Refinement of Corridors for FlexPLI Dynamic Assembly Certification Tests

4th Meeting of the
Task Force Review and Update Certification Corridors (TF-RUCC)
of the
Informal Group GTR9 Phase 2
June 18th, 2012

Oliver Zander
Bundesanstalt für Straßenwesen

Bundesanstalt für Straßenwesen
(Federal Highway Research Institute)

Content

Background

Inverse test results & analysis

Revision of inverse certification corridors

Pendulum test results & analysis

Revision of pendulum certification corridors

Summary

Background

- The schedule of TF-RUCC foresees inverse and pendulum testing of three completely overhauled FlexPLI impactors in three different test houses
- As impactors, SN01, SN03 and a so called Engineering Leg (E-Leg) were used
- Test laboratories to perform the tests are JARI, BASt and Bertrandt
- The test results are to be validated against the current draft inverse and pendulum certification corridors
- If necessary, the draft corridors are to be updated by re-calculation or shifting
- As a method to updating the corridors (if necessary), BASt suggests to use the established method as agreed by TEG
- An equal weighting (i.e. the same number of test results) of the impactors used is not considered being necessary, because the corridors are based on the achieved minimum and maximum values
- This presentation gives an update of the latest test results, including a proposal for revised assembly certification corridors

Background

Procedure for determination of certification corridors (as established within TEG):

1) Definition of reproducibility corridors

CV calculation of all segments of each impactor
Determination of segments for reproducibility corridor
Requirement: CV < 5%
Calculation of pooled means of all seven segments with CV < 5%
Calculation of reproducibility corridors (pooled mean +/- 10%)

2) Definition of certification corridors

Determination of reproducible test results
Results supposed to be within reproducibility corridor
Determination of maxima and minima for each segment
Determination of corridor limits
Consideration of scatter: maxima + 5% / minima -5%

Revision of Inverse Certification Test

Inverse test results & analysis

- **Three completely overhauled Flex-GTR impactors have been inverse tested at JARI, BASt and Bertrandt (SN01, SN03 and E-Leg)**
- **Test results overview:**

pass **fail**

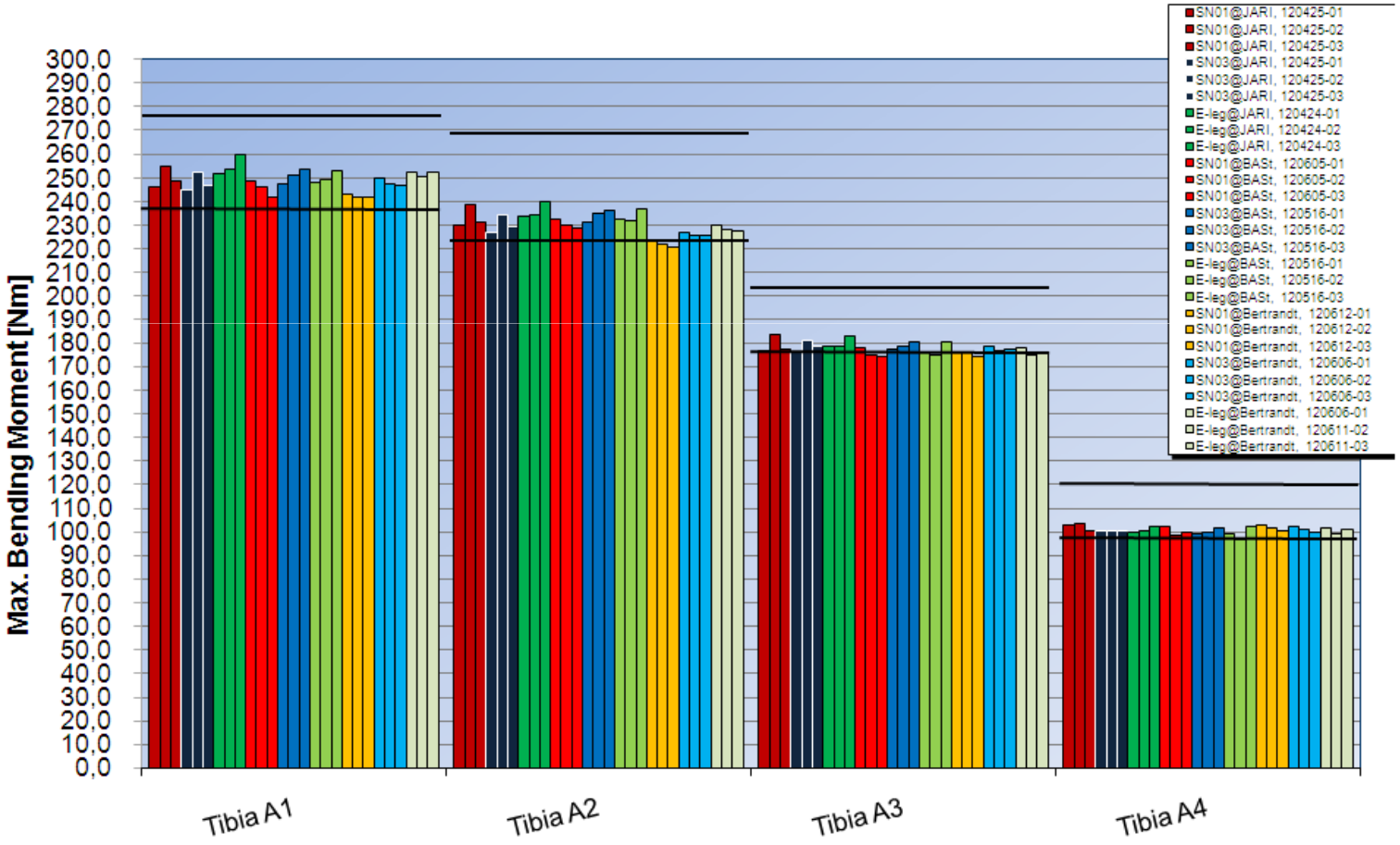
Test #	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
SN01@JARI, 120425-01	245,8	229,9	176,7	103,0	8,6	4,9	19,5
SN01@JARI, 120425-02	254,8	238,7	183,7	103,3	8,5	4,9	19,6
SN01@JARI, 120425-03	248,6	231,1	177,3	100,1	8,6	4,7	19,1
SN03@JARI, 120425-01	245,0	226,8	176,0	100,7	9,0	4,8	19,2
SN03@JARI, 120425-02	252,0	234,6	181,0	100,7	9,0	4,6	18,8
SN03@JARI, 120425-03	247,0	229,5	178,6	100,3	9,3	4,4	18,6
E-leg@JARI, 120424-01	251,9	233,4	178,2	100,1	8,6	5,4	19,8
E-leg@JARI, 120424-02	253,5	234,4	178,4	100,2	8,8	5,3	19,4
E-leg@JARI, 120424-03	260,0	240,1	183,0	102,3	8,8	5,4	19,8
SN01@BASt, 120605-01	248,7	232,2	178,0	102,5	9,6	5,9	20,2
SN01@BASt, 120605-02	246,2	230,1	175,1	98,6	9,3	4,7	20,0
SN01@BASt, 120605-03	242,0	228,9	174,4	99,7	9,2	5,3	20,1
SN03@BASt, 120516-01	247,3	231,5	177,4	99,0	8,4	5,3	18,5
SN03@BASt, 120516-02	250,8	234,9	178,8	100,0	8,9	4,8	18,2
SN03@BASt, 120516-03	253,6	236,0	180,4	101,4	9,4	4,4	18,2
E-leg@BASt, 120516-01	247,9	232,3	176,2	98,9	8,5	5,8	19,5
E-leg@BASt, 120516-02	249,4	232,0	175,0	97,0	8,6	5,7	19,2
E-leg@BASt, 120516-03	252,8	236,8	180,4	102,4	9,1	5,2	19,2
SN01@Bertrandt, 120612-01	243,2	223,5	176,1	102,8	9,4	4,6	19,0
SN01@Bertrandt, 120612-02	241,7	221,8	175,8	101,4	8,9	4,9	18,9
SN01@Bertrandt, 120612-03	241,9	220,5	173,9	100,4	9,0	5,0	18,9
SN03@Bertrandt, 120606-01	249,5	227,0	178,5	102,1	9,4	4,5	18,6
SN03@Bertrandt, 120606-02	247,1	225,8	176,9	101,1	8,8	4,8	18,4
SN03@Bertrandt, 120606-03	246,9	225,9	177,1	100,1	9,0	4,7	18,6
E-leg@Bertrandt, 120606-01	252,3	229,7	178,0	101,8	8,8	5,1	18,8
E-leg@Bertrandt, 120611-02	250,4	227,9	174,8	99,5	9,9	5,3	18,8
E-leg@Bertrandt, 120611-03	252,0	227,4	175,7	100,9	1,8	5,2	18,6

