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Working Group 12 Report

Status of Side Impact Dummy Developments in Europe
ES-2 Prototype Development

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Abstract
This document reviews the status of side impact dummy developments in Europe. Side impact harmonisation, new restraint systems and higher levels of required occupant protection in side impact are the incentive for intensified research and development work in this area. Recently the prototype of an upgraded EUROSID-1 dummy, called ES-2, became available for evaluation. This document gives some background and evidence for the modifications to EUROSID-1 incorporated in the ES-2 prototype dummy. Also, recommendations for further research are given.

1. INTRODUCTION

With the introduction of the European Directive 96/27/EC "Protection of Occupants of Motor Vehicles in the Event of a Side Impact", the European Union set an important step in reducing the injury problem in road traffic. The current adult side impact dummy EUROSID-1, which is used in the test procedure of the European Directive, has been developed during the eighties by five research organisations within the European Experimental Vehicles Committee (EEVC). Its biofidelity has been assessed by comparing its performances to the available biomechanical data. Further tests confirmed its durability, reproducibility and repeatability so that the "Specification of the EEVC side impact dummy EUROSID-1" were approved and published in 1989. Since then, car manufacturers and research laboratories in Europe gained experience in the use of the EUROSID-1 dummy which was recognised as incorporating important features and measurement tools.

Since the development of the EUROSID-1, discussions and research on side impact protection have continued on a world-wide level, especially concerning the crash test dummies used in side impact compliance testing. These -ongoing- discussions concentrate on the following issues:

- The need to harmonise side impact dummies world-wide in order to reduce the development efforts and costs required by manufacturers of cars and restraint systems to comply with different standards specified in different areas of the world;
- The level of biofidelity, i.e. the resemblance of a crash dummy to actual human impact response data, of existing side impact dummies and the biomechanical data used to evaluate their biofidelity;
- Current dummy design enhancements and the appropriateness of dummy designs to evaluate recently introduced restraint systems, such as side airbags, or future restraints;
- The transition from dummy responses in crash tests to the reduction in injury risk, hence specifying the protection performance of cars and restraints.

To this background a number of activities have been initiated in Europe that will be discussed in this document. The objective is to map out Europe's current involvement in improving the assessment of side impact protection (as far as the crash test dummy is concerned) and to identify the role of the European Experimental Vehicle Committee.

2. EUROPEAN SIDE IMPACT DUMMY (EUROSID-1) DEVELOPMENTS

EUROSID is the EURopean Side Impact Dummy and has been developed in four European countries under auspices of the former EEVC WG 9. EUROSID-1 is the production version of the dummy and the successor to the prototype dummies manufactured during 1987/9. The EUROSID-1 is essentially the same as the production prototype apart from some minor design and biofidelity enhancements. The European Directive 96/27/EC on side impact that has gone into effect on October 1st, 1998, specifies the EUROSID-1 dummy as the injury assessment device to be used in the test procedure.

The design and performance of the EUROSID-1 dummy has in principle not been changed since September 1990. The time has come, however, to review the specifications of the side impact dummy in the light of the level of side impact protection assessment required for the year 2000 and beyond. Specific reasons for this are:

- The criticisms made of the EUROSID-1 dummy expressed by its day-to-day users over the years on the design and/or performance of a number of parts of the dummy;
- The introduction of new restraint systems on the market such as side airbags, which existence was not taken into account when developing the EUROSID-1 but will be widely used in cars in the near future;
- The improved biomechanical knowledge available compared to that at the time when the EUROSID-1 was developed, both in terms of biofidelity as real-world accident data, and
- The ambition to use the EUROSID-1 dummy as the European development platform for the development of a single world-wide harmonised side impact dummy, and/or as an intermediate harmonised side dummy.

With the expansion of the EEVC WG12 mandate to cover all adult crash test dummies, it is this Working Group's responsibility to ensure that the crash dummy specified in the European Directive of the future will meet the required level of assessment of side impact protection. Therefore WG12 has initiated and guided the work in this area of research.

In the long term, the side impact dummy in Europe will be replaced by a "next generation" dummy, which development has already started under the umbrella of the ISO/TC22/SC12/WG5 "Anthropomorphic Test Devices". This WorldSID, for which enhanced biofidelity is an important starting point, is supported by the EEVC through participation in IHRA Biomechanics and Side Impact working groups. For the intermediate period, updates to the EUROSID have been proposed to address its main points of criticism.

The development of an updated EUROSID dummy, referred to as ES-2, so far has followed a two step approach. Initially, improved hardware parts have been developed in the neck, shoulder, thorax and pelvis area. These have been brought together in the so called "EUROSID-1 Research Tool Kit". At the same time, alternative certification procedures have been proposed for pelvis, abdomen and lumbar spine. The second step deals with the remaining issues. Of these, the most important issues are:

- The 'flat top' issue : internationally co-ordinated research should lead to a re-design of the EUROSID-1 rib module. Shoulder-arm and back plate are generally associated with the 'flat-top problem' which could lead to additional modifications of these dummy parts.
- The 'knee contact' issue as brought up by Volkswagen AG at the 14th EEVC WG12 meeting in Cologne. The occurrence of spikes in pubic symphysis readings as the result of leg to leg contact has been recently investigated by BASt. Further research efforts are necessary to be able to carry out hardware modifications to the EUROSID-1 legs.

- Neck certification procedure and criteria evaluation.

In addition to the Research Tool Kit, these issues have been addressed in the ES-2 prototype. The following gives a brief overview of the background to the EUROSID-1 modification programme.

2.1. EUROSID-1 MODIFICATIONS BASED ON USER CONCERNS

The European project SID-2000 compiled a list of dummy concerns, based on feedback from users in European, Japanese and the US markets. This list includes the items expressed by the American Automotive Manufactures Association, dealing with dummy design and calibration procedures, as part of their petition to NHTSA to adopt FMVSS 214. The following issues were presented at the 14th EEVC WG12 meeting in October 1997:

1. Mechanical issues:
   - ‘Flat tops’ at the peak of rib deflection data curves i.e. suspected rib binding;
   - Projecting backplate grabbing into seatback;
   - Bending of “flexible” plastic ilium of the pelvis;
   - Upper femur contact with pubic load cell hardware;
   - Clavicle binding in the shoulder assembly;
   - Lumbar spine ringing, and
   - Spikes in pubic symphysis readings attributed to knee tot knee contact.
2. Instrumentation issues:
   - Abdominal load cell update.
3. Certification issues:
   - Severity of abdominal certification test (too high);
   - Severity of pelvis certification test (too low), and
   - Input and output requirements for lumbar (and neck) certification tests.

Figure 1: ES-2 Prototype

In 1997 TNO started an extensive research programme to investigate most of the above concerns. From 1998 on, as part of the SID-2000 programme, a number of hardware parts have been re-designed, built, and validated to upgrade the EUROSID-1 dummy. In addition, the certification of neck, abdomen, pelvis and lumbar spine has been subject of evaluation leading to proposed new procedures for these body parts. The upgraded EUROSID-1 dummy does not necessarily fulfil the requirements of European Directive 96/27/EC or EC Regulation 95/0. Hence, awaiting possible update of the regulation, the dummy can only be used for research purposes. To emphasise this fact, the upgraded EUROSID-1 is referred to as ES-2 Prototype.

2.2. ES-2 PROTOTYPE DUMMY

The ES-2 Prototype dummy comprises modifications and procedure changes with respect to EUROSID-1 for the following body parts :

Design:

Hardware modifications

- Head: Upper neck load cell introduction for improved HIC assessment
- Neck: Buffer dislocation prevention and improved locking of spherical screw
- Shoulder: Coated low friction top and bottom plate and flexible clavicle
- Thorax: New rib module guide system that eliminates the flat top issue.
- Abdomen: T12 load cell between thoracic spine and abdomen
- Lumbar Spine: Minor structural changes for T12 load cell
- Pelvis: Abduction end stop buffer to prevent metal to metal contact
  Simplified and reduced size pubic load cell attachment hardware
- Legs: Shift of mass from femur bone to thigh flesh for more human like behaviour

Positioning:

Reproducible dummy positioning in the car prior to testing, will be aid by positioning tools.

- Tilt sensors: Thorax and the pelvis equipped with provisions for tilt sensors
- Door to dummy distance:
  H-point to door distance measurement tool.

Certification :

Change of the certification procedures for :

- Neck: Rationalised certification input and output criteria
- Thorax: Full rib module test of 1 m/s to be skipped.
  Damper and rib only test to be done if full rib module tests fail
- Abdomen: Decrease of certification test severity to prevent overloading.
- Lumbar spine: Rationalised certification input and output criteria
- Pelvis: Increased of certification severity to line-up with pelvis criterion level

The modifications will be discussed separately in the remaining part of this section.

Head Assembly - The current EUROSID-1 dummy head is a standard Hybrid III head. Inside the head a mounting block can be attached to the skull base facilitating the application of three linear accelerometers at the head centre of gravity position. The injury parameter to be assessed for the head is the HIC (Head Injury Criterion). This criterion must be calculated during contact of the head with part in the dummy environment. The establishment of this contact is hardly possible with the instrumentation of EUROSID-1. Alternatively, the HIC_{15} or HIC_{36} (being the HIC values established over a period of 15 or 36 ms) are calculated.
To improve the HIC injury assessment capability of the dummy as well as to enable assessment of the Nij injury criterion an upper neck load cell has been developed and integrated in head assembly. The ES-2 head assembly incorporates the following features and modifications with respect to EUROSID-1:

- Six axis load cell (Load cell capacity : F_x = 10 kN, F_y = 10 kN, F_z = 15 kN, M_x = 300 Nm, M_y = 300 Nm and M_z = 300 Nm.)
- Mass of head including load cell equivalent to the EUROSID-1 head assembly mass
- Centre of gravity position of head including load cell equivalent to that of the EUROSID-1 head assembly
- Modified head-neck interface however on the same location as in EUROSID-1
- Modified head-drop bracket for certification test.
- Provisions to accept a 9 accelerometer ROTAC device

Figure 2: ES-2 Prototype head assembly
Left : Upper neck load cell and it structural replacement
Middle : Skull skin and structural replacement
Right : Head assembly with head drop bracket in certification rig.

Evaluation : The HIC assessment procedure in the event of head contact and some results of the evaluation are given in Annex A

<u>Neck Assembly</u> - The neck of the EUROSID-1 dummy consist of central moulded rubber beam with buffered interface plates on top a bottom side connected to the central moulding with half spherical screws. The modifications applied to neck assembly are made to improve the handling properties and to facilitate the upper neck load cell introduction. The ES-2 neck assembly incorporates the following features and modifications with respect to EUROSID-1:

- Improved shape of replaceable neck buffers to prevent buffer dislocation in case of extensive neck bending.
- Improved locking of spherical screw by a larger shoulder and a finer thread.
- New interface to the upper neck load cell in the head assembly
- Standard use of the lower neck load cell is recommended to enable Nij injury criterion assessment at the lower neck location.
- New neck to head form interface plate for certification.
- The neck certification procedure is evaluated and new, rationalised, in- and output criteria are proposed. This subject is covered in detail later in the report.

Figure 3: ES-2 prototype neck component
Left : Central moulding, top and bottom interface plates and half spherical screws
Middle : Buffers three harnesses
Right : New neck to head form interface plate for certification

Evaluation : The ES-2 prototype neck is tested in a standard certification test set-up. Overload tests performed on a neck pendulum test rig showed no buffer dislocation in case of extensive neck bending.

<u>Shoulder Assembly</u> - The current shoulder design of the EUROSID-1 includes clavicles that can move between two parallel metal plates. In (vertical) impacts to the shoulder, contact between the moving clavicle and the metal plates may occur. However, this should not substantially restrict the clavicle motion, i.e. inward movement of the upper arm, nor should the clavicle be damaged in this situation. In practice the shoulder show a binding effect in case of extensive vertical application. The lack of vertical flexibility results in rapid built-up of a peaking vertical load. This vertical load on its turn results in high contact load between the clavicle and the top and bottom plates of the shoulder. It is likely that these normal loads can induce considerable friction that can stop the motion. Additional modifications to the EUROSID-1 shoulder assembly include the re-design of the shoulder foam cap, arm to clavicle attachment screw and the elastic cord holder. The shoulder foam cap has been modified to prevent damage due to handling at the neck recess and to prevent wear due to interference with the arm during the arm inwards stroke travel at the outward foam cap ends. The new arm to shoulder-cam-clavicle attachment screw has a self-locking feature and the elastic cord attachment has been redesigned to improve handling and the durability of the cord. To ease handling a hole in the suit sleeve provides access to the arm to clavicle attachment screw without removing the suit from the dummy. The modifications to shoulder assembly are made to reduce binding effect significantly and to improve the handling. The ES-2 shoulder assembly incorporates the following features and modifications with respect to EUROSID-1:

- Reduced vertical stiffness of the clavicle by material change and reduced cross-sectional area. This to prevent a rapid built-up of a peaking vertical load. This reduces the clavicle binding effect.
- Coated top and bottom plate to reduce the friction of the clavicle
- Reshaped shoulder foam cap
- New elastic cord holder
- Self locking arm attachment screw
- Hole in suit sleeve to reach arm attachment screw
- Provisions for a thorax tilt sensor at the lower side of the shoulder box.
  The tilt sensor can aid the positioning in the car prior to the crash test.

Figure 4: ES-2 Prototype shoulder assembly
Left : Cam clavicle standard (left) and shortened for clavicle load cell application (right)
Middle : Shoulder assembly (exploded)
Right : Shoulder assembly (from aft side) note the new elastic cord holder

Evaluation : Apart form some dummy model validation tests the shoulder has not yet been tested dynamically. Static tests show a friction reduction of 20% at high vertical loads. The clavicle stiffness is reduced with a factor 3.0. The merits of the shoulder assembly modifications will have to be demonstrated by evaluating the ES-2 Prototype in actual crash conditions.

<u>Thorax Assembly</u> – The EUROSID-1 thorax consists of three rib modules, a spine box and a torso back plate. To guide the rib displacement motion the rib modules embody a linear guide system equipped with Glacier journal bearings. These bearings can operate with friction coefficients as low as 0.05. However, due to oblique impacts considerable off axis loading can result in significant bearing friction. This friction is believed to cause a early stop of the rib motion that is shown in the displacement signal as a so call “Flat Top”. Flat tops can also occur due to interference of the torso back plate and intruding car door panel. The sharp edged shape of the EUROSID-1 torso back plate can result in grabbing of its in the seat back. This effect is not human like and car manufactures can

make use of this unintended dummy feature to reduce rib displacements in their cars. Countermeasures to minimise these effects are integrated in the dummy by complete redesign of the rib modules and modification to the torso back plate.
The ES-2 thorax assembly incorporates the following features and modifications with respect to EUROSID-1:

- Integration of standard heavy duty needle bearings to eliminate piston-cylinder friction
- Piston guide bearing to restrain piston torsion eliminated
- Buffered initial position and end stop
- Increased tuning spring stiffness' to restore the rib performance
- Polycarbonate cover to protect the open bearing system
- Redesigned spine box for rib integration and T12 load cell interface provisions
- Rib, damper and stiff damper spring not changed
- Reduced width (140 mm was 180 mm) torso back plate
- Torso back plate curved in the XY-plane based on human anthropometric data
- Torso back load cell with four axis (Fx, Fy, My and Mz).

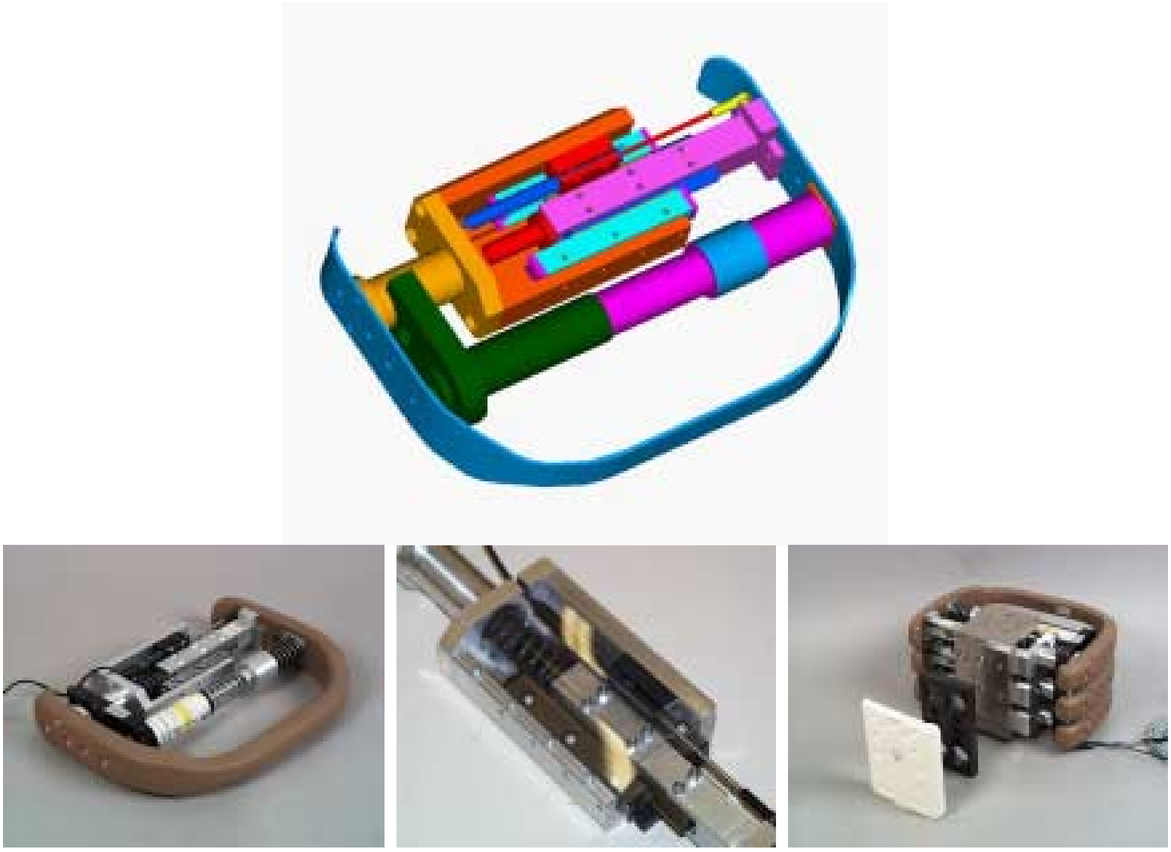

Figure 5: ES-2 Prototype thorax assembly
Top : ES-2 rib unit with the newly designed needle bearing guide system
Left : ES-2 rib unit assembly
Middle : ES-2 needle bearing rib guide system with protection cover
Right : ES-2 thorax assembly (ribs, spine box, replacement load cell and curved back plate)

Evaluation : The design options evaluation and some results of the component and full body tests performed to show the behaviour of the selected ES-2 prototype rib module design are presented in annex C

Abdomen Assembly – EuroNCAP requested the introduction of a T12 load cell on EUROSID-1, to enable the assessment of load transfer front the abdomen and upper lumbar spine towards the lower side of the thoracic spine. This in spite of the high loads that may occur in this area and the limited space available. Moreover, the upper and lower body must remain easily to separate, preferable with the bolts accessible from the back side as on EUROSID-1.
The ES-2 abdomen assembly incorporates the following features and modifications with respect to EUROSID-1 (application of the T12 load cell on EUROSID-1 is also possible):

- Introduction of new designed load cell or blank replacement
- Load cell (Denton model B-4284) capacity specification :
  Fx = 14 kN, Fy = 14 kN, Mx = 1000 Nm, My = 1000 Nm)
- New accelerometer mounting block at the T12 location mounted on the T12 loadcell.
- Base adapter between load cell and abdomen upper side
- Two M6x8x60 close tolerance shoulder bolts for load cell to base adapter attachment
- Interface to thoracic spine box lower face with 4 bolts was welded
- Interface to abdomen drum and lumbar spine upper face with 4 bolts (was 2 bolts)

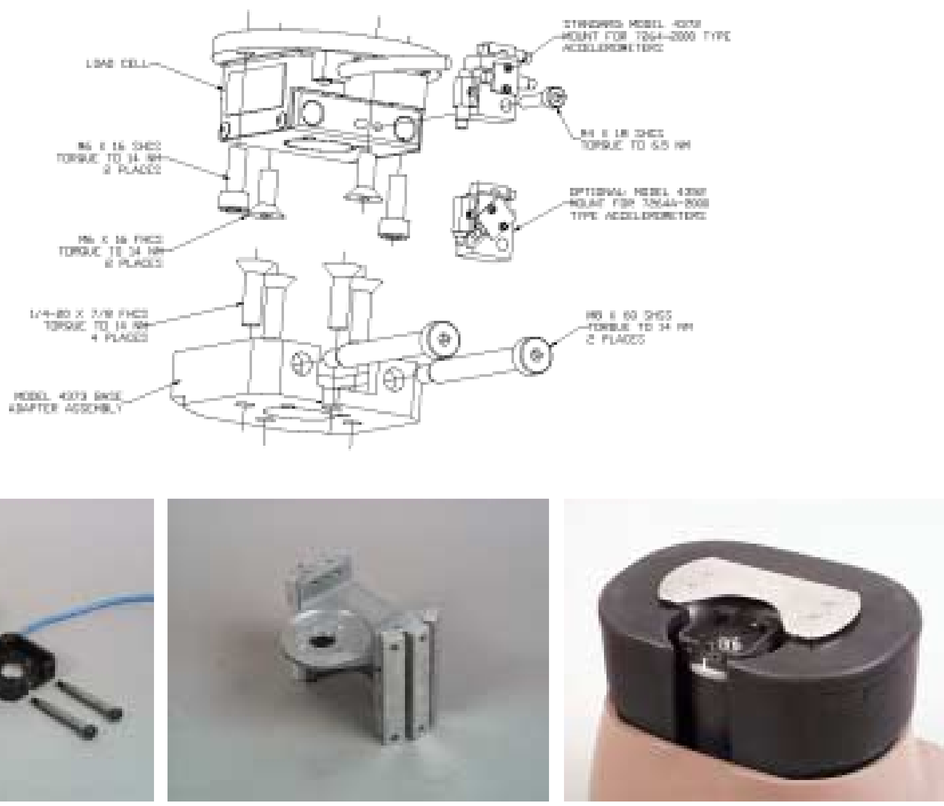

Figure 6: ES-2 Prototype abdomen assembly.
Top : T12 load cell with base adapter and accelerometer mountings (Denton model 4284).
Left : T12 load cell, base adapter and shoulder bolts (apart) and structural replacement and base adapter (assembled).
Middle : Abdomen drum (with four hole in lug)
Right : Abdomen assembly with base adapter on top.

