



BSI Standards Publication

Road vehicles — Design and performance specifications for advanced Pedestrian Legform Impactor (aPLI)

National foreword

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Road vehicles — Design and performance specifications for advanced Pedestrian Legform Impactor (aPLI)

*Véhicules routiers — Spécifications de conception et de performance
pour l'impacteur en forme de jambe de piéton (aPLI)*



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Foreword

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

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

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

Introduction

This document has been prepared on the basis of the existing design, specifications and performance of advanced pedestrian legform impactor (aPLI) standard build level B (SBL-B). The purpose of this document is to document the design and specifications of this pedestrian legform impactor in a form suitable and intended for worldwide harmonized use.

In 2014, aPLI development started, with the aims of defining a globally accepted next-generation pedestrian legform impactor, with enhanced biofidelity and injury assessment capability by implementing an upper mass to represent the influence of the upper body of a pedestrian, and suitable for harmonized use. Participating in the development were research institutes, dummy and instrumentation manufacturers, governments and car manufacturers from around the world. Details are given in [Annex A](#) through [Annex G](#) and [Annex P](#).

aPLI drawings in electronic format are available. Details are given in [Annex I](#) and [Annex H](#).

Road vehicles — Design and performance specifications for advanced Pedestrian Legform Impactor (aPLI)

1 Scope

This document provides definitions, symbols, mechanical requirements, certification test procedure, electronic subsystem requirements and user's manual for advanced pedestrian legform impactor (aPLI), a standardized pedestrian legform impactor with an upper mass for pedestrian subsystem testing of road vehicles. It is applicable to impact tests involving:

- vehicles of category M1, except vehicles with the maximum mass above 2 500 kg and which are derived from N1 category vehicles and where the driver's position, R-point, is either forward of the front axle or longitudinally rearwards of the front axle transverse centreline by a maximum of 1 100 mm;
- vehicles of category N1, except where the driver's position, R-point, is either forward of the front axle or longitudinally rearwards of the front axle transverse centreline by a maximum of 1 100 mm;
- impacts to the bumper test area as defined by UN R127^[1] and UN GTR No.9^[2];
- pedestrian subsystem tests involving use of a legform for the purpose of evaluating compliance with vehicle safety standards.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

[ISO 6487](#), *Road vehicles — Measurement techniques in impact tests — Instrumentation*

[ISO/TS 13499](#), *Road vehicles — Multimedia data exchange format for impact tests*

SAE J2570, *Performance Specifications for Anthropomorphic Test Device Transducers*

SAE J211-1, *Instrumentation for Impact Test Part 1 — Electronic Instrumentation*

3 Terms and definitions

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

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

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

abduction

rotation of the *lower limb* (3.34) relative to the *upper mass* (3.49) as the lower limb is rotated toward the *struck side* (3.37)

3.2

adduction

rotation of the *lower limb* ([3.34](#)) relative to the *upper mass* ([3.49](#)) as the lower limb is rotated toward the *non-struck side* ([3.35](#))

3.3

adult

person who is sixteen years old or older

3.4

aPLI

advanced pedestrian legform impactor

modified pedestrian legform impactor which incorporates a mass representing the inertial effect of the upper part of a pedestrian body to enhance *biofidelity* ([3.8](#)) and *injury assessment capability* ([3.26](#)) of conventional pedestrian legforms

3.5

aluminium honeycomb

manufactured material comprising multi-layered bonded sheets of aluminium bent or corrugated in a rib pattern, in which there is an internal pattern of hexagonal cylindrical spaces

Note 1 to entry: The aluminium honeycomb is used in this document as an energy-absorbing element in full assembly *certification* ([3.13](#)) tests.

3.6

AAUM

angular acceleration of upper mass

angular acceleration observed at the upper mass of the *advanced pedestrian legform impactor (aPLI)* ([3.4](#)) which is obtained by differentiating the angular velocity sensor (X), installed in the *upper mass* ([3.49](#)) as a required sensor

Note 1 to entry: See [7.1.3.4](#).

3.7

Belleville washer

type of spring which can be loaded along its axis, with its frusto-conical shape giving the spring characteristics

3.8

biofidelity

aspect of an *advanced pedestrian legform impactor (aPLI)* ([3.4](#)) capability to represent impact responses of human subjects

3.9

bone core

beam with a rectangular cross-section made of glass fibre reinforced plastic installed in the centre of the *femur* ([3.14](#)) and the *tibia* ([3.40](#)) that provides human-like bending stiffness

3.10

bumper angle

acute angle formed by the vertical plane tangential to the surface of a car bumper and the vertical transverse plane relative to the car

3.11

bumper system

component installed at the *hip joint* ([3.24](#)) inside the *upper mass* ([3.49](#)) composed of the bumper, the bumper mount and the compression surface, designed to apply a force on the upper part of the *femur* ([3.14](#)) in *adduction* ([3.2](#)) to enhance *injury assessment capability* ([3.26](#)) of the *advanced pedestrian legform impactor (aPLI)* ([3.4](#))

3.12

capacity

maximum value of a physical quantity which can be measured by a sensor without causing sensor damage

3.13

certification

process by which the relevant *advanced pedestrian legform impactor (aPLI)* (3.4) component or full assembly is verified and documented to meet the specifications

3.14

femur

portion of the *lower limb* (3.34) between the *femur top* (3.15) and the upper *knee block* (3.29), excluding the *flesh* (3.22) and the *skin* (3.36)

3.15

femur top

aluminium part that forms the *hip joint* (3.24) and the junction between the *upper mass* (3.49) and the *femur* (3.14)

3.16

femur-1

measurement location of the *femur* (3.14) bending moment (137 mm vertically up from the flat surface of the knee meniscus) used in the development and evaluation phase of the *advanced pedestrian legform impactor (aPLI)* (3.4)

3.17

femur-2

measurement location of the *femur* (3.14) bending moment (217 mm vertically up from the flat surface of the knee meniscus) used in the development and evaluation phase of the *advanced pedestrian legform impactor (aPLI)* (3.4)

3.18

femur-3

measurement location of the *femur* (3.14) bending moment (297 mm vertically up from the flat surface of the knee meniscus) used in the development and evaluation phase of the *advanced pedestrian legform impactor (aPLI)* (3.4)

3.19

femur-LO

measurement location of the *femur* (3.14) bending moment which is equal to the measurement location of *femur-1* (3.16) used in the development and evaluation phase of the *advanced pedestrian legform impactor (aPLI)* (3.4)

Note 1 to entry: For the femur-LO, the femur's bending moment is specified in [ISO/TS 13499](#).

3.20

femur-MID

measurement location of the *femur* (3.14) bending moment which is equal to the measurement location of *femur-2* (3.17) used in the development and evaluation phase of the *advanced pedestrian legform impactor (aPLI)* (3.4)

Note 1 to entry: For the femur-MID, the femur bending moment is specified in [ISO/TS 13499](#).

3.21

femur-UP

measurement location of the *femur* (3.14) bending moment which is equal to the measurement location of *femur-3* (3.18) used in the development and evaluation phase of the *advanced pedestrian legform impactor (aPLI)* (3.4)

Note 1 to entry: For the femur-UP, the femur bending moment is specified in [ISO/TS 13499](#).

3.22

flesh

moulded soft part constituting the outer layer of the *lower limb* (3.34) positioned inside the *skin* (3.36)

3.23

high-bumper car

car with a *lower bumper reference line height* (3.33) of 425 mm or more

3.24

hip joint

uniaxial joint that allows *abduction* (3.1) and *adduction* (3.2) and connects the *upper mass* (3.49) with the *lower limb* (3.34)

3.25

impact carriage

moving part of the full assembly *certification* (3.13) test fixture comprising the impact surface with an *aluminium honeycomb* (3.5) and a linearly guided rigid mass

3.26

injury assessment capability

aspect of an *advanced pedestrian legform impactor (aPLI)* (3.4) capability to produce peak injury values that correlate with those obtained from human body model impact simulations

3.27

ISO metric

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

Note 1 to entry: For more information on the ISO metric, refer to [ISO/TS 18571](#).

3.28

knee

middle part of the *lower limb* (3.34) that involves the knee joint, comprises the upper and lower *knee blocks* (3.29) and provides a junction between the *femur* (3.14) and the *tibia* (3.40)

3.29

knee block

aluminium block that forms either the upper part of the knee joint with condyles, or the lower part of the knee joint with the meniscus attached, accommodating knee ligaments, *Belleville washers* (3.7) that represent stiffness of the knee ligaments and sensors to measure elongation of the knee ligaments and linear acceleration and angular rate of the *knee* (3.28)

3.30

lateral

direction from the *struck side* (3.37) to the *non-struck side* (3.35)

3.31

leg

portion of the *lower limb* (3.34) below the lower *knee block* (3.29), including the *flesh* (3.22) and the *skin* (3.36)

3.32

low-bumper car

car with a *lower bumper reference line height* (3.33) less than 425 mm

3.33

lower bumper reference line height

LBRL height

height of the geometric trace of the lowermost points of contact between a straight edge and the bumper, measured from the ground

3.34

lower limb

lower part of the *advanced pedestrian legform impactor (aPLI)* (3.4) attached to the *upper mass* (3.49) via a *hip joint* (3.24), representing the *thigh* (3.39), *knee* (3.28) and *leg* (3.31) of a human in a standing position

3.35

non-struck side

opposite side of the *struck side* (3.37)

3.36

skin

sheet of polychloroprene with fabric surface that covers the *flesh* (3.22), forming the outermost layer of the *lower limb* (3.34)

3.37

struck side

side facing a car in car tests, representing the outer side of the *lower limb* (3.34) of a pedestrian

3.38

subsystem test

test to evaluate safety performance of cars where subsystem impactors representing individual body regions of a pedestrian are propelled into a front-end collision with a stationary car, in impact conditions representing specific load cases in car-pedestrian accidents, as described in UN R127[1] and UN GTR No.9[2]

3.39

thigh

portion of the *lower limb* (3.34) between the *femur top* (3.15) and the upper *knee block* (3.29), including the *flesh* (3.22) and the *skin* (3.36)

3.40

tibia

portion of the *lower limb* (3.34) below the lower *knee block* (3.29), excluding the *flesh* (3.22) and the *skin* (3.36)

3.41

tibia-1

measurement location of the *tibia* (3.40) bending moment (134 mm vertically down from the flat surface of tibia plateau) used in the development and evaluation phase of the *advanced pedestrian legform impactor (aPLI)* (3.4)

3.42

tibia-2

measurement location of the *tibia* (3.40) bending moment (214 mm vertically down from the flat surface of tibia plateau) used in the development and evaluation phase of the *advanced pedestrian legform impactor (aPLI)* (3.4)

3.43

tibia-3

measurement location of the *tibia* (3.40) bending moment (294 mm vertically down from the flat surface of tibia plateau) used in the development and evaluation phase of the *advanced pedestrian legform impactor (aPLI)* (3.4)

3.44

tibia-4

measurement location of the *tibia* (3.40) bending moment (374 mm vertically down from the flat surface of tibia plateau) used in the development and evaluation phase of the *advanced pedestrian legform impactor (aPLI)* (3.4)

3.45

tibia-LO

measurement location of the *tibia* (3.40) bending moment which is equal to the measurement location of *tibia-4* (3.44) used in the development and evaluation phase of the *advanced pedestrian legform impactor (aPLI)* (3.4)

Note 1 to entry: For the tibia-LO, the tibia bending moment is specified in [ISO/TS 13499](#).

3.46

tibia-MID-LO

measurement location of the *tibia* (3.40) bending moment which is equal to the measurement location of *tibia-3* (3.44) used in the development and evaluation phase of the *advanced pedestrian legform impactor (aPLI)* (3.4)

Note 1 to entry: For the tibia-MID-LO, the tibia bending moment is specified in [ISO/TS 13499](#).

3.47

tibia-MID-UP

measurement location of the *tibia* (3.40) bending moment which is equal to the measurement location of *tibia-2* (3.44) used in the development and evaluation phase of the *advanced pedestrian legform impactor (aPLI)* (3.4)

Note 1 to entry: For the tibia-MID-UP, the tibia bending moment is specified in [ISO/TS 13499](#).

3.48

tibia-UP

measurement location of the *tibia* (3.40) bending moment which is equal to the measurement location of *tibia-1* (3.44) used in the development and evaluation phase of the *advanced pedestrian legform impactor (aPLI)* (3.4)

Note 1 to entry: For the tibia-UP, the tibia bending moment is specified in [ISO/TS 13499](#).

3.49

upper mass

block of mass attached on top of the *lower limb* (3.34) via a *hip joint* (3.24) to represent inertial contribution of the upper part of a pedestrian body when hit by a car

3.50

validation of biofidelity

evaluation of an anthropomorphic test device in terms of its representativeness of impact responses of a human body

3.51

validation of injury assessment capability

evaluation of an anthropomorphic test device in terms of the correlation of the peak values of its injury metrics with those of a human body, specifically represented by multiple HBMs

4 Abbreviated terms

See [Table 1](#).