potentiometer failure

- **Only 15 (out of 189) segments did not pass the current draft inverse corridors !**

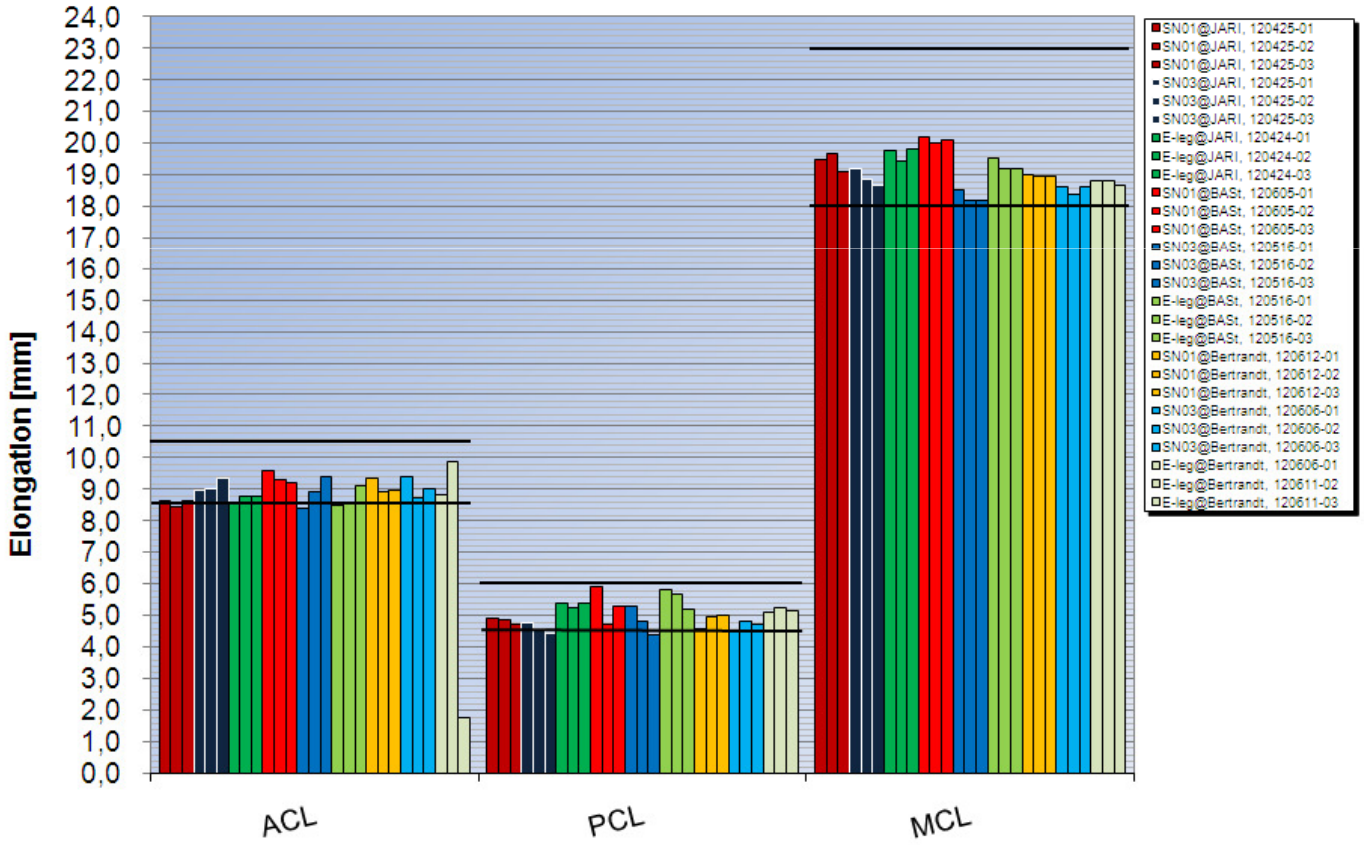
Inverse test results & analysis

- Tibia 1 corridor met without any problem during all tests
- Tibia 2 corridor not met during two tests
- Borderline results for tibia 3 and 4 (at the lower end or just out of the corridors)



Inverse test results & analysis

- MCL corridors met without any problem during all tests
- Partly borderline results for ACL & PCL (at the lower end or out of the corridors)
- ACL corridor three times, PCL corridor two times not met
- E-Leg with significantly higher PCL results in two labs
- SN03 with lowest MCL results in all labs



Revision of inverse corridors

Coefficients of variation:
(27 inverse test results, thereof nine setups with SN01, SN03 and E-Leg)

Segment	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
Setup 1 - SN01 - JARI	1,84	2,04	2,18	1,70	1,08	2,17	1,50
Setup 2 - SN03 - JARI	1,46	1,71	1,38	0,21	2,20	3,47	1,42
Setup 3 - E-leg - JARI	1,68	1,54	1,49	1,21	1,12	1,34	1,13
Setup 4 - SN01 - BASt	1,38	0,72	1,09	2,01	2,22	11,32	0,50
Setup 5 - SN03 - BASt	1,26	1,00	0,84	1,20	5,62	9,33	0,95
Setup 6 - E-leg - BASt	1,00	1,15	1,60	2,75	3,68	5,77	0,90
Setup 7 - SN01 - Bertrandt	0,34	0,68	0,69	1,16	2,68	4,57	0,17
Setup 8 - SN03 - Bertrandt	0,58	0,31	0,49	0,99	3,54	3,55	0,84
Setup 9 - E-leg - Bertrandt	0,41	0,52	0,95	1,14	64,57	1,50	0,43

Most segments with good repeatability (CV < 5%)

Due to repeatability reasons, five segments (out of 63) could not be used for the definition of the reproducibility corridor

Revision of inverse corridors

Definition of reproducibility corridor:

(Setups and segments with repeatable test results [CV < 5%]):

Segment	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
Setups for Reproducibility Corridor [CV < 5%]	1-9	1-9	1-9	1-9	1234678	123789	1-9
Pooled Mean with CV < 5%	248,98	230,47	177,61	100,74	8,95	4,91	19,09
Upper Limit	273,88	253,52	195,37	110,81	9,84	5,41	21,00
Lower Limit	224,08	207,42	159,85	90,67	8,05	4,42	17,18

Determination of reproducible test results:

