the standard, 23.4 kg – 150 mm diameter, dummy certification impactor. Full details on the test procedures and results from these tests have not been widely published. Three tests were performed at 90° (perpendicular to the shoulder) and one 15° forward of the perpendicular, on the horizontal plane.

Thoracic Response

HSRI (1978) [13]
The first biofidelity pendulum requirements were based on tests performed by HSRI. These tests were performed at an impact velocity of 4.3m/s using the standard 'dummy certification' impactor (23.5kg * 150mm diameter face). Four cadaveric tests were available (test numbers 76TO62, 76TO65, 77TO71 and 77TO74) of which one (76TO65) is different than the rest as the cadaver had a lower than expected effective mass when its response was being normalised. Two further impactor tests were performed by HSRI, tests 77TO77 and 77TO80, at 21.9 km/h resulting in 3 and 16 ribs fractured AIS 3 & 4 respectively (both of which were aged 75 years).

ONSER (1981) [14]
performed a number of impactor tests to the thoracic region focused on looking at the protective affect of the arm with the thorax. The ONSER impactor face was slightly different from that used by other researchers having a hemispherical contact surface with a radius of 600mm. Excluding tests with arm involvement ONSER performed only two PMHS tests at 24.6 km/h and 20.8 km/h which resulted in 9 and 14 ribs fractured both coded as AIS 4, with subjects aged 80 and 79 respectively. It is felt that these tests are too severe and too few on which to base a good biofidelity target. The age of the specimens in the ONSER tests was high. It is hypothesised that this could be a useful impact severity for a more normal population but there is no test data to support this hypothesis.

WSU/GMRL (1989) [15]
Impactor tests have been performed by Viano et al.. They have performed sixteen thoracic tests using fourteen PMHSs based on three impact velocity ranges 3.8-5.5 m/s (5 tests) and two higher velocity ranges, 5.99-6.73 m/s (6 tests) and 8.3-10.2 m/s (5 tests). The test procedures were not the same as the HSRI procedure in that the impact consisted of a two-stage impactor with one impactor hitting an intermediate loading piston. The stroke of the loading piston was terminated at a

displacement of 150 mm. Tests were performed by WSU/GMRL perpendicular to the thorax (90°) and from an offset 'oblique' angle of 30° to the front. The oblique tests were performed to prevent the thorax rotating during the impact, due to the misalignment of the impactors axis and the centre of gravity of the thorax, a feature that the researchers had observed in perpendicular impacts, but not noted by HSRI or ONSER. At the highest velocity tests, 9.2 m/s, five of the six specimens sustained flail chest injuries, with an average of 14 rib fractures (AIS≥3). The intermediate velocity tests, 5.99-6.73 m/s, resulted in an average of 5.2 rib fractures (AIS 2-4). It is felt that tests at these velocity are becoming 'unacceptable' and might be considered to be the upper limit of impact severity against which biofidelity targets could be set. Few fractures were generated in the lower velocity tests, 4.3 m/s (AIS ≤2).

Abdominal Response

<u>Talantikite (1993) [16]</u>
Talantikite undertook several tests on the right side of the abdomen of 7 cadavers. Only cadavers without deterioration of the abdominal organs were kept. Those with bad bone condition were eliminated. A sandows linear impactor was used. The impactor mass was 23.4 kg, the rigid impacting surface was a disc of 15 cm diameter. The impact velocity were between 3 and 10 m/s. The impactor was positioned 7.5 cm below the xiphoid (15 cm below the middle of the sternum). The surface of the impactor covered the seventh, eighth, ninth and tenth ribs. The subjects were seated on a height adjustable frame and held in position by straps. The ribs and the spinal column were instrumented with accelerometers. The external abdominal deflection was measured with a system of potentiometers. The two potentiometers measured the abdominal deflection on a horizontal plane passing through the twelfth vertebra which corresponded approximately to the plane passing through the middle of the liver.

<u>WSU/GMRL (1989) [15]</u>
Impactor tests performed by Viano et al.. See also thorax for remarks. Viano conducted 14 tests on 9 different unembalmed cadavers with a pendulum. 7 cases of injuries were obtained. The cadaver was suspended upright with hands and arms overhead. The cadavers were submitted to pendulum impact centred at 7.5 cm below the xiphoid (15 cm below midsternum) and rotated 30°. The pendulum was 23.4 kg and a 15 cm diameter disc impacting surface, smooth and flat with rounded edges. A suspension system released the arms at impact. A triaxial accelerometer is attached to the eighth and twelfth thoracic vertebrae. The impact force is calculated from the pendulum acceleration multiplied by the pendulum mass. The deflection was measured by film analysis.

Pelvic Response

ONSER (1982) [17]

The ONSER conducted 60 tests on 22 cadavers to determine pelvic tolerance. The cadavers were impacted at increasing impact speed in order to reach pelvic fracture. The ISO kept only the first impact on pelvis for which cadavers, which had acceptable bone condition, sustained no injury. 13 tests remained : 12 rigid impacts and 1 padded impact. The cadaver is seated and struck by a spherical impactor (r=60 mm, R=175 mm) of 17.3 kg , horizontally guided, at the right great trochanter level. Strain gages measured strain in the pelvis. An accelerometer measured acceleration at sacrum level. Impact force and acceleration were measured on the impactor.

Nusholtz (1982) [18]

Nusholtz conducted several tests on pelvises (frontal impacts on knee and lateral impacts on great trochanter) to determine the kinematics and the injury response of the pelvis in a automotive environment. He submitted 19 cadavers to lateral impacts, only 12 tests were reported with their impact conditions and results. A pendulum impactor or a pneumatic impactor were used as test devices. Indirect loads to the pelvis were delivered to the acetabulum by impacting the femur laterally. Impactor masses used were 25 kg and 56 kg. The impacting surface could be covered with 2.5 cm ensolite padding or with a 2.5 cm ensolite plus 1.3 cm styrofoam. In other cases, a rigid impactor was used. The subject was placed in a restraint harness and suspended in a seated position, the impactor was centred 8 cm anterior to the great trochanter. A triaxial accelerometer measured pelvic accelerations at sacrum level, a second one measured accelerations at great trochanter level. A film analysis was also made.

Chamouard et al. (1993) [19]

Chamouard conducted static and dynamic tests on pelvis cadavers in order to evaluate lateral protection with 1D simulation. 7 subjects were used on which 17 dynamic tests and 2 static tests were conducted. Some of the dynamic tests were performed with a 23.4 kg impactor mass and a disc impacting surface of 15 cm diameter. The rest of the tests were performed with a 24 × 24 cm surface. The impactor surface was rigid. Three different velocities were tested: 4.4 m/s, 6.7 m/s and 9.3 m/s. The impacting surface was approximately centred on the great trochanter. The tests with the plate impacting surface also loaded the iliac crest. The static tests compressed the pelvis on one side with the 24 × 24 cm impacting surface whereas the opposite side is fixed. The impact was centred on the great trochanter. The cadavers were in lying position. The pelvic accelerations and the impactor acceleration were recorded.

LAB & INRETS (1994, 1998) [20] [21]

LAB and INRETS conducted several series of tests on pelvis with an impactor. The first series of tests on 10 cadavers were performed with a 23.4 kg impactor and an rectangular impacting surface (10-20 cm). The speed is ranged from 3.46 m/s to A second series of 11 tests were conducted on unembalmed cadavers between 1997 and 1998 by LAB and INRETS. All the cadavers were injured expect one. The cadavers were submitted to 90° impact direction. The impactor is centred on the great trochanter, but struck also the iliac wing. The impacting surface is separated in two parts which allow discovering the distribution of the applied force on the great trochanter and on the iliac wing. The impactor mass is 12 or 16 kg and 20×20 cm square surface. A triaxial accelerometer was attached to the sacrum, the applied force on pelvis was measured on the impactor, the deflection was measured by film analysis on half pelvis (distance between sacrum and pendulum).

<u>WSU/GMRL (1989) [15]</u>
See also thorax for remarks. Viano conducted 14 tests on 8 different unembalmed cadavers with a pendulum. Only two cases of pubic ramus fracture were obtained. These tests were done in order to determine the tolerance level for pelvis. The cadaver was suspended upright with hands and arms overhead. The cadavers were submitted to 90° impact direction centred on the great trochanter. The pendulum was 23.4 kg and a 15 cm diameter disc impacting surface, smooth and flat with edges rounded. A suspension system released the arms at impact. A triaxial accelerometer was attached to the pelvis region (S3). The impact force was calculated from the pendulum acceleration multiplied by the pendulum mass. The deflection was measured by film analysis on half pelvis (distance between sacrum and pendulum).