Table 1 — Abbreviated terms

Abbreviation	Meaning
AAUM	Angular Acceleration of Upper Mass
ACL	Anterior Cruciate Ligament
aPLI	advanced Pedestrian Legform Impactor
BLE	Bonnet Leading Edge

Abbreviation	Meaning
BM	Bending Moment
BP	Bumper
DAS	Data Acquisition System
FE	Finite Element
HBM	Human Body Model
LBRL	Lower Bumper Reference Line
MCL	Medial Collateral Ligament
PCL	Posterior Cruciate Ligament
PMHS	Post Mortem Human Subjects
RCM	Real Car Model
SCM	Simplified Car Model
SP	Spoiler
TG	Task Group

5 Mechanical requirements for an aPLI

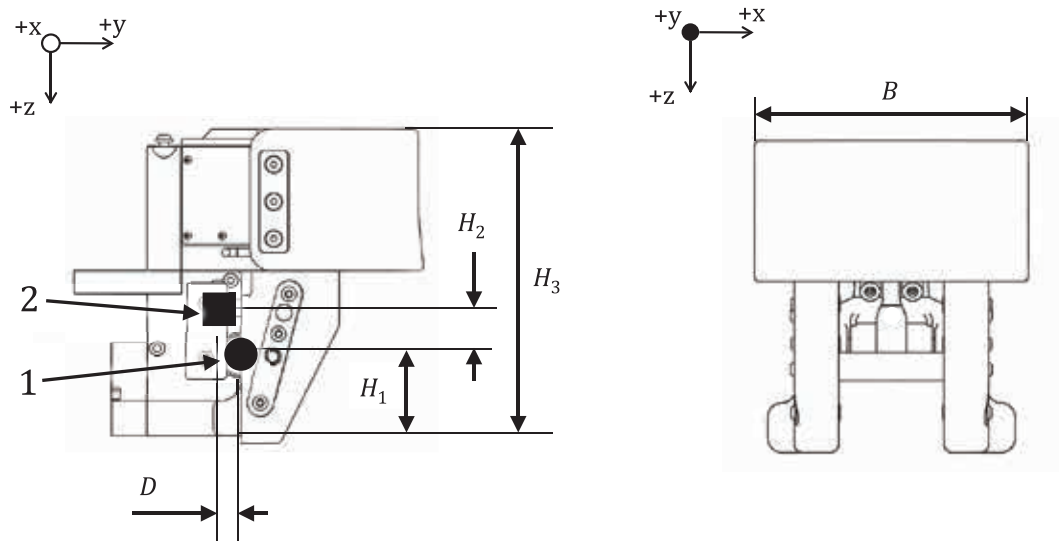
5.1 Upper mass

5.1.1 General description

The upper mass assembly shall consist of the components and assemblies listed in the upper mass assembly drawing aPLI-11000 (see [Annex I](#)).

5.1.2 Drawings and specifications

- The upper mass assembly and components shall conform to the assembly drawing aPLI-11000 (see [Annex I](#)) and the subassembly and component drawings listed therein.
- The total assembly (including sensors and DAS) shall have a mass of $11,8 \text{ kg} \pm 0,3 \text{ kg}$.
- The overall dimensions and the centre of gravity shall be located as indicated in [Figure 1](#).
- The flesh material and/or external surface characteristics shall enable attachment of adhesive targets.



Key

- 1 hip joint
- 2 centre of gravity of upper mass
- D horizontal distance between the centre of gravity of upper mass and hip joint: $8 \text{ mm} + 10 \text{ mm} / - 0 \text{ mm}$
- H_1 height of hip joint: $58 \text{ mm} \pm 2 \text{ mm}$
- H_2 height of centre of gravity: $31 \text{ mm} + 10 \text{ mm} / - 0 \text{ mm}$
- H_3 height of upper mass: $220 \text{ mm} + 16 \text{ mm} / - 2 \text{ mm}$
- B breadth of upper mass: $200 \text{ mm} \pm 5 \text{ mm}$

NOTE 1 An empty circle at the origin of the coordinate vector means a vector going into the page away from the viewer.

NOTE 2 A black circle at the origin of the coordinate vector means a vector coming out of the page toward the viewer.

Figure 1 — Overall dimensions of the upper mass and location of the centre of gravity

5.1.3 Compliant material specifications

The stiffness of the compliant materials included in the upper mass assembly are specified by the corridors described in this subclause.

- The performance of the hip abduction stop (part aPLI-11062) is specified by the corridor presented in [Figure 2](#). Tabulated data of the corridor is described in [Table 2](#). Performance shall be confirmed using component samples. Load is applied to the sample using a flat indenter at a rate not exceeding $15 \text{ mm} / \text{min}$.
- The performance of the solid flesh material on the impact face of the upper mass (reference part aPLI-11010) is described in [5.3.3](#).
- The performance of the hip adduction bumper (part aPLI-11059) is specified by the certification procedure described in [6.1.1](#).

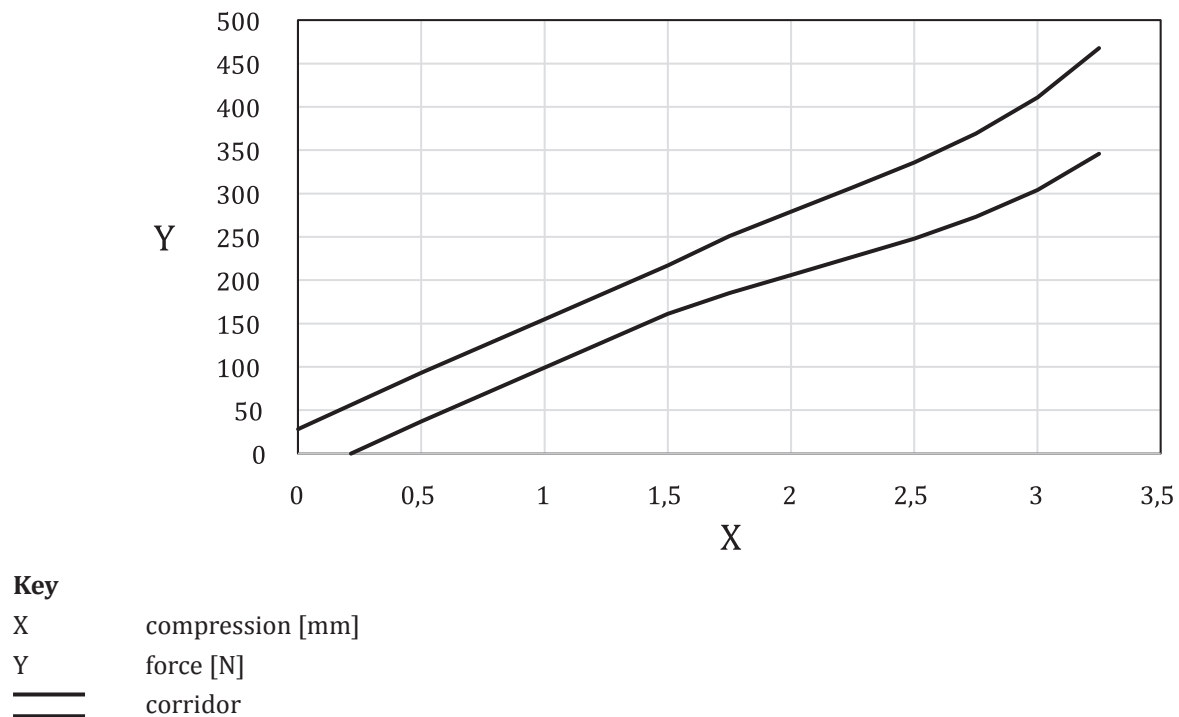


Figure 2 — Mechanical properties for the hip abduction stop (specified by corridor)

Table 2 — Mechanical properties for the hip abduction stop (specified by tabulated data)

Compression [mm]	Force [N]	
	Upper corridor	Lower corridor
0,00	28	-28
0,50	93	37
1,00	155	99
1,50	217	161
1,75	251	185
2,00	279	206
2,25	307	227
2,50	336	248
2,75	369	273
3,00	411	304
3,25	468	346

5.1.4 Certification

When the upper mass is assembled according to [8.1.1](#), the upper mass shall be tested using the procedure specified in [6.1](#), and the test results shall meet the specifications given in [6.1](#).

5.2 Lower limb

5.2.1 General description

The lower limb assembly shall consist of the components and sub-assemblies listed in the lower limb assembly drawing aPLI-00010 ([Annex I](#)).

5.2.2 Drawings and specifications

The lower limb assembly and components shall conform to the assembly drawing aPLI-00010 (see [Annex I](#)) and the subassembly (femur, knee and tibia) and component drawings listed therein. The total assembly (including sensors and DAS) shall have a mass of $12,9 \text{ kg} \pm 0,3 \text{ kg}$.

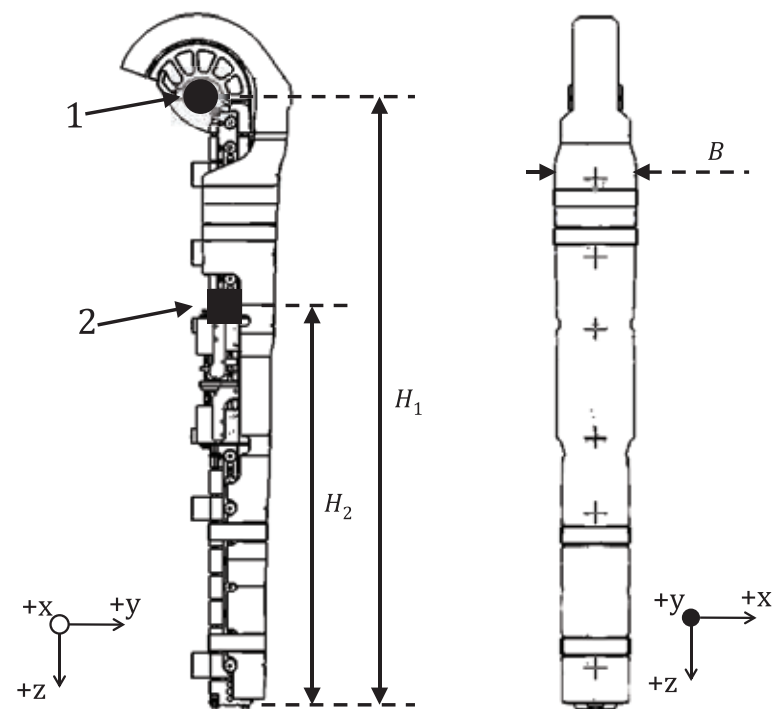
- The femur assembly shall conform to the assembly drawing aPLI-21000 (see [Annex I](#)) and shall have a mass of $4,3 \text{ kg} \pm 0,2 \text{ kg}$.
- The knee assembly shall conform to the assembly drawing aPLI-23000 (see [Annex I](#)) and shall have a mass of $2,80 \text{ kg} \pm 0,1 \text{ kg}$.
- The tibia assembly shall conform to the assembly drawing aPLI-26000 (see [Annex I](#)) and shall have a mass of $2,35 \text{ kg} \pm 0,1 \text{ kg}$.

The femur and tibia assemblies include cable arrangements to protect the bone and sensors from overload condition and damage during impact testing. A clearance gap at these cables is set to provide adequate protection and avoid early engagement that might influence overall aPLI response. It is recommended that the clearances at these cable assemblies are checked frequently as described in [Annex N](#). The appropriate clearances are shown in drawings aPLI-21000 and aPLI-26000 and are repeated here:

- 13,6 mm for the femur assembly;
- 11,3 mm for the tibia assembly.

The overall dimensions and the centre of gravity for the lower limb and constituent subassemblies (femur, knee and tibia) shall be located as indicated in [Figure 3](#) and [Figure 4](#).

The flesh material and/or external surface characteristics shall enable attachment of adhesive targets.



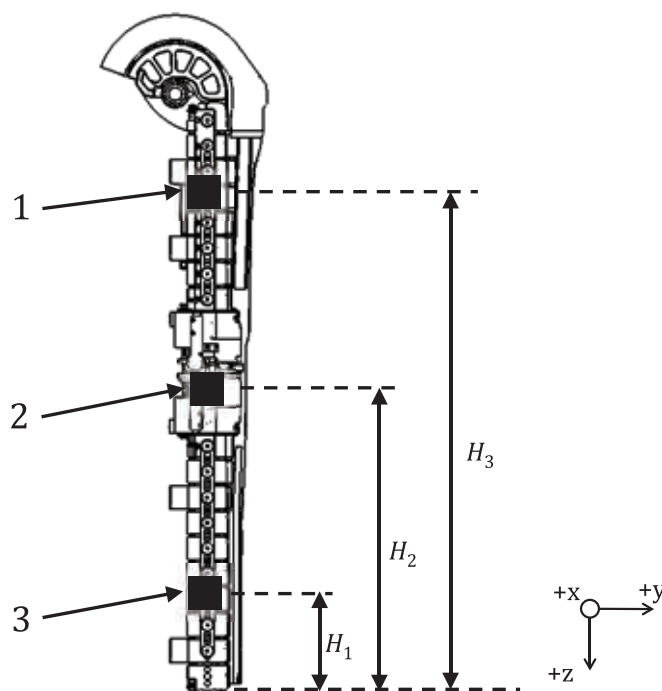
Key

- 1 hip joint
- 2 centre of gravity of lower limb
- H_1 height of hip joint: 933 mm $\pm$ 5 mm
- H_2 height of centre of gravity of lower limb: 600 mm $\pm$ 10 mm
- B breadth of lower limb including flesh: 120 mm $\pm$ 2 mm

NOTE 1 An empty circle at the origin of the coordinate vector means a vector going into the page away from the viewer.

NOTE 2 A black circle at the origin of the coordinate vector means a vector coming out of the page toward the viewer.

Figure 3 — Overall dimensions of the lower limb and location of the centre of gravity



Key

- 1 centre of gravity for the femur
- 2 centre of gravity for the knee
- 3 centre of gravity for the tibia
- H_1 height of centre of gravity for the femur: 860 mm $\pm$ 10 mm
- H_2 height of centre of gravity for the knee: 495 mm $\pm$ 5 mm
- H_3 height of centre of gravity for the tibia: 205 mm $\pm$ 5 mm

NOTE An empty circle at the origin of the coordinate vector means a vector going into the page away from the viewer.