Test #	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
SN01@JARI, 120425-01	245,82	229,89	176,67	102,97	8,62	4,92	19,46
SN01@JARI, 120425-02	254,78	238,67	183,73	103,27	8,47	4,85	19,64
SN01@JARI, 120425-03	248,60	231,13	177,33	100,13	8,63	4,71	19,07
SN03@JARI, 120425-01	245,04	226,85	176,04	100,67	8,96	4,77	19,17
SN03@JARI, 120425-02	252,03	234,59	180,96	100,65	9,02	4,59	18,83
SN03@JARI, 120425-03	246,98	229,52	178,59	100,29	9,33	4,45	18,65
E-leg@JARI, 120424-01	251,90	233,39	178,23	100,06	8,61	5,39	19,77
E-leg@JARI, 120424-02	253,50	234,41	178,39	100,21	8,76	5,27	19,40
E-leg@JARI, 120424-03	259,98	240,13	182,95	102,25	8,79	5,40	19,79
SN01@BASt, 120605-01	248,70	232,20	178,00	102,50	9,60	5,90	20,20
SN01@BASt, 120605-02	246,20	230,10	175,10	98,60	9,30	4,70	20,00
SN01@BASt, 120605-03	242,00	228,90	174,40	99,70	9,20	5,30	20,10
SN03@BASt, 120516-01	247,30	231,50	177,40	99,00	8,40	5,30	18,50
SN03@BASt, 120516-02	250,80	234,90	178,80	100,00	8,90	4,80	18,20
SN03@BASt, 120516-03	253,60	236,00	180,40	101,40	9,40	4,40	18,20
E-leg@BASt, 120516-01	247,90	232,30	176,20	98,90	8,50	5,80	19,50
E-leg@BASt, 120516-02	249,40	232,00	175,00	97,00	8,60	5,70	19,20
E-leg@BASt, 120516-03	252,80	236,80	180,40	102,40	9,10	5,20	19,20
SN01@Bertrandt, 120612-01	243,23	223,50	176,14	102,75	9,35	4,59	18,99
SN01@Bertrandt, 120612-02	241,68	221,78	175,83	101,42	8,91	4,94	18,94
SN01@Bertrandt, 120612-03	241,93	220,47	173,90	100,40	8,95	5,00	18,93
SN03@Bertrandt, 120606-01	249,53	227,03	178,50	102,08	9,39	4,51	18,63
SN03@Bertrandt, 120606-02	247,14	225,78	176,94	101,05	8,75	4,84	18,35
SN03@Bertrandt, 120606-03	246,94	225,87	177,07	100,07	9,04	4,71	18,61
E-leg@Bertrandt, 120606-01	252,33	229,69	178,03	101,75	8,84	5,11	18,78
E-leg@Bertrandt, 120611-02	250,40	227,87	174,78	99,48	9,86	5,26	18,78
E-leg@Bertrandt, 120611-03	252,03	227,43	175,73	100,94	1,77	5,15	18,64

Revision of inverse corridors

Definition of certification corridor:
(using reproducible test results only):

Test #	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
SN01@JARI, 120425-01	245,82	229,89	176,67	102,97	8,62	4,92	19,46
SN01@JARI, 120425-02	254,78	238,67	183,73	103,27	8,47	4,85	19,64
SN01@JARI, 120425-03	248,60	231,13	177,33	100,13	8,63	4,71	19,07
SN03@JARI, 120425-01	245,04	226,85	176,04	100,67	8,96	4,77	19,17
SN03@JARI, 120425-02	252,03	234,59	180,96	100,65	9,02	4,59	18,83
SN03@JARI, 120425-03	246,98	229,52	178,59	100,29	9,33	4,45	18,65
E-leg@JARI, 120424-01	251,90	233,39	178,23	100,06	8,61	5,39	19,77
E-leg@JARI, 120424-02	253,50	234,41	178,39	100,21	8,76	5,27	19,40
E-leg@JARI, 120424-03	259,98	240,13	182,95	102,25	8,79	5,40	19,79
SN01@BASt, 120605-01	248,70	232,20	178,00	102,50	9,60		20,20
SN01@BASt, 120605-02	246,20	230,10	175,10	98,60	9,30	4,70	20,00
SN01@BASt, 120605-03	242,00	228,90	174,40	99,70	9,20	5,30	20,10
SN03@BASt, 120516-01	247,30	231,50	177,40	99,00	8,40	5,30	18,50
SN03@BASt, 120516-02	250,80	234,90	178,80	100,00	8,90	4,80	18,20
SN03@BASt, 120516-03	253,60	236,00	180,40	101,40	9,40		18,20
E-leg@BASt, 120516-01	247,90	232,30	176,20	98,90	8,50		19,50
E-leg@BASt, 120516-02	249,40	232,00	175,00	97,00	8,60		19,20
E-leg@BASt, 120516-03	252,80	236,80	180,40	102,40	9,10	5,20	19,20
SN01@Bertrandt, 120612-01	243,23	223,50	176,14	102,75	9,35	4,59	18,99
SN01@Bertrandt, 120612-02	241,68	221,78	175,83	101,42	8,91	4,94	18,94
SN01@Bertrandt, 120612-03	241,93	220,47	173,90	100,40	8,95	5,00	18,93
SN03@Bertrandt, 120606-01	249,53	227,03	178,50	102,08	9,39	4,51	18,63
SN03@Bertrandt, 120606-02	247,14	225,78	176,94	101,05	8,75	4,84	18,35
SN03@Bertrandt, 120606-03	246,94	225,87	177,07	100,07	9,04	4,71	18,61
E-leg@Bertrandt, 120606-01	252,33	229,69	178,03	101,75	8,84	5,11	18,78
E-leg@Bertrandt, 120611-02	250,40	227,87	174,78	99,48		5,26	18,78
E-leg@Bertrandt, 120611-03	252,03	227,43	175,73	100,94		5,15	18,64
Maximum	259,98	240,13	183,73	103,27	9,60	5,40	20,20
Minimum	241,68	220,47	173,90	97,00	8,40	4,45	18,20
Max * 1,05 (Consideration of scatter)	272,98	252,14	192,92	108,44	10,08	5,67	21,21
Min * 0,95 (Consideration of scatter)	229,60	209,45	165,21	92,15	7,98	4,23	17,29
Certification Corridor Upper Limit	272	252	192	108	10	6	21
Certification Corridor Lower Limit	230	210	166	93	8	4	17

Calculated tibia values have been rounded in a way such that the corridors are kept tight.

For feasibility reasons, the ligament corridors have been widened slightly.