Evaluation : The performance of the T12 load cell is checked in full body abdomen and pelvis certification tests. In annex D the results of the tests performed are summarised.

Lumbar Spine Assembly – The Lumbar spine is only modified to facilitate the application of the T12 load cell at the top and the lower lumbar spine load cell at the bottom as standard options. The ES-2 lumbar spine assembly incorporates the following modification with respect to EUROSID-1:

- Introduction of two extra threaded holes at the lumbar spine top side to accept the T12 load cell attachments
- Introduction of three extra threaded holes at the lumbar spine bottom top side to accept the lower lumbar spine load cell attachments

The lumbar spine certification procedure is evaluated and new in- and output criteria are proposed. This subject is covered in detail later in the report.

Pelvis Assembly – The current EUROSID-1 upper femur to iliac wing connection at the pelvis H-point allows 15° of upper leg abduction. At the end of this range of motion the upper femur bracket and the H-point back plate may produce metal- to metal contact. In the case of adduction combined with femur flexion, the upper femur bracket buffer may interfere with the pubic symphysis attachment hardware. Moreover, some items that cause inconveniences in handling, reported by the users, can be improved.
The ES-2 pelvis assembly incorporates the following features and modifications with respect to EUROSID-1:
At the H-point location:

- Replacement of ball bearing at the H-point with an new increased size bearing allowing 19° of upper leg abduction.
- Introduction of a new upper femur bracket.
- Provisions for easy replacement of the existing buffer at the inside of the upper femur bracket.
- Modified ileac wings to accept the new upper femur brackets.
- Introduction of a rubber buffer at the inside of the H-point back plate will become effective at 15° abduction. The remaining 4° are available to damp the contact.
- Introduction of a plastic tube stop to prevents metal to metal in the remote event of using the full available stroke of the rubber damper when reaching 19° of upper leg abduction.
- Reduced size H-point back plate (diameter 75 mm was 80 mm) to ease the installation of it in the H-point foam block cavity.
- Rounded of H-point back plate outer edge to prevent pelvis flesh or foam block cutting during impact
- Indication of the H-point of the manikin on the H-point back plate
- H-point back plate attachment bolt changed from countersunk- to hex-head to ease the disassembly and assembly.
- Deletion of H-point foam block centre hole to improve the handling durability.

At pubic symphysis location:

- Reduced size torque head on the pubic symphysis load transducer bushes to minimise the change on interference with upper femur buffer
- Symmetrical pubic symphysis load transducer spacers replace the spacers and bellville washers of EUROSID-1. This to prevents the possibility of mis-orientation of the parts.

General:

- Provisions for a pelvis tilt sensor in the sacrum block.
  The tilt sensor can aid the positioning in the car prior to the crash test.

Figure 7: ES-2 pelvis assembly
Left : New upper femur bracket with attachment pin
Middle : H-point back plate with tube stop and H-point back plate buffer for abduction
Right : Pelvis assembly (flesh foam partly cut away)

Evaluation : A brief report on the evaluation of the efficiency of the new pelvis assembly is given in Annex G. The value of the pelvis modification will have to be further demonstrated by evaluating the ES-2 prototype in actual crash conditions.

Leg Assemblies – The legs applied on EUROSID-1 are those for the Hybrid II frontal crash dummy. Some users have reported sharp peaking pubic symphysis readings in the event that there is knee to knee contact. This phenomenon is more frequently noticed now that consumer tests have driven the pubic symphysis load to lower levels, loading the femur and knee directly in the event. This is particularly true when the dummy is used in the rear of the car. The extreme readings due to knee to knee contact loading at the pubic is primarily caused by the mass distribution in the upper leg structure. The EUROSID-1 upper leg consists of a relative low-mass foam part that represents the thigh flesh and a steel shaft that represents the femur bone part. The upper leg total mass is tuned by filling a cavity integrated with the steel shaft with lead. The distribution of mass between the upper leg “flesh” and “bone” parts is in the dummy approximately 25% to 75%. Whereas the human leg mass distribution is the other-way-round having 80% of the mass in the in the flesh and 20% in the “rigid” bone structure.
To reduce the knee to knee contact problem it was decided to change the two dummy leg parts that represents almost half the upper leg mass (5.45 kg).
The ES-2 leg assemblies incorporates the following features and modifications with respect to EUROSID-1:

- Thigh flesh representing foam part increased mass by 2.75 kg from 1.35 kg to 4.15 kg.
- Upper femur bone representing steel part decreased in mass by 2.75 kg from 4.05 kg to 1.30 kg
- The use of the femur load cell between the knee assembly and the upper femur bone representation is recommended.
- The femur load cell mass is reduced with 0.25 kg per load cell by application of aluminium end pieces
- The provisions on the upper femur region that can be used to support the dummy during storage are restored on the new parts.

Figure 8: ES-2 leg parts modified
Left : Upper leg thigh flesh foam part (left) and femur bone steel part (right)
Right : Aluminium femur load cell end pieces (the dowel pin hole locations are not correct)

Evaluation : A brief report on the evaluation of the efficiency of the new pelvis assembly is given in Annex I. The value of the pelvis modification will have to be further demonstrated by evaluating the ES-2 prototype in actual crash conditions.

2.3. POSITIONING TOOLS

In reaction to the proposal for a seating procedure for EUROSID-1 by EEVC WG13, TNO co-operated with MSC GmbH in the development of a set of angle transducers. These transducers, installed in the pelvis and the torso allow measurement of the dummy orientation about the body x- (anterior-posterior) and y- (left-right) axes. Measurement of the angle around the z-axis is not possible, since the transducers use gravity to determine their orientation.
Once the dummy is installed in the vehicle, the transducers are hooked up to a portable read-out unit, which shows the four angles (two from each transducer) simultaneously. This facilitates setting up the dummy in the required position. The transducers are available for both EUROSID-1 and ES-2.

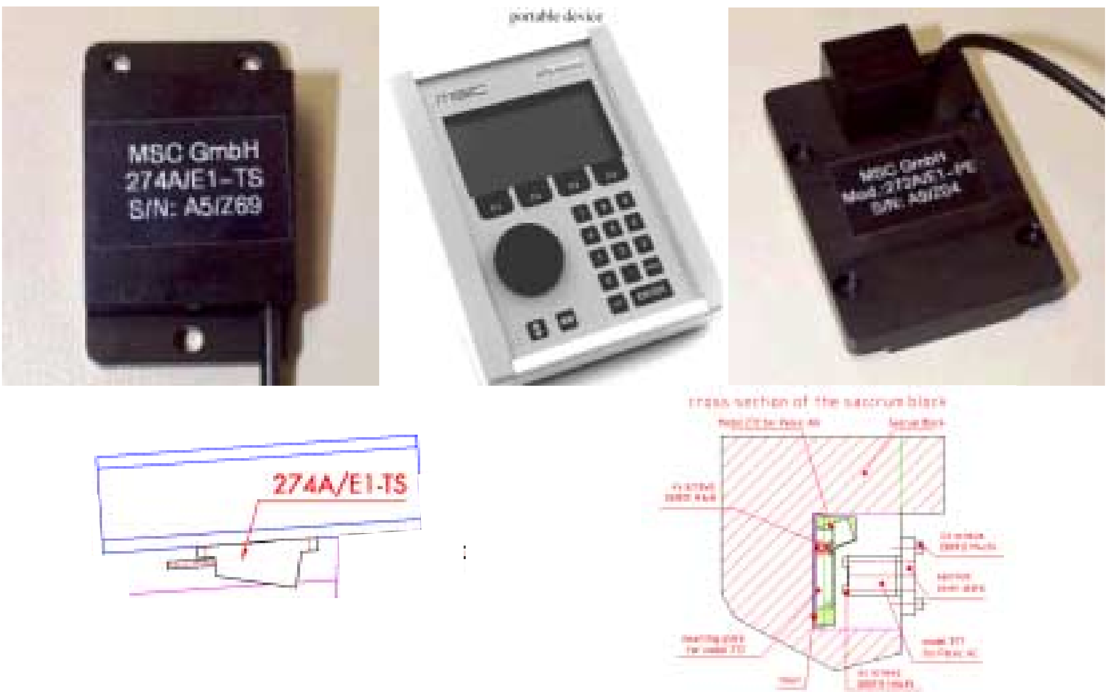

Figure 9: ES-2 tilt sensors
Left : Upper torso tilt sensor mounted at the bottom side of the shoulder assembly
Middle : Portable tilt sensor display unit
Right : Pelvis tilt sensor mounted in the sacrum block

A second tool for the positioning procedure is still in development. It is basically a tape measure, but a specially designed one to allow accurate measurement of the distance between the dummy H-point and the door. This tool was developed because existing tools could often not be used in the small and narrow spaces inside a vehicle.

2.4. CERTIFICATION PROCEDURES

Head certification - The certification procedure of the head is not changed. The head - upper neck load cell (or replacement) combination must be certified as a unit. As the head neck interface changed the suspension of the head in the drop rig must be done with a modified head drop bracket.

Figure 10: ES-2Head drop certification set up
Left : Head drop bracket (ready for a right hand side drop test)
Right : Head assembly with head drop bracket in certification rig (left hand side test)

Neck certification - The prototype EUROSID neck was certified (before 1990) in a dynamic test with Part 572-neck pendulum with a head mounted on the neck. Lateral and vertical displacements of the head were measured with high-speed film that proved to be very expensive and time consuming. For the EUROSID-1 (in 1990), an alternative for the film was developed. This method uses a special head form instrumented with three angular potentiometers that measure the fore and aft angle on the pendulum base plate and the top angle on the head form (relative to the shaft of the fore potentiometer). The potentiometer signals were used as input for an algorithm which calculated the two dimensional displacements of the head form [5]. Criteria were determined for the maximum head form flexion angle (the sum of fore angle and top angle) and the head form lateral and vertical displacements (Y and Z) as well as the time of occurrence of these three maxima.

Still, the new procedure caused problems because the algorithm was over sensitive to small variations in the measured potentiometer angles. Alternatively (in 1994), it was decided to define the criteria directly for the measured potentiometer angles, instead of the lateral and vertical displacements. These angle based output criteria were accepted and form the basis for the current neck certification procedure defined in chapter 5 paragraph 10 of the “EUROSID-1 Assembly and Certification Procedures” manual [6].

In practice, EUROSID-1 necks do not often fail to certify. However, after redefinition of the lumbar spine certification (as described later in this report) it was felt that the neck certification should be defined along the same lines for consistency. Therefore, a re-evaluation of the current neck certification procedure is performed based on a theoretical analysis and a review of original test data.

For the input corridor an alternative velocity change corridor was developed instead of the acceleration based corridor (see Annex B).

The output criteria were found not been uniquely determined in the past. A proposed set of revised output criteria has been developed that better meets the desired specification.

An extra complication for ES-2 is the necessity to use a neck - head form mounting plate (Figure 3) where the EUROSID-1 certification can be performed without that plate. The result of this additional interface plate in the test set-up is a shift of all the maxima with respect to those of EUROSID-1.

In annex B the steps of the neck certification re-evaluation as well as the applied shifts are summarised. The proposed revised criteria for ES-2 are:

Note : Figures including the shift due to the additional mounting plate in the test set-up for ES-2

Input criteria : pendulum deceleration		
1	Impact speed	3.30 – 3.50 m/s
2	Velocity change corridor	(see Annex B, Table 3 and *Figure 18*)
Output criteria : neck bending		
1	Maximum head form flexion	49.0 - 59.0 degrees
2	Time of maximum head form flexion	54.0 - 66.0 ms
3	Maximum fore angle dQA	32.0 - 37.0 degrees
4	Time of maximum fore angle dQA	53.0 - 63.0 ms
5	Maximum aft angle dQB	between 0.81 * dQA + 1.75 and 0.81 * dQA + 4.25 degrees
6	Time of maximum fore angle dQB	53.0 - 64.0 ms

The effect of the proposed revised input and output criteria on a set of evaluation data provided by 4 different labs was investigated (Annex B). Application of the proposed revised criteria reduced the failure rate of neck certifications from 21 to 7 %.

Shoulder certification - The certification procedure for the shoulder is not changed.

Thorax certification - The current EUROSID-1 rib unit certification procedure is a rather extensive exercise. Besides the full rib module certification tests also damper and rib only certification tests are required. The rib units are tested in a drop rig (Figure 11), with an impactor mass of 7.78 kg. The EUROSID-1 is tested on four speed levels : 1.0, 2.0, 3.0 and 4.0 m/s.
The ES-2 rib module the certification procedure is essentially not changed. Two adjustments are proposed.

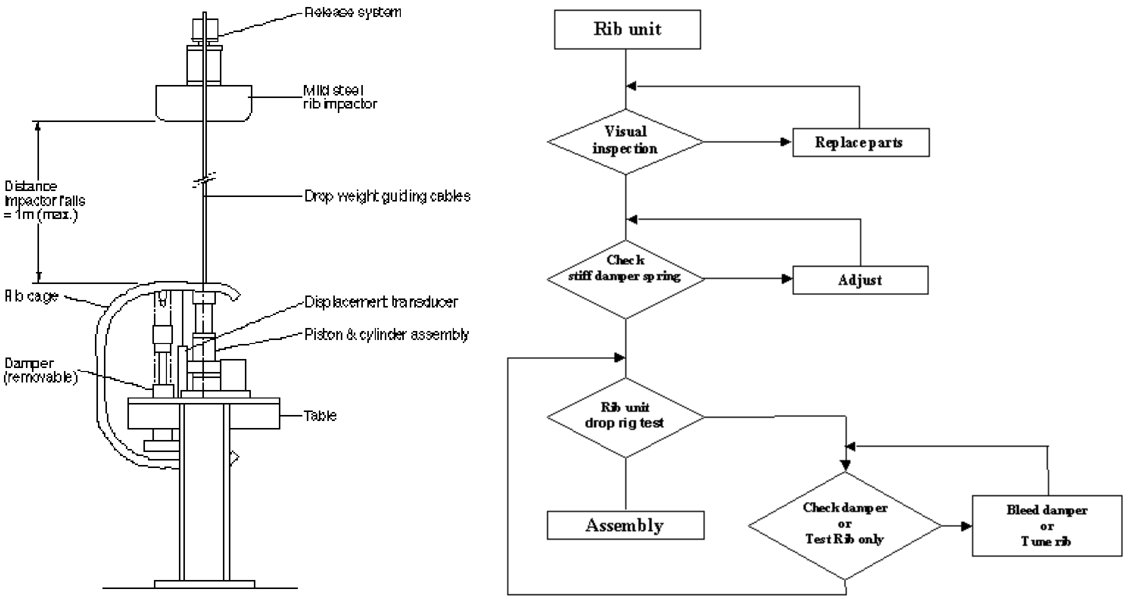

Figure 11 : ES-2 Rib unit certification
Left : ES-2 Rib unit in drop rig
Right : Flow chart of rib unit certification

- The lowest drop-rig certification impact speed 1.0 m/s, however, is felt to be obsolete. The reason is that the impact energy of this test in very low 3.9 J. This energy level less than 10% of the energy level that is necessary to produce the injury criterion displacement of 42 mm. Moreover the test speed is far below the contact speed the can be expected in a full-scale car crash. Therefore it proposed to skip the full rib certification test with 1.0 m/s impact speed.
- The damper and rib only tests can be considered as acceptance tests for these sub-assemblies. Therefore it is proposed to skip these tests as long as the full rib modules comply with the certification test requirement. This procedure is shown in Figure 11. The additional damper and rib only tests are to be performed to check the parts in case of the full rib certification fails.

Abdomen certification - The EUROSID-1 abdomen certification test is derived from the original biomechanical tests, which were performed by APR [1]. These tests, which have been included in the ISO document [2] involved dropping cadavers from 1 and 2 meter drop heights onto a hard surface. This surface was not flat, but had a representation of the armrest of the car door. A series of 11 tests were performed, of which 8 were considered to be suitable for further analysis. From these tests, it was concluded that the tolerance level for the abdomen in lateral impacts (AIS 3) was 39 mm deflection and 4.5 kN external impact force[1].
In the EUROSID-1 certification, the impact is delivered by a 23.4 kg impactor, diameter 152.4±0.25 mm, to which a wooden block with a length of 150 mm, a 70 mm width, and a 60 mm minimum height, is attached. The shape of the wooden block corresponds to that of the simulated car door armrest that was used in the original APR biomechanical tests. The prescribed impact velocity is 6.3 m/s. The certification acceptance requirement is 6.4 ± 0.5 kN internal force.

Several years of full scale test experience with the EUROSID-1 dummy have shown that the level of abdominal forces measured in side impacts are much lower than those measured in impact tests. Actual measurement values of the EUROSID-1 are available from a database of test results, the data of which was used in a paper by Beusenberg et al [3]. The database, set up with data of tests performed at the TNO Crash-Safety Research Centre, shows that the average measured force level lies below the injury criterion value of 2.5 kN internal force. The average value lies around 2 kN, and the maximum value recorded in a test has been 4.5 kN. It has therefore been suggested that the certification test impact severity should be reduced in order to certify the dummy using approximately the same loading level as in full-scale tests.
A new certification test has been defined a lower speed, resulting in loading values closer to those experienced in actual crash tests. A brief report on the tests performed to establish the new targets is given in Annex B. The proposed certification requirement is:

Test set-up:	No changes (as described in EUROSID-1 Assembly and Certification Procedures)
Pendulum speed:	**4.0 ± 0.1 m/**s (was 6.3 m/s)
Acceptance corridors:	
Peak abdomen force (internal):	**2.45 ± 0.25 kN**; occurring between 10.0 and 12.3 ms
Peak impactor force (external):	**4.4 ± 0.4 kN**; occurring between 10.6 and 13.0 ms

[1] Pendulum impact tests showed that the impact force measured by the impactor lies a factor approximately 1.5 higher than the internal forces. The value of external 4.5 kN force was chosen to match 2.5 kN internal force.

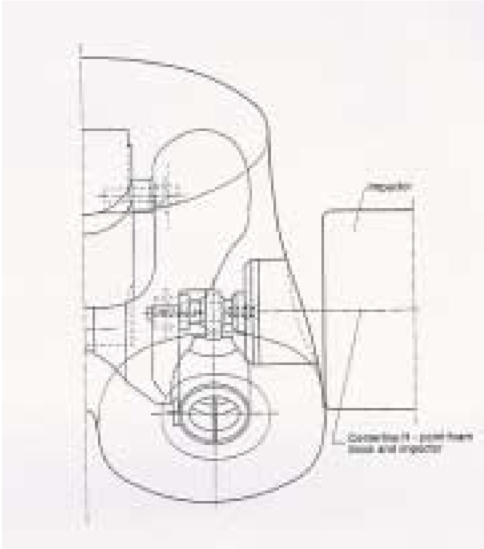

Figure 12: EUROSID-1 Pelvis Certification Impact.