Femur Response

<u>Mather (1968) [22]</u>
Mather performed static and dynamic drop tests on fresh unembalmed adult femurs. The femur was supported at both ends, and loaded at its centre on its anterior surface.

<u>Pritz (1975) [23]</u>
Pritz studied impact between a pedestrian and the front of a vehicle in side impact. 15 tests were performed at velocities between 4.4 to 13 m/s. The cadaver leg is fully extended and 90 % of the body weight was supported by the leg closest to the vehicle. The frontal portion of the impacting vehicle is simulated by 2 impactors for the hood edge and the bumper. Horizontal and vertical ground reaction force, bumper and hood impact force, and pelvic acceleration were recorded. The impactor height and impacting surface were different to simulate different vehicle front portions. Injuries to the cadavers were recorded.

<u>Melvin (1975) [24]</u>
Melvin performed impactor tests on seated unembalmed cadavers. The impactor was with a limited displacement. The impacting mass was 20.9 kg. The striker was a 15.2 cm-diameter rigid disc covered with a 2.5 cm Ensolite padding. To prepare cadavers, a longitudinal incision in the soft tissue of the upper leg to the distal end of the femur was performed. Strain gauges were struck on the femur at 10.2 cm

from the distal ends. Afterwards the cadavers were after seated on a sliding surface in front of the impactor with the thigh in a horizontal position and in line with the impactor axis. The knee is flexed to 90°. In some tests, the thigh was abducted relative to the axis to perform oblique frontal impacts, or abducted and the cadaver oriented such that the impact axis was along the femoral axis rather than the antero-posterior axis of the cadaver. A total of 31 impact tests were conducted on 14 cadavers. The velocity ranged from 6 to 11 m/s.

<u>Porta (1994) [25]</u>
Porta conducted tests on embalmed cadavers. Stalnaker et al. [ ] demonstrated in 1976 that "the unembalmed skeletal system of the lower extremities is capable of carrying significantly greater loads than those determined in tests with embalmed subjects". They used an accelerator that propelled a cart headed by a 10 cm^2 section of pipe with a 4.13 cm outside diameter, or a 2.5×10 cm plate. The thighs were mounted in two test configurations that simulated a standing or a seated position. For the standing tests, the thighs were supported perpendicular to the impact and the lateral surface of the midshaft was impacted. For the seated position, the femur was suspended by a cord with the long axis placed parallel to the impact plane. The condyle of the femur was impacted (a mass simulated the upper body).

<u>Kress (1990) [26]</u>
Kress performed tests on human cadaver legs with a pneumatic impactor. The impactor was made of a cart accelerator system, the specimen holding device and the impactor support cart. Tests on human cadaver legs, tibias, femurs, goat and horse legs were performed with different impactor shapes. The impactor velocity, force, cart acceleration, bone dimension and end damage state were measured. A series of femur lateral impacts were conducted on 12 femurs with 4.12 cm diameter pipe and on 1 femur with a flat plate. Force levels of fracture were investigated. Antero-posterior tests were performed on tibias.

Full Body Response

<u>APR drop tests (1980-1986) [27] [28] [29]</u>
The full body drop tests performed by APR consisted of suspending the PMHS horizontally by means of ropes around the body linked onto a single point release mechanism. The PMHS's were allowed to free fall onto a range of test surfaces, some of which covered the shoulder area, with arms in different orientations with respect to the thorax. Separate programmes were run for head [27], shoulder/thorax /abdomen [28] and pelvis [29]. Published photographs of the test set up show that shape of the body was badly distorted due to the displacement of visceral contents under gravitational effects, such that the lower or struck side, portion of the body was much distended. Thus the inertial mass and body shape on the struck side was not equivalent to the live human.

HSRI / University of Heidelberg sled tests (1983) [30] [31]

A number of tests have been performed in which the whole body, arm, shoulder, thorax, abdomen and pelvis have been simultaneously impacted. The initial sled based tests were performed at the Highway Safety Research Institute and further tests were performed at the University of Heidelberg. It is against this latter data that the current range of side impact dummies have been developed. Since then other similar tests into other structures with enhanced force measuring capability

WSU sled tests (1990-1992) [32] [33]

WSU performed 17 sled tests using a HYGE sled and a Heidelberg-type seat fixture. The velocity of the sled ranged from 6.7 m/s to 10.5 m/s. The cadaver impacted a side wall which could have 3 different characteristics : a flat rigid wall, a rigid wall with 15.24 cm pelvic offset, or a flat padded surface. The sled was accelerated and rapidly decelerated , so that the cadaver would continue to slid laterally into the wall. The cadaver pelvis was instrumented with a triaxial accelerometer. The impacted wall was instrumented with two load cells to measure impact force at pelvis level. Zhu & Cavanaugh (1993) [34] realised additional tests in same conditions as WSU sled tests.

Appendix B Head Test 1

Test Set-up - The original test by Hodgson and Thomas [4] is reproduced using only the dummy's head. Position the head with a 200 mm space between it and a flat, rigid horizontal surface. Place the head so that its mid-sagittal plane makes an angle of 35° with the impact surface and its a-p axis is horizontal. Drop the head using a quick-release mechanism.

Instrumentation - Instrument the dummy's head with a triaxial accelerometer located at the head CG. Attach a second triax within the head cavity to the non-impacted side at a point on the transverse that passes through the head CG. Filter the accelerations according to SAE Recommended Practice J211.

Response Requirement - The dummy head should meet the following response requirement :

Head peak resultant acceleration at non-impact side between 100 and 150 G

Appendix C Head Test 2

Test Set-up - Dummy in seated posture without support.

Instrumentation - Instrument the dummy's head with a triaxial accelerometer located at the head CG. Filter the accelerations according to SAE Recommended Practice J211.

Response Requirement - The dummy head should meet the following response requirement: the peak impactor force for 2.0 and 5.5 m/s impact respectively should lie within the force/duration windows defined in Figure 1.

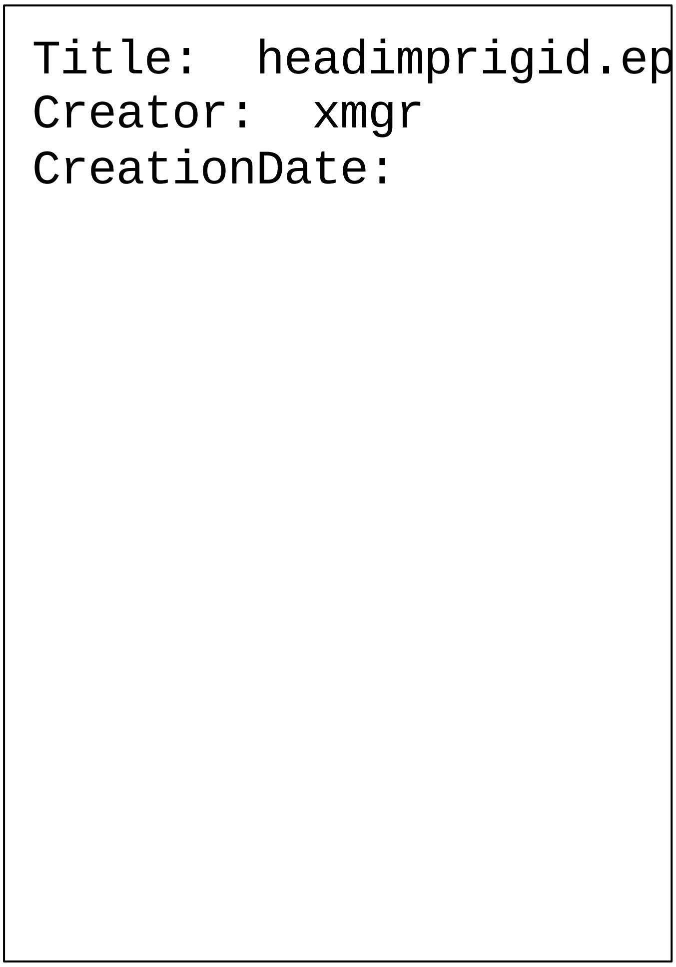


Figure 1: Non-fracture response of head for impact with rigid impactor.

Appendix D   Neck Test 1

Test set-up - To reproduce the original NBDL test set-up, fasten a rigid chair, functionally similar to the one used by Ewing et al [9] to a HYGE sled, facing sideways to the direction of sled travel. Attach a vertical side board to the seat to restrict upper torso rotation and to support the torso during sled translation. The top of the side board should be 40 to 50 mm below the top of the dummy's shoulder. Seat the dummy upright with its shoulder and hip against the side board and the anterior-posterior axis of its head horizontal. Position the dummy with its mid-sagittal plane vertical and perpendicular to the direction of sled travel. The thorax movement is to be restrained with a strap attached to the back of the seat to limit shoulder forces. The pelvis is to be restrained by a lap belt and an inverted 'V' pelvis strap tied to the lap belt. Both arms should be positioned alongside the thorax and restrained with suitable straps. The anterior-posterior axis of the head is to be horizontal. The sled acceleration and the measured T1 lateral acceleration should lie within the corridors specified in Figure 2 and Table 1. The sled velocity should be 6.9 ± 0.2 m.s^{-1}.