Revision of inverse corridors

Verification of certification corridors (Application to 27 Flex-GTR tests):

Test #	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
SN01@JARI, 120425-01	245,8	229,9	176,7	103,0	8,6	4,9	19,5
SN01@JARI, 120425-02	254,8	238,7	183,7	103,3	8,5	4,9	19,6
SN01@JARI, 120425-03	248,6	231,1	177,3	100,1	8,6	4,7	19,1
SN03@JARI, 120425-01	245,0	226,8	176,0	100,7	9,0	4,8	19,2
SN03@JARI, 120425-02	252,0	234,6	181,0	100,7	9,0	4,6	18,8
SN03@JARI, 120425-03	247,0	229,5	178,6	100,3	9,3	4,4	18,6
E-leg@JARI, 120424-01	251,9	233,4	178,2	100,1	8,6	5,4	19,8
E-leg@JARI, 120424-02	253,5	234,4	178,4	100,2	8,8	5,3	19,4
E-leg@JARI, 120424-03	260,0	240,1	183,0	102,3	8,8	5,4	19,8
SN01@BASt, 120605-01	248,7	232,2	178,0	102,5	9,6	5,9	20,2
SN01@BASt, 120605-02	246,2	230,1	175,1	98,6	9,3	4,7	20,0
SN01@BASt, 120605-03	242,0	228,9	174,4	99,7	9,2	5,3	20,1
SN03@BASt, 120516-01	247,3	231,5	177,4	99,0	8,4	5,3	18,5
SN03@BASt, 120516-02	250,8	234,9	178,8	100,0	8,9	4,8	18,2
SN03@BASt, 120516-03	253,6	236,0	180,4	101,4	9,4	4,4	18,2
E-leg@BASt, 120516-01	247,9	232,3	176,2	98,9	8,5	5,8	19,5
E-leg@BASt, 120516-02	249,4	232,0	175,0	97,0	8,6	5,7	19,2
E-leg@BASt, 120516-03	252,8	236,8	180,4	102,4	9,1	5,2	19,2
SN01@Bertrandt, 120612-01	243,2	223,5	176,1	102,8	9,4	4,6	19,0
SN01@Bertrandt, 120612-02	241,7	221,8	175,8	101,4	8,9	4,9	18,9
SN01@Bertrandt, 120612-03	241,9	220,5	173,9	100,4	9,0	5,0	18,9
SN03@Bertrandt, 120606-01	249,5	227,0	178,5	102,1	9,4	4,5	18,6
SN03@Bertrandt, 120606-02	247,1	225,8	176,9	101,1	8,8	4,8	18,4
SN03@Bertrandt, 120606-03	246,9	225,9	177,1	100,1	9,0	4,7	18,6
E-leg@Bertrandt, 120606-01	252,3	229,7	178,0	101,8	8,8	5,1	18,8
E-leg@Bertrandt, 120611-02	250,4	227,9	174,8	99,5	9,9	5,3	18,6
E-leg@Bertrandt, 120611-03	252,0	227,4	175,7	100,9	11,8	5,2	18,6
Upper Limit	**272**	**252**	**192**	**108**	**10**	**6**	**21**
Lower Limit	**230**	**210**	**166**	**93**	**8**	**4**	**17**

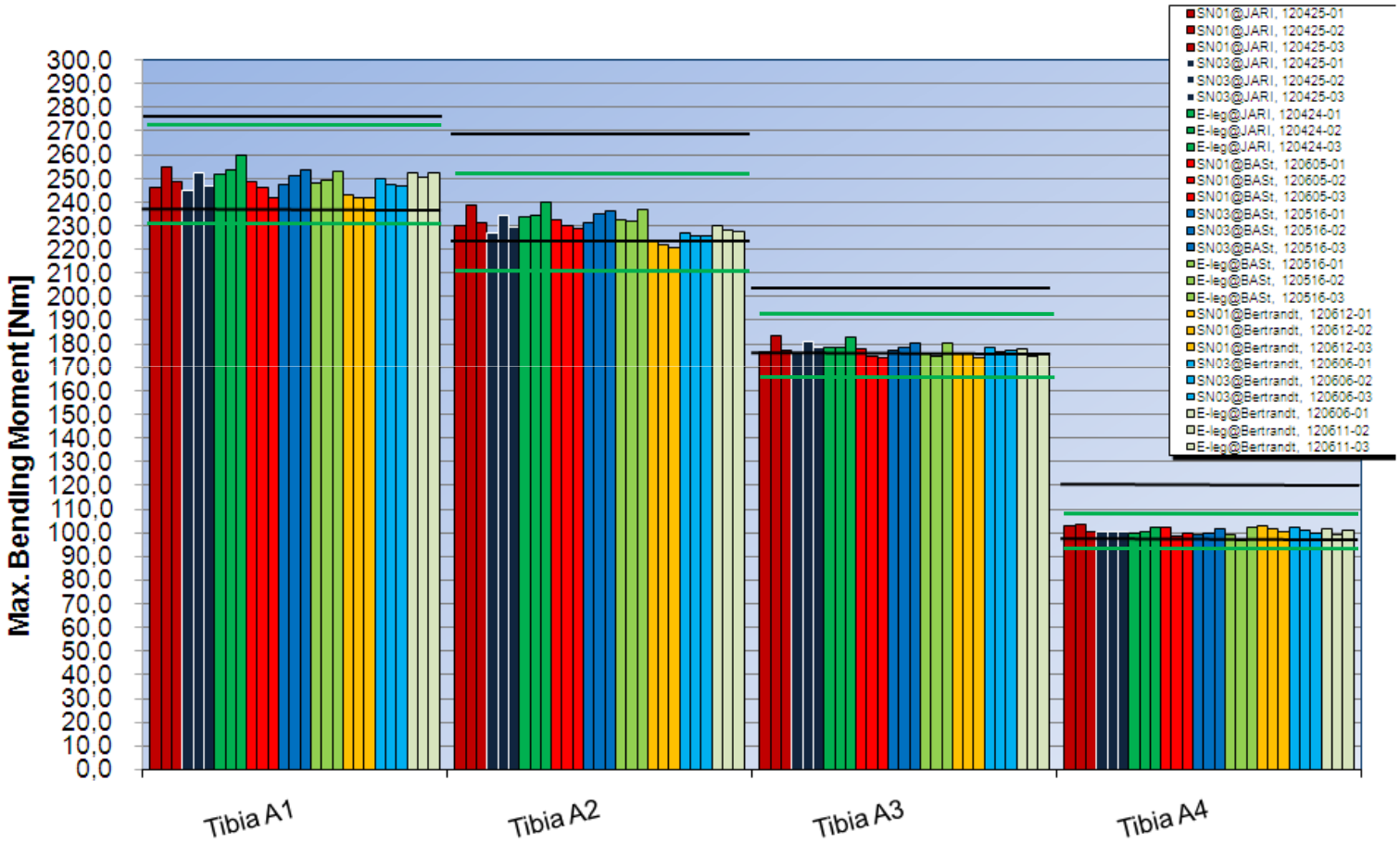
potentiometer failure

- **All regular certification tests passed the complete set of defined draft inverse criteria**