Pelvis certification - The EUROSID-1 pelvis certification test requires an impact on the lateral aspect of the upper leg and pelvis area. The pendulum used is the standard part 572 pendulum of 23.4 ± 0.02 kg mass and 152.4 ± 0.25 kg mm diameter. The impactor is suspended by 8 wires to allow a free swing onto the pelvis with an impact speed of 4.3 ± 0.1 m/s. The pelvis certification test is based on test originally performed by INRETS [4]. This test involved impactor human cadavers with a spherical impactor. The striking surface of this impactor has a radius of 175 mm and an outer diameter of 120 mm. The mass of the impactor was 17.3 kg. The test were carried out at velocities between 6 and 10 m/s. The spherical impactor was later replaced by the part 572 impactor. This was probably done for practical reasons as it was already available for use with the US Dummies such as the Hybrid-III.

The certification requires an impactor force of 4.9 ± 0.5 kN between 10.3 and 15.5 msec after impact and a pubic symphysis load of 1.34 kN ± 0.30 kN between 9 and 15.9 msec after impact. Actual (full-scale) measurement values of the EUROSID-1 are available from a database of test results, the data of which was used in a paper by Beusenberg et al [3]. The database shows that the maximum pubic symphysis force measured was 6.6 kN, and the average value was 3.4 kN. This is significantly higher than values measured in the certification.

The impact severity of the pelvis tests should be increased, but the impact level should not be adjusted in a way that results in exceeding of the biomechanical corridors. As an alternative for the pelvis certification process described in the manual EUROSID-1 Assembly and Certification Procedures, the following procedure has been developed (see Annex C). The objective of this development was to define a certification test with generates an output signal more close to the performance criterion for the pubic load signal (6 kN). The following changes are proposed:

Test set-up:	No changes (as described in EUROSID-1 Assembly and Certification Procedures)
Pendulum speed:	**6.3 ± 0.1 m/s** (was 4.3 m/s)
Acceptance corridors	
Peak impact force:	**11.0 ± 1.2 kN**; occurring between 9.5 and 12.5 ms
Peak pubic compression force:	**3.05 ± 0.35 kN**; occurring between 10.0 and 13.0 ms

Lumbar Spine certification - The prototype EUROSID lumbar spine certification was certified in a dynamic test with Part 572 neck pendulum with a head mounted on the spine. Lateral and vertical displacements of the head were measured with high speed film which proved to be very expensive and time consuming. For the EUROSID-1, an alternative for the film was developed. This method uses a special head form instrumented with three angular potentiometers that measure the fore and aft angle on the pendulum base plate and the top angle on the head form (relative to the shaft of the fore potentiometer). The potentiometer signals were used as input for an algorithm which calculated the two-dimensional head form [5]. Criteria were determined for the maximum head(form) flexion angle (the sum of fore angle and top angle) and the head (form) lateral and vertical displacements (Y and Z) as well as the time of occurrence of these three maxima.
Still, the new procedure caused problems because the algorithm was over sensitive to small variations in the measured potentiometer angles. Alternatively, it was decided to define the criteria directly for the measured potentiometer angles, instead of the lateral and vertical displacements. These angle based output criteria were accepted and form the basis for the current lumbar spine certification procedure defined in chapter 5 paragraph 10 of the “EUROSID-1 Assembly and Certification Procedures” manual [6].
Nevertheless, in practice EUROSID-1 lumbar spines often fail to certify. It is felt that the set of requirements for the lumbar spine certification is more tight than strictly necessary for the desired performance of the part during full-scale testing. Therefore, a re-evaluation of the current lumbar spine certification procedure is performed based on a theoretical analysis and a review of original test data.
It has become clear that the pendulum acceleration is responsible for many test certification failures, due to the presence of relatively large vibrations in the signal. These vibrations were found to be laboratory dependent. An alternative velocity change corridor was developed for the input corridor that is less sensitive for laboratory differences (see Annex D). Besides that, it is found that the current certification output criteria have not been uniquely determined in the past. A proposed set of revised output criteria has been developed that better meets the desired specification. The proposed revised criteria are:

Input criteria : pendulum deceleration		
1	Impact speed	5.95 - 6.15 m/s
2	Velocity change corridor	(see Annex F, Table 14 and Figure 33)
Output criteria : lumbar spine bending		
1	Maximum head form flexion	45.0 - 55.0 degrees
2	Time of maximum head form flexion	39.0 - 53.0 ms
3	Maximum fore angle dQA	31.0 - 35.0 degrees
4	Time of maximum fore angle dQA	44.0 - 52.0 ms (revised)
5	Maximum aft angle dQB	between 0.8 * dQA + 4.5 and 0.8 * dQA + 2.0 degrees (revised)
6	Time of maximum fore angle dQB	44.0 - 52.0 ms (revised)

The effect of the proposed revised input and output criteria on at set of evaluation data provided by 5 different labs was investigated (Annex F). Application of the proposed revised criteria reduced the failure rate of lumbar spine certifications from 53 to 24 %.

3. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

This reports gives an overview of the proposed dummy modifications incorporated in ES-2. The data given in the Annexes supports the new designs, yet in some cases only use of the dummy in full scale tests can demonstrate the merit of the enhancements. Four ES-2 prototype dummies are currently under evaluation. Two have been shipped to North America (one in December 2000 and one in February 2000) for evaluation on behalf of NHTSA and Transport Canada in certification, component and full body dummy tests as well as in full scale car crash tests. A third prototype is evaluated on behalf of ACEA in certification, sled and full-scale tests at Porsche, Volkswagen, LAB and Ford. The fourth prototype is evaluated on behalf of SID-2000 in certification, sled and full-scale tests at Porsche, BMW, Volvo, BASt, TRL, INRETS and TNO Automotive. After completion of these evaluation programmes in July 2000, an ES-2 Prototype dummy will be sent to Japan for JAMA Side Impact Working Group evaluation.

The data from the world-wide evaluations have to demonstrate the added value of the ES-2 dummy with respect to the EUROSID-1. If so, the dummy specifications (changing EUROSID-1 into EUROSID-2) in the ECE and federal directives could be amended. In that case, the ES-2 will become the intermediate harmonised side impact dummy.

The WorldSid project is the first step in the long-term strategy. Ultimately, one single side impact dummy should be used world-wide in side impact compliance testing. The EC funded SID-2000 project has provided the basic knowledge and tools for the definition of such dummy from the European perspective. Following the SID-2000 project, additional research is anticipated, in particular in the prototype evaluation phase of a WorldSid in Europe and the establishment of injury risk functions for the dummy.

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ANNEX A : HIC ASSESSMENT PROCEDURE

<u>Use of the upper neck load cell to calculate moments about OC</u> - The OC joint of the EUROSID lies at the upper spherical joint. The loacation is 5 mm below the interface plane between the neck interface plate and the load cell, which means that the OC joint lies 20 mm below the neutral axes of the transducer. The measured moments must be corrected as follows:

$$M_{x,oc} = M_{x,measured} - 0.02 \cdot F_{y,measured}$$

and

$$M_{y,oc} = M_{y,measured} + 0.02 \cdot F_{x,measured}$$

<u>Use of the upper neck load cell to calculate HIC</u> - ISO TR 12351 describes a procedure for calculating the head injury criterion (HIC). The method is based on the use of the upper neck load cell to calculate head contact forces. For each of the three perpendicular axes of the head, the difference between the upper neck forces and the inertial forces (F = m*a at the head CG) is determined. If the resultant of these differences exceeds a certain threshold value, then head contact is assumed to have taken place. For the Hybrid-III, this value is 500 Newton. If the event is recorded, then the first point where the force difference exceeded 200 Newton before the 500 Newton event is taken as the starting point and the first point after the 500 Newton event where the force drops below 200 Newton is taken as the end point. The HIC is then determined for this interval. The signal is then scanned for multiple occurrences of the 500 Newton event, and the HIC is calculated for each event. Finally, the highest HIC is determined from the list of HIC values.

This procedure was proposed for the side impact dummies as well by ISO WG3. TNO evaluated the procedure in 1994 for the EuroSID-1 using the <u>lower</u> neck load cell, but the findings were not accepted by WG3. In 1999, with the development of the upper neck load cell, the procedure was repeated with this new transducer, while the lower neck load cell was used as well.

The test consisted of a part 572 pendulum test, using the EUROSID head and neck system. The new neck configuration and the new EuroSID-2 head were used. To simulate impact, a stiff wooden board was used. Tests were performed with no board (no contact), the board at different distances from the head, and a padded board (CONFOR foam). Table 1 shows an overview of a subset of the tests with a number of characteristic impact conditions as well as the test results.

Table 1: Test configurations and ES-2 head impact results

Test No.	Test ID	Configuration	External Force [kN]		HIC		
			Upper Load cell	Lower Load cell	Lower load cell	Upper Load cell	All Data
1	997777	No contact, 2.9 m/s	1180	269	12	-	20
2	997778	Contact at 60 mm, 4.9 m/s	6495	5617	605	605	605
3	997779	Contact at 60 mm, 2.9 m/s	2599	1858	84	84	84
4	997782	Contact at 60 mm, 4.9 m/s, with Confor foam	4807	3340	456	456	456
5	997784	Contact at 120 mm, 4.9 m/s	5277	3777	459	459	459
6	997786	No contact, 4.9 m/s	2275	499	57	-	75

The three rightmost columns list the HIC's calculated using the lower neck load cell, the upper neck load cell, and using all data (the complete range, from the beginning to the end of the experiment). Although the upper neck load cell detects head contact correctly, the difference between load cell forces and head inertial forces (F=m*a) can be surprisingly high. Part of this can be contributed to the measurement error : the accuracy of the loadcell, the accelerometers, and the complete measurement chain. In addition, the accelerometers need to be exactly at the centre of gravity of the head, otherwise they will also measure the components in the acceleration caused by angular velocity and angular acceleration. In reality, the accelerometers will always be some millimeters away from the true centre of gravity. TNO concludes that the procedure works but that the threshold value should be increased to a higher value (750 Newton). Some examples of the derived external force signals and the ranges used for the HIC calculation are shown below.

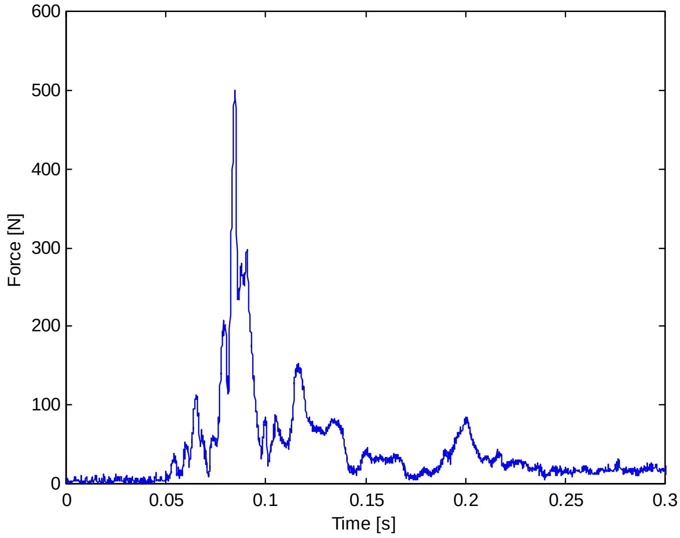


*Figure 13: Resultant of difference between measured forces and head accelerations (F=m*a) at 4.9 m/s, without head contact.
No HIC calculation. Test 997786.*

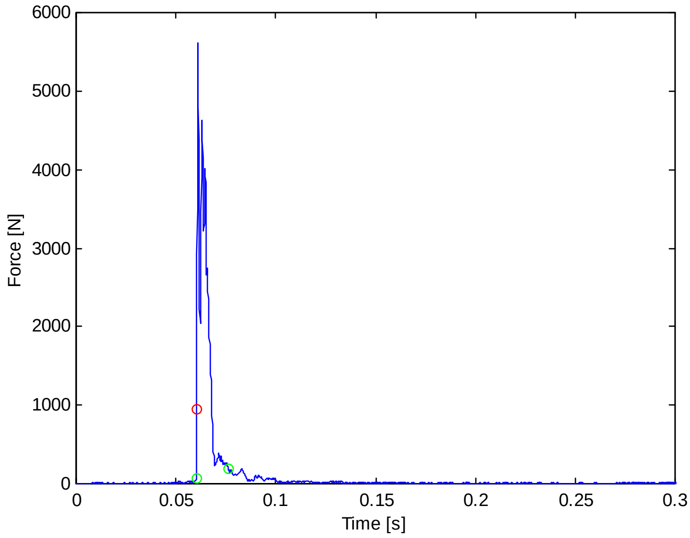


*Figure 14: Resultant of difference between measured forces and head accelerations (F=m*a) at 4.9 m/s, with hard contact. The left and right circles indicate the width of the head contact duration.
HIC = 605. Test 997778.*

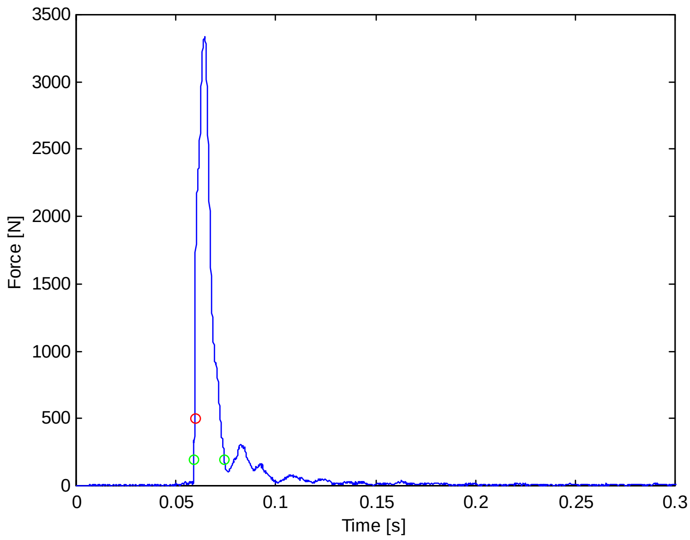


*Figure 15: Resultant of difference between measured forces and head accelerations (F=m*a) at 4.9 m/s, with padded contact. The left and right circles indicate the width of the head contact duration. HIC = 456. Test 997782.*

ANNEX B : NECK CERTIFICATION EVALUATION

Objective - The objective of the neck certification procedure re-evaluation was twofold :

1. Rationalise and re-definition of the input and output criteria along the same lines as followed for the lumbar spine certification to obtain consistency;
2. Investigate the effect of the proposed revised criteria using evaluation data provided by four different labs (Europe).

Input criteria - The acceleration corridor as specified in the existing certification procedure is presented in Table 2 for respectively the lower and upper boundary of the corridor.

Table 2: Pendulum acceleration corridor for neck certification

Lower Boundary		**Upper Boundary**	
Time [s]	Acceleration [G]	Time [s]	Acceleration [G]
0.0009	0.0	0.0	-3.3
0.0039	-25.0	0.0035	-35.2
0.011	-27.6	0.0113	-37.0
0.014	0.0	0.0168	-5.1

The actual acceleration of the pendulum measured by three different certification laboratories were related to this corridor. A graph of these accelerations is shown in *Figure 16*. Time synchronisation is performed by setting the time of the first 10 g value, in the initial slope, to 1.417 ms. This corresponds with the middle of the corridor at 10 g.

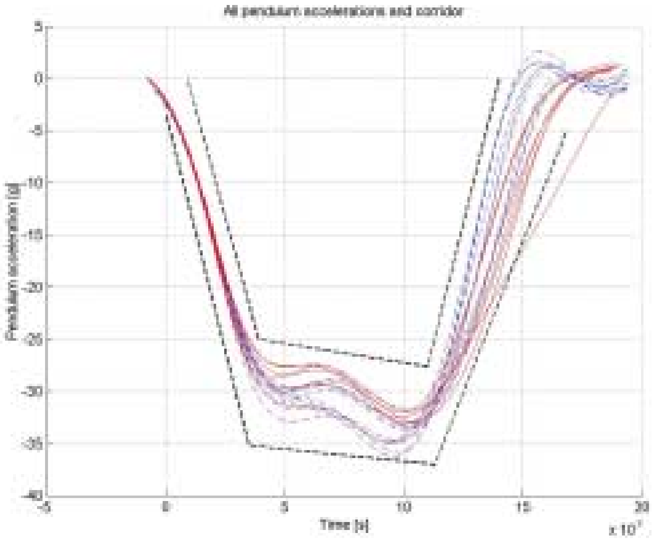


Figure 16: The pendulum accelerations filtered CFC 60 of two certification labs and the acceleration corridor

For the lumbar spine certification, a velocity-based corridor is developed to overcome problems with vibrations in the pendulum set-up. To be consistent with the lumbar spine certification input corridor, it is decided to develop a velocity based pendulum input corridor for the neck certification as well. The corridor to be developed should still comply with the overall shape of the acceleration pulse, magnitude and time duration.

The pendulum accelerations and the acceleration corridor were integrated starting at time zero after time synchronisation. Thus the data before time zero are neglected. The result is shown in *Figure 17*.

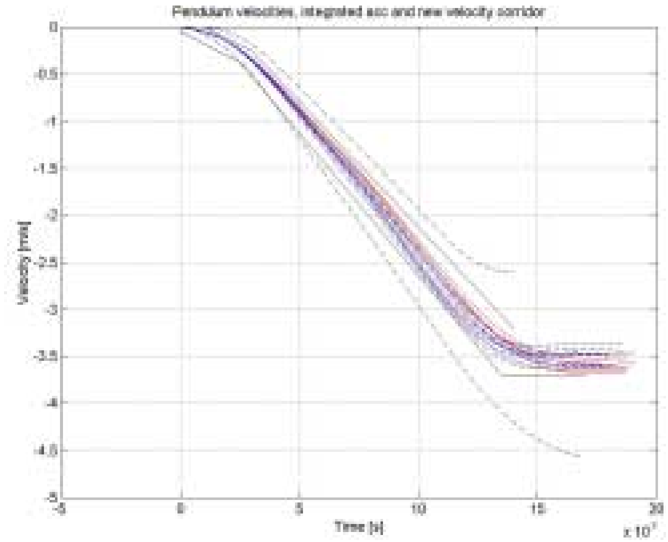


Figure 17: The integrated pendulum accelerations of two certification labs and the integrated acceleration corridor [dashed lines

The velocity time histories do fit easily in the velocity corridor obtained by integration of the upper and lower boundary acceleration corridor. The vibrations in the accelerometer data are not recognisable anymore and do not affect the certification result. This was assumed as stated in the previous section. The final velocities vary from approximately –3.35 to -3.68 m/s. This exceeds the required velocity, as specified in the certification procedure, 3.4 ±0.1 m/s. This is a general known problem in data processing. The quality of integration of accelerations depends on:

- the procedure of determining the zero load output of the accelerometer
- the systematic offset of the accelerometers sensitivity
- the linearity of the sensitivity
- the accuracy of the velocity measurement of the pendulum

The pendulum velocity at impact could be included in the integration of the pendulum acceleration. It was decided to omit this as most laboratories measure the pendulum velocity independent from their data-acquisition system used for recording the pendulum acceleration. This makes it possible to add an integration routine to the data-acquisition system that automatically processes the acceleration data to obtain the time history of the pendulum velocity change without requiring extra input from the operator.

The velocity corridor should guarantee the general shape of the acceleration pulse. The acceleration shows a positive value after approximately 0.016 sec. The wide space in the integrated corridor allows a large remaining velocity of the pendulum at the end off the acceleration pulse. Narrowing the velocity corridor at the end can prevent this.

The onset of the pulse is also important and can be set to the same limits set by the acceleration corridor by using the integrated acceleration corridor for the first interval of the velocity corridor. Although the first value of the upper velocity boundary can not be zero as the integration constant is set to 0.

Two straight lines for the velocity corridor define the average acceleration value, in the top part of the acceleration corridor.

The time duration of the pulse is defined in the integrated acceleration by the moment that the velocity comes to an almost constant value, at approximately 0.015 seconds in Figure 17. The time

duration can be defined by limiting the final value of the integrated acceleration to a minimum and setting a minimum time for this minimum.
This results in the velocity corridor as presented in Table 3 and shown in Figure 18.