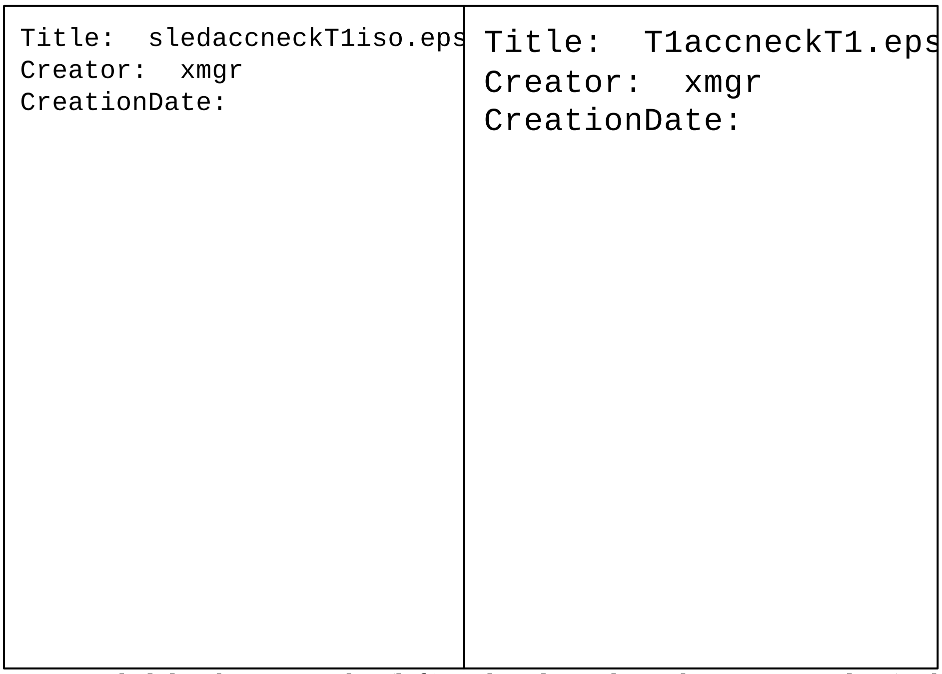


Figure 2: Sled deceleration pulse (left) and T1 lateral acceleration corridor (right) for 7.2 G test.

Table 1: Neck Test Sled (left) and T1 lateral (right) Acceleration Corridors.

Time (ms)	Upper (g)	Lower (g)
35		-1.0
57	-1.0	
71		-7.3
95	-6.7	
125		-7.3
144	-4.4	
161	-1.0	
169		-4.6
184		-1.0

Time (ms)	Upper (g)	Lower (g)
t	0.0	-0.5
t+5		-0.5
t+15	0.0	
t+35		-5.0
t+43	-5.5	
t+52	-13.0	-17.0
t+67	-4.0	-10.0
t+145	0.0	
t+150		-7.0

Note: Since neck biofidelity is considered, the T1 lateral acceleration is of more importance than the sled deceleration, therefore slight deviations in sled acceleration from the corridor can be tolerated provided the T1 lateral acceleration meets the corridor. Alternatively to the above procedure, the T1 acceleration time history can be used as input in an isolated head-neck assembly test on a (mini) HYGE sled.

Instrumentation - Instrument the dummy with triaxial accelerometers at the centres of gravity of the head and chest, a uniaxial accelerometer at the base of the neck with its sensitive axis directed laterally, and a six-axis neck transducer at the neck to head interface (at the level of the occipital condyles). In place of the six-axis neck transducer, the dummy's head may be instrumented with sufficient accelerometers to calculate the reactions at the head to neck interface. Use photographic targets to monitor the translation of the centre of gravity of the head, lateral head rotation, head twist and horizontal translation of the base of the neck. Measure the sled acceleration and record the required dummy displacements with onboard cameras. Filter all response data according to the requirements of SAE Recommended Practice J211.

Response Requirement - The dummy should meet the following response requirements:

Head CG peak horizontal displacement rel. to T1	between 130 and 162 mm
Head CG peak vertical displacement rel. to T1	between 64 and 94 mm
Time of peak head excursion	between 0.159 and 0.175
Head horizontal acceleration versus time	meet corridor in Figure 3
Head vertical acceleration versus time	meet corridor in Figure 3
Peak lateral flexion angle	between 44° and 59°
Peak twist angle	between -45° and -32°
Peak lateral bending moment at the O.C.	between 30 and 50 Nm
Peak torsion twist angle at the O.C.	between 15 and 26 Nm

Appendix D

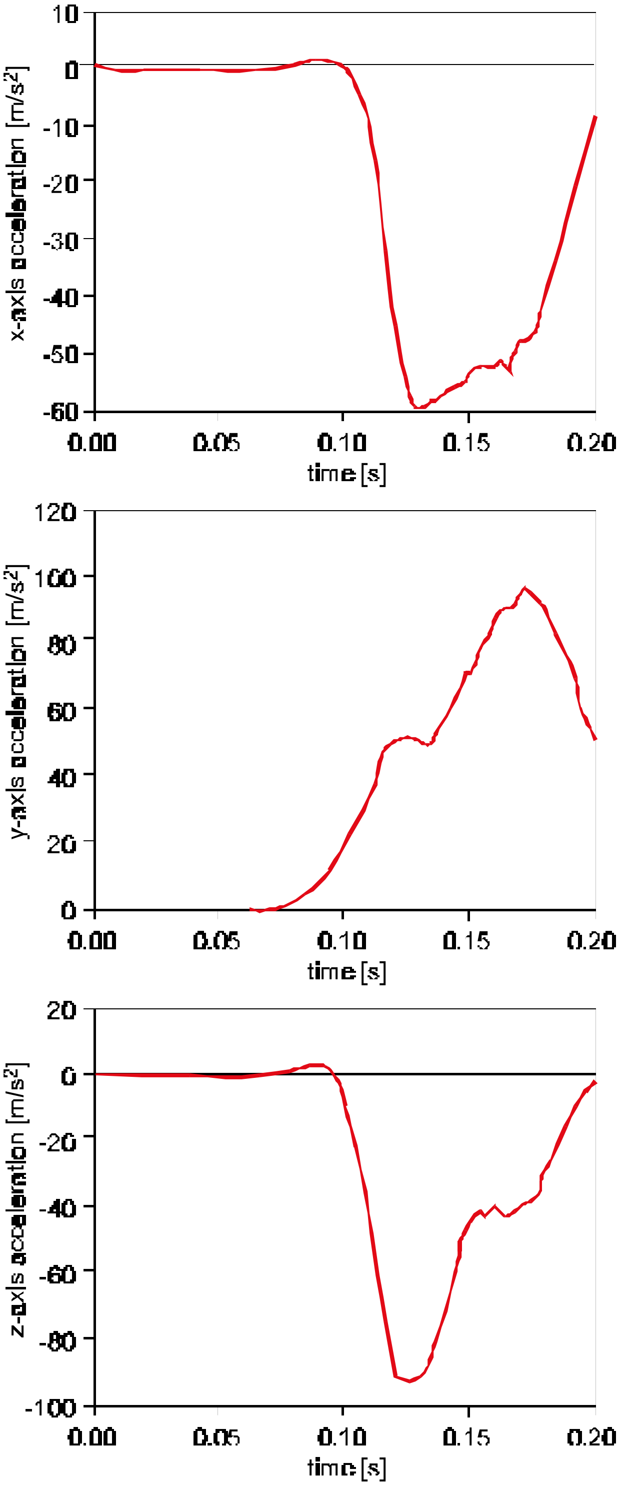


Figure 3: Mean head CG acceleration versus time histories: components in head local x and (y and) z direction.

Appendix E Shoulder Test 1

<u>Test Set-Up</u> - The shoulder impactor test shall be performed on a complete dummy using a linearly guided impactor. The impactor mass shall be 23.4 kg with a smooth flat face 6" diameter, the edge of the impact face being relieved with a 6mm radius. The dummy shall be seated upright with no additional lateral supports on a flat horizontal rigid surface with the legs straight and parallel. The arms shall be positioned parallel to the thorax. The axis of the impactor shall be aligned with the shoulder pivot ∀ 10 mm and at 90E to the mid sagittal plane. Impact velocity at the point of impact shall be 4.5 m/s ∀ 0.1 m/s.