Figure 4 — Locations of the lower limb sub-assemblies segment centres of gravity

5.2.3 Compliant material specifications

The stiffness of the compliant materials included in the lower limb assembly is specified by the corridors described in this subclause.

- The performance of the material installed between the segments of the femur and tibia assemblies (part 133-5512) is specified by the corridor presented in [Figure 5](#). Tabulated data of the corridor is described in [Table 3](#). Performance shall be confirmed using manufactured parts or specially prepared material samples.
- The load is applied to the samples using a flat indenter at a rate not exceeding 15 mm/min.

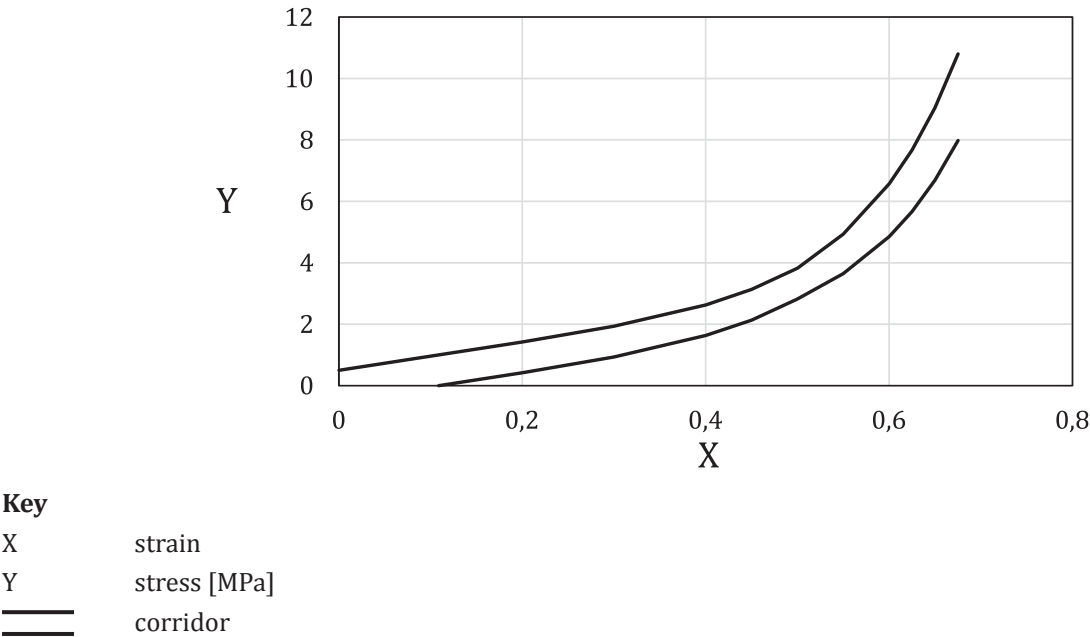


Figure 5 — Mechanical properties for the inter-segment buffer material (specified by corridor)

Table 3 — Mechanical properties for the inter-segment buffer material (specified by tabulated data)

Strain	Stress [MPa]	
	Upper corridor	Lower corridor
0,000	0,50	-0,50
0,100	0,96	-0,04
0,200	1,42	0,42
0,300	1,93	0,93
0,400	2,63	1,63
0,450	3,13	2,13
0,500	3,82	2,82
0,550	4,93	3,65
0,600	6,57	4,85
0,625	7,67	5,67
0,650	9,05	6,69
0,675	10,80	7,98

NOTE The performance of the inter-segment buffer is the same as that specified in Reference [1] Annex 5, Figure 2a.

5.2.4 Certification

When the lower limb is assembled according to 8.1.1, the lower limb shall be tested using the procedure specified in 6.2 and the test results shall meet the specifications given in 6.2.

5.3 Flesh and skin assembly

5.3.1 General description

The flesh and skin assembly shall consist of the components and sub-assemblies listed in flesh and skin assembly drawing aPLI-27000 (see [Annex I](#)).

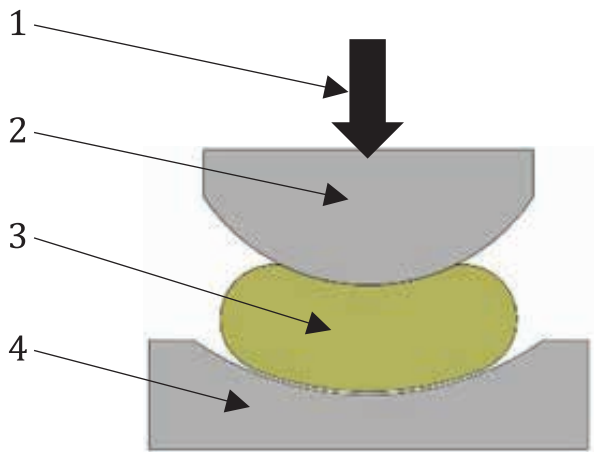
5.3.2 Drawings and specifications

- The upper mass flesh part shall conform to drawing aPLI-11010.
- The femur top flesh part shall conform to drawing aPLI-27010.
- The lower limb flesh assembly part shall conform to drawing aPLI-27000 and have a mass of $3,20 \text{ kg} \pm 0,1 \text{ kg}$.
- The lower limb skin shall conform to drawing aPLI-27011 and have a mass of $0,38 \text{ kg} \pm 0,05 \text{ kg}$.

5.3.3 Compliant material specifications

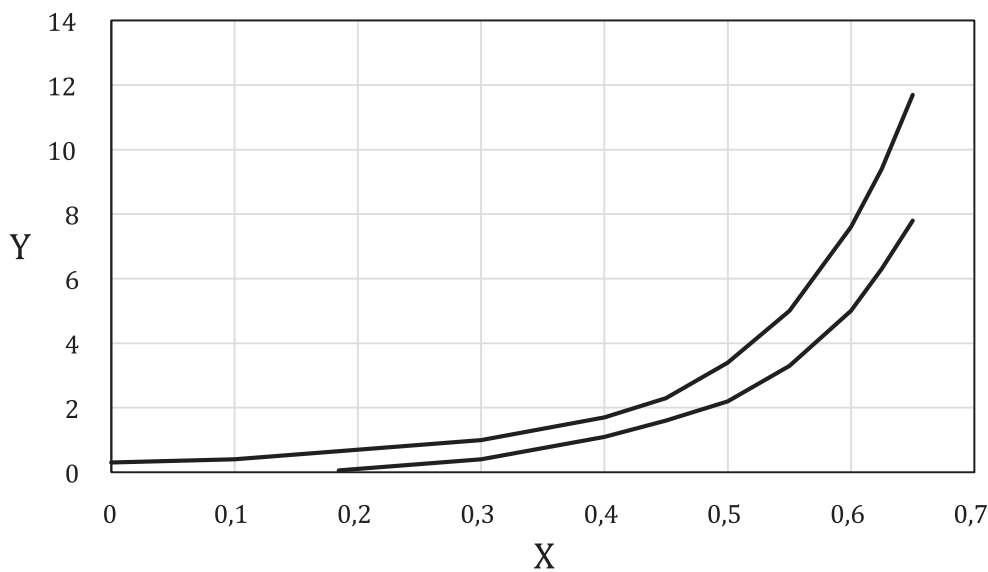
The stiffness of the compliant materials included in the flesh and skin assembly is specified by the corridors described in this subclause.

- The performance of the solid flesh material (parts aPLI-11010, aPLI-27004, aPLI-27010) is specified by the corridor presented in [Figure 7](#). Tabulated data of the corridor is described in [Table 4](#). Performance shall be confirmed using samples of the material specified in the solid flesh drawings (aPLI-11010, aPLI-27044, aPLI-27010). Material samples shall have dimensions of 50 mm diameter and 12 mm thickness and be supported and loaded between flat faces.
- The performance of the foam flesh material (parts aPLI-27002 and aPLI-27003) is specified by the corridor presented in [Figure 8](#). Tabulated data of the corridor is described in [Table 5](#). Performance shall be confirmed using samples cut from part aPLI-27002. The length of the samples may be varied to suit the loading equipment. To accommodate the shape of the foam flesh material samples, a curved support block and indenter shall be used as shown in [Figure 6](#). To calculate the loaded area the linear width of the part is used.
- The performance of the lower limb skin material (part aPLI-27011) is specified by the corridor presented in [Figure 9](#). Tabulated data of the corridor is described in [Table 6](#). Performance shall be confirmed using cut samples of material. The dimensions of the samples may be varied to suit the loading equipment. The component under test shall be supported and loaded between flat faces.
- All material data is based on a loading rate not exceeding 15 mm/min.



- Key**
- 1 applied force
 - 2 loading indenter, contact surface radius 35,5 mm
 - 3 part sample
 - 4 support block, contact surface radius 55,5 mm

Figure 6 — Schematic image of shaped support and loading blocks for foam flesh material testing



- Key**
- X strain
 - Y stress [MPa]
 - corridor

Figure 7 — Mechanical properties for the solid flesh material (specified by corridor)

Table 4 — Mechanical properties for the solid flesh material (specified by tabulated data)

Strain	Stress [MPa]	
	Upper corridor	Lower corridor
0,000	0,3	-0,3

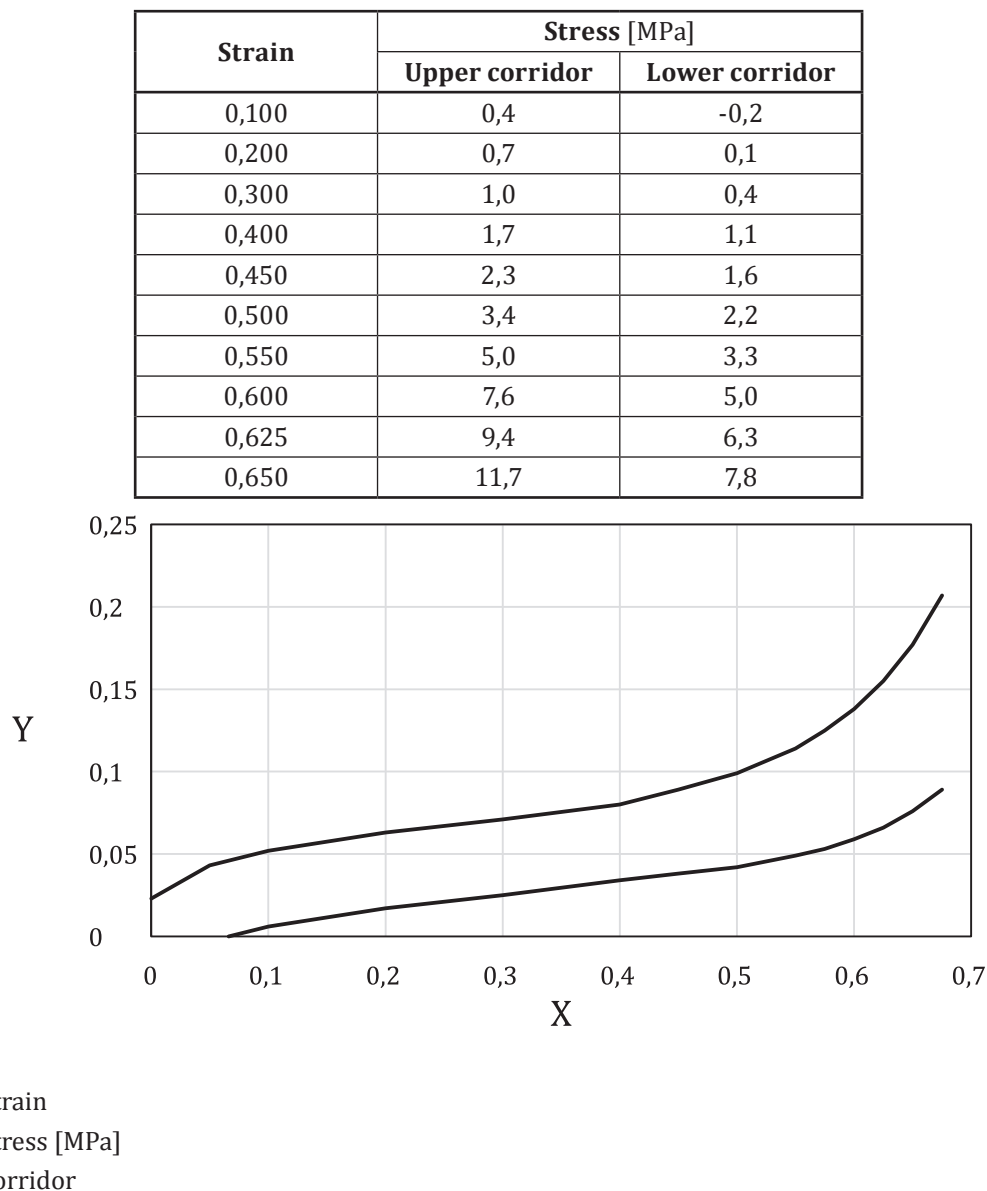


Figure 8 — Mechanical properties for the foam flesh material (specified by corridor)

Table 5 — Mechanical properties for the foam flesh material (specified by tabulated data)

Strain	Stress [MPa]	
	Upper corridor	Lower corridor
0,000	0,023	-0,023
0,050	0,043	-0,003
0,100	0,052	0,006
0,200	0,063	0,017
0,300	0,071	0,025
0,400	0,080	0,034
0,450	0,089	0,038
0,500	0,099	0,042
0,550	0,114	0,049
0,575	0,125	0,053