Table 3: Pendulum velocity corridor for the neck certification

Upper Boundary		**Lower Boundary**	
Time [s]	Velocity [m/s]	Time [s]	Velocity [m/s]
0.0010	0.00	0	-0.050
0.0030	-0.25	0.0025	-0.375
0.0140	-3.20	0.0135	-3.700
		0.0170	-3.700

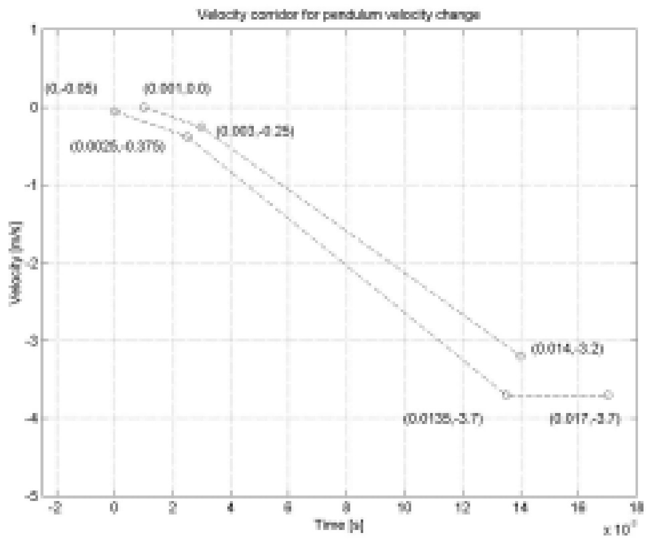


Figure 18: The neck pendulum velocity certification corridor

<u>Output criteria</u> - The initially defined criteria based on displacements (trajectory) were superseded by criteria that are directly based on the measured fore and aft angle. The angle-based criteria were derived from nine neck certification tests. In Table 4 the results of the tests and the defined criteria are summarised.

Table 4: Basic test results (9 tests) and defined (current) output criteria

	TEST RESULTS (9 tests)		CURRENT CRITERIA	
OUTPUT PARAMETERS	Mean value	Standard deviation	Mean value	Allowable range
Max. head form flexion [degrees]	49.8	1.59	51.0	± 5.0
Time of max. head form flexion [ms]	55.9	1.85	56.0	± 6.0
Maximum $d\Theta_A$ [degrees]	31.8	1.10	32.0	± 2.0
Time of maximum $d\Theta_A$ [ms]	54.2	2.18	55.0	± 5.0
Maximum $d\Theta_B$ [degrees]	28.2	1.09	28.0	± 2.0
Time of maximum $d\Theta_B$ [ms]	55.5	4.13	55.0	± 5.0

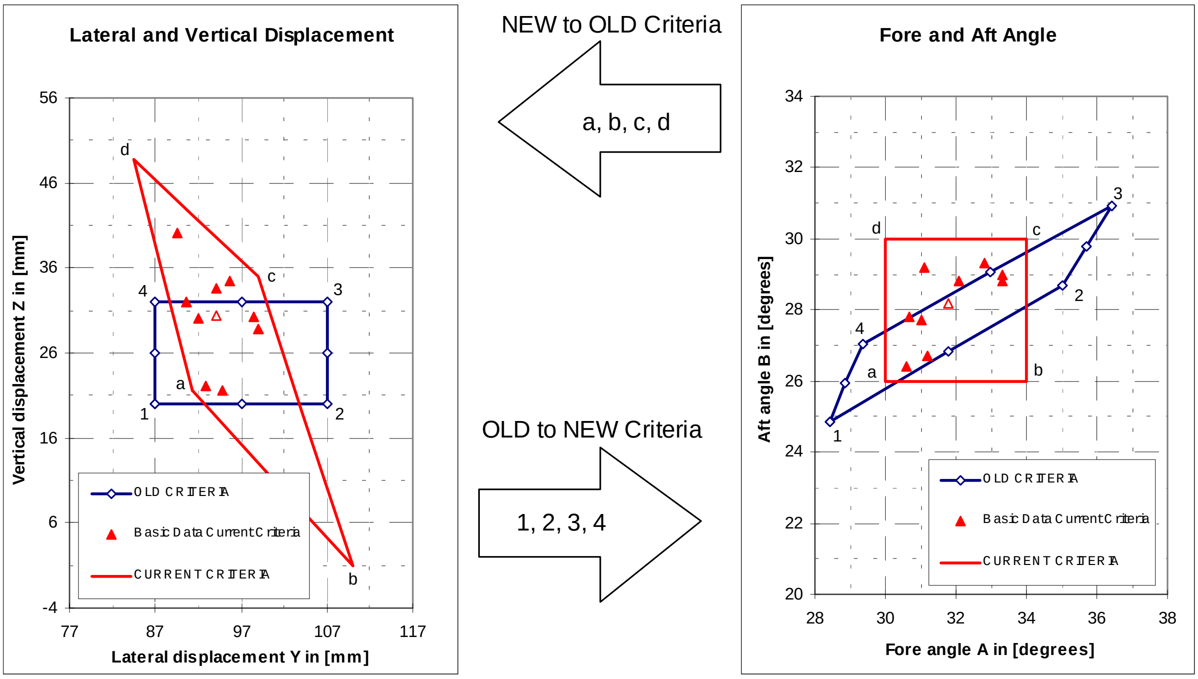


Figure 19: Relation between the old and the current neck certification criteria on deflection measured in displacements (old) and angles (current).

Since the lateral and vertical displacements have a straightforward relation to the measured angles through the algorithm used in [5], it should be possible to translate the criteria envelop for displacements to a criteria envelop in angles, and the other way round. In Figure 19 the relations between the criteria are shown.

The triangle data points indicate the results of the 9 tests on which the current fore and aft angle criteria were based. Note that the old displacement criteria envelop results in angular envelop shaped as a narrow parallelogram. On the other hand, the current angular criteria envelop permits much larger ranges of lateral en vertical displacements than allowed under the old criteria. The corner “b” (Y = 110.0 mm, Z = 1.0 mm), however, is physically impossible because the neck (135.3 mm long) will not elongate 70 mm to reach that point. During the pendulum test the neck will primarily bend, a minor elongation because of axial neck loads is possible.

In Figure 20 the principle of the neck deflection is shown. During the test, the neck is attached to the upper and lower adapter of the head form; the upper adapter is attached to the base plate of the Part 572 pendulum arm. The head form measures the angle in a triangle with an initial height equal to the sum of the neck length and the adapter dimensions defining the potentiometer positions (45mm).

An absolute physical boundary for the neck deflection is the radius (R =135.3 + 45 mm) as indicated in 20. The actual deformed shape of the neck is dictated by the rigid adapters, the fixed support at the pendulum base plate and the neck loading. The loading of the neck consists of shear, tension and bending all three varying over the length of the neck. The moment is increasing considerable towards the pendulum base plate. As a realistic estimate of the theoretical deformation, the trajectory is calculated for the head form, assuming a fixed length neck (135.5 + 45 mm) bent with a constant moment. In Figure 21, the absolute circular deformation boundary and the estimated trajectory are shown together with the old and current criteria envelops.

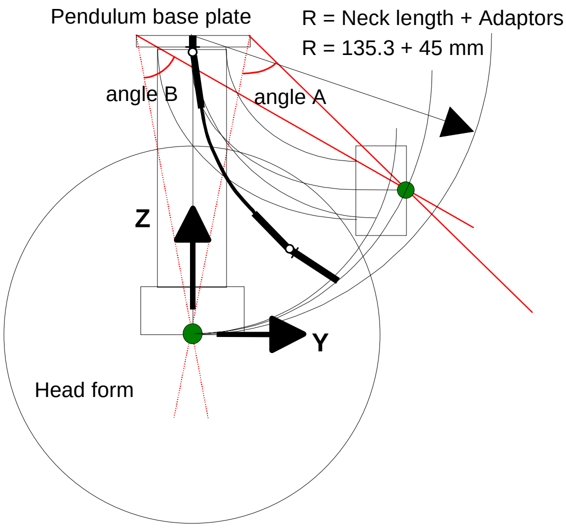


Figure 20: Principle of the neck deflection during the certification test

From Figure 21 it can be concluded that the actual neck displacement theoretically can not reach a large part of the old displacement criteria envelop. If readings from a test indicate displacement beyond the circular deformation boundary, this must be caused by the measurement error on the displacement. The results of the 9 tests on which the current angular criteria are based are all but two with in or close to the theoretical limit. For two tests, an accuracy of at least ±0.5 degree working in the same direction must be assumed to reach even the absolute deflection boundary.

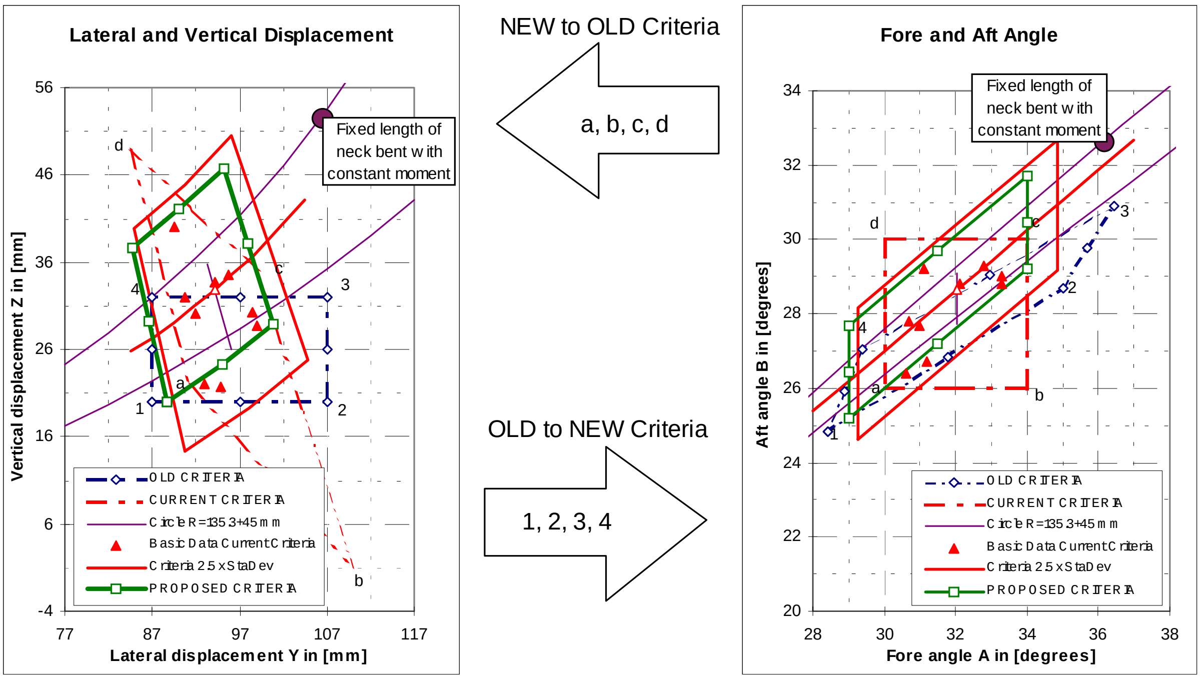


Figure 21: Neck absolute circular deformation boundary and the estimated real trajectory. The triangle data points indicate the results of the 9 tests on which the current fore and aft angle criteria were based. Also shown : The definition of proposed revised maximum fore and aft angle criteria.

Based on the set of 9 certification tests in Table 4 and taking into account the results of above analysis, the new criteria can now be defined. For a given neck, the actual displacement will follow trajectory that is most likely somewhere above the absolute circular boundary and close to the estimated trajectory. In terms of angles, a linear relation between the maximum of angle A and B can be assumed. Ignoring the two outliners in the data, a new envelop is defined by using the local approximations of the lines for the absolute deflection boundary and the estimated trajectory in the *angle B over angle A graph*. A criteria envelop of 2.5 times the standard deviation is set round the results of the 7 basic tests based on the linear relation and the mean angle A. The rounded off envelop values are thus given by:

$29.0 < \mathbf{d\Theta_A} < 34.0$ (The upper boundary is unchanged)

$0.8 * d\Theta_A + 2.0 < \mathbf{d\Theta_B} < 0.8 * d\Theta_A + 4.5$

The proposal for the revised certification output criteria can be summarised as follows:

Table 5: Proposed revised certification output criteria for the neck

CRITERION	PROPOSED CRITERIA Mean value	 Allowable range	Remark
Max. head form flexion [deg]	**51.0**	**± 5.0**	Unchanged (see note 1)
Time of max. head form flexion [ms]	**57.0**	**± 6.0**	(see note 2)
Maximum $d\Theta_A$ [deg]	**31.5**	**± 2.5**	(see note 3)
Time of maximum $d\Theta_A$ [ms]	**55.0**	**± 5.0**	Unchanged
Maximum $d\Theta_B$ [deg]	**0.8*$d\Theta_A$+3.25**	**± 1.25**	Relation between $d\Theta_B$ and $d\Theta_A$
Time of maximum $d\Theta_B$ [ms]	**55.0**	**± 5.0**	Unchanged

Note 1 : The maximum head form flexion is not changed because this criterion is set right from the beginning and remains unchanged so far.

Note 2 : On the time of the maximum head flexion no failures are reported, however the distribution of the results is in the upper parts of the allowable criteria range. Therefore, a small shift of 1 millisecond upward is applied to make this criterion more consistent with the maximum fore angle and maximum aft angle time criteria.

Note 3: The criterion is one degree mitigated and half a degree shifted downward. The new tolerance range is still a bit smaller than 2.5 times the standard deviation. The downshift applied results in a lower boundary that lines up with the lower boundary of the old displacement based criterion (Y min = 87 mm)

Effect of revised input and output criteria - Four users or provided data of 119 certifications in total, regarding 25 different necks. Two of them provided not only the certification results, as far as the criteria are concerned, but also the raw data and the processed data files from the tests. This input enables an evaluation of the procedures followed at those labs in full detail. Two labs provided signal plots on paper that only allows a provisional evaluation of the procedures. Participating laboratories are specified in Table 6.

Table 6: Definition of participating laboratories.

ID	Region	Number of tests for which data is provided	Remark
A	EUROPE	**10**	Raw and process digital data
B	EUROPE	**60**	Raw and process digital data
C	EUROPE	**8**	Signal plots on paper only
D	EUROPE	**41**	Signal plots on paper only
Total		**119**	

The alternative deceleration input criterion solves all the input corridor problems reported by one of the participating labs and enables an accurate application of a proper pendulum impact pulse (see Figure 17). The distribution of the 119 evaluation responses with regards to the maximum deflection relative to the proposed revised criteria envelop is given in *Figure 22*.

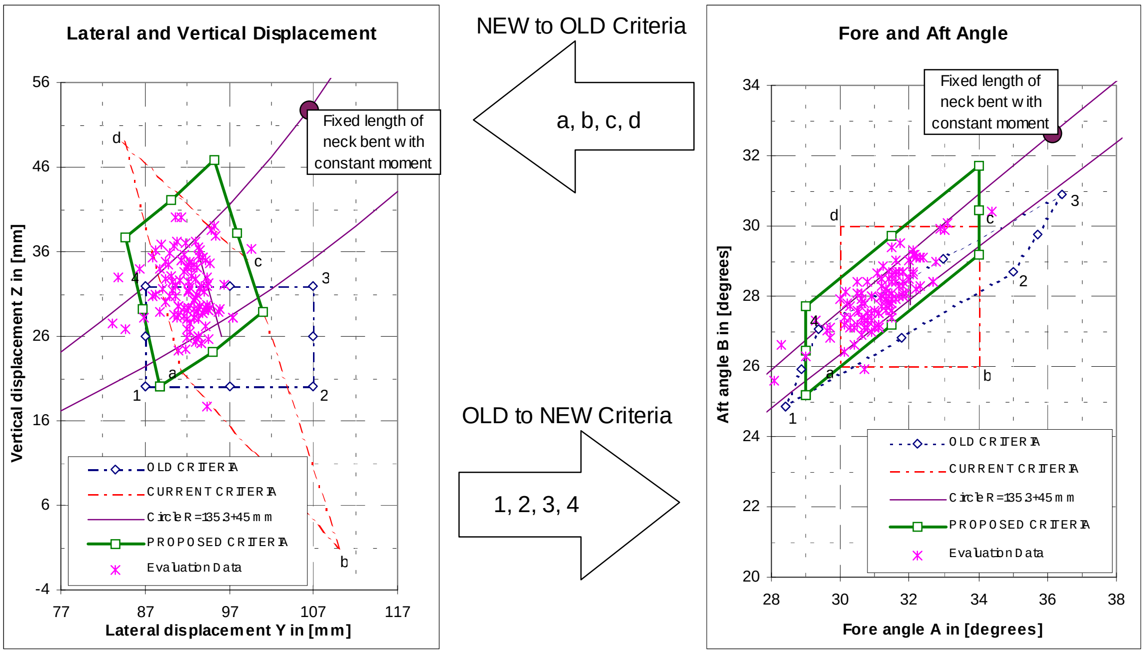


Figure 22: *Distribution of the evaluation test results (119 tests) relative to the proposed revised fore and aft angle criteria envelop.*

In Table 7 the effect of the proposed revised output criteria is shown by comparing the failures which occur either when the current or the proposed revised criteria are applied. Application of the proposed revised criteria reduces the failure rate of neck certifications from 21% to 7%

<u>Transformation of EUROSID-1 to ES-2 results</u> – The neck-head form set up for certification of

Table 7: *Comparison of certification failures for current and proposed revised neck criteria on the EVALUATION database*

Criterion	**FAIL original**	***FAIL Revised***	**Remark** Values : Current *(Revised)*
INPUT CRITERIA			
Pendulum impact speed [m/s]	**0**	***0***	
Pendulum acceleration time history	**12**	***0***	12 *(0) failures at lab B*
OUTPUT CRITERIA			
Max. head(form) flexion angle [°]	**0**	***0***	
Time of max. head flexion angle [ms]	**0**	***0***	
Maximum fore angle ($d\Theta_A$) [°]	**9**	***4***	9 *(4) failures at lab B*
Time of maximum fore angle [ms]	**4**	***4***	*4 (4) failures at lab D*
Maximum aft angle ($d\Theta_B$) [°]	**5**	***1***	*4 (0) failures at lab B* *1 (1) failures at lab D*
Time of maximum aft angle [ms]	**2**	***2***	*2 (2) failures at lab D*
			Number of certifications failed for: Current *(Revised)*
Overall test results	**25**	***8***	1 criterion : 18 *(5)* 2 criteria : 7 *(3)* 3 criteria : 0 *(0)*
	21 %	*7 %*	
Overall result per Lab:	See note		Note : Values including the strict interpretation of the input criteria (between brackets the values for output criteria only).
Lab A	**0 (0)**	***0***	
Lab B	**21 (10)**	***4***	
Lab C	**0 (0)**	***0***	
Lab D	**4 (4)**	***4***	

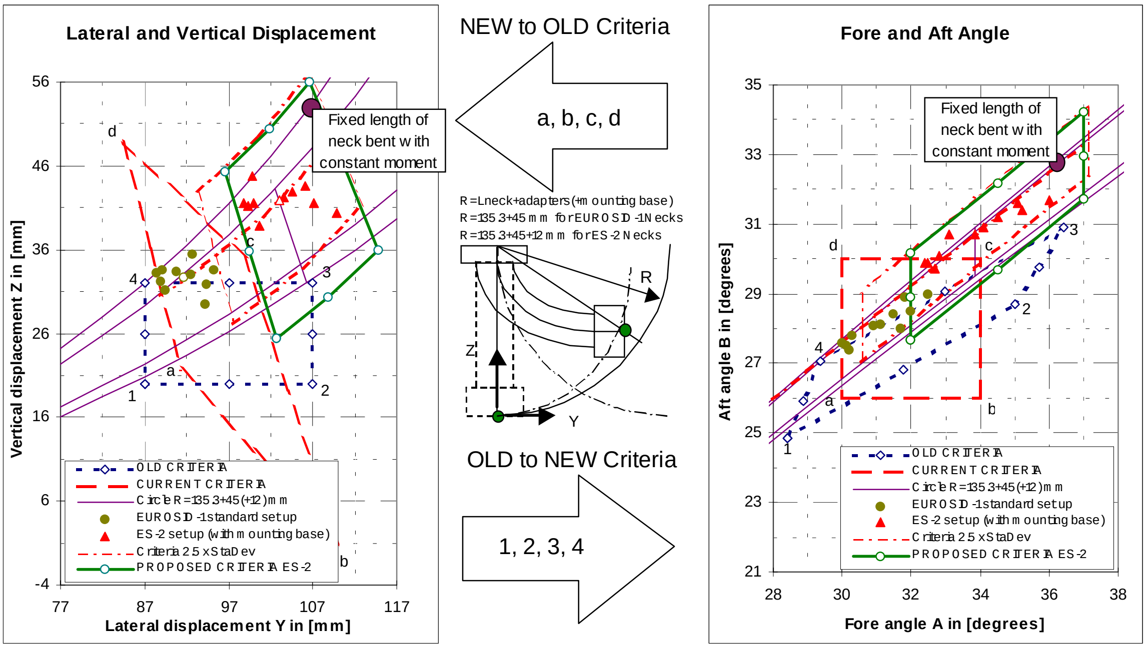


Figure 23: Definition of the proposed ES-2 maximum fore and aft angle criteria

the ES-2 necks is slightly different from that used for EUROSID-1. The EUROSID-1 head-neck interface plate is mounted directly to the head form. The ES-2 neck, however, is attached to the head form with a 12 mm thick aluminium mounting base between the neck and the head form (see Figure 3). This change is necessary because the head neck interface plate changed to accept the upper neck load cell. The neck mounting plate, that is available in the ES-2 Toolbox, assures the symmetric attachment of the neck to the head form. The consequence of the change in the neck-head form set up is a 206 gram mass increase of the head form and a 12 mm increase length of the set up. These two effects have a direct influence on the output results of the tests. To ensure equivalency of neck acceptance limits, the output criteria must be transformed from EUROSID-1 to ES-2 criteria. The input requirements for the pendulum test pulse remain unchanged. In order to enable a proper definition of the ES-2 criteria 2 series of 10 tests (5 left-hand side and 5 right-hand side) are performed with 5 different EUROSID-1 necks. The first series of 10 tests were done in the standard EUROSID-1 neck-head form set up. The second series of 10 tests were done with the same necks in the new ES-2 neck-head form set up. The test results are summarised in Table 9. The definition of the maximum aft angle criterion for ES-2 is done with the same method as described for EUROSID-1 in the first part of this annex. The results of this exercise are summarised Figure 23. The proposal for the revised certification output criteria can be summarised as follows:

Table 8: Proposed ES-2 neck certification output criteria

	PROPOSED CRITERIA for ES-2		**Remark** (Shift with respect to EUROSID-1)
CRITERION	**Mean value**	**Allowable range**	
Max. head form flexion [degrees]	**54.0**	**± 5.0**	(3.0)
Time of max. head form flexion [ms]	**60.0**	**± 6.0**	(3.0)
Maximum $d\Theta_A$ [degrees]	**34.5**	**± 2.5**	(3.0)
Time of maximum $d\Theta_A$ [ms]	**58.0**	**± 5.0**	(3.0)
Maximum $d\Theta_B$ [degrees]	**$0.81 \cdot d\Theta_A + 3.0$**	**± 1.25**	(2.5)
Time of maximum $d\Theta_B$ [ms]	**59.0**	**± 5.0**	(4.0)

Table 9: *Test results of neck certification tests in EUROSID-1 and ES-2 neck-head form set up configuration:*
EUROSID-1 : Standard neck-head form test configuration.
ES-2 : Test configuration with 12 mm thick mounting base between neck and head form

Part number EBA-	Impact direction LHS / RHS	Neck-Head test set-up	Pendulum impact speed	Maximum head flexion	Time to max head flexion	Maximum fore angle A	Time to max fore angle	Maximum aft angle B	Time to max aft angle
Unit			m/s	degrees	ms	degrees	ms	degrees	ms
13	LHS	EUROSID-1	3.50	50.4	60.5	31.5	57.5	28.4	55.6
99023	LHS	EUROSID-1	3.37	51.9	58.2	31.8	56.9	28.9	52.8
99025	LHS	EUROSID-1	3.33	49.5	59.4	32.0	57.9	28.5	53.5
99027	LHS	EUROSID-1	3.41	48.1	57.4	30.0	56.0	27.6	52.5
99028	LHS	EUROSID-1	3.41	48.3	57.9	30.3	51.9	27.8	53.5
13	RHS	EUROSID-1	3.50	51.1	58.7	30.2	53.8	27.4	55.0
99023	RHS	EUROSID-1	3.48	51.0	57.8	32.5	57.1	29.0	52.4
99025	RHS	EUROSID-1	3.48	48.5	59.8	30.1	52.5	27.5	52.4
99027	RHS	EUROSID-1	3.50	52.5	58.3	31.7	51.9	28.0	51.9
99028	RHS	EUROSID-1	3.45	50.1	58.0	30.9	56.5	28.1	52.6
MEAN		**EUROSID-1**	**3.44**	**50.14**	**58.60**	**31.10**	**55.20**	**28.12**	**53.22**
Standard Deviation			**0.06**	**1.53**	**0.99**	**0.91**	**2.41**	**0.57**	**1.21**
13	LHS	ES-2	3.48	53.7	61.2	34.5	60.4	31.2	59.2
99023	LHS	ES-2	3.48	53.7	61.6	35.1	58.5	31.6	58.1
99025	LHS	ES-2	3.48	54.6	62.3	36.0	58.2	31.7	58.2
99027	LHS	ES-2	3.48	52.5	62.3	32.7	57.9	29.7	57.3
99028	LHS	ES-2	3.45	53.3	60.6	33.1	58.4	30.7	56.5
13	RHS	ES-2	3.50	51.6	61.9	32.8	57.5	30.1	57.5
99023	RHS	ES-2	3.43	55.4	63.2	35.2	57.8	31.4	59.4
99025	RHS	ES-2	3.48	51.8	58.3	32.5	56.6	29.9	56.2
99027	RHS	ES-2	3.45	52.8	62.3	32.4	57.0	29.9	57.1
99028	RHS	ES-2	3.45	53.7	61.5	34.1	57.8	30.9	55.7
MEAN		**ES-2**	**3.47**	**53.31**	**61.52**	**33.84**	**58.01**	**30.71**	**57.52**
Standard Deviation			**0.02**	**1.18**	**1.34**	**1.31**	**1.03**	**0.76**	**1.22**
SHIFT EUROSID-1 to ES-2				**3.17**	**2.92**	**2.74**	**2.81**	**2.59**	**4.30**
Proposed shift of the criteria				**3.0**	**3.0**	**3.0**	**3.0**	**2.5**	**4.0**

ANNEX C : THORAX ASSEMBY EVALUATION

The thorax assembly modifications are quite extensive. This annex summarises the results from ES-2 prototype rib unit testing at TNO and TRL as part of the SID2000 project. The objective of the tests was to tune the new designs to standard EUROSID-1 certification requirements, to assess the level of reduction in flat-topping.

Concept Evaluation - Three different design options for the new ES-2 thorax have been evaluated and compared with the standard EUROSID-1 configuration. The design options were:

- ES-2 Needle bearing concept
- ES-2 Coated Piston concept (improved EUROSID-1 rib assembly)
- ASTC Ball bearing concept

Finally one of the concepts is recommended for full scale testing in America at NHTSA and Transport Canada and in Europe at ACEA members and SID2000 partners. (NHTSA and Transport Canada were provided one dummy with hardware for all three design options)

The following tests have been performed on the prototyped concepts in the lats two mouth of 1999:

- **Static friction tests at TNO Automotive and FTSS-Europe**
  Objective: Investigate role of piston guide bearing design in flat top behaviour of the rib module
  Method : Measurement of friction coefficient in rib unit, applying torque and off axis loads
  Concepts : Standard EUROSID-1 versus Coated Piston.
- **Certification tests at TNO automotive and FTSS-Europe**
  Objective : Tune performance to standard EUROSID-1 requirements and selection of the appropriate tuning the springs
  Method: Rib unit drop tests conform EUROSID-1 User Manual
  Concepts: Standard EUROSID-1, Needle bearing, Coated piston and ASTC Ball bearing concept
- **Full body pendulum biofidelity assessment at TNO Automotive and FTSS-Europe.**
  Objective: Check biofidelity based on impactor test and off-axis behaviour:
  Method: Full body impactor tests 23.4 kg at 4.3 and 6.7 m/s, lateral and 30° forward oblique : Comparison to EEVC-WG9 and ISO TR9790 corridors
  Concepts: Standard EUROSID-1, Needle bearing and Coated piston concept.
- **Single rib dynamic testing at TRL**
  Objective: Check reduction in flat top behaviour under off-axis loading conditions
  Method: Suspended rib unit, impacted with 23.4 kg at 2.5 m/s; 30° forward and 5° roll and 30° forward and -20° roll
  Concepts: Standard EUROSID-1, Needle bearing, Coated piston and ASTC Ball bearing concept

The results for the four different thorax configurations were extensively evaluated. Thirteen different aspects were used to compare the performance of the thorax designs. In Table 10 a summary of the evaluation on these aspects is given. Per aspect the most favourable design is indicated by grey shading.

The following general conclusions were drawn:

- The ES-2 Needle bearing design is favourable on nearly all performance aspects.
- The ES-2 Needle bearing design allows sufficient possibilities for fine-tuning of the design if necessary.

The evaluation showed that the ES-2 Needle bearing design requires some detailed design adjustments with regards to items listed below. The implementation of these items was fixed from the second prototype on.

- Tuning spring stiffness (standardisation of spring length for production version necessary),
- Initial position buffering,
- Integration of end stop buffer,
- Protection of rib module against foreign objects
- Decreased number of bolts in rib module to spine attachment
- Potentiometer wire routing improvement.

Implementation of the above mentioned design refinements is expected not to influence the rib performance. The stiffer tuning springs are also subsequently delivered to NHTSA for the first prototype

Table 10: Evaluation matrix for rib unit design options

	Aspect	EUROSID-1 (base line)	ES-2 Needle bearing	ES-2 Coated Piston	ASTC Ball bearing
1	Static friction and Piston guide bearing (PGB) limitations	Friction 0.073 Capability PGB factor 10 short	**Minimal friction No PGB friction**	Friction 0.033 ?? Capability PGB adequate	Minimal friction Capability PGB factor 10 short ?
2	Certification drop tests	Certifications well in corridor	Certification corridor to be reconsidered	Certification corridor to be reconsidered	Certification corridor to be reconsidered
3	Tuning spring stiffness	Tuneable with spring 1 to 5	Very stiff spring required. Design space available.	**Tuneable with spring 1 to 5**	Very stiff spring required. Not possible in room available.
4	Biofidelity full body pendulum 6.7 m/s	Peak well in the corridor Unloading considerable out of corridor	**Peak well in the corridor Unloading very well in corridor**	Peak well in the corridor Unloading considerable out of corridor	Not tested
5	Biofidelity full body pendulum 6.7 m/s	Peak just out of the corridor Unloading considerable out of corridor	**Peak just out of the corridor Unloading very well in corridor**	Peak just out of the corridor Unloading considerable out of corridor	Not tested
6	Rib displacement middle rib in lateral full body tests	34.6 (4.3 m/s) 51.7 (6.7 m/s)	34.5 (4.3 m/s) 52.7 (6.7 m/s)	35.2 (4.3 m/s) 52.8 (6.7 m/s)	Not tested
7	Full body, 30 degrees forward oblique tests	FLAT TOP 2 ms	**NO FLAT TOP**	NO FLAT TOP Discontinuous VC signal	Not tested
8	Mass of moving parts	610 gram	710 gram	610 gram	610 gram
9	End stop buffer at max'm displacement	Rubber	Rubber	Rubber	Rubber
10	End stop buffer at initial position	Very poor	**Good**	Poor	Poor
11	High acceleration performance and Durability	Excellent	Good	**Very Good**	Poor
12	Single rib testing at TRL (first series)	FLAT TOP 4 ms	**NO FLAT TOP**	NO FLAT TOP Discontinuous VC signal 11 ms	NO FLAT TOP Discontinuous VC signal 7 ms
13	Single rib testing at TRL (second series)	FLAT TOP 11 ms	**NO FLAT TOP**	FLAT TOP 6 ms	NO FLAT TOP Discontinuous VC signal 8 ms

ES-2 Prototype versus EUROSID-1 evaluation - In the remaining part of this annex the results of the tests on the ES-2 prototype equipped with the needle bearing design versus the standard EUROSID-1 results are presented. The tests that show the difference in performance between the ES-

2 Prototype and the standard EUROSID-1 are the full body pendulum and the single rib dynamic tests. The results of both tests are summarised.

Full Body Biofidelity Pendulum Tests – The full body pendulum tests with a lateral impact are performed to check the thorax biofidelity performance. The T1 and pendulum acceleration for both the ES-2 prototype and the EUROSID-1 are given in Figure 24. For comparison the available ISO TR9790 and EEVC-WG9 corridors are shown in the graphs.

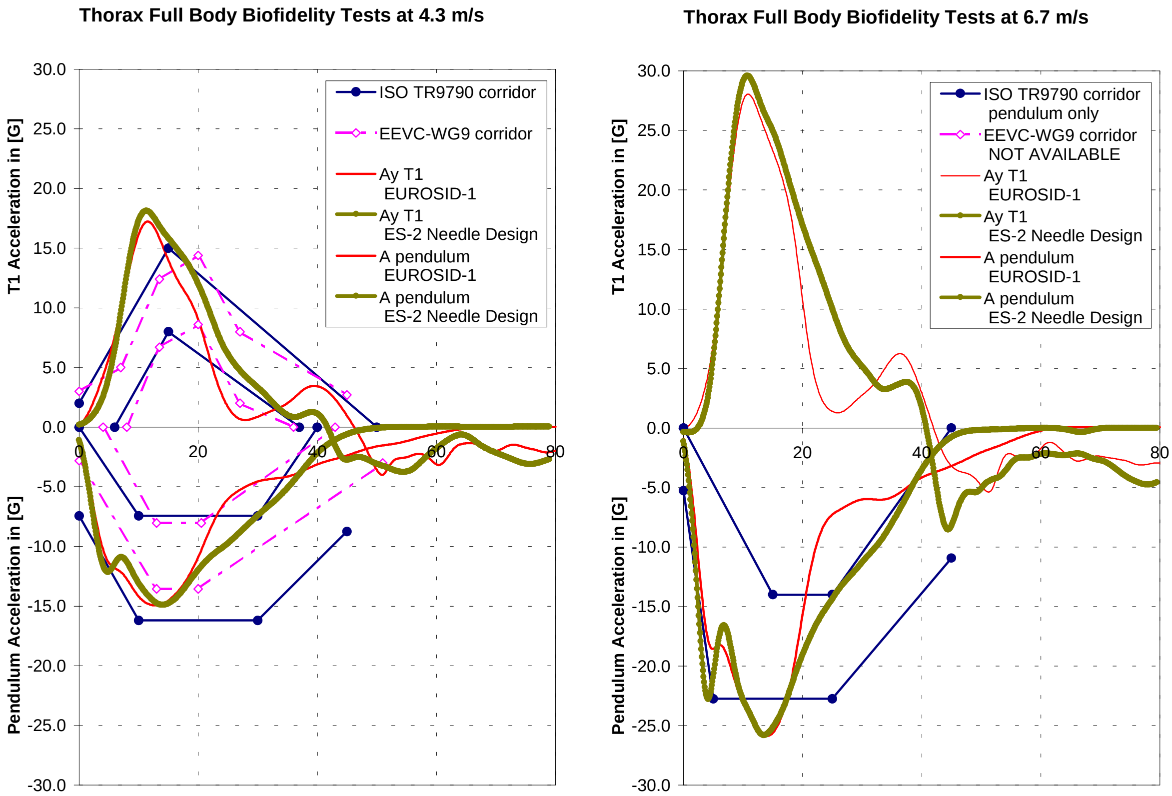


Figure 24: EUROSID-1 and ES-2 Prototype thorax fully body biofidelity pendulum tests at 4.3 and 6.7 m/s For comparison the available ISO TR9790 and EEVC-WG9 corridors are shown

EUROSID-1 results:

- The EUROSID-1 results reproduce the test results published by Harigae, et all.[2] quite well.
- The pendulum and T1 acceleration obtained in the full body 4.3 m/s lateral tests are shown.
- The small initial peak in the pendulum acceleration signal is nearly removed by the filtering.
- Both, the T1 and the pendulum signals show a dip in the unloading phase.
- The signals considerably exceed the lower boundary of the ISO corridor.

ES-2 Prototype (needle bearing equipped) results:

- The ES-2 Prototype results for the Needle bearing design show a loading phase similar to that of EUROSID-1.
- The initial peak in the pendulum acceleration signal is somewhat more pronounced. The 100 gram extra moving mass may cause this.
- The unloading signals fit very well in the ISO corridor.
- The ES-2 Prototype shows improved biofidelity with respect to EUROSID-1.

2 Harigae, T. et all. JARI/JAMA ESV paper 91-S8-O-01 "Evaluation of Impact Responses of the EUROSID-1 & BIOSID"

The tests with an impact at 4.3 m/s are done with 30 degrees forward oblique impact direction as well. The EUROSID-1 shows minor displacement signal discontinuities in this test configuration. In Figure 25 the displacement signals and the calculated V*C are shown.

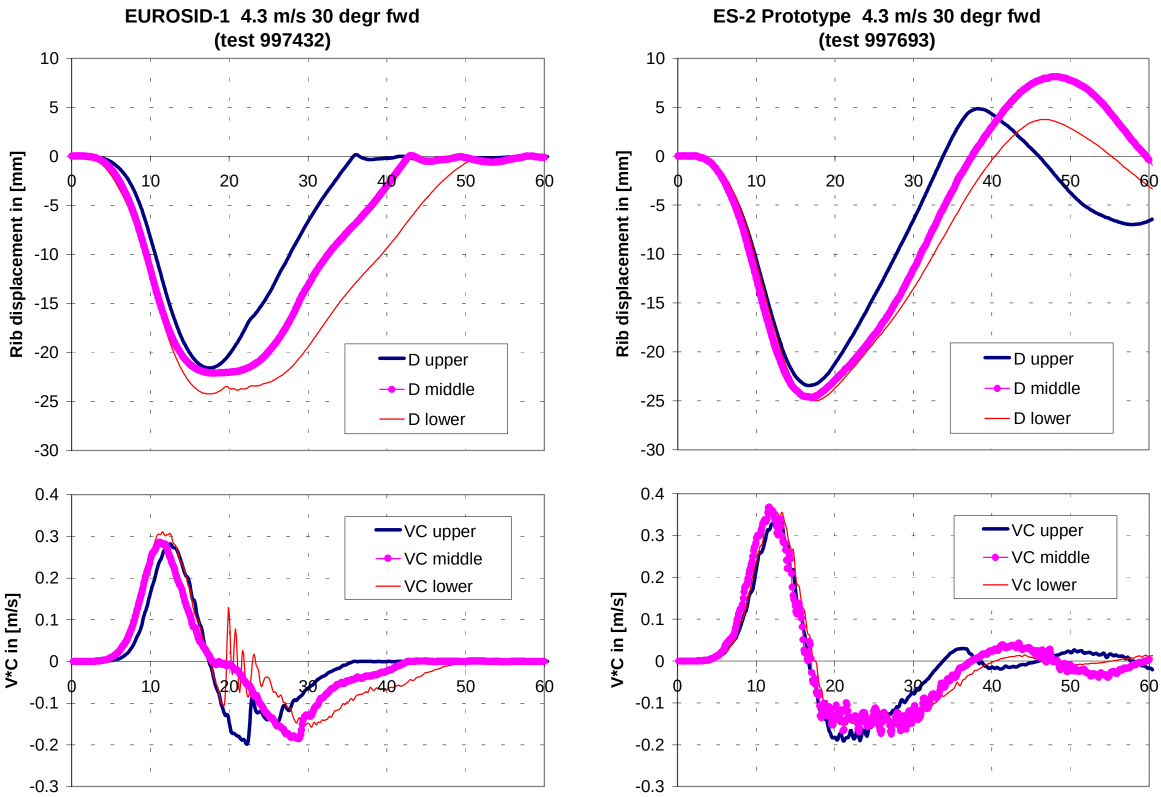


Figure 25: EUROSID-1 and ES-2 Prototype thorax fully body pendulum tests at 4.3 m/s, 30 degrees forward oblique impact direction.

*Note : The V*C signals are calculated with the raw data. Calculation as usual with the filtered displacement signal should have given a more steady result.*

<u>Single rib dynamic tests</u> – The single rib tests at TRL in December 1999 are performed with a standard Part 572-pendulum. The test set-up is shown in Figure 26. Two different series of tests are performed :

- Rib unit 30 degrees forward impact, under 5 degrees roll; 4 wire parallel suspension
  Set-up : Rib + mounting 10.9 kg, Suspended with 4 parallel wires.
  Impact : Pendulum 23.4 kg, Speed 2.5 m/s
  Direction : 30 degrees forward and 5 degrees roll
  Results (See Figure 26):
  EUROSID-1: Small Flat Top 4 msec (slightly down sloped), Rib displacement 19.6 mm
  ES-2 Prototype: No Flat Top, Continuous V*C signal, Rib displacement 20.8 mm
- Rib unit 30 degrees forward impact, under -20 degrees roll; single point suspension
  Set-up: Rib + mounting 17.8 kg, Single point suspended 800 mm above the rib module.
  Impact: Pendulum 23.4 kg, Speed 2.5 m/s
  Direction: 30 degrees forward and -20 degrees roll
  Results (See Figure 26):
  EUROSID-1 : Flat Top 11 msec (5 msec slightly down sloped), Rib displacement 15.6 mm
  ES-2 Prototype: No Flat Top, Slight discontinuous V*C over 2 msec, Rib displacement 18.8 mm

Conclusion:
The full body and component tests performed at TNO Automotive / FTSS Europe and TRL show a significant improvement of the rib performance with regards the continuity of the rib displacement signal. The ES-2 prototype rib units equipped with the needle bearing guide system provide a good prospective to eliminate the flat top behaviour of the EUROSID-1 thorax.