<u>Instrumentation</u> – For/aft impactor acceleration shall be measured according to CFC 180. Photographic targets should be fixed to the impactor and the dummy upper thoracic spine to calculate the shoulder deflection relative to the spine from high speed film. The external shoulder displacement is defined as the lateral displacement of the face of the impactor relative to the upper thoracic spine perpendicular to the anterior posterior axis of the dummy. Impactor acceleration shall be normalised according to the procedure described in the Appendix based on a thorax standard mass (M_s) of 20.5 kg.

<u>Requirements</u> – The maximum normalised shoulder deflection relative to the thoracic spine has to be at least equal to 32 mm. The normalised force time response has to be within the corridor described below.

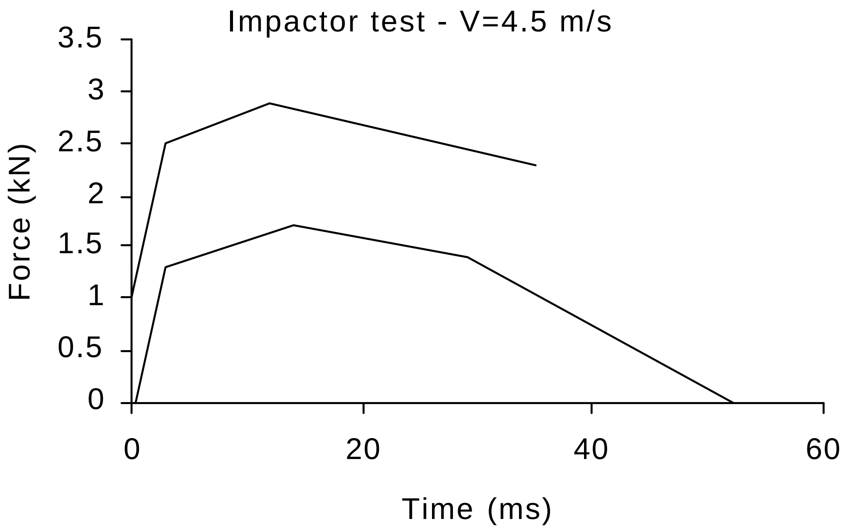


Figure 3 : Shoulder force/time corridor – Impactor mass=23.4 kg, Velocity =4.5 m/s

Table 2 : Shoulder impactor force corridor co-ordinate

Time (ms)	Lower limit (kN)	Upper limit (kN)
0		1.0
0.5	0	
3	1.3	2.5
12		2.9
14	1.7	
29	1.4	
35		2.3
52	0	
60		0.7

Quasi-static motion shoulder targets

Table 3: Quasi-static motion of the shoulder complex, measured at the centre of the glenohumeral joint.

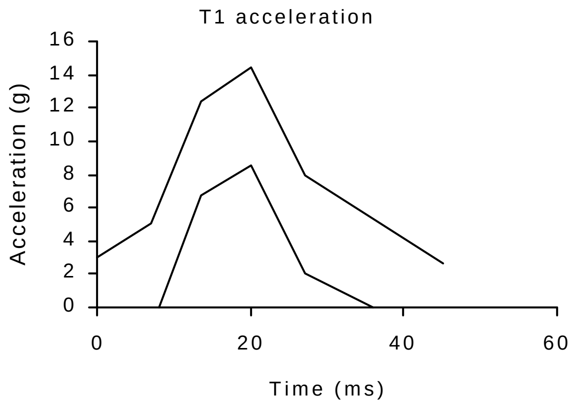
Shoulder motion	Design target
Forward motion (x) (protrusion)	50-100 mm
Rearward motion (x) (dorsi-trusion)	100 mm
Elevation (z)	20° with respect to the sternoclavicular joint
Depression (z)	10° with respect to the sternoclavicular joint

Appendix F Thorax Test 1

Test Set-Up – The impactor test shall be performed on a complete dummy using a linearly guided impactor. The impactor shall have a mass of 23.4 kg and a smooth flat face 6” diameter. The dummy is seated upright with no additional lateral support on a flat horizontal rigid surface with the legs straight forward and parallel. Both arms shall be positioned vertically upright above the head. The axis of the impactor shall be aligned with the centre of the rib cage (vertically and laterally), at 90° to the mid-sagittal plane. Impact velocity shall be 4.3 m/s ∀0.1m/s.

Instrumentation –The fore/aft impactor acceleration and the T1 lateral acceleration shall be measured according to CFC 1000 and filtered with a 100 Hz Finite Impulse Filter (FIR). Data shall be normalised according to the procedure described [3], annex 2.3 based on a thorax standard mass of 29.6 kg.

Requirements – Impactor deceleration and dummy T1 acceleration shall be within the corridors described below.



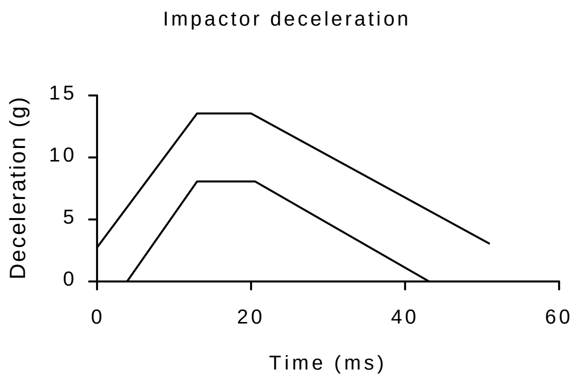


Figure 4 : Thorax impactor acceleration and thorax T1 lateral acceleration – M=23.4 kg, Velocity =4.3 m/s

Appendix F

Table 4 : Thorax impactor deceleration corridor co-ordinates

Time (ms)	**Lower limit (g)**	**Upper limit (g)**
0		2.0
5	0	
15.5	8	13.5
24		13.5
24.5	8	
50	0	
58		3.0

Table 5 : Thorax impactor T1 acceleration corridor co-ordinates

Time (ms)	**Lower limit (g)**	**Upper limit (g)**
0		3.0
8		5.0
9	0	
15.5	6.5	12.5
21.5	8.9	14.8
31.5	1.7	7.5
40.5	0	
54		2.7

Appendix G Thorax Test 3

Test Set-Up –The whole body tests can be performed on either a standard deceleration impact sled or on a HYGE impact sled. The sled must be fitted with a rigid vertical impact wall onto which two force measuring plates are fitted. Perpendicular to the rigid wall a rigid low friction bench seat is attached, in line with the motion of travel of the sled. The dimensions of the test seat and force measuring load cells are given in Figure 15. (The sliding test seat used by the University of Heidelberg for the cadaver tests was 1.5 m in length.) Since precise positioning of the horizontal slats is not available, the slats can be replaced by an alternative low friction surface for dummy testing. The dummy must be supported vertically on the non struck side during the acceleration phase of a non HYGE impact sled. The arms of the dummy are to be placed alongside the thorax (0E). Impacts are to be performed into the rigid wall at two impact velocities 7.6 and 10.3 m/s. One further test is to be performed at 10.3 m/s into the same wall onto which two foam blocks are mounted. Impact velocity tolerance shall be ∀ 0.1 m/s. The specified impact velocity includes any rebound velocity that may exist with a deceleration type sled. On both types of test sled the dummy must strike the wall at the prescribed velocity. The block specification is described in Section 3. The upper pad is to be located on the thorax force plate, the upper surface of the pad being in line with the top edge of the plate, parallel to the seat pan. The lower pad is to be located on the pelvis plate with the lower surface of the pad resting on the seat pan.

Note: It is advisable to restrain the legs from excessive lateral articulation after the dummy strikes the wall in order to prevent damage to the knee joints.

The padding specification in [2], Appendix I.

Instrumentation – Plate forces shall be measured at CFC 1000 and lateral dummy accelerations at T1 and at the pelvis CFC 180. The force measuring plates are to be inertialy compensated by placing an accelerometer in the centre of each force plate, its axis perpendicular to the surface of the plate. Data shall be normalised according to the procedure described in [3] annex 2.3 based on a thorax standard mass of 37 kg.

Requirements – Shoulder~~s~~ and thorax force/time corridors are specified for different speeds.