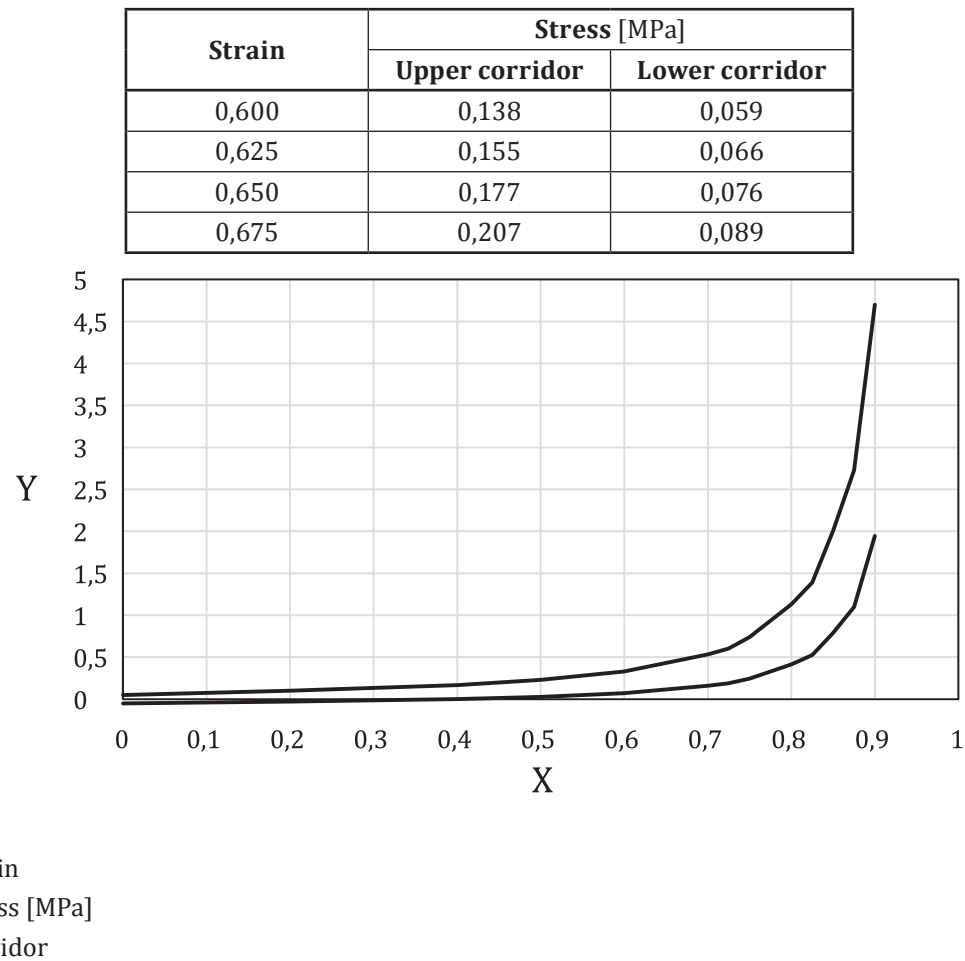


Figure 9 — Mechanical properties for the skin layer material (specified by corridor)

Table 6 — Mechanical properties for the skin layer material (specified by tabulated data)

Strain	Stress [MPa]	
	Upper corridor	Lower corridor
0,000	0,050	-0,050
0,200	0,100	-0,028
0,400	0,168	0,001
0,500	0,228	0,026
0,600	0,329	0,070
0,700	0,534	0,157
0,725	0,603	0,187
0,750	0,740	0,246
0,800	1,129	0,413
0,825	1,389	0,524
0,850	2,003	0,787
0,875	2,729	1,098
0,900	4,701	1,943

NOTE The performance of the lower limb skin material is the same as that specified in Reference [1] Annex 5, Figure 2b.

5.3.4 Certification

No certification test is specified for the flesh and skin assembly, however periodic inspection for visible damage is recommended according to the procedure specified in [Annex N](#).

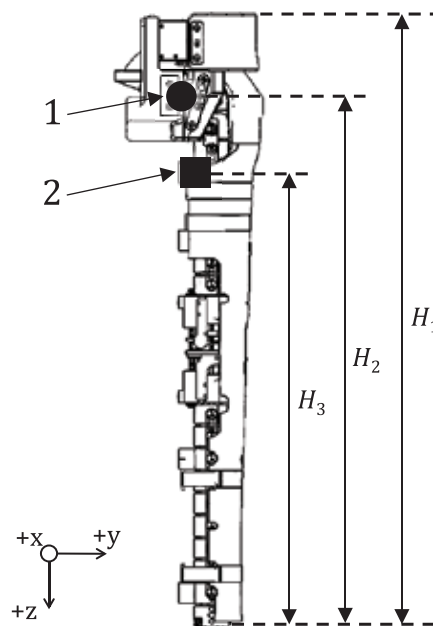
5.4 Full assembly

5.4.1 General description

The full assembly shall consist of the components and subassemblies listed in the full assembly drawing aPLI-00000 ([Annex I](#)).

5.4.2 Drawings and specifications

- The full assembly and components shall conform to the assembly drawing aPLI-00000 (see [Annex I](#)) and the subassembly and component drawings listed therein.
- The total assembly (including sensors and DAS) shall have a mass of $24,7 \text{ kg} \pm 0,3 \text{ kg}$.
- The overall dimensions shall be located as indicated in [Figure 10](#).
- The flesh material and/or external surface characteristics shall meet the requirements of [5.3](#) and accommodate the attachment of adhesive targets.



Key

- 1 hip joint
- 2 centre of gravity for full assembly
- H_1 height of full assembly aPLI: $1\,096 \text{ mm} + 16 \text{ mm} / -2 \text{ mm}$
- H_2 height of hip joint: $933 \text{ mm} \pm 5 \text{ mm}$
- H_3 height of full assembly centre of gravity: $770 \text{ mm} \pm 10 \text{ mm}$

NOTE An empty circle at the origin of the coordinate vector means a vector going into the page away from the viewer.

Figure 10 — Overall dimensions and location of the centre of gravity of the aPLI full assembly

5.4.3 Certification

When the upper mass and the lower limb is assembled as full assembly according to [8.1.1](#), the full assembly shall be tested using the procedure specified in [6.3](#), and the test results shall meet the specifications given in [6.3](#).

6 Certification test procedure

The signals measured by the aPLI hardware are certified by following the procedures as specified in paragraphs [6.1](#) through [6.3](#).

6.1 Upper mass

6.1.1 Hip joint

6.1.1.1 Principle

A hip-joint certification test shall be performed to certify the response of the hip joint in a quasi-static loading condition.

6.1.1.1.1 Materials

- Use fully assembled aPLI as specified in [5.4](#).
- Skin and flesh parts fitted to the upper mass and lower limb as specified in [5.3](#) may be removed during the test.

6.1.1.1.2 Apparatus

Hip adduction certification test equipment conforming to the performance criteria is shown in [Table 7](#) and the operational criteria are described in [6.1.1.1.4](#) and [6.1.1.1.5](#).

Table 7 — Hip adduction certification test equipment – Performance criteria

Parameter	Requirement
Loading capability	Provide a moment input to the upper mass about the hip joint up to 350 Nm and angular displacement of the upper mass of at least 28°.
Holding capability	Provide a secure fixation for aPLI to ensure that no displacement or deformation of the femur occurs during the test. This can be confirmed by demonstrating that the maximum BM recorded at any femur sensor location does not exceed 10 Nm.
Measurement capability	Measure the angular displacement of the upper mass at the hip joint relative to the femur.
	Measure the moment applied to the upper mass about the hip joint.
Note An exemplar test rig is described in Annex Q .	

6.1.1.1.3 Sensors

Perform the test using the sensors given in [Table 8](#).

Table 8 — Sensors for hip-joint certification tests

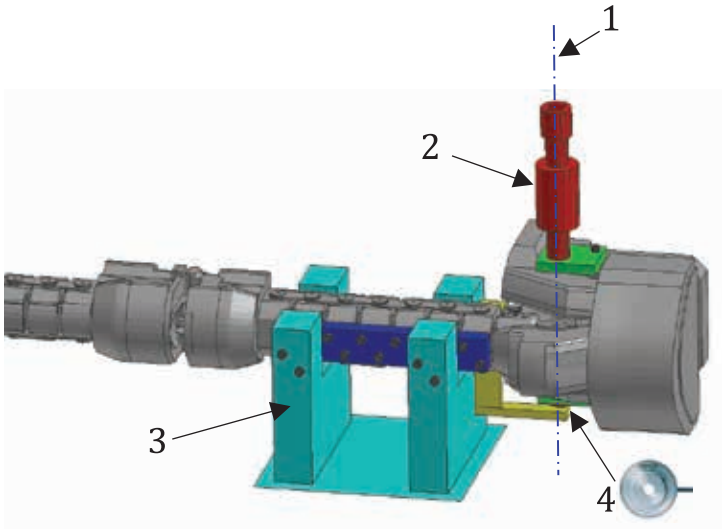
Variables	Sensor	Performance
Hip-joint adduction moment	Moment sensor	SAE J2570
Hip-joint adduction angle	Angular potentiometer	SAE J2570

6.1.1.1.4 Preparation

- Expose the PLI to the conditions specified in [Table 9](#) for at least two hours prior to a test.
- Secure the aPLI by using a support fixture that prevents any deflection of the femur of aPLI as shown in [Figure 11](#).
- Attach a sensor that can record the angular displacement of the upper mass relative to the femur.
- Attach a moment sensor that can record the moment applied about the hip joint.

Table 9 — Precondition for hip-joint certification tests

Variable	Specification
Temperature [°C]	20,0 ± 2,0
Relative humidity [%]	40,0 ± 30,0



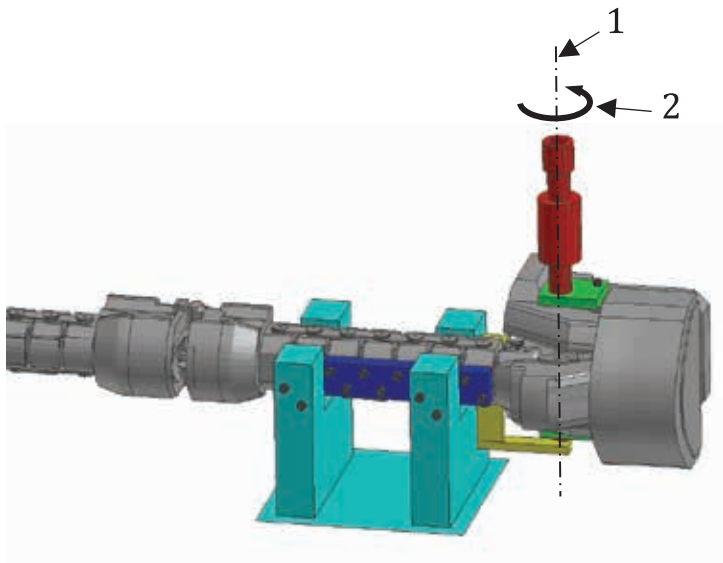
Key

- 1 axis of hip joint
- 2 moment sensor
- 3 support fixture of femur
- 4 angular potentiometer

Figure 11 — Schematic image of preparation for a hip-joint certification test

6.1.1.1.5 Procedure

- Record the data (hip-joint adduction torque, hip-joint adduction angle).
- Ensure the upper mass is aligned with the femur.
- Adjust the moment and displacement measurement values to zero.
- Apply a moment to the upper mass about the hip-joint axis as shown in [Figure 12](#) at a rate not exceeding 5° per second until a minimum angle of 28° between the upper mass and femur has been achieved.

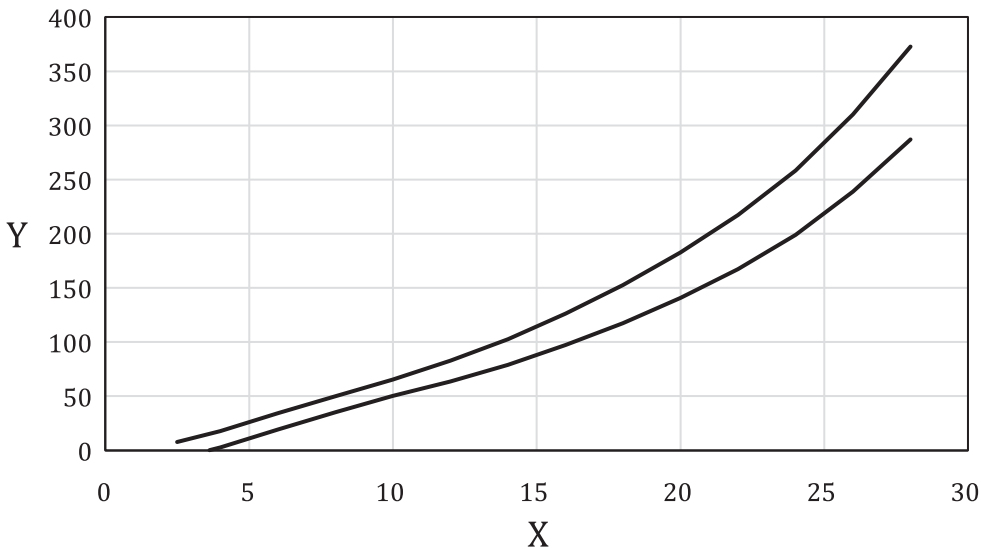


- Key**
- 1 axis of hip joint
 - 2 applied adduction moment

Figure 12 — Schematic image of hip-joint certification tests

6.1.1.1.6 Certification specifications

The hip-joint certification test results shall meet the certification specifications defined by the corridor presented in [Figure 13](#). Tabulated data of the corridor are described in [Table 10](#).