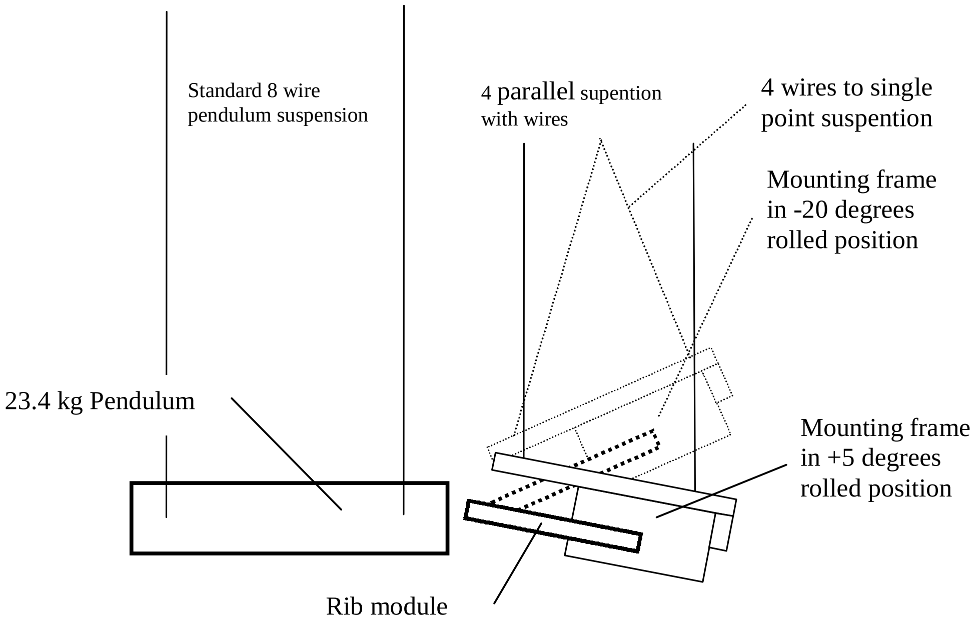
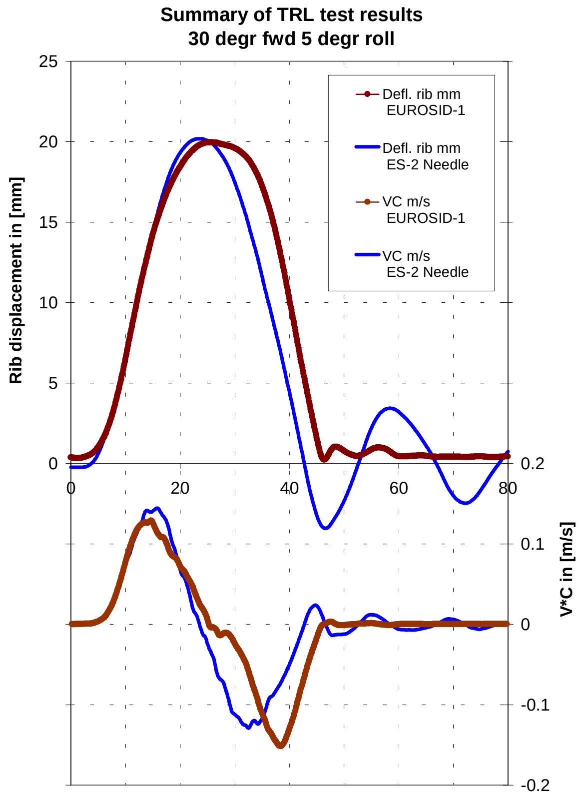


Figure 26: Single rib dynamic test set-up. Rib unit mounted on a frame total mass 10.9 kg; impact direction 30 degrees forward oblique and 5 degrees roll. (Dashed line shown the -20 degrees roll set-up)



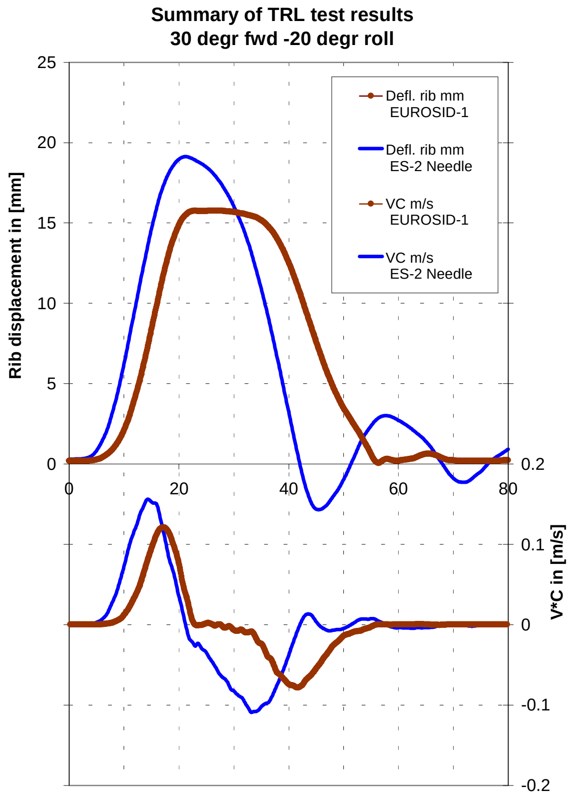


Figure 27: *TRL Single rib dynamic test results for EUROSID-1 and ES-2 Prototype impact speed 2.5 m/s direction 30 degrees forward 5 degrees roll and –20 degrees roll.*

ANNEX D : T12 LOAD CELL TEST RESULTS

The T12 load cell performance is checked with the full body abdomen and pelvis certification tests. The results of these tests are summarised in Figure 28 and Table 11. The load cell performed as expected. The capacity of the load cell is used for 44% for forces (Fy) and 31% for moments (Mx). Results from full-scale tests should make clear whether or not the load cell capacity can be decreased.

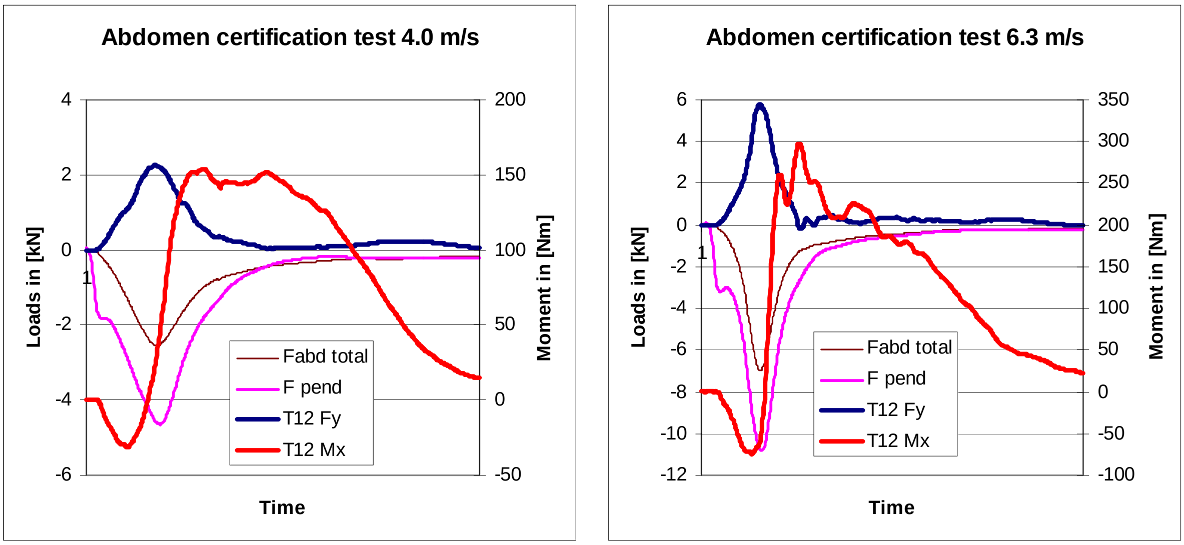


Figure 28: T12 Load Cell performance in abdomen certification tests at 4.0 and 6.3 m/s
T12 Fy and Mx as well as abdomen force (total) and pendulum force

Table 11: T12 Load Cell evaluation test results maximum and minimum values measured

Parameter	**Load cell Capacity**	**Abdomen tests**				**Pelvis tests**	
Impact direction **Pend. Speed (nominal)** **Max'm Pend. Force**		**Lateral** **4.0** **4.66**	**Lateral** **6.3** **11.00**	**20 fore** **6.3** **11.89**	**20 aft** **6.3** **10.56**	**Lateral** **4.3** **5.41**	**Lateral** **6.3** **11.37**
Fx in kN	***14***	0.22 -0.35	0.48 -0.68	0.13 **-1.75**	**1.81** -0.15	0.09 -0.18	0.13 -0.17
Fy in kN	***14***	2.26 -0.11	5.94 -0.20	**6.14** **-0.29**	5.10 -0.18	0.60 -0.03	-0.96 -0.04
Mx in Nm	***1000***	154.18 -31.45	299.58 -86.80	**311.34** -83.50	206.46 -80.29	56.91 -68.60	36.49 **-110.76**
My in Nm	***1000***	12.48 -14.88	32.56 -32.53	**117.41** -21.83	38.53 **-94.84**	17.25 -6.05	28.51 -9.16

ANNEX E : ABDOMEN CERTIFICATION TESTS

Objective – Determine a new impact speed for the EUROSID-1 abdomen certification test.
Test set-up – To determine the new impact velocity for the abdomen certification test, a series of tests were carried out at increasing speeds, starting from 3.0 m/s up to 6.3 m/s. The procedure followed was as prescribed by the EUROSID-1 certification manual, including the data processing.
Results – The non-linearity of the abdomen load cells is less than 1 percent according to the product specifications. If an error of 1 percent is assumed, then the total error for 3 load cells can be as high as 3 percent. For the abdomen load cells this means an error of 150N.
The relationship between impact energy and impact force is shown in Figure 40. For the impact velocity range of 3.0 m/s to 6.3 m/s, a linear relationship may be assumed, taking into account the error in the measurement. As the impact force is derived by multiplying the impact acceleration by the impactor mass, the error is determined by the accelerometer accuracy, which is 3 percent of the measured value. Below 3.0 m/s the relationship must be non-linear, as the line through the measurement points would intersect the y-axis at 0.72 kN.
The plot of the impact energy versus the abdomen force does not suggest a linear relationship (Figure 30). A measurement error of 150 N does not allow the fitting of all points along a straight line. The relationship can be described by a second order polynomial.

Table 12: Overview of abdomen tests performed at various speeds.

Test ID	target velocity [m/s]	actual velocity [m/s]	energy [J]	max. impact force [kN]	time of maximum [ms]	max. abdominal force [kN]	time of maximum [ms]
980601	6.30	6.33	489	9.90	9.50	6.55	9.20
980602	6.30	6.33	489	9.98	9.40	6.62	9.10
980603	3.00	2.90	103	2.72	11.90	1.52	11.80
980604	3.00	2.93	105	2.77	12.00	1.55	11.70
980605	3.50	3.52	151	3.55	12.10	1.97	11.80
980606	3.50	3.52	151	3.55	12.10	1.98	11.70
980607	4.00	4.06	201	4.41	11.90	2.50	11.30
980608	4.00	4.06	201	4.46	11.80	2.50	11.30
980609	4.30	4.35	231	5.07	11.70	2.89	11.10
980610	4.30	4.35	231	5.03	11.70	2.89	11.00
980611	5.00	5.08	315	6.70	11.00	3.95	10.50
980612	5.00	5.08	315	6.58	11.00	3.84	10.30
980613	5.50	5.61	384	7.91	10.50	4.87	9.80
980614	5.50	5.61	384	7.99	10.40	4.88	9.80
980615	6.00	6.00	439	9.06	10.00	5.76	9.50
980616	6.00	6.00	439	8.96	10.00	5.73	9.50
980617	4.00	4.05	200	4.43	11.70	2.46	11.10
980618	4.00	4.03	198	4.38	11.80	2.43	10.80
980619	4.00	4.03	198	4.42	11.80	2.42	11.30
980620	4.00	4.03	198	4.34	11.9	2.44	11.10

As the relationship between impact energy and abdomen force is not linear, the relationship between the external impact force and the internal load cell force is also not linear. At an impact speed velocity the ratio of the two is 1.8, and at 6.3 m/s it is 1.5.
Selection of impact velocity level – A new impact level of 4.0 m/s proposed for the EUROSID-1 abdomen certification test. This level will result in an abdomen force that is exactly the injury criterion of 2.5 kN. At this impact velocity speed, the dummy is used within the biofidelity impact response limits.

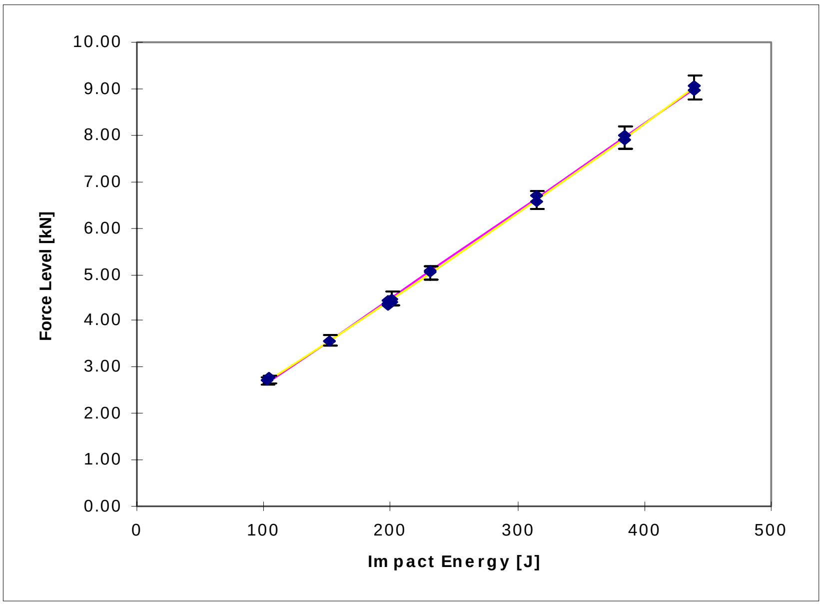


Figure 29: Relationship between impactor energy and measured impact force.

Proposed new abdomen certification requirement :

- Peak abdomen force between: 2.2 and 2.7 kN between: 10.0 and 12.3 msec
- Peak impactor force between: 4.0 and 4.8 kN between: 10.6 and 13.0 msec

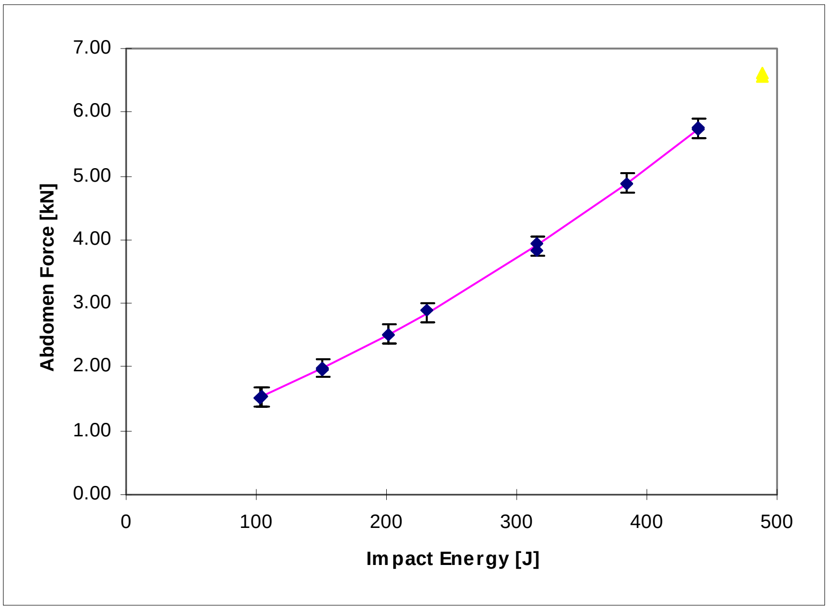


Figure 30: Relationship between impact energy and abdomen force

ANNEX F : LUMBAR SPINE CERTIFICATION EVALUATION

Objective – The objective of the lumbar spine certification procedure re-evaluation was twofold :

1. Investigate the cause of failing in the input and output certification requirement, and re-definition of the input and output criteria;
2. Investigate the effect of the proposed revised criteria using evaluation data provided by 5 different labs (Europe, US).

Input criteria – The acceleration corridor as specified in the existing certification procedure is presented in Table 13 for respectively the lower and upper boundary of the corridor.

Table 13: Pendulum acceleration corridor lumbar spine certification

Lower Boundary		Upper Boundary	
Time [s]	Acceleration [m/s]	Time [s]	Acceleration [m/s]
0.001	-18.1	0	-28.1
0.0098	-25.9	0.01	-34.1
0.0235	-17.6	0.0272	-21.1
0.0266	0	0.0318	0

The actual acceleration of the pendulum measured by three different certification laboratories were related to this corridor. A graph of these accelerations is shown in Figure 31. Time synchronisation is performed by setting the time of the first 10 g value, in the initial slope, to 1.588 ms. This corresponds with the middle of the corridor at 10 g.
It can be seen that several data sets exceed the upper corridor due to a superimposed "high" frequency vibration which appear to have frequencies between 60 and 160 Hz. The frequency of

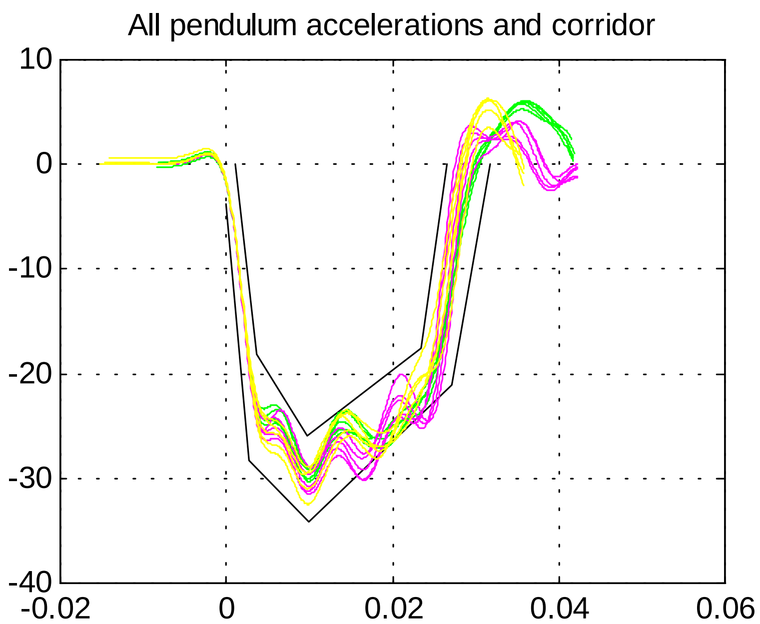


Figure 31: The pendulum accelerations filtered CFC 60 of three certification labs and the acceleration corridor

these vibrations is not high enough to be damped sufficiently by the CFC 60 filter. The vibrations appear to be caused by the construction of the pendulum support. The vibration magnitude and frequency have a typical value for each individual laboratory.

It can be concluded that the specification of the pendulum in the certification procedure is not sufficient to exclude the phenomenon of this superimposed vibration. Adding a specification for the support construction is not desired here. The assumption can be made that the response of the spine will not be influenced significantly by these relative low energy vibrations as the frequency of the overall spine response is approximately 6 Hz. Therefore it is decided to develop a velocity based certification corridor for the pendulum input. With this approach it is assuming that the effect of the vibrations will be reduced due to integrating the accelerations. The corridor to be developed should still comply with the overall shape of the acceleration pulse, magnitude and time duration.

The pendulum accelerations and the acceleration corridor were integrated starting at time zero after time synchronisation. Thus the data before time zero are neglected. The result is shown in Figure 32.