Appendix G

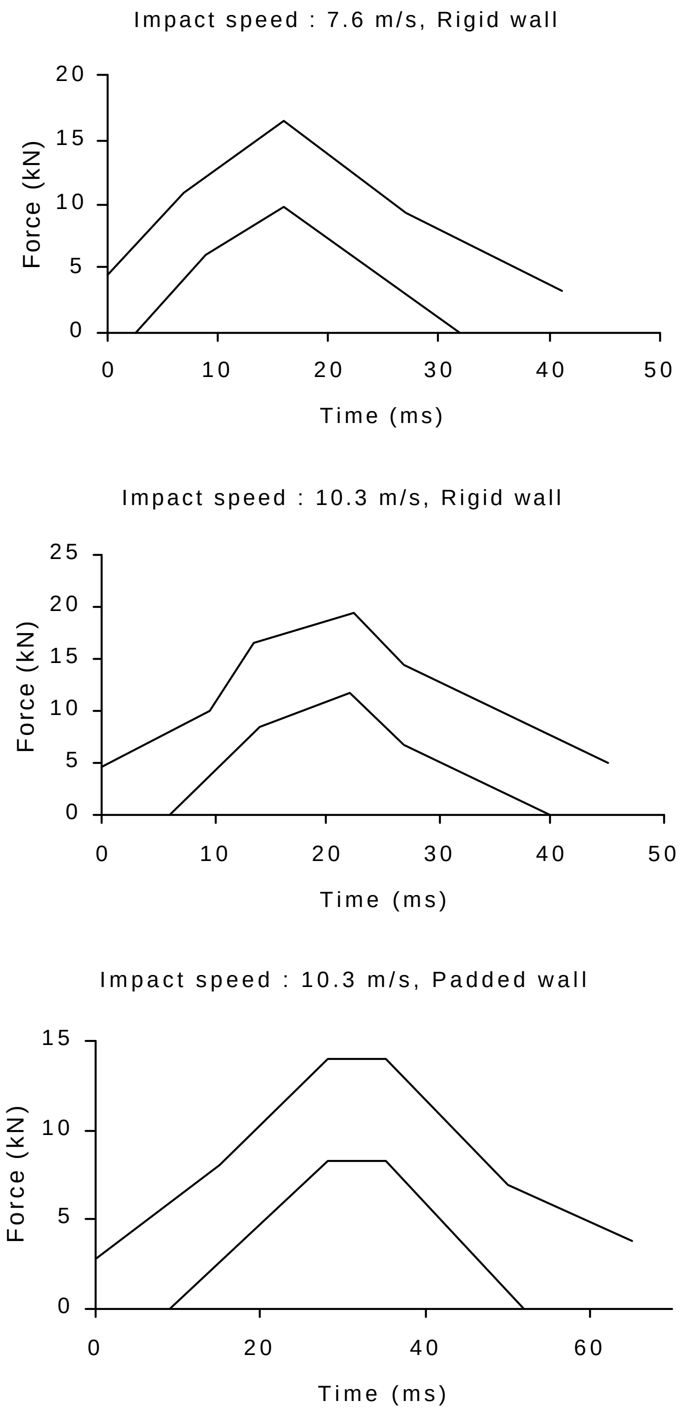


Figure 5 : Thoracic and Shoulder force/time corridors

Appendix G

Table 6 : Thoracic and shoulders rigid wall force corridor co-ordinates–Velocity=7.6 m/s

Time (ms)	Lower limit (kN)	Upper limit (kN)
0		4.5
2.5	0	
7		11.0
9	6.0	
16	9.8	16.5
27		9.25
32	0	
41		3.25

Table 7 : Thoracic and shoulders rigid wall force corridor co-ordinates;V=10.3 m/s

Time (ms)	Lower limit (kN)	Upper limit (kN)
0		4.5
6	0	
9.5		9.9
13.5		16.4
14	8.6	
22	11.75	
22.5		19.4
27	6.7	14.4
40	0	
45		5.0

Table: 8 Thoracic and shoulders padded wall force corridor co-ordinates – V=10.3 m/s

Time (ms)	Lower limit (kN)	Upper limit (kN)
0		2.8
9	0	
15		8.0
28	8.2	14.0
35	8.2	14.0
50		6.9
52	0	
65		3.7

Appendix H Abdomen Test 1

Test Set-Up - The dummy impacts a rigid side wall with no pelvic offset. A Hyge or decelerated sled can be used. The impact velocity should be 9 m/s. The wall geometry is shown below :

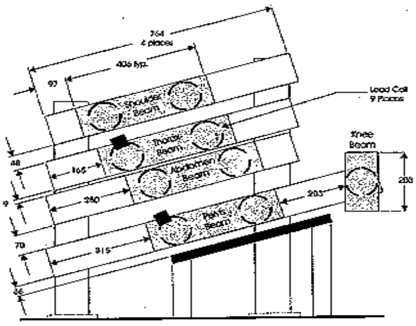


Figure 6 : WSU impact wall

The paper honeycomb used for padding is between 76 and 152 mm thick with a compression rating of 15 psi.

Instrumentation - Each wall plate is instrumented with two load cells to measure impact force at pelvis level and accelerometers to compensate plate inertia. Filter all the measurements according to SAE Recommended Practice J211. The pelvic deflection has to be measured to calculate the compression. Data shall be normalised according to the procedure described in [3], annex 2.3 based on a abdomen standard mass of 10.6 kg.

Requirements – Abdomen force/time corridors.

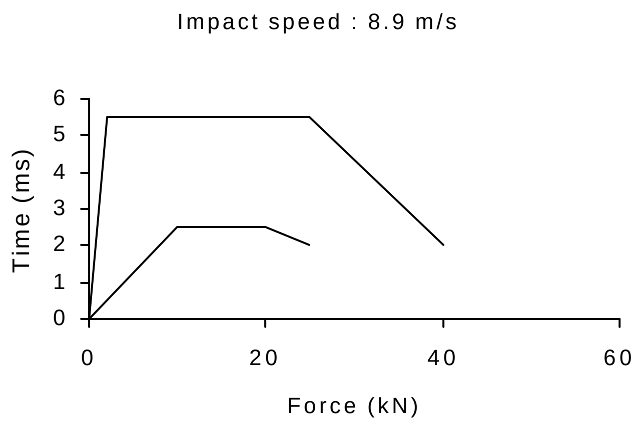


Figure 7 : Abdominal force/time corridor – Velocity = 8.9 m/s

Appendix H

Table 9 : Abdominal force/time corridor co-ordinates

Time (ms)	Upper (kN)	Lower (kN)
0	0	0
2	5.5	
10		2.5
20		2.5
25	5.5	2
40	2	

Appendix I Abdomen Test 2

Test Set-Up - The dummy is suspended upright with hands and arms overhead. As an alternative, if it is not possible that the dummy be upright because of pelvis design, the tests will be performed with the dummy seated on a flat, low friction surface. The dummy is submitted to pendulum impact centred at 7.5 cm below the xiphoid (15 cm below mid-sternum) and rotated 30°. The pendulum should weigh 23.4 kg and a 15 cm diameter disc impacting surface, which is smooth and flat with rounded edges.

Instrumentation - The impact force and the acceleration of the impactor have to be recorded to compensate impacting plate inertia ($F_{cadaver} = F_{plate} + M_{plate} \times Acc_{plate}$). The pelvic deflection has to be measured. Filter all the measurements according to SAE Recommended Practice J211. Data shall be normalised according to the procedure described in [3] annex 2.3 based on a abdomen standard mass of 26 kg for 4.8 m/s tests, 19.5 kg for 6.8 m/s tests and 20.5 kg for 9.4 m/s tests.

Requirements - Force/time corridors (M=23.4 kg, V=4.8, 6.8, 9.4 m/s)