- Key**
- X adduction angle [°]
 - Y adduction moment [Nm]
 - Corridor

Figure 13 — Certification specifications for the hip joint (specified by corridor)

Table 10 — Certification specifications for the hip joint (specified by tabulated data)

Hip-joint adduction angle [°]	Hip-joint adduction moment [Nm]	
	Upper corridor	Lower corridor
2,5	7,8	-7,3
4	17,7	2,7
6	34,3	19,3
8	50,1	35,1
10	65,5	50,4
12	82,7	63,7
14	102,6	79,0
16	126,3	97,2
18	152,5	117,4
20	182,6	140,6
22	217,4	167,4
24	258,5	199,0
26	310,1	238,8
28	372,8	287,0

6.1.1.1.7 Test report

The test report shall include:

- all information necessary for the identification of the component tested, details of the equipment used and test date;
- a graph of applied hip adduction moment and observed hip-joint adduction angle;
- a comparison of the measured values to the certification specifications.

6.2 Lower limb

6.2.1 Femur bone assembly

6.2.1.1 Principle

Perform a femur bone assembly certification test to certify the response of the femur bone assembly in a quasi-static loading condition.

6.2.1.2 Materials

Use femur bone assembly specified in the drawing aPLI-21001 (see [Annex I](#)).

6.2.1.3 Apparatus

- Support and loading fixtures specified in the drawing aPLI-41001 (see [Annex I](#)).
- Loading machine which has the capability to apply a load up to 13,8 kN or larger.

6.2.1.4 Sensors

Perform the test using the sensors given in [Table 11](#).

Table 11 — Sensors for femur bone assembly certification test

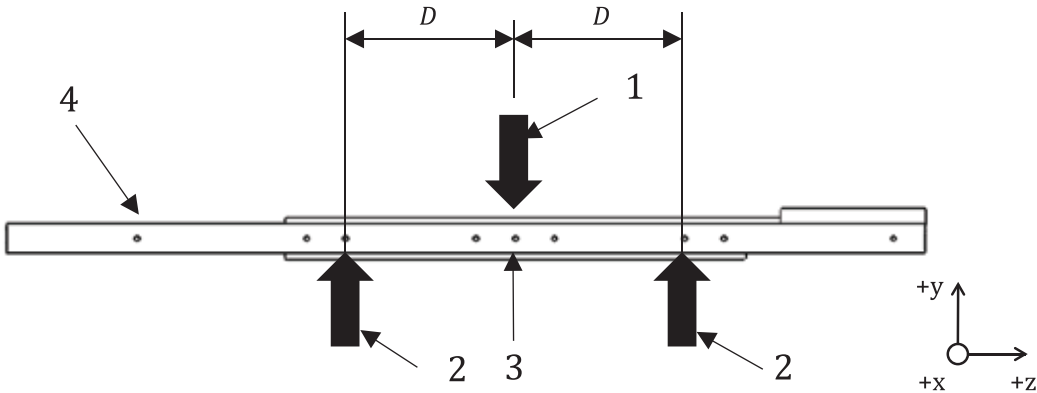
Variables	Sensor	Performance
Applied force at indenter	Load cell	SAE J2570
Displacement at indenter	Displacement potentiometer	SAE J2570

6.2.1.5 Preparation

- Expose the femur bone assembly to the conditions specified in Table 12 for at least two hours prior to a test.
- The support and loading fixtures shall be assembled around the femur bone core, so the loading fixture is aligned with the sensor and the support fixtures are equally located from the sensor.
- The support fixtures shall exhibit low friction against the base of the test machine.
- Location features shall be provided on the edge of the bone to assist with the accurate positioning of these fixtures, see Figure 14.
- The positions of loading and support fixture on the bone shall not change as the bone deflects during the test.

Table 12 — Precondition for femur bone assembly certification test

Variable	Specification
Temperature [°C]	20,0 ± 2,0
Relative humidity [%]	40,0 ± 30,0



Key

- 1 applied force at indenter
- 2 support force
- 3 sensor location
- 4 impact side
- D distance of support fixture from sensor : 65 mm ± 0,2 mm

NOTE An empty circle at the origin of the coordinate vector means a vector going into the page away from the viewer.

Figure 14 — Schematic image of location feature for support fixture arrangement for femur bone assembly

6.2.1.6 Procedure

- Record the data (applied force at indenter, displacement of indenter).

- Position the assembly under the loading machine so that the indenter shall be centred over the sensor location and between the loading supports with a $\pm 0,2$ mm tolerance.
- Lower the indenter until it just contacts the bone. Adjust the force and displacement measurement values to zero.
- A load to the bone up to 13,8 kN shall be applied by moving the indenter downwards at a rate not exceeding 30 mm/min.
- Repeat this procedure at each of three sensor locations.

6.2.1.7 Certification specifications

The femur bone assembly certification test results shall meet the certification specifications specified by the corridor presented in [Figure 15](#). Tabulated data of the corridor are described in [Table 13](#).

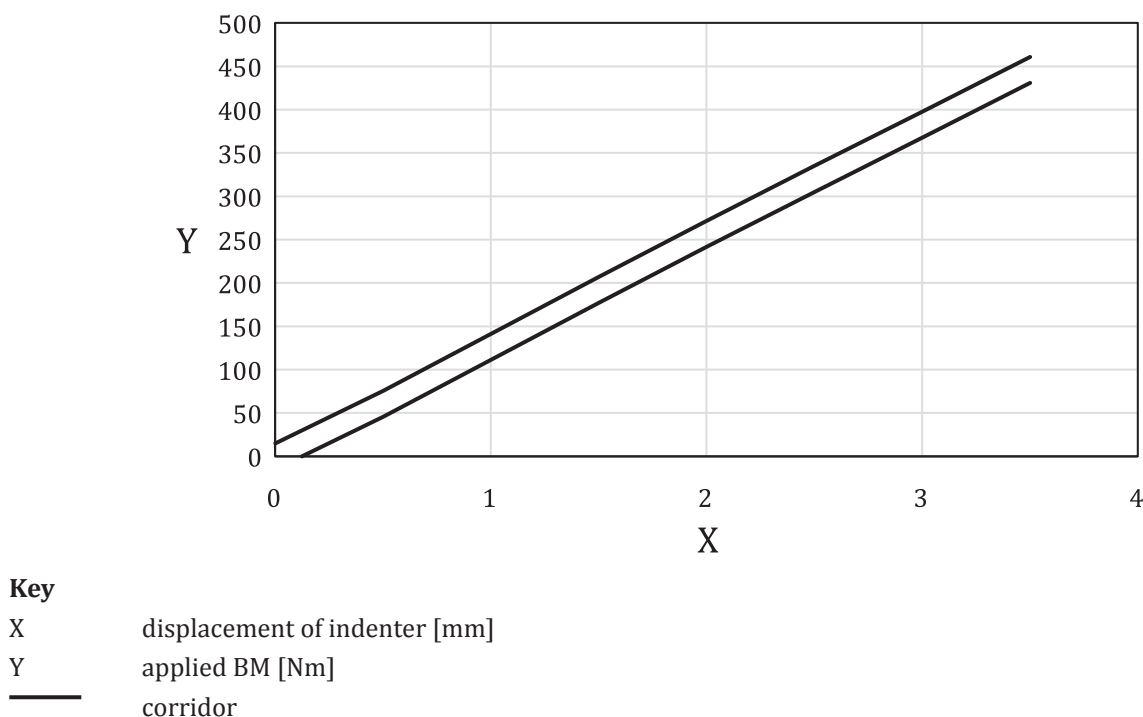


Figure 15 — Certification specifications for the femur bone assembly (specified by corridor)

Table 13 — Certification specifications for the femur bone assembly (specified by tabulated data)

Displacement at indenter [mm]	Femur bone core BM ^a [Nm]	
	Upper corridor	Lower corridor
0,0	15,0	-15,0
0,5	75,5	45,5
1,0	141,3	111,3
1,5	207,1	177,1
2,0	271,7	241,7
2,5	335,0	305,0
3,0	397,7	367,7

^a This is the BM applied at femur bone core calculated by multiplying half of the applied force at the indenter by the distance between the support fixture and the sensor (D).

Displacement at indenter [mm]	Femur bone core BM ^a [Nm]	
	Upper corridor	Lower corridor
3,5	460,9	430,9
^a This is the BM applied at femur bone core calculated by multiplying half of the applied force at the indenter by the distance between the support fixture and the sensor (D).		

6.2.1.8 Test report

The test report shall include:

- all information necessary for the identification of the component and location tested, details of the equipment used and test date;
- a graph of applied force at the indenter and observed displacement of the indenter;
- a comparison of the measured values to the certification specifications.

6.2.2 Tibia bone assembly

6.2.2.1 Principle

Perform a tibia bone assembly certification test to certify the response of the tibia bone assembly in a quasi-static loading condition.

6.2.2.2 Materials

Use the tibia bone core assembly specified in the drawing aPLI-26001 (see [Annex I](#)).

6.2.2.3 Apparatus

- Support and loading fixtures specified in the drawing aPLI-41002 (see [Annex I](#)).
- Loading machine which has a capability to apply a load up to 11,5 kN.

6.2.2.4 Sensors

Perform the test using the sensors given in [Table 14](#).

Table 14 — Sensors for tibia bone assembly certification tests

Variables	Sensor	Performance
Applied force at indenter	Load cell	SAE J2570
Displacement at indenter	Displacement potentiometer	SAE J2570

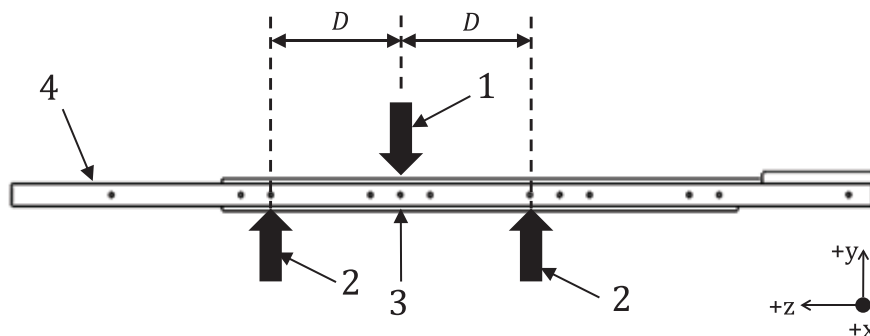
6.2.2.5 Preparation

- Expose the tibia bone assembly to the conditions specified in [Table 15](#) for at least two hours prior to a test.
- The support and loading fixtures shall be assembled around the tibia bone core, so the loading fixture is aligned with the sensor and the support fixtures are equally located from the sensor.
- The support fixtures shall exhibit low friction against the base of the test machine.
- Location features shall be provided on the edge of the bone to assist with the accurate positioning of these fixtures, see [Figure 16](#).

- The positions of loading and support fixture on the bone shall not change as the bone deflects during the test.

Table 15 — Precondition for tibia bone core certification tests

Variable	Specification
Temperature [°C]	$20,0 \pm 2,0$
Relative humidity [%]	$40,0 \pm 30,0$



Key

- 1 applied force at indenter
- 2 support force
- 3 sensor location
- 4 impact side
- D distance of support fixture from sensor: $65 \text{ mm} \pm 0,2 \text{ mm}$

NOTE A black circle at the origin of the coordinate vector means a vector coming out of the page toward the viewer.

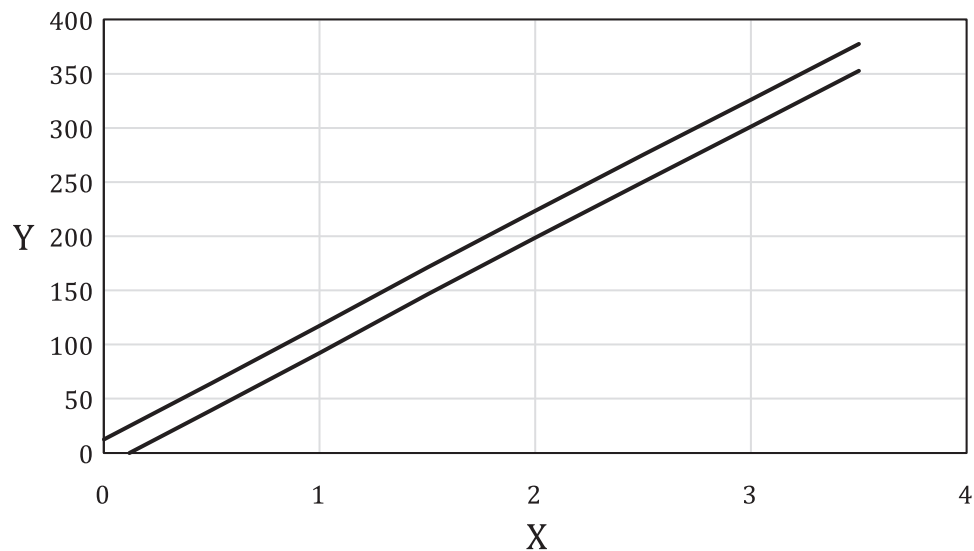
Figure 16 — Schematic image of location feature for support fixture arrangement for tibia bone assembly

6.2.2.6 Procedure

- Record the data (applied force at indenter, displacement of indenter).
- Position the assembly under the loading machine so that the indenter shall be centred over the sensor location and between the loading supports with a $\pm 0,2 \text{ mm}$ tolerance.
- Lower the indenter until it just contacts the bone. Adjust the force and displacement measurement values to zero.
- A load to the bone up to $11,5 \text{ kN}$ shall be applied by moving the indenter downwards at a rate not exceeding 30 mm/min .
- Repeat this procedure at each of four sensor locations.

6.2.2.7 Certification specifications

The tibia bone core certification test results shall meet the certification specifications defined by the curves presented in [Figure 17](#). Tabulated data of the specifications are described in [Table 16](#).