100 % passed
0 % failed

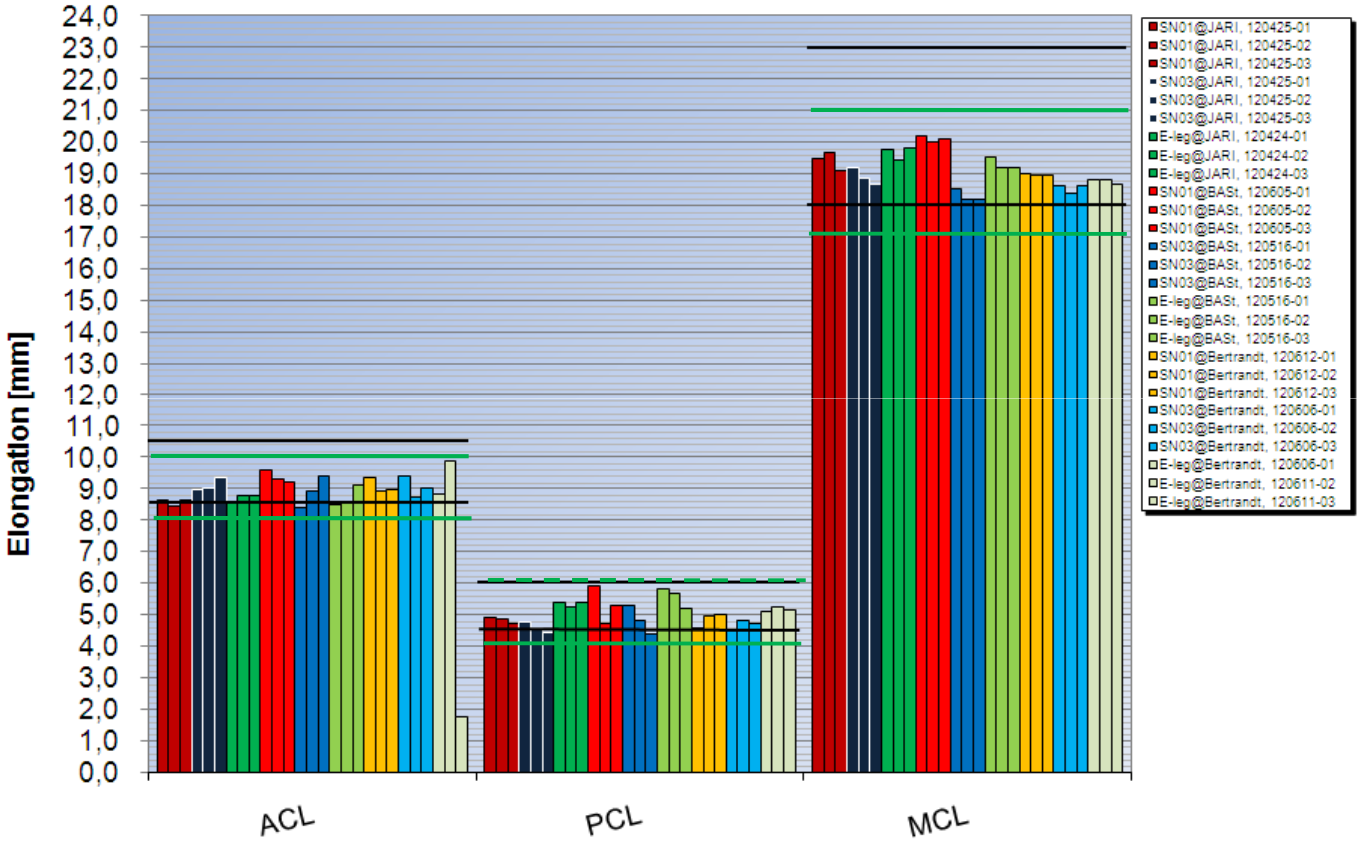
Revision of inverse corridors

Verification of certification corridors (Application to 27 Flex-GTR tests):



Revision of inverse corridors

Verification of certification corridors (Application to 27 Flex-GTR tests):



Comparison of inverse corridors

Old draft inverse certification corridors:

	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
upper	277	269	204	120	10,5	6	23
lower	237	223	176	98	8,5	4,5	18
average	257	246	190	109	9,5	5,25	20,5
range	40	46	28	22	2	1,5	5

Revised draft inverse certification corridors:

	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
upper	272	252	192	108	10	6	21
lower	230	210	166	93	8	4	17
average	251	231	179	100,5	9	5	19
range	42	42	26	15	2	2	4

Average shift old ➔ new:

	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
Average shift [abs]:	-6	-15	-11	-8,5	-0,5	-0,25	-1,5
Average shift [%]:	-2,33	-6,10	-5,79	-7,80	-5,26	-4,76	-7,32

Draft GTR text:

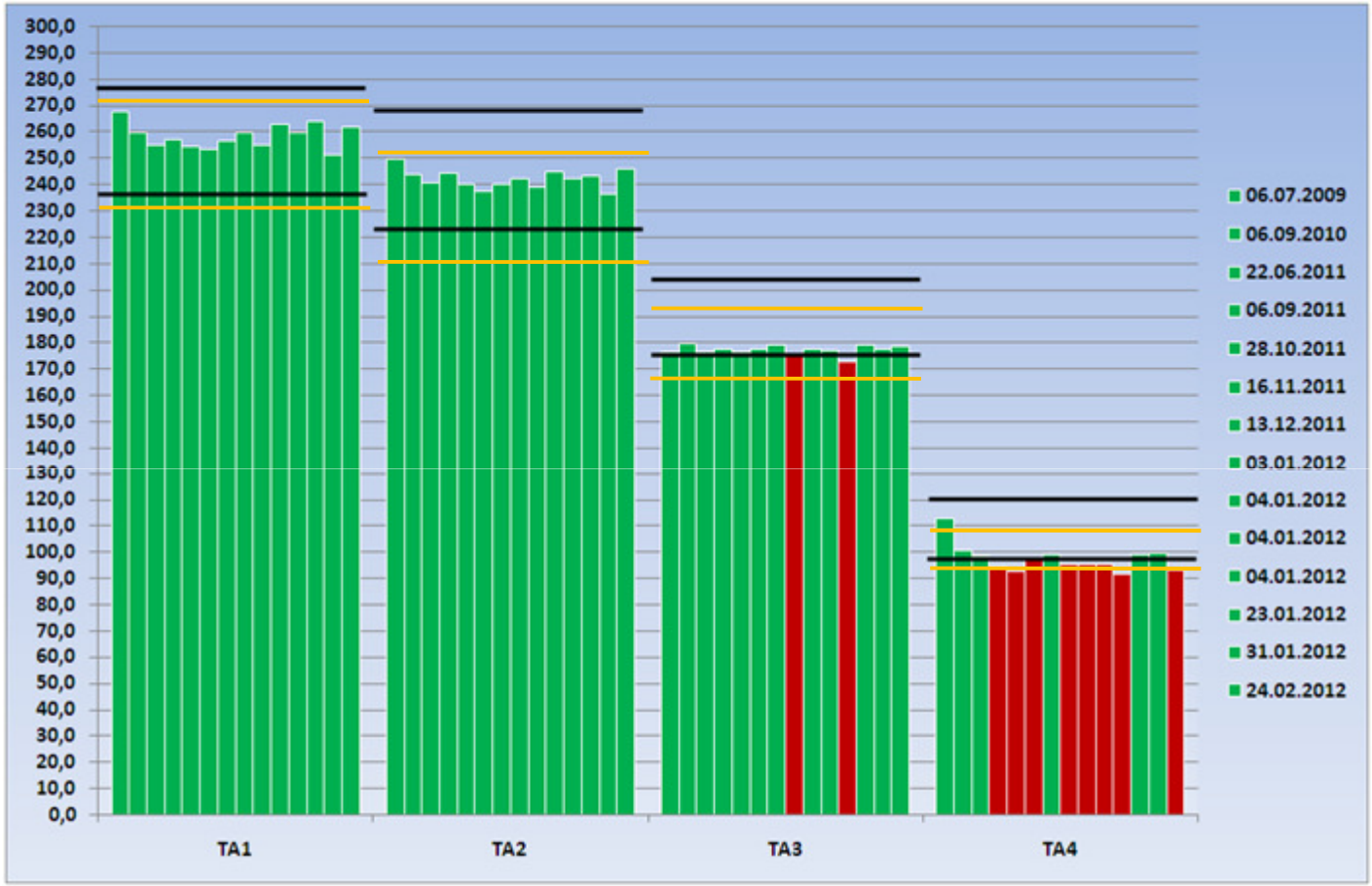
Draft proposal for modification of ECE/TRANS/WP.29/GRSP/2011/13:

8.2.3.3.1. When the Lower legform II is used for the test specified in paragraph 8.2.3.4., the maximum bending moment of the tibia at tibia-1 shall be not more than 272 Nm and not less than 230 Nm, the maximum bending moment at tibia-2 shall be not more than 252 Nm and not less than 210 Nm, the maximum bending moment at tibia-3 shall be not more than 192 Nm and not less than 166 Nm, and the maximum bending moment at tibia-4 shall be not more than 108 Nm and not less than 93 Nm.