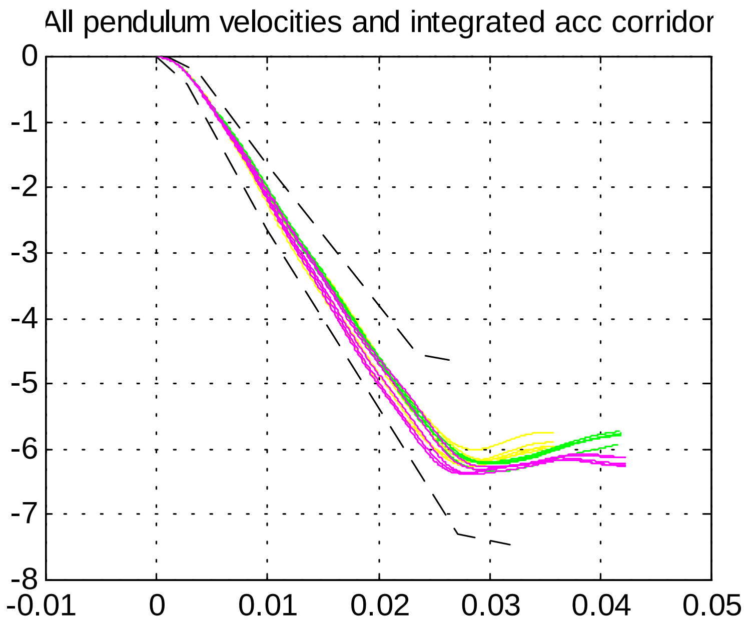


Figure 32: The integrated pendulum accelerations of three certification labs and the integrated acceleration corridor [dashed lines].

The velocity time histories do fit easily in the velocity corridor obtained by integration of the upper and lower boundary acceleration corridor. The vibrations in the accelerometer data are not recognisable anymore and do not affect the certification result. Which was assumed as stated in the previous section. The final velocities vary from approximately –6.0 to –6.4 m/s. This exceeds the required velocity, as specified in the certification procedure, 6.05 ±0.1 m/s. This is a general known problem in data processing. The quality of integration of accelerations depends on:

- the procedure of determining the zero load output of the accelerometer
- the systematic offset of the accelerometers sensitivity
- the linearity of the sensitivity
- the accuracy of the velocity measurement of the pendulum

The pendulum velocity at impact could be included in the integration of the pendulum acceleration. It was decided to omit this as most laboratories measure the pendulum velocity independent from their data-acquisition system used for recording the pendulum acceleration. This makes it possible to ad an integration routine to the data-acquisition system which automatically processes the acceleration data to obtain the time history of the pendulum velocity change without requiring extra input from the operator.

The velocity corridor should guarantee the general shape of the acceleration pulse. The acceleration shows a positive value after approximately 0.03 sec. The wide space in the integrated corridor allows a large remaining velocity of the pendulum at the end off the acceleration pulse. Narrowing the velocity corridor at the end can prevent this.
The onset of the pulse is also important and can be set to the same limits set by the acceleration corridor by using the integrated acceleration corridor for the first interval of the velocity corridor. Although the first value of the upper velocity boundary can not be zero as the integration constant is set to 0.
Two straight lines for the velocity corridor define the average acceleration value, in the top part of the acceleration corridor.
The time duration of the pulse is defined in the integrated acceleration by the moment that the velocity comes to an almost constant value, at approximately 0.0275 seconds in Figure 32. The time duration can be defined by limiting the final value of the integrated acceleration to a minimum and setting a minimum time for this minimum.
This results in the velocity corridor as presented in Table 14 and shown in Figure 33.

Table 14: Pendulum velocity corridor for the neck certification

Upper Boundary		**Lower Boundary**	
Time [s]	Velocity [m/s]	Time [s]	Velocity [m/s]
0.001	0	0	-0.05
0.0037	-0.2397	0.0027	-0.4251
0.0270	-5.8	0.0245	-6.5
		0.03	-6.5

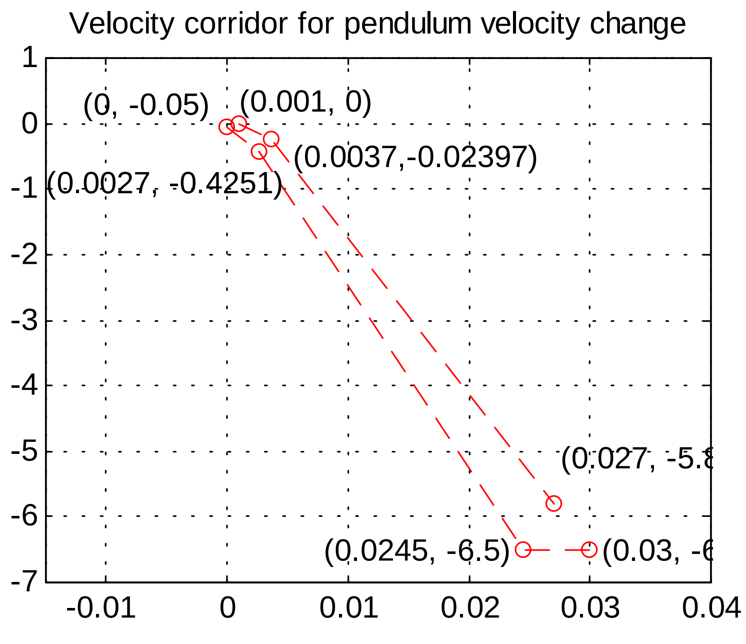


Figure 33: The spine pendulum velocity certification corridor

Output criteria – The initially defined criteria based on displacements (trajectory) were superseded by criteria that are directly based on the measured fore and aft angle. The angle based criteria were derived from 11 certification tests on 9 lumbar spines. In Table 15 the results of the tests and the defined criteria are summarised.

Table 15: Basic test results (11 tests) and defined (current) output criteria

OUTPUT PARAMETERS	TEST RESULTS (11 tests) Mean value	Standard deviation	CURRENT CRITERIA Mean value	Allowable range
Max. head form flexion [deg]	49.0	1.17	50.0	± 5.0
Time of max. head form flexion [ms]	48.5	1.47	46.0	± 7.0
Maximum $d\Theta_A$ [deg]	32.7	0.76	33.0	± 2.0
Time of maximum $d\Theta_A$ [ms]	48.2	1.53	50.0	± 5.0
Maximum $d\Theta_B$ [deg]	29.2	0.75	29.0	± 2.0
Time of maximum $d\Theta_B$ [ms]	48.8	1.35	50.0	± 5.0

Since the lateral and vertical displacements have a straightforward relation to the measured angles through the algorithm used in [5], it should be possible to translate the criteria envelop for displacements to a criteria envelop in angles, and the other way round. In Figure 34 the relations between the criteria are shown.

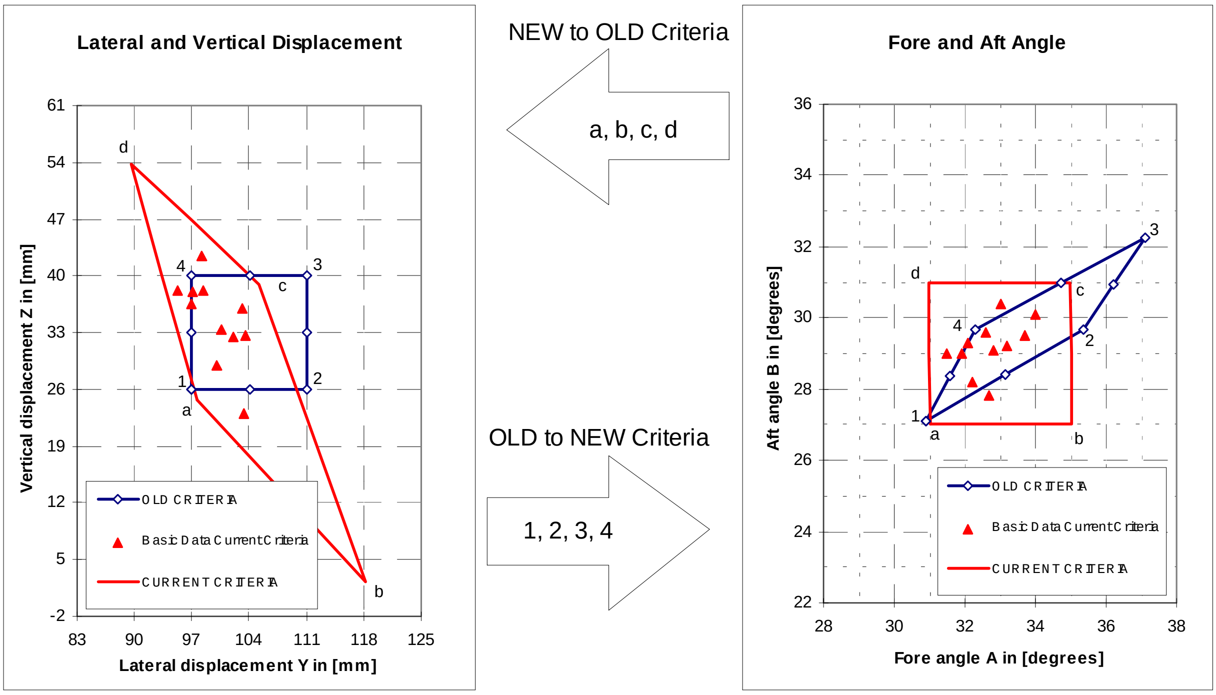


Figure 34: Relation between the old and the current lumbar spine certification criteria on deflection measured in displacements (old) and angles (current)..

The triangle data points indicate the results of the 11 tests on which the current fore and aft angle criteria were based. Note that the old displacement criteria envelop results in angular envelop shaped as a narrow parallelogram. On the other hand, the current angular criteria envelop permits much larger ranges of lateral en vertical displacements than allowed under the old criteria. The corner “b” (Y = 118.3 mm, Z = 2.2 mm), however, is physically impossible because the lumbar spine, which is equipped with steel cable, has a fixed length

The lumbar spine is equipped with a steel cable between the upper and lower end plates. This cable allows shear deflection and bending, but it restrains elongation of the spine. In Figure 35 the principle of the spine deflection is shown. During the test, the spine is attached to the upper and lower adapter of the head form; the upper adapter is attached to the base plate of the Part 572 pendulum arm. The head form measures the angle in a triangle with an initial height equal to the sum of the spine length and the adapter dimensions defining the potentiometer positions (55mm).

An absolute physical boundary for the spine deflection is the radius (R =133.5 +55 mm) as indicated in Figure 35. The actual deformed shape of the spine is dictated by the rigid adapters, the fixed support at the pendulum base plate and the spine loading. The loading of the spine consists of shear, tension and bending all three varying over the length of the spine. The moment is increasing considerable towards the pendulum base plate. As an realistic estimate of the theoretical deformation, the trajectory is calculated for the head form, assuming a fixed length spine (133.5 + 55 mm) bent with a constant moment. In Figure 36, the absolute circular deformation boundary and the estimated trajectory are show together with the old and current criteria envelops.

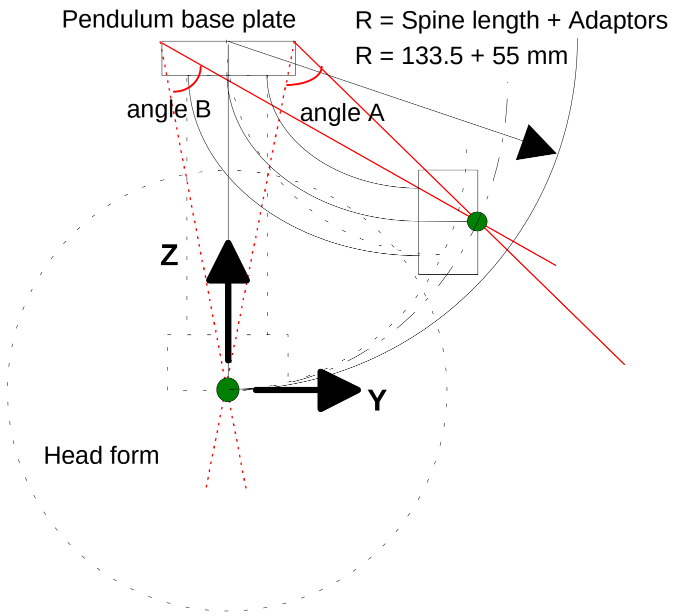


Figure 35: Principle of the lumbar spine deflection during the certification test

From Figure 36, it can be concluded that the actual spine displacement theoretically can not reach a large part of the old displacement criteria envelop. If readings from a test indicate displacement beyond the circular deformation boundary, this must be caused by the measurement error on the displacement. The results of the 11 tests on which the current angular criteria are based are all but one with in the theoretical limit. For one test an accuracy of at least ±0.5 degree working in the same direction must be assumed to reach even the absolute deflection boundary.

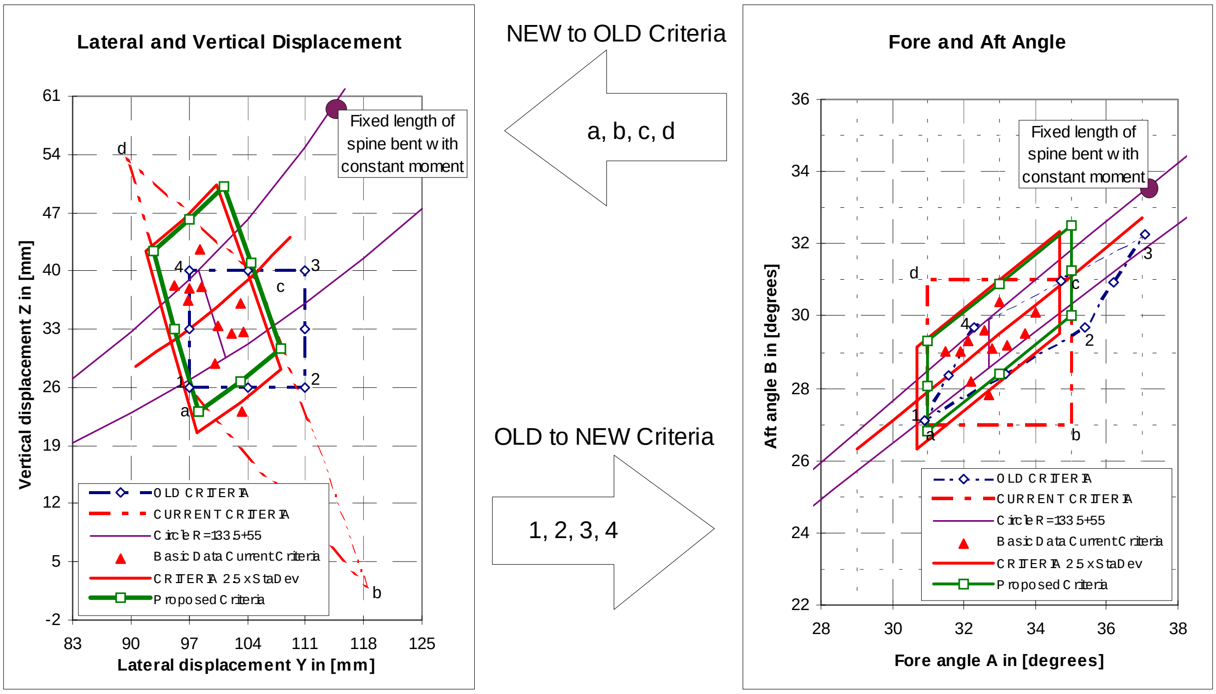


Figure 36: Lumbar spine absolute circular deformation boundary and the estimated real trajectory. The triangle data poinst indicate the results of the 11 tests on which the current fore and aft angle criteria were based. Also shown the definition of proposed revised maximum fore and aft angle criteria.

Based on the set of 11 certification tests in Table 15 and taking into account the results of above analysis, the new criteria can now be defined. For a given spine, the actual displacement will follow trajectory that is most likely somewhere above the absolute circular boundary and close to the estimated trajectory. In terms of angles, a linear relation between the maximum of angle A and B can be assumed. Ignoring the outliner in the data, a new envelop is defined by using the local approximations of the lines for the absolute deflection boundary and the estimated trajectory in the *angle B over angle A graph*. An criteria envelop of 2.5 times the standard deviation is set round the results of the 10 basic tests based on the linear relation and the mean angle A. The rounded off envelop values are thus given by:

$31.0 < \mathbf{d\Theta_A} < 35.0$ (no change with respect to the current criterion)
$0.8 * d\Theta_A + 2.0 < \mathbf{d\Theta_B} < 0.8 * d\Theta_A + 4.5$

The proposal for the revised certification output criteria can be summarised as follows:

Table 16: Proposed revised certification output criteria for the lumbar spine

CRITERION	PROPOSED CRITERIA Mean value	Allowable range	Remark
Max. head form flexion [deg]	**50.0**	**± 5.0**	Unchanged (see note)
Time of max. head form flexion [ms]	**46.0**	**± 7.0**	Unchanged (see note)
Maximum $d\Theta_A$ [deg]	**33.0**	**± 2.0**	Unchanged
Time of maximum $d\Theta_A$ [ms]	**48.0**	**± 4.0**	Changed on review of data
Maximum $d\Theta_B$ [deg]	**$0.8*d\Theta_A+3.25$**	**± 1.25**	Changed on review of data
Time of maximum $d\Theta_B$ [ms]	**48.0**	**± 4.0**	Changed on review of data

Note : The maximum head form flexion and the time of the maximum head form flexion are not changed because these criteria are set right from the beginning and remain unchanged so far

On the head flexion criteria only some failures and on the time of the maximum head flexion no failures are reported. So these criteria do not cause problems in practice. (A tighter allowable range may be defined for the maximum head flexion angle time criteria because no failures on this requirement are reported in the evaluation database nor in the TNO Crash Dummies BV certification database, containing more then 2300 certifications.)

Effect of revised input and output criteria – Five users or user groups provided data of 160 certifications in total, regarding 24 different Lumbar Spines. Three of them provided not only the certification results, as far as the criteria are concerned, but also the raw data and the processed data files from the tests. This input enables an evaluation of the procedures followed at those labs in full detail. One lab provided signal plots on paper which only allows a provisional evaluation of the procedures. Participating laboratories and organisations are specified in the table below.

Table 17: Definition of participating laboratories and organisations.

ID	Region	Number of tests for which data is provided	Remark
A	EUROPE	**5**	Raw and process digital data
B	USA	**31**	Certification output parameter results only
C	EUROPE	**35**	Raw and process digital data
D	EUROPE	**15**	Signal plots on paper only
E	EUROPE	**74**	
Total		**160**	

The alternative deceleration input criterion solves all the input corridor problems reported by the participating labs and enables an accurate application of a proper pendulum impact pulse (see Figure 17). The distribution of the 160 evaluation responses with regards to the maximum deflection relative to the proposed revised criteria envelop is given in Figure 37.
In Table 18 the effect of the proposed revised output criteria is shown by comparing the failures which occur either when the current or the proposed revised criteria are applied. Application of the proposed revised criteria reduces the failure rate of lumbar spine certifications from 53% to 24%.

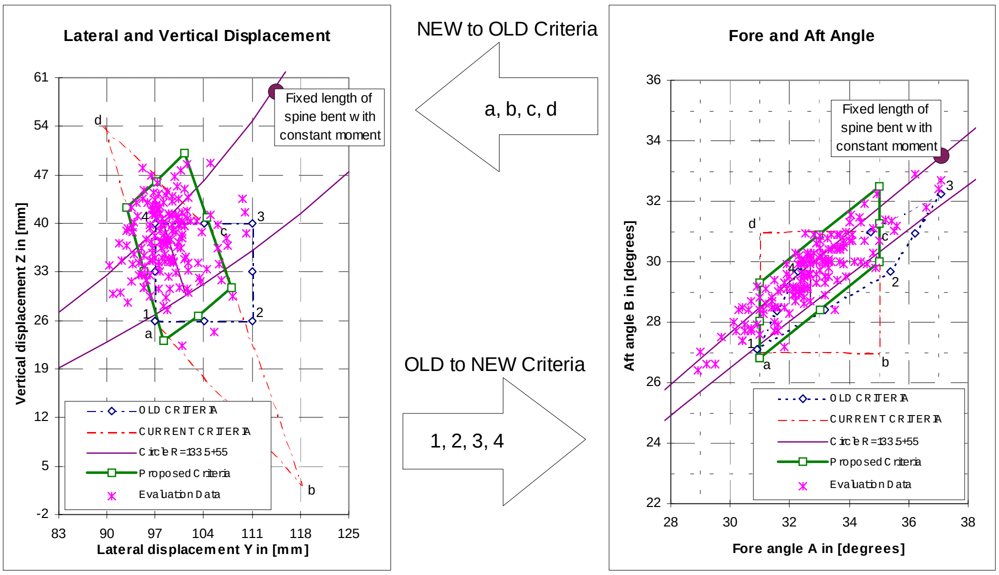


Figure 37: *Distribution of the evaluation test results (160 tests) relative to the proposed revised fore and aft angle criteria envelop.*

Table 18: *Comparison of certification failures for current and proposed revised lumbar spine criteria on the EVALUATION database*

Criterion	**FAIL original**	***FAIL revised***	**Remark** Values : Current *(Revised)*
INPUT CRITERIA			
Pendulum impact speed [m/s]	**0**	***0***	
Pendulum acceleration time history	**54**	***0***	34 *(0) failures at lab C* 14 *(0) failures at lab E*
OUTPUT CRITERIA			
Max. head(form) flexion angle [°]	**3**	***3***	3 *(3) failures at lab E*
Time of max. head flexion angle [ms]	**0**	***0***	
Maximum fore angle ($d\Theta_A$) [°]	**29**	***29***	8 *(8) failures at lab B* 20 *(20) failures at lab E*
Time of maximum fore angle [ms]	**22**	***6***	17 *(3) failures at lab C*
Maximum aft angle ($d\Theta_B$) [°]	**17**	***6***	11 *(2) failures at lab B*
Time of maximum aft angle [ms]	**10**	***1***	6 *(0) failures at lab C*
Overall test results	**85** 53 %	***39*** *24 %*	**Number of certifications failed for :** Current *(Revised)* 1 criterion : 52 *(34)* 2 criteria : 15 *(4)* 3 criteria : 16 *(1)* 4 criteria : 0 *(0)* 5 criteria : 2 *(0)*
Overall result per Lab :	See note		Note : Values including the strict interpretation of the input criteria (between brackets the values for output criteria only).
Lab A	**1 (1)**	***2***	
Lab B	**14 (14)**	***11***	
Lab C	**34 (18)**	***16***	
Lab D	**0 (0)**	***0***	
Lab E	**36 (22)**	***20***	

ANNEX G : PELVIS ASSEMBLY EVALUATION

Objective – The objective of the pelvis assembly evaluation was twofold :

1. Check whether the new pelvis assembly still meets the current certification requirement, and would allow definition of a certification requirement at higher speed;
2. Check whether the new pelvis assembly indeed buffers metal-to-metal contact in the hip-joint.