Appendix I

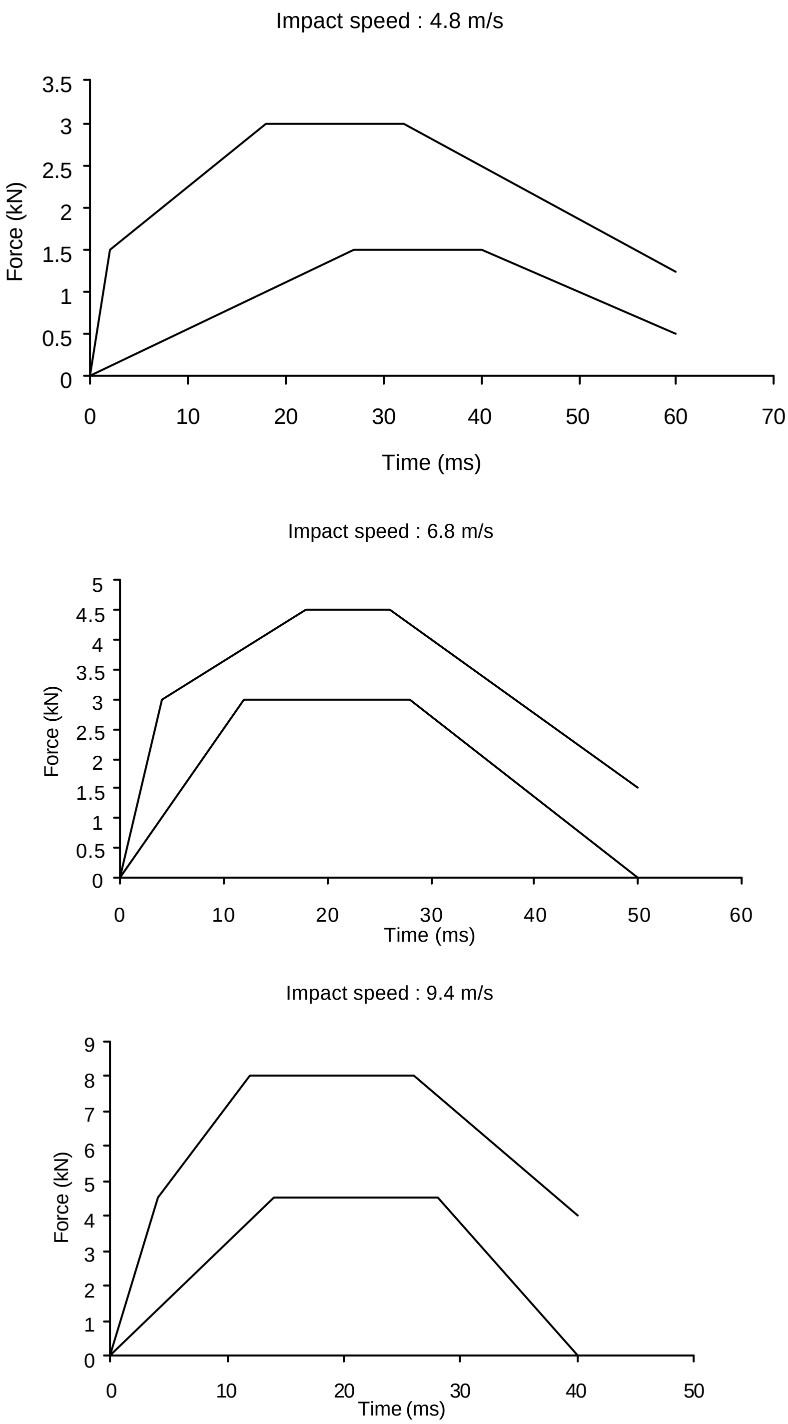


Figure 8: Abdominal force/time corridors – Impactor mass=23.4 kg, Impact velocity=4.8, 6.8, 9.4 m/s

Velocity=4.8 m/s

Time (ms)	Upper (kN)	Lower (kN)
0	0	0
2	1.5	
18	1.5	
27		1.5
32	3	
40		1.5
60	1.25	0.5

Velocity=6.8 m/s

Time (ms)	Upper (kN)	Lower (kN)
0	0	0
4	3	
12		3
18	4.5	
26	4.5	
28		3
50	1.5	0

Velocity=9.4 m/s

Time (ms)	Upper (kN)	Lower (kN)
0	0	0
4	4.5	
12	8	
14		4.5
26	8	
28		4.5
40	4	0

Table 10 : Abdominal force/time corridor co-ordinates

Appendix I

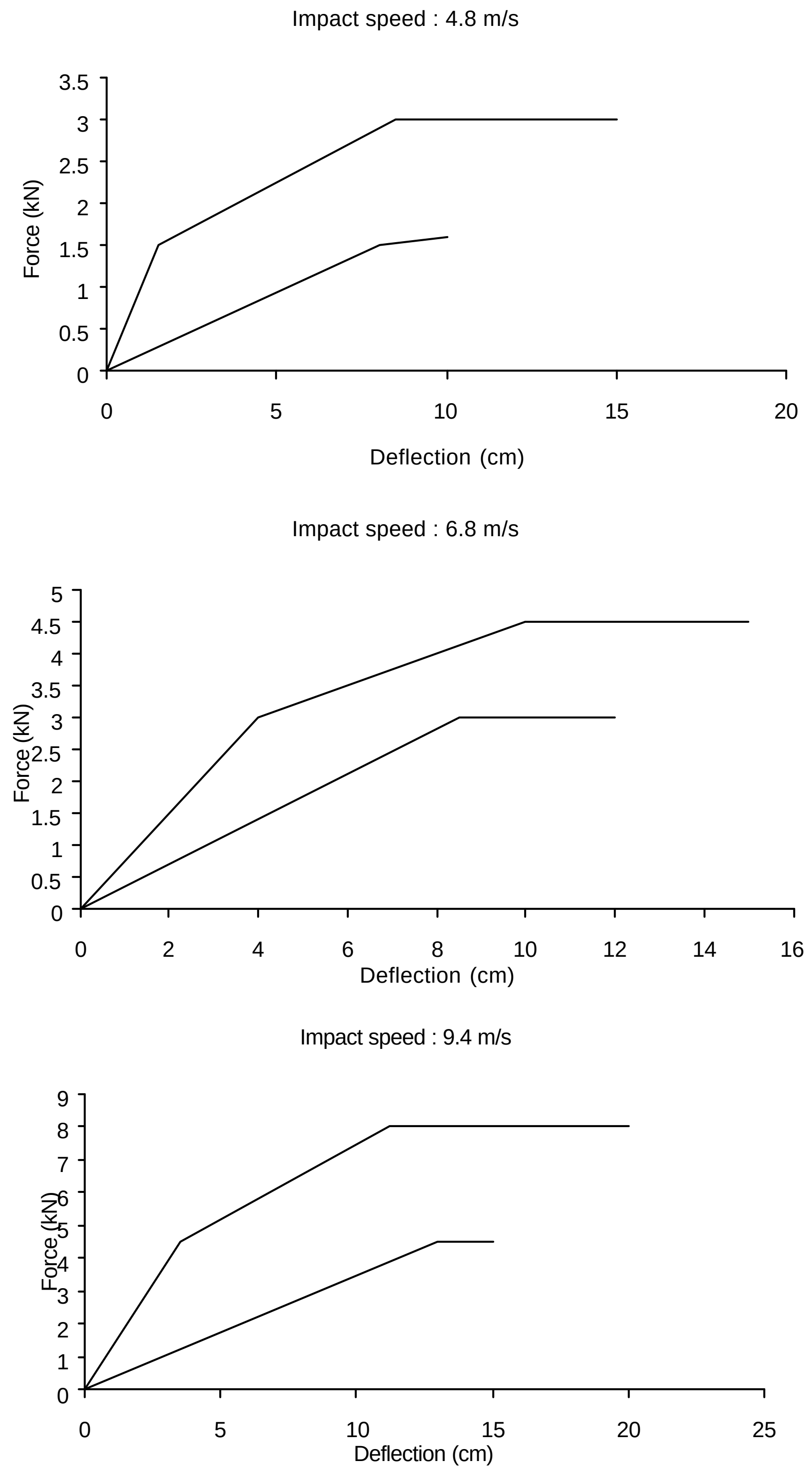


Figure 9: Abdominal force/deflection corridors – Impactor mass=23.4 kg, Impact velocity=4.8, 6.8, 9.4 m/s

Velocity=4.8 m/s

Deflection (cm)	Upper (kN)	Lower (kN)
0	0	0
1.5	1.5	
8		1.5
8.5	3	
15	3	

Velocity=6.8 m/s

Deflection (cm)	Upper (kN)	Lower (kN)
0	0	0
4	3	
8.5		3
10	4.5	
12		3
15	4.5	

Velocity=9.4 m/s

Deflection (cm)	Upper (kN)	Lower (kN)
0	0	0
3.5	4.5	
11.2	8	
13		4.5
15		4.5
20	8	

Table 11: Abdominal force/deflection corridor co-ordinates

Appendix J   Pelvis Test 1

Test Set-Up - The dummy is kept in a sitting position on a flat surface on which it can slide. It is submitted to a 90° impact centred on the great trochanter. The pendulum must be 23.4 kg and the impacting surface must be a 15 cm diameter disc, which is both smooth and flat with rounded edges.

Instrumentation – Impactor initial velocity, impactor acceleration, pelvic applied force and pelvic deflection have to be recorded. The deflection is measured between a target placed on the sacrum and another one placed on the pendulum. Filter all the measurements with 180 Hz FIR filter. As initial cadaveric data were not normalised, dummy data will not be normalised too.

Requirements – The force, the peak acceleration and the deflection should fall into the corridors shown below.