Key

- X displacement of indenter [mm]
Y applied BM [Nm]
— corridor

Figure 17 — Certification specifications for the tibia bone assembly (specified by corridor)

Table 16 — Certification specifications for the tibia bone assembly (specified by tabulated data)

Displacement at indenter [mm]	Tibia bone core BM ^a [Nm]	
	Upper corridor	Lower corridor
0,0	12,5	-12,5
0,5	64,5	39,5
1,0	117,4	92,4
1,5	171,3	146,3
2,0	223,6	198,6
2,5	275,1	250,1
3,0	326,2	301,2
3,5	377,6	352,6

^a This is the BM applied at tibia bone core calculated by multiplying half of the applied force at the indenter by the distance between the support fixture and the sensor (D).

6.2.2.8 Test report

The test report shall include:

- all information necessary for the identification of the component and location tested, details of the equipment used and test date;
- a graph of applied force at the indenter and observed displacement of the indenter;
- a comparison of the measured values to the certification specifications.

6.2.3 Femur assembly

6.2.3.1 Principle

Perform a femur assembly certification test to certify the response of the femur assembly in a quasi-static loading condition.

The output of the bone sensors may be monitored during the femur assembly certification test to confirm correct function and any change over time; however, the sensor outputs do not form part of the certification test acceptance criteria.

6.2.3.2 Materials

Use a femur assembly conforming to drawing aPLI-21000.

6.2.3.3 Apparatus

- Test fixture assembly conforming to drawing aPLI-42001.
- Loading machine which has a capability to apply a load up to 5,6 kN or larger.

6.2.3.4 Sensors

Perform the test using the sensors given in [Table 17](#).

Table 17 — Sensors for femur assembly certification tests

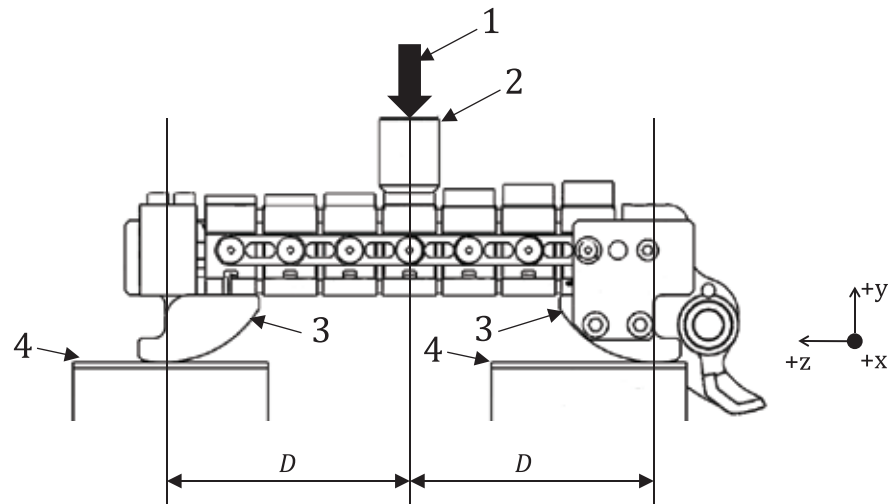
Variables	Sensor	Performance
Applied force at indenter	Load cell	SAE J2570
Displacement of indenter	Displacement potentiometer	SAE J2570

6.2.3.5 Preparation

- Expose the femur assembly to the conditions specified in [Table 18](#) for at least two hours prior to a test.
- Remove the curved femur top aPLI-21017 from the upper end of the femur assembly.
- Attach the testing brackets aPLI-42004 and pivot blocks aPLI-42005 to the upper and lower ends of the femur assembly and arrange the pivot blocks on the baseplate which has low friction surface made of polytetrafluoroethylene (PTFE).
- Position the assembly under the loading machine so that the indenter is aligned with the centre impact segment and between the loading supports with a $\pm 0,5$ mm tolerance as shown in [Figure 18](#).

Table 18 — Precondition for femur assembly certification tests

Variable	Specification
Temperature [°C]	20,0 $\pm$ 2,0
Relative humidity [%]	40,0 $\pm$ 30,0



Key

- 1 applied force
- 2 indenter
- 3 pivot block
- 4 low friction surface
- D distance from centre of rotation of support fixture to indenter: $165 \text{ mm} \pm 0,5 \text{ mm}$

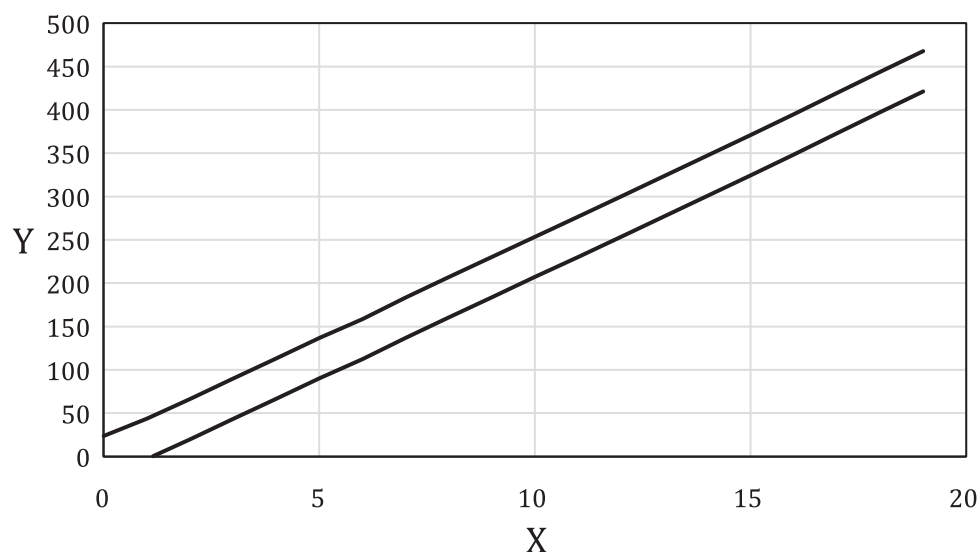
Figure 18 — Femur assembly certification test arrangement

6.2.3.6 Procedure

- Record the data (applied force at indenter, displacement of indenter).
- Lower the indenter until it just contacts the femur assembly. Adjust the force and displacement measurement values to zero.
- A load to the femur shall be applied as shown in [Figure 18](#) by moving the indenter downwards at a rate of $60 \text{ mm/min} \pm 5 \text{ mm/min}$ until a minimum 20 mm displacement has been achieved.

6.2.3.7 Certification specifications

The femur assembly certification test results shall meet the certification specifications defined by the corridor presented in [Figure 19](#). Tabulated data of the corridor are described in [Table 19](#).



Key

X displacement of indenter [mm]

Y femur BM [Nm]

corridor

NOTE Femur BM is calculated by using following formula: half of the applied force at indenter [N] $\times$ 0,165 [m].

Figure 19 — Certification specifications for the femur assembly (specified by corridor)

Table 19 — Certification specifications for the femur assembly (specified by tabulated data)

Deflection at indenter [mm]	Femur BM ^a [Nm]	
	Upper corridor	Lower corridor
0	23,8	-22,7
1	43,7	-2,8
2	66,3	19,8
3	89,7	43,2
4	113,1	66,6
5	136,7	90,2
6	158,7	112,2
7	183,3	136,7
8	206,9	160,4
9	230,1	183,6
10	253,7	207,2
11	276,9	230,4
12	300,0	253,5
13	323,6	277,1
14	347,5	301,0
15	371,1	324,5
16	395,0	348,5
17	419,4	372,9

^a This is the BM applied at femur calculated by multiplying half of the applied force at the indenter and the half length of support distance.

Deflection at indenter [mm]	Femur BM ^a [Nm]	
	Upper corridor	Lower corridor
18	443,9	397,4
19	467,7	421,2
^a This is the BM applied at femur calculated by multiplying half of the applied force at the indenter and the half length of support distance.		

6.2.3.8 Test report

The test report shall include:

- all information necessary for the identification of the component tested, details of the equipment used and test date;
- a graph of the applied femur BM and indenter displacement;
- a comparison of the measured values to the acceptance criteria.

6.2.4 Knee assembly

6.2.4.1 Principle

Perform a knee assembly test to certify the response of the knee assembly in a quasi-static loading condition.

6.2.4.2 Materials

Use a knee assembly conforming to drawing aPLI-23000, fitted with displacement sensors at ACL, PCL and MCL locations.

6.2.4.3 Apparatus

- Test fixture assembly including loading indenter conforming to assembly drawing aPLI-42001.
- Loading machine which has a capability to apply force up to 4,0 kN or larger.

6.2.4.4 Sensors

Perform the test using the sensors given in [Table 20](#).

Table 20 — Sensors for knee assembly certification tests

Variables	Sensor	Performance
Applied force at indenter	Load cell	SAE J2570
MCL/ACL/PCL elongation	Displacement potentiometer	SAE J2570

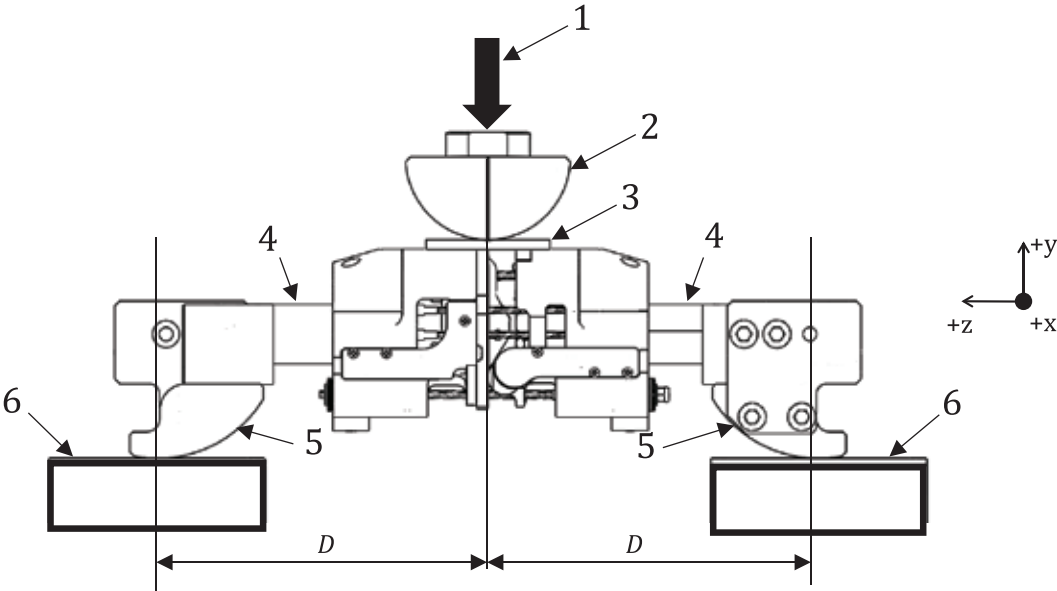
6.2.4.5 Preparation

- Expose the knee assembly to the conditions specified in [Table 21](#) for at least two hours prior to a test.
- Attach the knee connectors (aPLI-42011 and aPLI-42012), testing brackets aPLI-42004 and pivot blocks aPLI-42005 to the upper and lower ends of the knee and arrange the pivot blocks on the baseplate which has a low friction surface made of polytetrafluoroethylene (PTFE).
- Position the assembly under the loading machine so that the indenter shall be aligned with the upper surface of the knee meniscus and between the loading supports with a $\pm 0,5$ mm tolerance as shown in [Figure 20](#).

- Place a patch of polychloroprene material with $5\text{ mm} \pm 1\text{ mm}$ thickness and a minimum dimension of $75\text{ mm} \times 75\text{ mm}$, the same material as specified in 5.3.3 and drawing aPLI-27011, over the test area.

Table 21 — Precondition for knee assembly certification tests

Variable	Specification
Temperature [°C]	$20,0 \pm 2,0$
Relative humidity [%]	$40,0 \pm 30,0$



Key

- 1 applied force
- 2 indenter
- 3 patch of polychloroprene material
- 4 connector
- 5 pivot block
- 6 low friction surface
- D distance from centre of rotation of support fixture to indenter: $200\text{ mm} \pm 0,5\text{ mm}$

NOTE A black circle at the origin of the coordinate vector means a vector coming out of the page toward the viewer.

Figure 20 — Knee assembly certification test arrangement

6.2.4.6 Procedure

- Record the data (applied force at indenter, MCL elongation, ACL elongation, PCL elongation).
- Lower the indenter until it just contacts the polychloroprene sheet. Adjust the indenter force, indenter displacement and ligament elongation measurement values to zero.
- A load to the knee assembly up to 4,8 kN shall be applied by moving the indenter downwards at a rate of $40\text{ mm/min} \pm 5\text{ mm/min}$.

6.2.4.7 Certification specifications

The knee assembly certification test results shall meet the certification specifications defined by the corridor presented in [Figure 21](#) through [Figure 23](#). Tabulated data of the corridor are described in [Table 22](#) through [Table 24](#).