The maximum elongation of the MCL shall be not more than 21 mm and not less than 17 mm, that of the ACL shall be not more than 10 mm and not less than 8 mm, and that of the PCL shall be not more than 6 mm and not less than 4 mm […]

Verification of inverse corridors

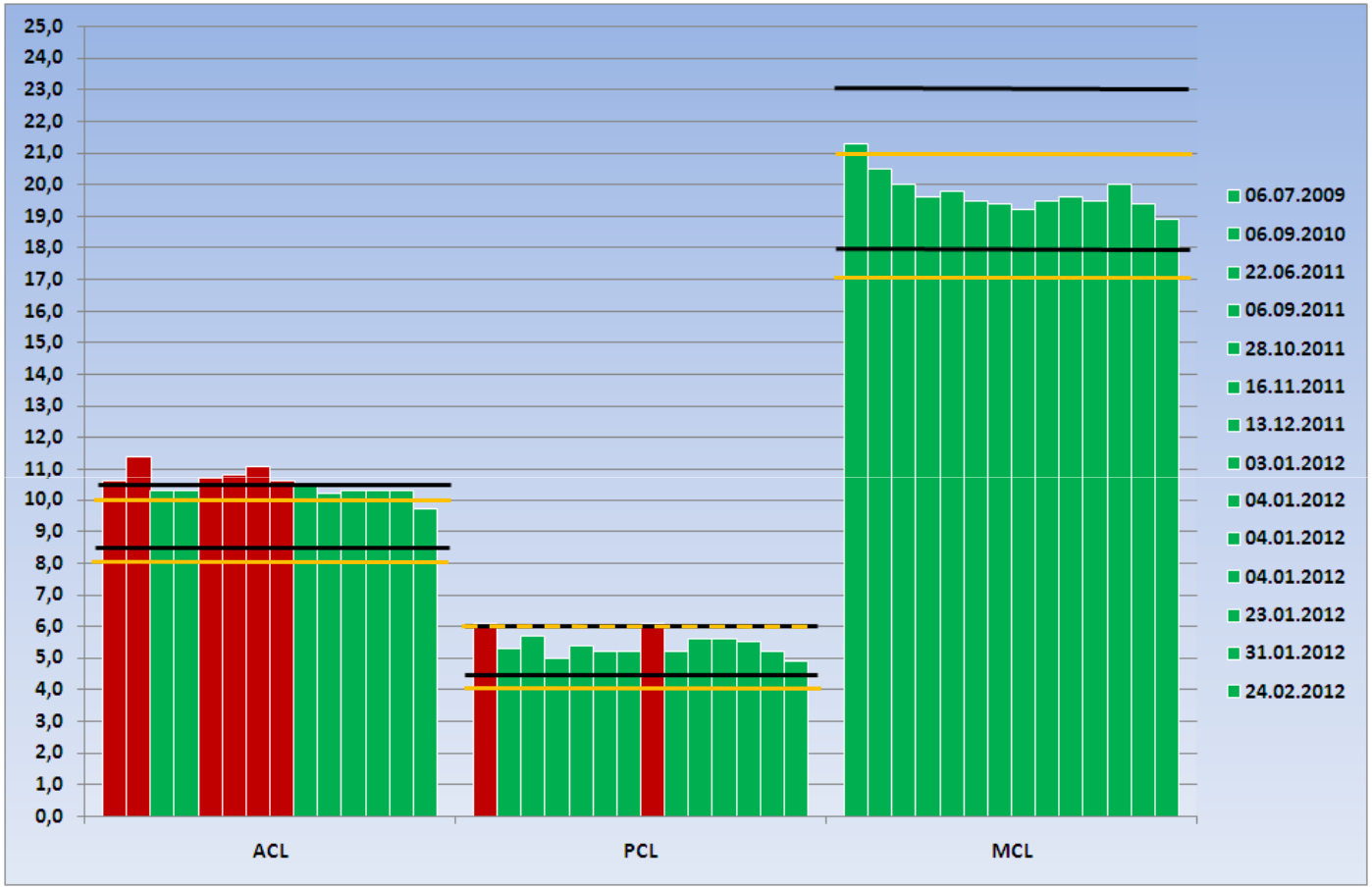
- **Verification of revised inverse corridors against SN04 tests**



Tibia 1-3 pass
Tibia 4 low out in two cases, high out in one case

Verification of inverse corridors

- **Verification of revised inverse corridors against SN04 tests**



ACL one pass only
PCL high out in two cases
MCL high out in one case

Revision of Pendulum Certification Test

Pendulum test results & analysis

- **Three completely overhauled Flex-GTR impactors have been pendulum tested at JARI, BASt and Bertrandt (SN01, SN03 and E-Leg)**
- **Test results overview:**