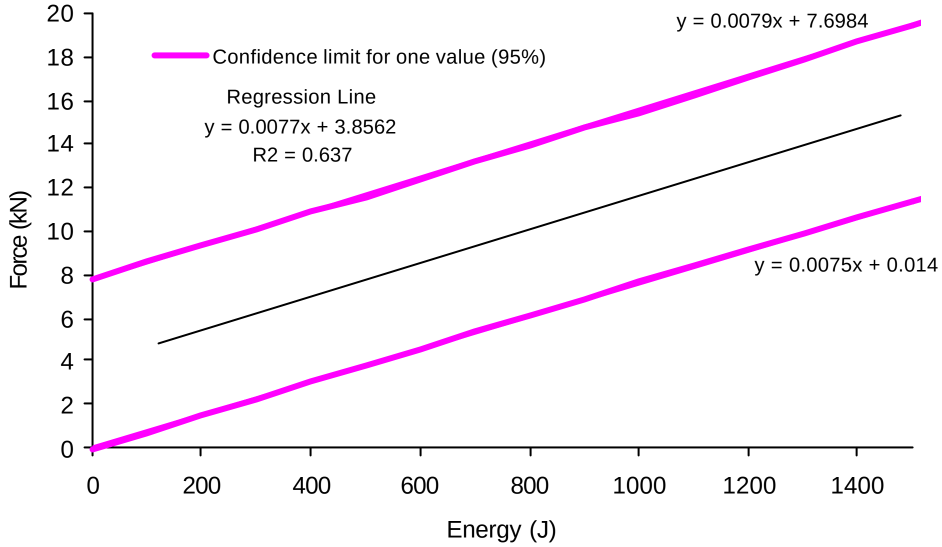


Figure 10: Maximum applied force versus impact energy

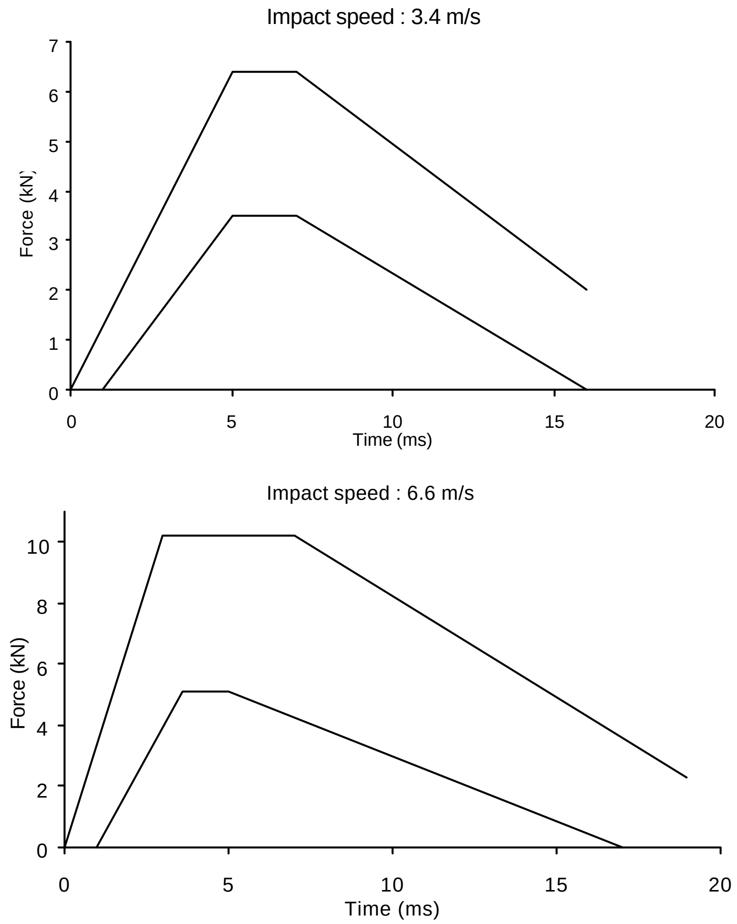


Figure 11 : Pelvic force/time corridors – Impactor mass=23.4 kg, Impact velocity=3.4, 6.6 m/s

Velocity = 3.4 m/s

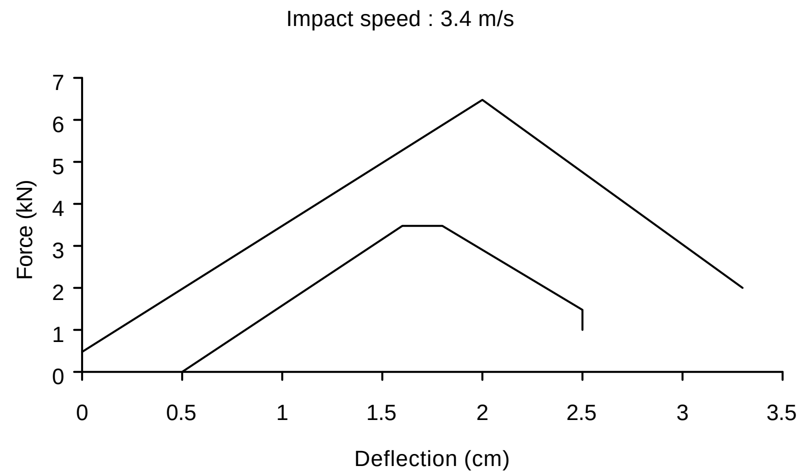
Time (ms)	Upper (kN)	Lower (kN)
0	0	
1		0
5	6.4	3.5
7	6.4	3.5
16	2	0

Velocity =6.6 m/s

Time (ms)	Upper (kN)	Lower (kN)
0	0	
1		0
3	10.2	
3.6		5.1
5		5.1
7	10.2	
17		0
19	2.3	

Table 12 : Pelvic force/time corridor co-ordinates

Appendix J



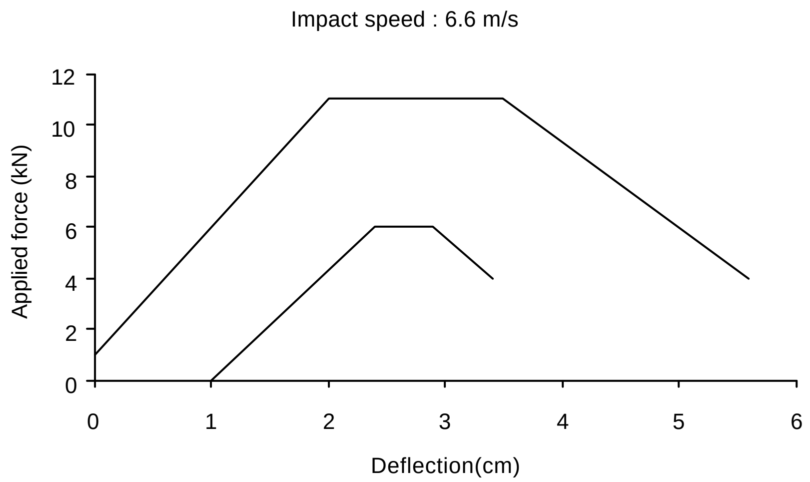


Figure 12 : Pelvic force/deflection corridors – Impactor mass=23.4 kg, Impact velocity=3.4, 6.6 m/s

Velocity=3.4 m/s

Deflection (cm)	**Upper (kN)**	**Lower (kN)**
0	0.5	
0.5		0
1.6		3.5
1.8		3.5
2	6.5	
2.5		1.5
2.5		1
3.3	2	

Velocity=6.6 m/s

Deflection (cm)	Upper (kN)	Lower (kN)
0	1	
1		0
2	11	
2.4		6
2.9		6
3.4		4
3.5	11	
5.6	4	

Table 13 : Pelvic force/deflection corridor co-ordinates

	Boundaries for the peak impactor force (kN)	Boundaries for the peak resultant pelvic acceleration (g)
3.4 m/s test	4.9 (±1.2)	34 (±8.5)
6.6 m/s test	9 (±2.2)	62 (±15)

Appendix K Pelvis Test 2

Test Set-Up - The dummy is seated on a low-friction bench, at 1 m from a vertical wall. A Hyge or decelerated sled should be used. The velocity of the sled is 7.6 m/s or 10.3 m/s taking into consideration the rebound velocity. When the sled stops, the dummy slides into the rigid wall. The wall used is described below and in [3].

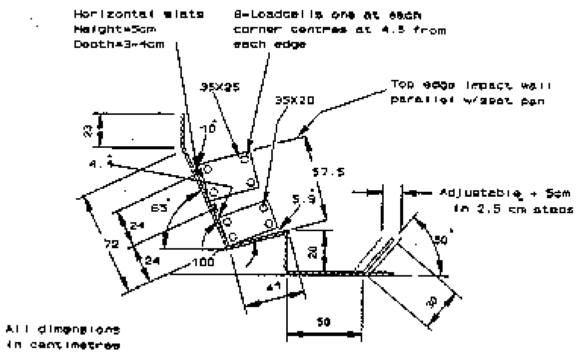


Figure 13 : Heidelberg wall impact

For the 10.3 m/s padded tests, , the APR paddings will be used. It is polyurethane foam blocks of 140×140×420 mm with a density of 135-150 gm/l. The quasi-static force/deflection characteristics (with a loading rate of 100 mm/min) are shown in [2] appendix I.