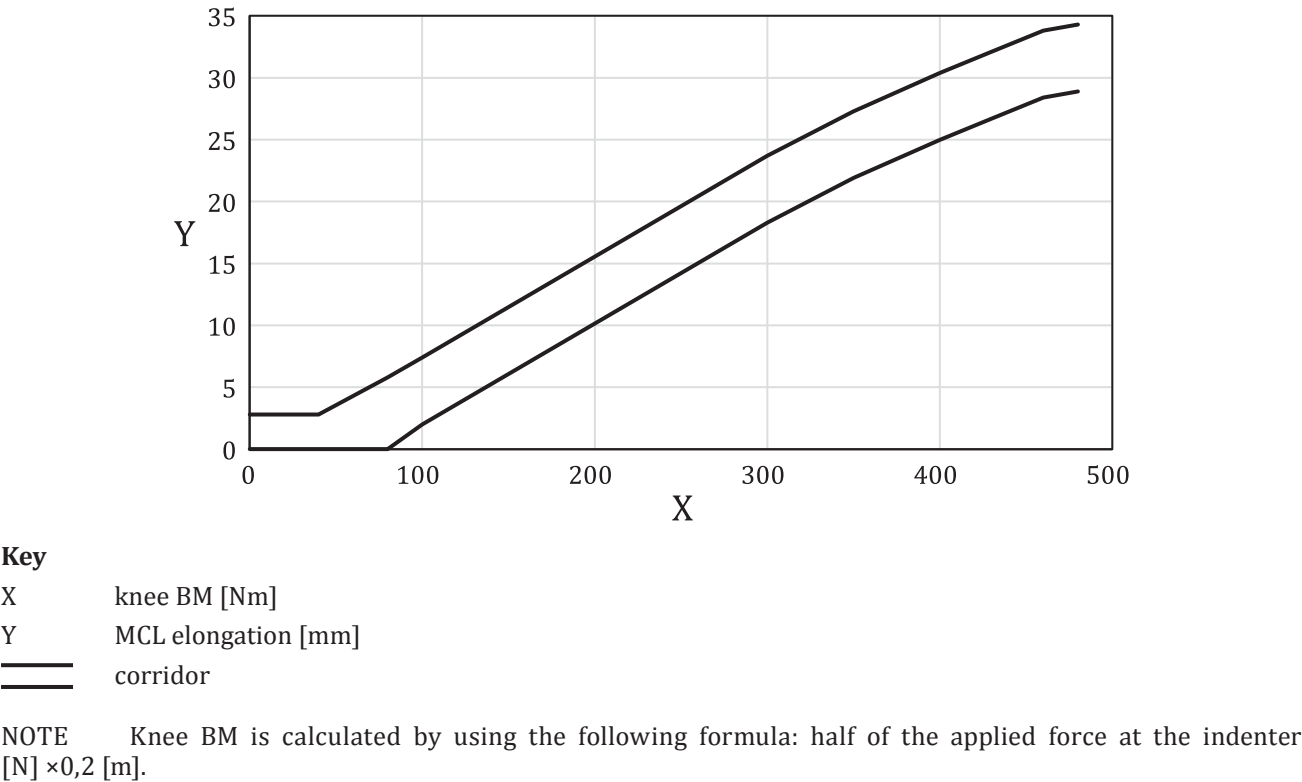


Figure 21 — Certification specifications for the knee assembly (specified by corridors) – MCL

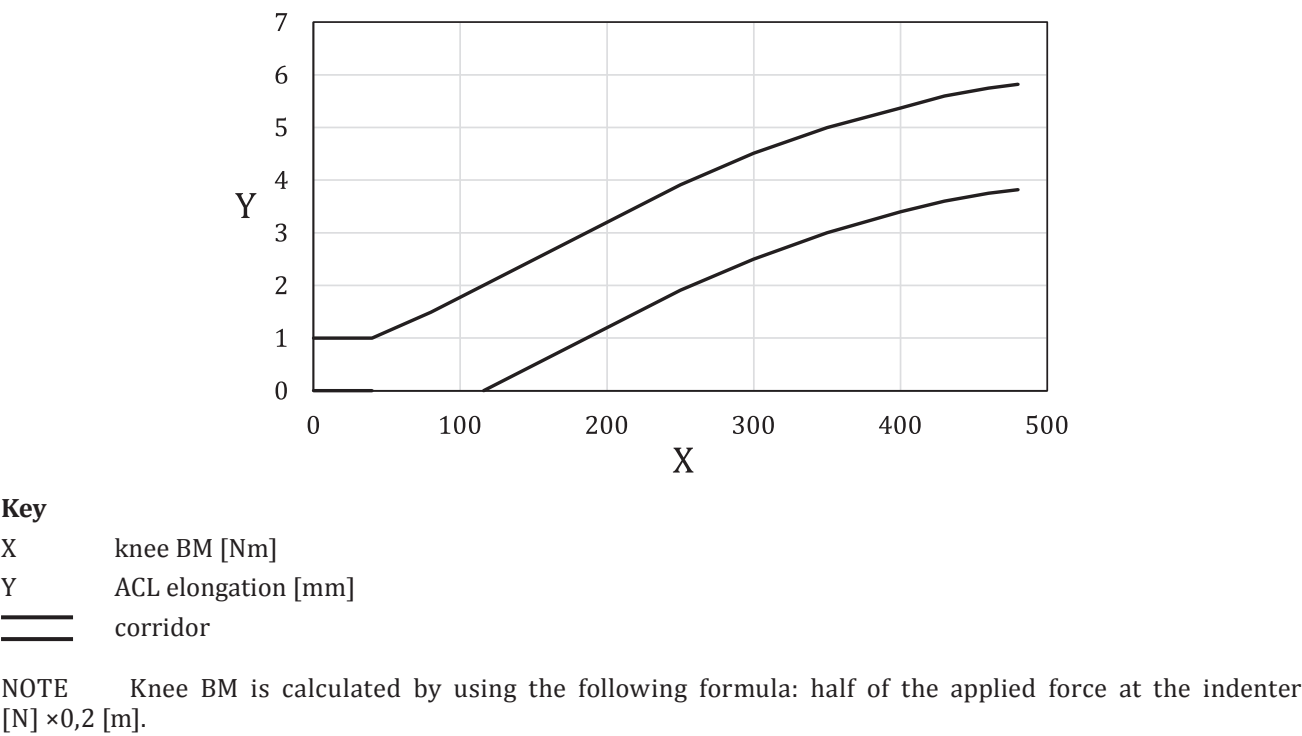
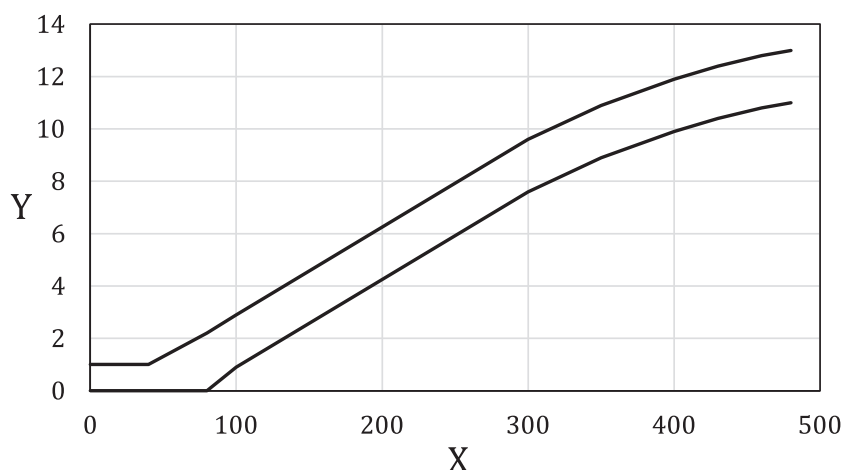


Figure 22 — Certification specifications for the knee assembly (specified by corridors) – ACL



Key

X knee BM [Nm]
Y PCL elongation [mm]
— corridor

NOTE Knee BM is calculated by using the following formula: half of the applied force at the indenter [N] $\times 0,2$ [m].

Figure 23 — Certification specifications for the knee assembly (specified by corridors) – PCL

Table 22 — Certification specifications for the knee assembly (specified by tabulated data) - MCL

Knee BM ^a [Nm]	MCL elongation [mm]	
	Upper corridor	Lower corridor
0	2,8	-
40	2,8	-
80	5,8	0,0
100	7,4	2,0
300	23,7	18,3
350	27,3	21,9
400	30,4	25,0
430	32,1	26,7
460	33,8	28,4
480	34,3	28,9

^a This is the bending moment applied at the knee calculated by multiplying half of the applied force at the indenter and half the length of the support distance.

Table 23 — Certification specifications for the knee assembly (specified by tabulated data) – ACL

Knee BM ^a [Nm]	ACL elongation [mm]	
	Upper corridor	Lower corridor
0	1,00	-
40	1,00	-

^a This is the bending moment applied at the knee calculated by multiplying half of the applied force at the indenter and half the length of the support distance.

Knee BM ^a [Nm]	ACL elongation [mm]	
	Upper corridor	Lower corridor
80	1,49	-0,51
250	3,91	1,91
300	4,51	2,50
350	5,00	3,00
400	5,37	3,40
430	5,60	3,60
460	5,75	3,75
480	5,82	3,82

^a This is the bending moment applied at the knee calculated by multiplying half of the applied force at the indenter and half the length of the support distance.

Table 24 — Certification specifications for the knee assembly (specified by tabulated data) – PCL

Knee BM ^a [Nm]	PCL elongation [mm]	
	Upper corridor	Lower corridor
0	1,0	-
40	1,0	-
80	2,2	0,0
100	2,9	0,9
300	9,6	7,6
350	10,9	8,9
400	11,9	9,9
430	12,4	10,4
460	12,8	10,8
480	13,0	11,0

^a This is the bending moment applied at the knee calculated by multiplying half of the applied force at the indenter and half the length of the support distance.

6.2.4.8 Test report

The test report shall include:

- all information necessary for the identification of the component tested, details of the equipment used and test date;
- graphs of the applied knee BM and ligament elongation of ACL, PCL and MCL;
- a comparison of the measured values to the acceptance criteria.

6.2.5 Tibia assembly

6.2.5.1 Principle

Perform a tibia assembly certification test to certify the response of the tibia assembly in a quasi-static loading condition.

The output of the bone sensors may be monitored during the tibia assembly certification test to confirm correct function and any change over time; however, the sensor outputs do not form part of the certification test acceptance criteria.

6.2.5.2 Materials

Use a tibia assembly conforming to drawing aPLI-26000.

6.2.5.3 Apparatus

- Test fixture assembly conforming to drawing aPLI-42001.
- Loading machine which has a capability to apply a load up to 2,3 kN.

6.2.5.4 Sensors

Perform the test using the sensors given in [Table 25](#).

Table 25 — Sensors for femur assembly certification tests

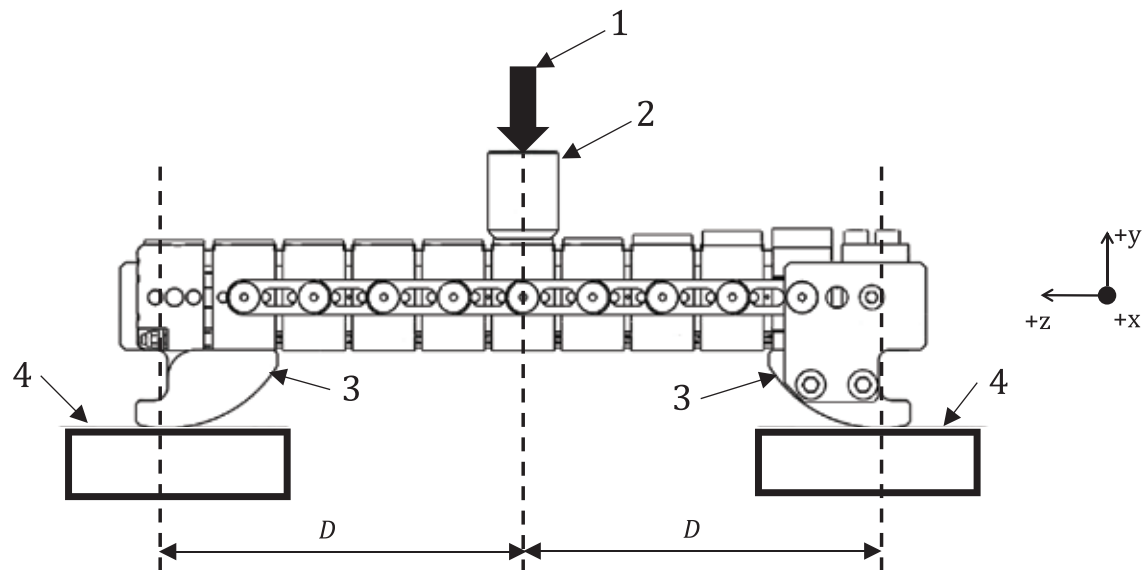
Variables	Sensor	Performance
Applied force at indenter	Load cell	SAE J2570
Displacement of indenter	Displacement potentiometer	SAE J2570

6.2.5.5 Preparation

- Expose the tibia assembly to the conditions specified in [Table 26](#) for at least two hours prior to a test.
- Attach the testing brackets aPLI-42004 and pivot blocks aPLI-42005 to the upper and lower ends of the tibia assembly and arrange the pivot blocks on the baseplate which has a low friction surface made of polytetrafluoroethylene (PTFE).
- Position the assembly under the loading machine so that the indenter shall be aligned with the centre impact segment and between the loading supports with a $\pm 0,5$ mm tolerance as shown in [Figure 24](#).

Table 26 — Precondition for tibia assembly certification tests

Variable	Specification
Temperature [°C]	$20,0 \pm 2,0$
Relative humidity [%]	$40,0 \pm 30,0$



Key

- 1 applied force
- 2 indenter
- 3 pivot block
- 4 low friction surface
- D location of support fixture from indenter: $205 \text{ mm} \pm 0,5 \text{ mm}$

NOTE A black circle at the origin of the coordinate vector means a vector coming out of the page toward the viewer.