pass **fail**

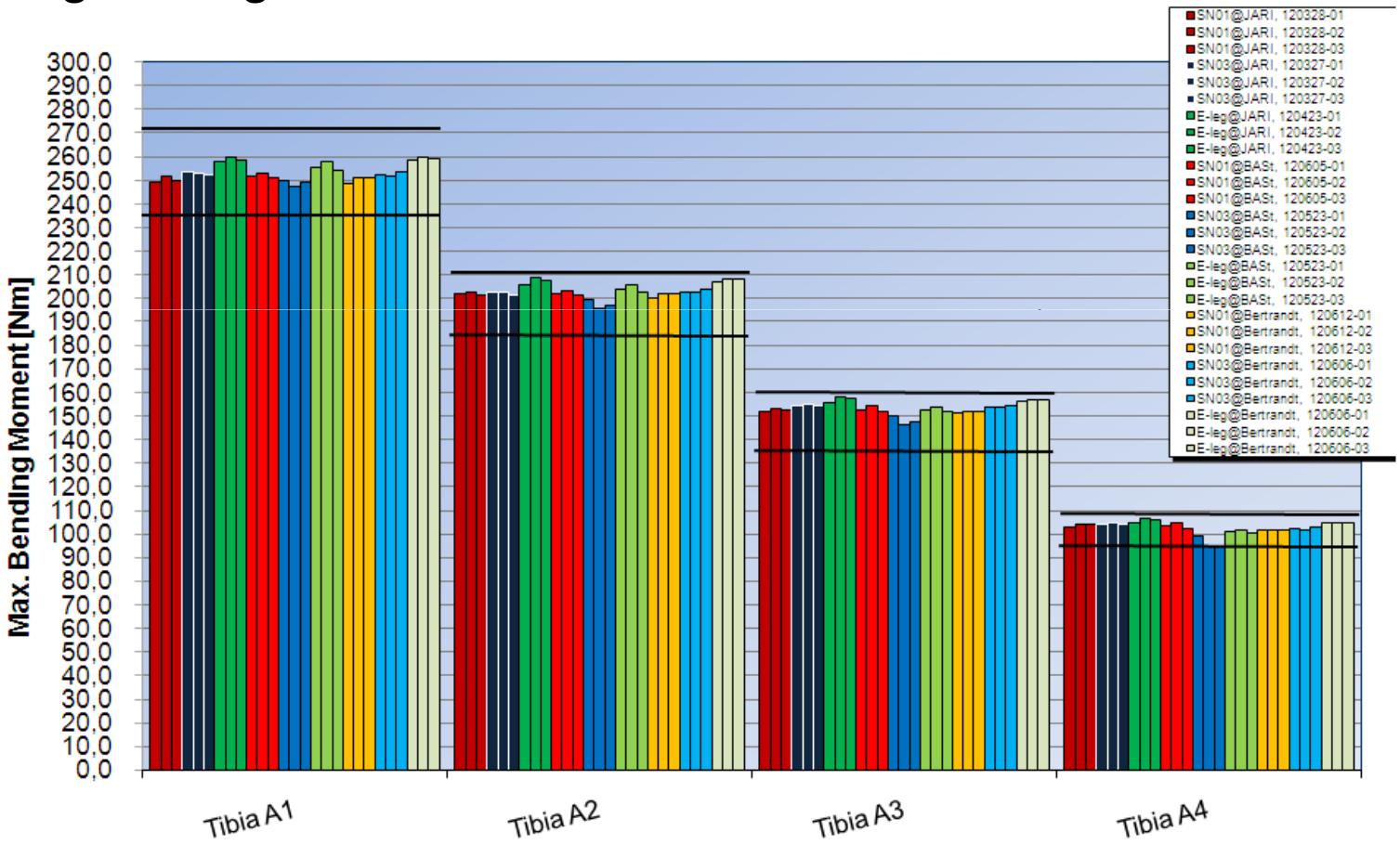
Test #	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
SN01@JARI, 120328-01	249,4	201,8	151,7	102,6	8,9	4,4	22,6
SN01@JARI, 120328-02	251,6	202,9	152,9	103,9	8,9	4,5	22,8
SN01@JARI, 120328-03	249,8	201,2	152,3	103,9	8,8	4,5	22,5
SN03@JARI, 120327-01	253,4	202,6	154,2	104,4	9,0	4,4	22,1
SN03@JARI, 120327-02	252,8	202,9	155,0	104,6	9,0	4,4	22,2
SN03@JARI, 120327-03	252,0	201,5	154,3	104,3	9,0	4,4	22,3
E-leg@JARI, 120423-01	258,0	205,6	155,6	105,0	9,2	4,6	22,4
E-leg@JARI, 120423-02	259,9	208,8	158,3	106,4	9,2	4,8	22,8
E-leg@JARI, 120423-03	258,7	207,6	157,5	106,1	9,4	4,4	22,4
SN01@BASt, 120605-01	251,8	202,1	152,7	103,6	9,6	4,0	23,0
SN01@BASt, 120605-02	252,7	203,2	154,1	104,8	9,4	4,3	23,1
SN01@BASt, 120605-03	251,2	201,6	151,9	102,4	9,4	4,3	23,0
SN03@BASt, 120523-01	250,0	199,4	150,1	99,2	9,7	3,8	22,1
SN03@BASt, 120523-02	247,3	195,8	146,1	94,7	9,7	3,7	22,0
SN03@BASt, 120523-03	249,1	196,8	147,5	95,0	9,7	3,7	22,1
E-leg@BASt, 120523-01	255,1	203,8	152,5	101,1	9,9	4,1	22,3
E-leg@BASt, 120523-02	257,6	206,0	153,8	101,9	9,8	4,2	22,4
E-leg@BASt, 120523-03	254,0	202,9	151,7	100,3	9,6	4,0	21,9
SN01@Bertrandt, 120612-01	248,5	200,0	151,1	101,6	9,2	4,4	22,7
SN01@Bertrandt, 120612-02	251,2	202,1	152,1	101,8	9,4	4,1	22,9
SN01@Bertrandt, 120612-03	251,3	202,2	152,1	101,9	9,6	4,0	22,8
SN03@Bertrandt, 120606-01	252,2	202,6	154,0	102,5	9,2	4,0	21,7
SN03@Bertrandt, 120606-02	251,9	202,5	153,6	102,0	9,5	3,8	21,8
SN03@Bertrandt, 120606-03	253,4	203,9	154,6	102,6	9,5	3,9	22,0
E-leg@Bertrandt, 120606-01	258,3	207,3	156,2	104,7	9,5	4,2	22,1
E-leg@Bertrandt, 120606-02	259,7	208,4	156,9	104,9	9,6	4,2	22,3
E-leg@Bertrandt, 120606-03	259,3	208,1	156,8	104,9	9,7	4,3	22,5

Rounded up values

- **Most MCL and some ACL/PCL segments did not pass the current draft pendulum corridors !**

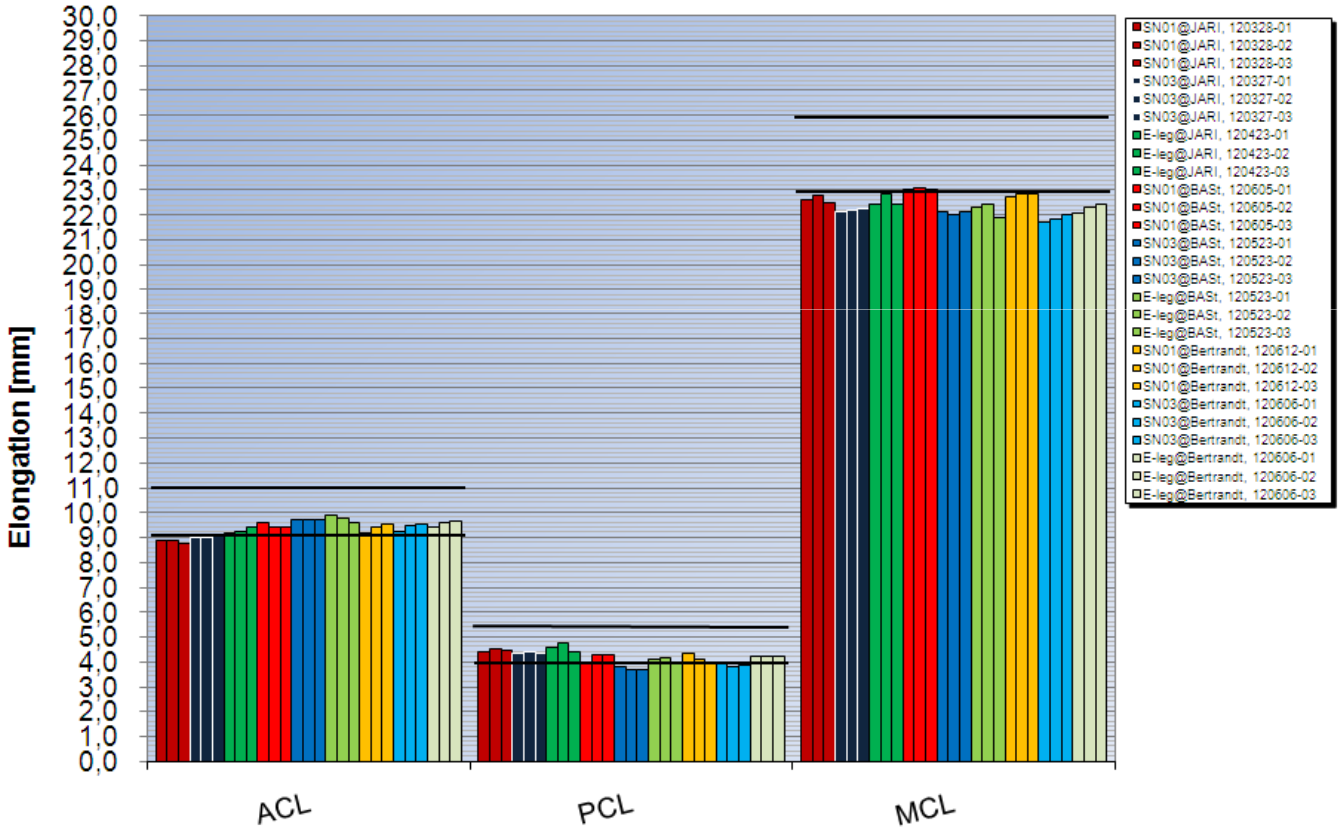
Pendulum test results & analysis

- All tibia corridors met during all tests
- Partly borderline results for tibia 4 (at the upper end of the corridors in lab #1 but at the lower end in lab #2)
- E-leg with highest tibia results in all test houses