Instrumentation – Each wall plate is instrumented with four load cells to measure the applied force. Each load cell is also equipped with an accelerometer to compensate plate inertia. The initial cadaver data were filtered using a 100 Hz FIR filter as the cadaver data. If this filter is not available, data shall be filtered according to the SAE J211 recommendation. Data shall be normalised according to the procedure described in [3] annex 2.3 based on a pelvis standard mass of 14.5 kg.

Requirements - Peak impact forces measured on the wall should be within the corridors.

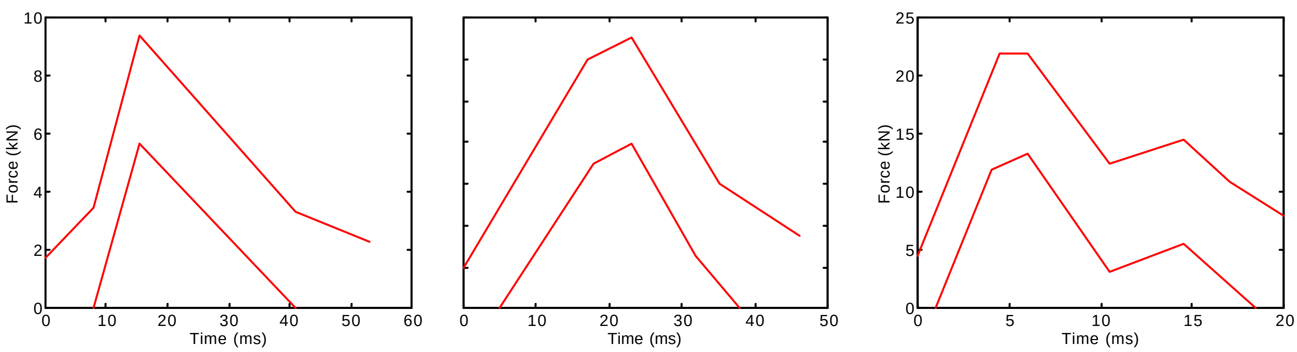


Figure 14: Pelvic force/time corridors - Lower wall force-time 7.6 (rigid), 10.3 (rigid), 10.3 (padded) m/s

Table 14 : Pelvis rigid wall force corridor coordinates – Velocity=7.6 m/s

Time (ms)	Lower (kN)	Upper (kN)
0		1.75
8	0	3.5
15.5	5.7	9.4
41	0	3.3
53		2.25

Table 15 : Pelvis rigid wall force corridor coordinates – Velocity=10.3 m/s

Time (ms)	Lower (kN)	Upper (kN)
0		2
5	0	
17		12
18	7	
23	7.9	13.1
32	2.5	
35		6
38	0	
46		3.5

Table 16 : Pelvis padded wall force corridor coordinates – Velocity=10.3 m/s

Time (ms)	Lower (kN)	Upper (kN)
0		4.5
1	0	
4	12	
4.5		22
6	13.25	22
10.5	3.2	12.5
14.5	5.5	14.5
17		11
18.5	0	
20		8

Normalised pelvis acceleration at 7.6 m/s against a rigid wall : 52.7 – 87.9 g
Normalised pelvis acceleration at 10.3 m/s against a rigid wall : 79.5 -132.5 g
Normalised pelvis acceleration at 10.3 m/s against a padded wall : 65.8 –109.7 g

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Appendix L Pelvis Test 3

Test Set-Up - The dummy impacts a rigid side wall with no pelvic offset. A Hyge or decelerated sled can be used. The impact velocity should be 6.7 m/s or 9 m/s. The wall geometry is shown below :

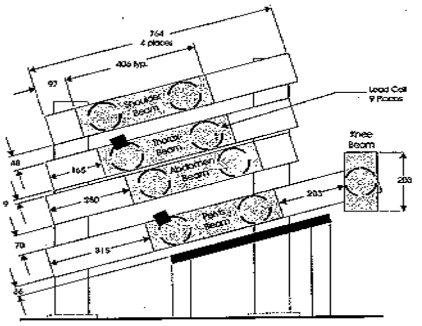

Figure 15 : WSU impact wall

Instrumentation - Each wall plate is instrumented with two load cells to measure impact force at pelvis level and accelerometers to compensate plate inertia. Filter all the measurements according to SAE Recommended Practice J211. The pelvic deflection has to be measured to calculate the compression. The compression is calculated as follow : C=D/W×100, where D is the pelvic deflection of the struck side and W is the half pelvic width. Data shall be normalised according to the procedure described in [3] annex 2.3 based on a pelvis standard mass of 17.1 kg.
Requirements – Pelvic force/time and compression/time corridors defined as plus or minus average standard deviation.

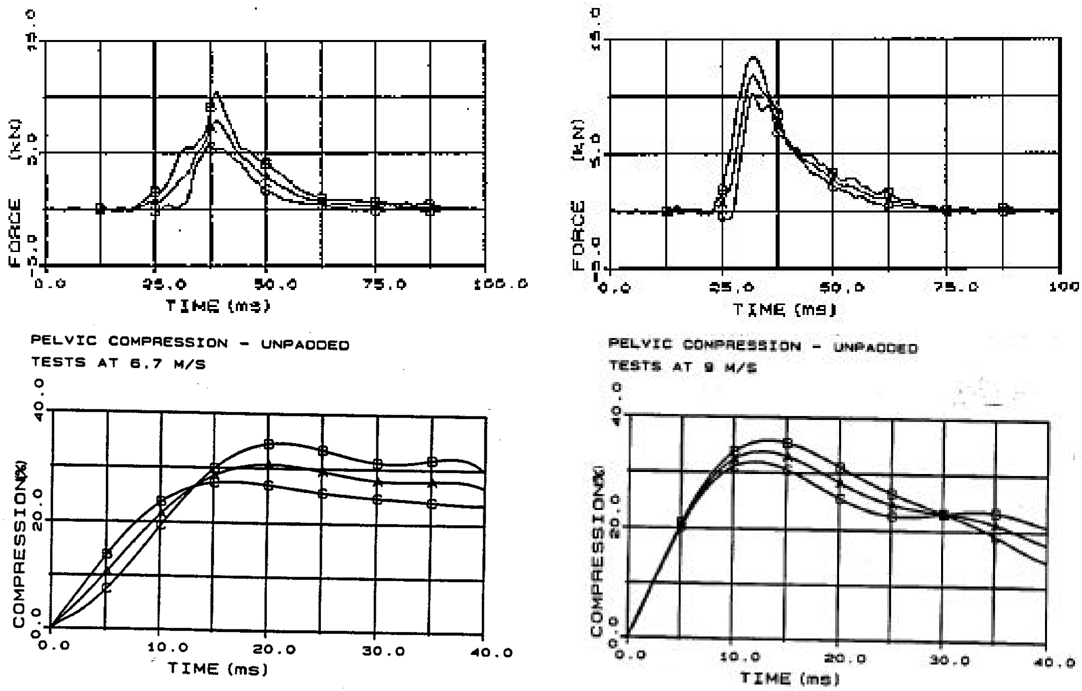

Figure 16 : Pelvic force/time and compression/time corridors – Sled tests at 6.7 and 9 m/s

Appendix L

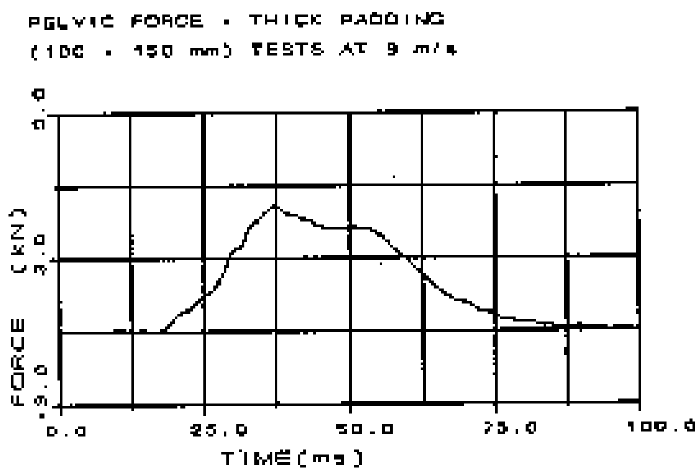

Figure 17 : Pelvic force/time target – Sled test at 9 m/s with thick padding

6.7 m/ rigid impact :
Maximum pelvic acceleration : 83 g
Maximum pelvic compression : 31%

8.9 m/s rigid impact :
Maximum pelvic acceleration : 74 g
Maximum pelvic compression : 31%

8.9 m/s padded impact (thick padding):
Maximum pelvic acceleration : 53 g
Maximum pelvic compression : 34%