Test set-up – Tests on the research tool pelvis assembly have been carried out at the Certification lab of TNO Crash Dummies BV in week 52, 1997. The tests comprise of 24 pendulum impacts based on the EUROSID-1 pelvis certification test. The standard certification test signals were recorded:

- Pendulum acceleration;
- Pubic load.

Some additional measurements were taken to assess the design performance e.g. :

- Accelerations of the H-point back plate at both sides;
- Acceleration of the pelvis sacrum block.

The dummy was placed in three different seating positions (see Figure 38 below):

1. Legs straight ahead (certification position);
2. Lower legs hanging down, upper leg straight ahead;
3. Lower legs hanging down, upper leg apart (166 mm extra at knees).

The latter seating configuration is considered more extreme with respect to metal-to-metal contact.

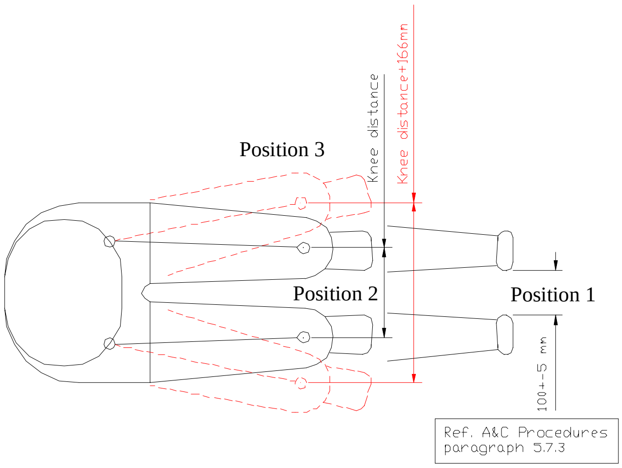


Figure 38: Definition of seating positions

Certification Results – The graphs in Figure 38 show the maximum pendulum acceleration and the maximum pubic force plotted against the time of occurrence of the maximum. The results are given for impacts at a pendulum speed of 4.3 and 6.3 m/s. In the graphs the required certification envelop (at 4.3 m/s) is indicated. All tests on 4.3 m/s pendulum impact speed fulfilled the certification requirements.

The high speed tests are also well within a limited area. This means that for high speed pendulum tests a definition of certification requirements seems to be possible. However, high speed certification tests result in an increased risk of damage to the dummy upper body. As the impact is quite heavy the dummy upper body may fall into the pendulum support wires. To avoid damage to the dummy it is important to take precautions for a proper catch of the dummy after the impact.

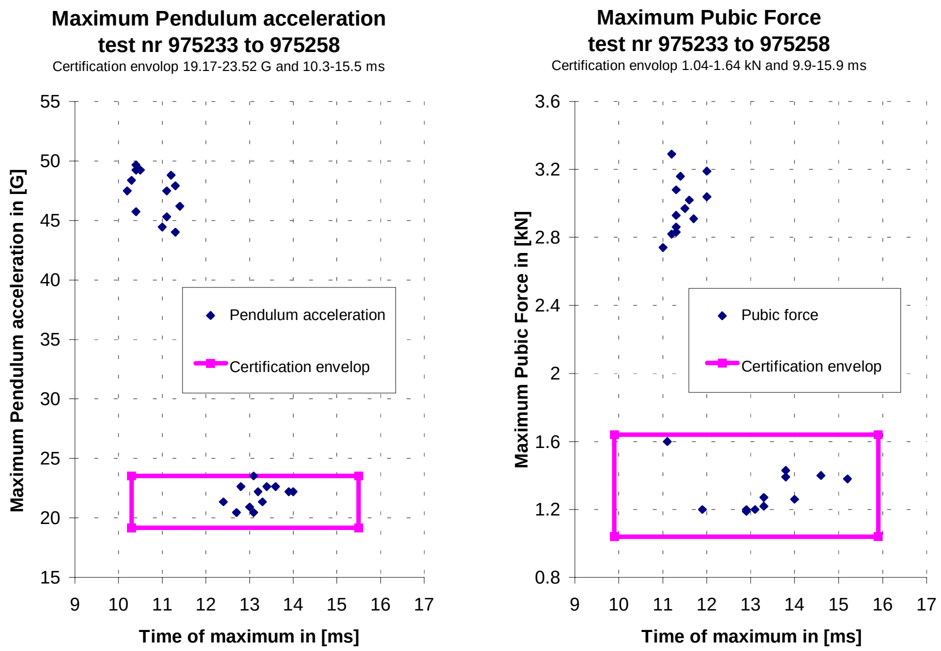


Figure 39: Summary of certification test results (tests 975233 to 975258)

Metal-to-Metal Contact – Investigation of the displacements of the pendulum and the pelvis, obtained by double integration of the acceleration signals, provide the means to estimate of the exact moment at which the buffer is likely to become active. Table 19 gives the estimated delay times for different seating positions. The effect of having a buffer in contact during this delay time was investigated.

Table 19: Estimated delay time at which buffer contact can be excepted

Impact	**4.3 m/s**			**6.3 m/s**		
Seating position	Test nr	Pubic tension	Delay time in [ms]	Test nr	Pubic tension	Delay time in [ms]
1 Legs straight ahead (Certification position)	33 45 34 46	**0 / +**	**55 -- 75**	35 47 36 48	**0 / +**	**35 -- 55**
2 Lower legs down, Upper legs straight ahead	37 49 38 50	**0**	**50 -- 70**	39 51 40 52	**0**	**40 -- 60**
3 Lower legs down, Upper legs apart (166 mm extra at knees)	41 53 42 54	**++**	**20 -- 40**	43 55 44 56 58	**+++**	**10 -- 30**

Note : Indication of pubic tension
0 = none , **+** = minor, **++** = medium , **+++** = major

When significant buffer contact occurs this will result in tension at the pubic load cell. In the seating positions 1 and 2 there is no significant tension recorded in the pubic load signal, from which is concluded that in the tests in seating position 1 and 2 no significant contact is made between the buffer and the upper femur. Tests in seating position 3 show medium tension (200 – 400 N) with 4.3 m/s impact speed and major tension (700 – 900 N) with 6.3 m/s impact speed, indicating that the buffer has become active in these cases.

Table 20: Measured pubic tension

Impact speed **Seating position 3** Lower legs down, upper legs apart (166 mm extra at knees)	**4.3 m/s**		**6.3 m/s**	
	Test nr		Test nr	
	Maximum Pubic Tension [N]			
Existing EUROSID-1	06 10 18 22	514 527 418 551	08 12 20 24	- 1153 1164 1226
Mean value (metal-to-metal contact)		502		1181
Research tool pelvis	41 42 53 54	488 378 392 285	43 44 55 56 58	869 700 881 967 685
Mean value (buffered contact)		386		820
Percentage of reduction (%)		**23**		**31**

The comparison of the maximum pubic tension is shown in the Table 20. From this table it is concluded that the buffer design concept reduces the tension loads significantly. Furthermore, the effectiveness of the buffer was confirmed by application of clay on the edge of the H-point back plate round the buffer : the H-point back plate buffer was compressed 2.7 mm at the outer edge (see Figure 40).

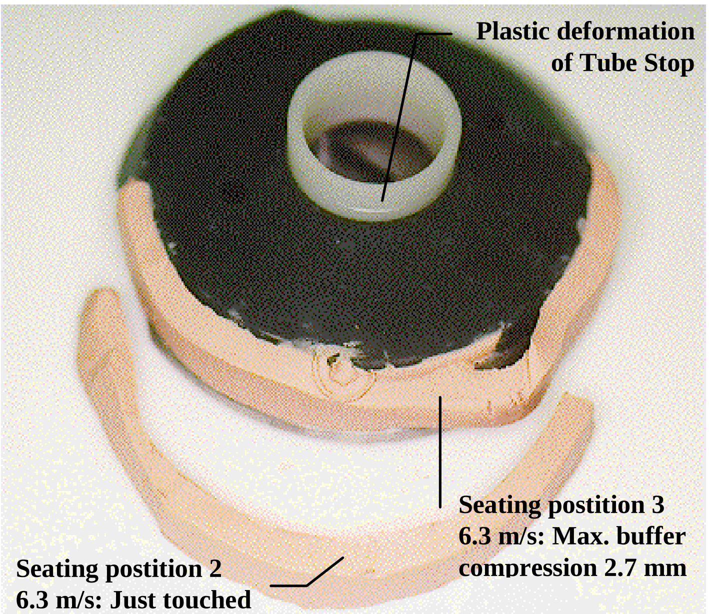


Figure 40: Clay indicated buffer contact

ANNEX H : PELVIS CERTIFICATION TESTS

Objective – Determine a new impact speed for the EUROSID-1 pelvis certification test.
Test set-up – Impact tests were carried out at two impact velocities : 4.3 and 6.3 m/s. The normal EUROSID-1 certification procedures were followed, in which the pubic load and the impactor acceleration were measured.
Results – The results are summarised in Table 21. The tests were repeated at 6.3 m/s. The results are summarised in Table 22. The pubic symphysis load cell values for these tests are very close to the average value measured in the EUROSID-1 in full scale tests (3.0 kN). This value is lower than the current performance criterion limit defined in the European side impact regulation (6.0 kN).

Table 21: Standard EUROSID-1 Certification test at 4.3 m/s.

test ID	Impact Velocity [m/s]	Time of maximum acceleration [msec]	Maximum acceleration [g]	Maximum Impactor Force [kN]	Time of maximum force [msec]	Maximum pubic force [kN]
975233	4.36	13.6	22.8	5.2	13.9	1.43
975234	4.32	13.2	22.5	5.2	13.5	1.39
975237	4.32	12.6	20.4	4.7	12.8	1.19
975238	4.32	13.0	20.4	4.7	12.7	1.20
975241	4.33	12.7	22. 7	5.2	11.8	1.20
979542	4.31	13.0	23.4	5.3	13.1	1.27
975245	4.34	13.8	22.1	5.1	14.5	1.40
975246	4.32	13.8	22.4	5.1	15.1	1.38
975249	4.34	12.9	21.0	4.8	13.2	1.22
975250	4.32	13.2	21.4	4.9	14.0	1.26
975253	4.32	12.4	21.2	4.9	11.2	1.16
975254	4.31	13.1	22.3	5.1	13.0	1.20

Table 22: EUROSID-1 certification tests at 6.3 m/s.

test ID	Impact Velocity [m/s]	Time of maximum acceleration [msec]	Maximum acceleration [g]	Maximum Impactor Force [kN]	Time of maximum force [msec]	Maximum pubic force [kN]
975235	6.31	11.2	46.2	10.6	11.8	3.04
975236	6.31	11.1	49.1	11.3	11.5	3.02
975339	6.27	10.3	45.9	10.5	11.0	2.74
975240	6.31	11.0	45.7	10.5	11.2	2.86
975243	6.30	10.2	48.6	11.1	11.5	2.97
975244	6.35	10.3	49.7	11.4	11.1	3.29
975247	6.27	11.2	48.0	11.0	11.9	3.19
975248	6.31	11.1	49.0	11.2	11.5	3.08
975251	6.35	11.2	44.3	10.1	11.2	2.84
975252	6.35	10.9	44.9	10.3	11.1	2.82
975255	6.27	10.0	47.7	11.0	11.2	2.93
975256	6.31	10.2	49.3	11.3	11.1	3.08

Biofidelity - The results can be compared to two sets of biofidelity requirements, The first is based on the ONSER/INRETS tests of 8 cadavers which is included in the ISO TR9790 document. The second is the set of 4 tests performed by Viano [7] on 4 cadavers. The degree of biofidelity of the EUROSID-1 pelvis depends on the requirements the measurement results are compared to. Study has shown [8] that the agreement with the Viano data is good, but the pelvis is too stiff according to the ISO requirements. It must be noted that the impactor used in the EUROSID-1 certification test is different from the impactor described in ISO 9790. The mass difference is 7.1 kg (41 percent of the ISO impactor mass). The spherical shape of the ISO impactor results in local loading around the impact point. Directly behind the impact point is the H-point back plate, and as a consequence the pelvis is loaded almost directly when a spherical impactor is used. The part 572 impactor spreads the load over a much larger area, which means that more of the PVC is compressed. This results in a lower overall pelvic stiffness.

It is proposed to raise the impact velocity to 6.3 ± 0.1 m/s. The corresponding average measured impactor force is 10.9 kN. To determine the corridor, the 10% method is used [9], 10% of the mean value of the certification tests is used as the corridor. This is a value of 1.1 kN (rounded off). The peak value should lie between 9.5 and 12.5 m/s.

Peak impactor force 11.0 ± 1.2 kN
Lying between 9.5 and 12.5 msec after t0 (impact point)

in which t0 is defined according to the EUROSID-1 certification manual.

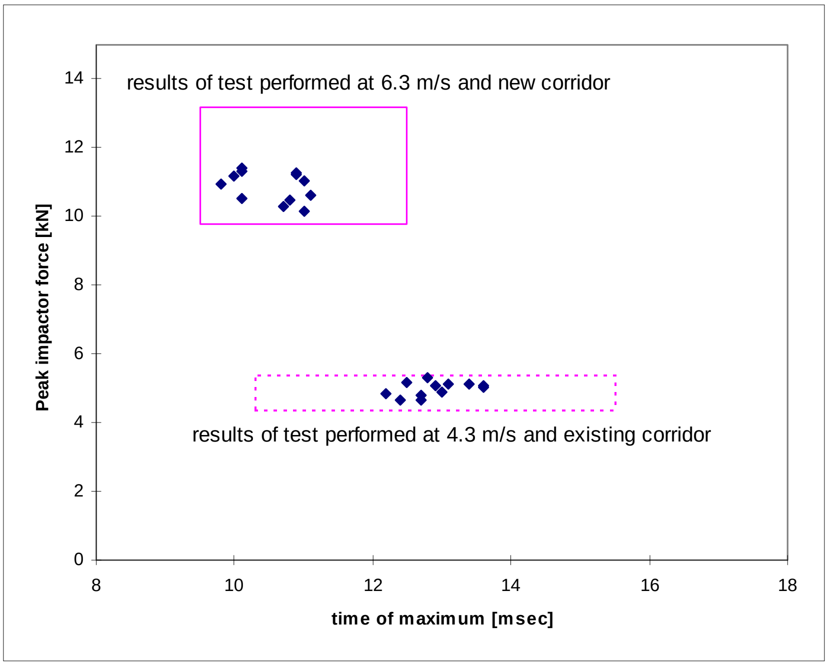


Figure 41: Plot of impactor peak forces and certification corridors at 4.3 (old corridor indicated by dashed line type) and 6.3 m/s (new, corridor indicated by solid line type)

Peak pubic force 3.00 ± 0.35 kN
Lying between 10.0 and 13.0 after t0

in which t0 is defined according to the EUROSID-1 certification manual.

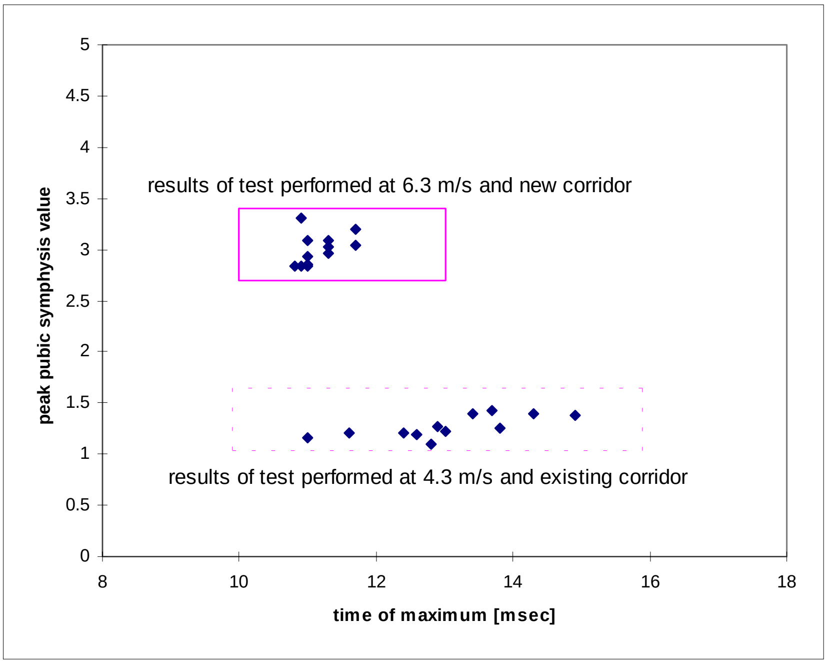
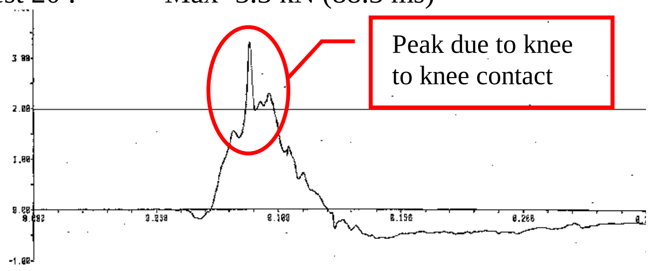
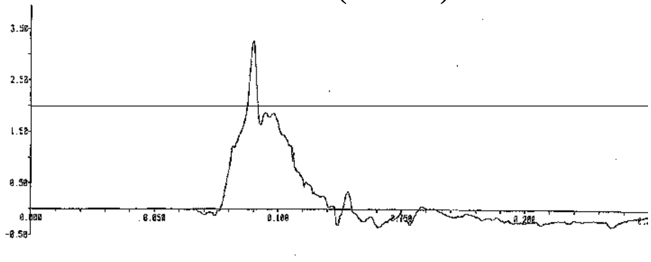
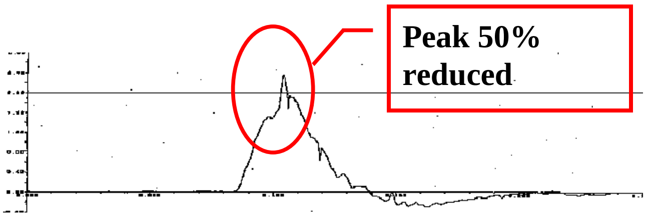


Figure 42: Plot of pubic symphysis peak forces and certification corridors at 4.3 (old, corridor in dashed line type) and 6.3 m/s (new, corridor indicated by solid line type).

ANNEX I : LEG MODIFICATION EVALUATION

The leg design options were tested at BASt Bundesanstalt für Sta enwessen Germany April 1999. Some results of the sled test are show in Table 23.

Table 23: Sled test results obtain at BASt, April 1999 .

Configuration	**Pubic symphasis signal from sled test**
Standard EUROSID-1	Test 20 : Max=3.3 kN (88.3 ms) 
Research Tool Kit Pelvis **+** **High damping foam at the knees**	Test 31 : Max=3.27 kN (89.8 ms) 
Research Tool Kit Pelvis **+** **Modified legs** **(mass shift from femur bone into thigh flesh 3.1 kg see note)** **+** **High damping foam at the knees**	Test 32 : Max=2.35 kN (103.8 ms) 

Note: *The final mass shift applied in the ES-2 leg is 2.75 kg*