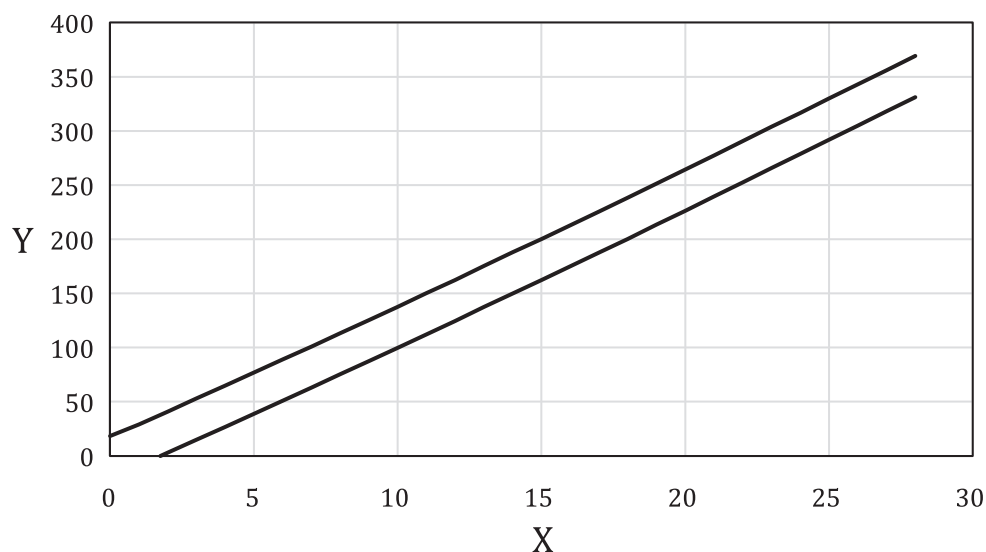
Figure 24 — Tibia assembly certification test arrangement

6.2.5.6 Procedure

- Record the data (applied force at indenter, displacement of indenter).
- Lower the indenter until it just contacts the tibia assembly. Adjust the force and displacement measurement values to zero.
- A force to the femur shall be applied as shown in [Figure 24](#) by moving the indenter downwards at a rate of $60 \text{ mm/min} \pm 5 \text{ mm/min}$ until 30 mm displacement has been achieved.
- Record the force and displacement values during this test.

6.2.5.7 Certification specifications

The tibia assembly certification test results shall meet the certification specifications defined by the corridor presented in [Figure 25](#). Tabulated data of the corridor are described in [Table 27](#).



Key

X displacement of indenter [mm]

Y tibia BM [Nm]

— corridor

NOTE Tibia BM is calculated by using the following formula: half of the applied force at the indenter [N] $\times 0,205$ [m].

Figure 25 — Certification specifications for the tibia assembly (specified by corridor)

Table 27 — Certification specifications for the tibia assembly (specified by tabulated data)

Displacement of indenter [mm]	Tibia BM ^a [Nm]	
	Upper corridor	Lower corridor
0	18,5	-19,5
1	29,0	-9,0
2	40,9	2,9
3	52,9	14,9
4	64,7	26,7
5	76,9	38,9
6	89,0	51,0
7	100,9	62,9
8	113,3	75,3
9	125,5	87,5
10	137,6	99,6
11	150,1	112,1
12	162,4	124,4
13	175,4	137,4
14	187,9	149,9
15	200,3	162,3
16	213,0	175,0
17	225,7	187,7

^a This is the BM applied at the tibia calculated by multiplying half of the applied force at the indenter and the half length of support distance.

Displacement of indenter [mm]	Tibia BM ^a [Nm]	
	Upper corridor	Lower corridor
18	238,3	200,3
19	251,4	213,4
20	264,3	226,3
21	277,4	239,4
22	290,5	252,5
23	303,8	265,8
24	316,7	278,7
25	329,8	291,8
26	342,9	304,9
27	356,0	318,0
28	369,2	331,2

^a This is the BM applied at the tibia calculated by multiplying half of the applied force at the indenter and the half length of support distance.

6.2.5.8 Test report

The test report shall include:

- all information necessary for the identification of the component tested, details of the equipment used and test date;
- a graph of applied tibia BM and indenter displacement;
- a comparison of the measured values to the acceptance criteria.

6.3 Full assembly

Perform certification tests for a fully assembled aPLI to certify its response in dynamic loading conditions. aPLI is impacted below the knee (full-assembly certification test with impact below knee) and at the knee (full-assembly certification test with impact at knee) by a linearly guided impact carriage with a honeycomb impact surface in the tests.

6.3.1 Full-assembly test setup

6.3.1.1 Materials

- Use a fully assembled aPLI as specified in [5.4](#).
- Block of 5052 aluminium honeycomb with a crush strength of 75 psi $\pm$ 10 psi and dimensions: width 200 mm $\pm$ 5 mm, height 160 mm $\pm$ 5 mm and depth 60 mm $\pm$ 2 mm. The honeycomb block should be covered with paper cloth of thickness less than 1 mm.

6.3.1.2 Apparatus

- Full-assembly certification test equipment conforming to the performance criteria shown in [Table 28](#).
- A description of the equipment assessment method is given in [Annex O](#).

Table 28 — Full-assembly certification test equipment - performance criteria

Parameter	Assessment conditions	Requirement
Impact carriage mass	Including honeycomb block	8,15 kg $\pm$ 0,1 kg

Parameter	Assessment conditions	Requirement
Impact velocity	Measured less than 20 mm before impact	11,1 m/s $\pm$ 0,2 m/s
Impactor travel	Free travel, before impact	at least 70 mm
	Free travel, after impact	at least 190 mm
Impact carriage friction	See Annex O	less than 150 N
Impact carriage deflection	See Annex O	less than 5 mm
Suspension fixture(s)	Release time, after impact	earlier than 10 ms

6.3.1.3 Sensors

Perform the test using the sensors given in [Table 29](#).

Table 29 — Sensors for full-assembly certification tests

Variables	Sensor	Performance
Velocity of impact carriage	Not specified	Resolution 0,02 m/s or better
Femur BM (femur-UP, femur-MID, femur-LO)	aPLI instruments specified in 7.1.3.2	SAE J2570
Tibia BM (tibia-UP, tibia-MID-UP, tibia-MID-LO, Tibia-LO)	aPLI instruments specified in 7.1.3.2	SAE J2570
MCL/ACL/PCL elongation	aPLI instruments specified in 7.1.3.3	SAE J2570

6.3.1.4 Preparation

- Expose the fully assembled aPLI to the conditions specified in [Table 30](#) for at least two hours prior to a test.
- Fit the suspension hanger assembly aPLI-44001 to the top of the upper mass.
- Attach the honeycomb block to the impact carriage using double-sided adhesive tape.

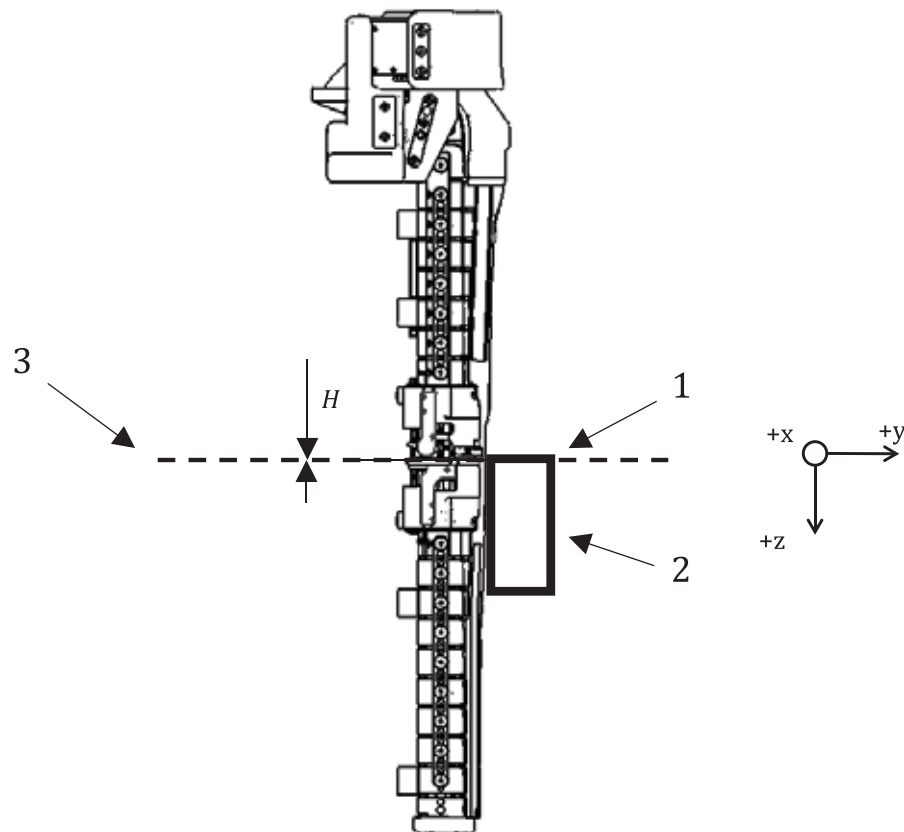
Table 30 — Precondition for full-assembly certification tests

Variable	Specification
Temperature [°C]	20,0 $\pm$ 2,0
Relative humidity [%]	40,0 $\pm$ 30,0

6.3.1.5 Setup procedure

- Remove aPLI lower limb skin and flesh and suspend the aPLI in position for the test.
- aPLI lower limb and upper mass shall hang within 0,5° of vertical, measured at both the rear of the knee and on the rear surface of the upper mass.
- Move the impact carriage up to the aPLI contact surface and adjust the height of the impact carriage to obtain the correct impact height as described below.
 - To conduct certification test with impact below the knee: the upper edge of the honeycomb block shall be coincident with the upper flat surface of the knee meniscus plate within ± 2 mm as shown in [Figure 26](#).

- To conduct certification test with impact at the knee: the upper edge of the honeycomb block shall be $120 \text{ mm} \pm 2 \text{ mm}$ above the upper flat surface of the knee meniscus plate as shown in [Figure 27](#).
- Remove aPLI from the suspended position and refit the flesh and skin.
- Reinstall aPLI into the suspended position adjusting the suspended angle as described above.

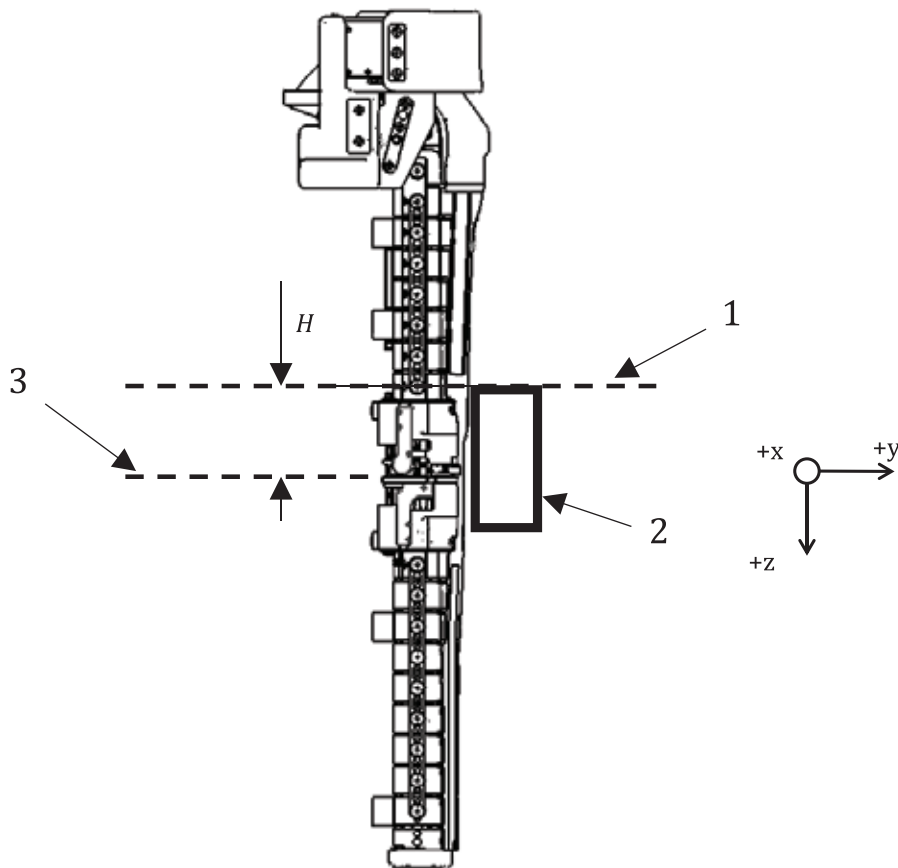


Key

- 1 upper edge of honeycomb
- 2 honeycomb attached at impact carriage
- 3 knee joint
- H impact height: $(0 \pm 2) \text{ mm}$

NOTE An empty circle at the origin of the coordinate vector means a vector going into the page away from the viewer.

Figure 26 — Schematic image of impact location of honeycomb in a full-assembly certification test with impact below the knee



Key

- 1 upper edge of honeycomb
- 2 honeycomb attached at impact carriage
- 3 knee joint
- H impact height: (120 ± 2) mm

NOTE An empty circle at the origin of the coordinate vector means a vector going into the page away from the viewer.

Figure 27 — Schematic image of impact location of honeycomb in a full-assembly certification test with impact at the knee

6.3.1.6 Procedure

- Impact aPLI with the impact carriage at $11,1 \pm 0,2$ m/s.
- All data channels shall be filtered at CFC180 and zero offset correction shall be applied as defined in [ISO 6487](#) or SAE J211-1, whichever reference is the most up to date.

6.3.1.7 Certification specifications

The maximum values recorded during the period up to 40 ms after impact shall be within the limits listed in [Table 31](#) and [Table 32](#) for the full-assembly certification test with impact below the knee and the full-assembly certification test with impact at the knee, respectively.

Only positive values during the assessment period shall be considered. See [Annex J](#) for information on sign convention for aPLI and the positive sense check procedure.