Pendulum test results & analysis

- **MCL corridor <u>not met</u> during most of the tests (low out)**
- **Partly borderline results for ACL and PCL (at the lower end of / outside the corridors)**



Revision of pendulum corridors

Coefficients of variation:

(27 pendulum test results, thereof nine setups with SN01, SN03 and E-Leg)

Segment	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
Setup 1 - SN01 - JARI	0,47	0,42	0,40	0,70	0,79	1,19	0,78
Setup 2 - SN03 - JARI	0,28	0,36	0,26	0,14	0,38	0,16	0,25
Setup 3 - E-leg - JARI	0,39	0,78	0,87	0,71	1,28	4,05	1,03
Setup 4 - SN01 - BASt	0,30	0,40	0,73	1,16	1,22	4,12	0,25
Setup 5 - SN03 - BASt	0,55	0,94	1,37	2,61	0,00	1,55	0,26
Setup 6 - E-leg - BASt	0,72	0,78	0,69	0,79	1,56	2,44	1,19
Setup 7 - SN01 - Bertrandt	0,64	0,60	0,35	0,13	1,95	4,16	0,31
Setup 8 - SN03 - Bertrandt	0,32	0,38	0,34	0,35	1,76	1,67	0,73
Setup 9 - E-leg - Bertrandt	0,29	0,28	0,24	0,09	1,07	0,36	0,87

All segments with good repeatability (CV < 5%)

Thus, all 63 segments could be used for the definition of the reproducibility corridors

Revision of pendulum corridors

Definition of reproducibility corridor:

(Setups and segments with repeatable test results [CV < 5%]):

Segment	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
Setups for Reproducibility Corridor [CV < 5%]	1-9	1-9	1-9	1-9	1-9	1-9	1-9
Pooled Mean with CV < 5%	253,34	203,09	153,32	102,63	9,38	4,20	22,40
Upper Limit	278,67	223,40	168,65	112,89	10,32	4,62	24,64
Lower Limit	228,00	182,78	137,99	92,36	8,44	3,78	20,16

Determination of reproducible test results:

Test #	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
SN01@JARI, 120328-01	249,38	201,77	151,68	102,63	8,86	4,40	22,59
SN01@JARI, 120328-02	251,59	202,88	152,91	103,92	8,88	4,51	22,81
SN01@JARI, 120328-03	249,80	201,23	152,31	103,86	8,75	4,45	22,46
SN03@JARI, 120327-01	253,43	202,57	154,24	104,44	8,98	4,38	22,14
SN03@JARI, 120327-02	252,77	202,89	154,97	104,57	8,98	4,39	22,21
SN03@JARI, 120327-03	252,01	201,51	154,29	104,26	9,04	4,38	22,25
E-leg@JARI, 120423-01	257,96	205,61	155,62	104,97	9,19	4,61	22,40
E-leg@JARI, 120423-02	259,94	208,81	158,31	106,39	9,25	4,79	22,82
E-leg@JARI, 120423-03	258,71	207,65	157,46	106,13	9,42	4,41	22,42
SN01@BASt, 120605-01	251,80	202,10	152,70	103,60	9,60	4,00	23,00
SN01@BASt, 120605-02	252,70	203,20	154,10	104,80	9,40	4,30	23,10
SN01@BASt, 120605-03	251,20	201,60	151,90	102,40	9,40	4,30	23,00
SN03@BASt, 120523-01	250,00	199,40	150,10	99,20	9,70	3,80	22,10
SN03@BASt, 120523-02	247,30	195,80	146,10	94,70	9,70	3,70	22,00
SN03@BASt, 120523-03	249,10	196,80	147,50	95,00	9,70	3,70	22,10
E-leg@BASt, 120523-01	255,10	203,80	152,50	101,10	9,90	4,10	22,30
E-leg@BASt, 120523-02	257,60	206,00	153,80	101,90	9,80	4,20	22,40
E-leg@BASt, 120523-03	254,00	202,90	151,70	100,30	9,60	4,00	21,90
SN01@Bertrandt, 120612-01	248,45	200,00	151,14	101,59	9,20	4,36	22,73
SN01@Bertrandt, 120612-02	251,20	202,05	152,09	101,75	9,44	4,13	22,87
SN01@Bertrandt, 120612-03	251,29	202,16	152,05	101,85	9,56	4,02	22,82
SN03@Bertrandt, 120606-01	252,21	202,56	153,98	102,49	9,22	3,96	21,68
SN03@Bertrandt, 120606-02	251,90	202,48	153,56	101,95	9,49	3,83	21,82
SN03@Bertrandt, 120606-03	253,41	203,86	154,59	102,62	9,52	3,89	22,00
E-leg@Bertrandt, 120606-01	258,26	207,25	156,24	104,72	9,45	4,22	22,07
E-leg@Bertrandt, 120606-02	259,71	208,36	156,93	104,86	9,59	4,24	22,32
E-leg@Bertrandt, 120606-03	259,33	208,11	156,84	104,91	9,65	4,25	22,45

Revision of pendulum corridors

Definition of certification corridor:
(using reproducible test results only):

Test #	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
SN01@JARI, 120328-01	249,38	201,77	151,68	102,63	8,86	4,40	22,59
SN01@JARI, 120328-02	251,59	202,88	152,91	103,92	8,88	4,51	22,81
SN01@JARI, 120328-03	249,80	201,23	152,31	103,86	8,75	4,45	22,46
SN03@JARI, 120327-01	253,43	202,57	154,24	104,44	8,98	4,38	22,14
SN03@JARI, 120327-02	252,77	202,89	154,97	104,57	8,98	4,39	22,21
SN03@JARI, 120327-03	252,01	201,51	154,29	104,26	9,04	4,38	22,25
E-leg@JARI, 120423-01	257,96	205,61	155,62	104,97	9,19	4,61	22,40
E-leg@JARI, 120423-02	259,94	208,81	158,31	106,39	9,25		22,82
E-leg@JARI, 120423-03	258,71	207,65	157,46	106,13	9,42	4,41	22,42
SN01@BASt, 120605-01	251,80	202,10	152,70	103,60	9,60	4,00	23,00
SN01@BASt, 120605-02	252,70	203,20	154,10	104,80	9,40	4,30	23,10
SN01@BASt, 120605-03	251,20	201,60	151,90	102,40	9,40	4,30	23,00
SN03@BASt, 120523-01	250,00	199,40	150,10	99,20	9,70	3,80	22,10
SN03@BASt, 120523-02	247,30	195,80	146,10	94,70	9,70		22,00
SN03@BASt, 120523-03	249,10	196,80	147,50	95,00	9,70		22,10
E-leg@BASt, 120523-01	255,10	203,80	152,50	101,10	9,90	4,10	22,30
E-leg@BASt, 120523-02	257,60	206,00	153,80	101,90	9,80	4,20	22,40
E-leg@BASt, 120523-03	254,00	202,90	151,70	100,30	9,60	4,00	21,90
SN01@Bertrandt, 120612-01	248,45	200,00	151,14	101,59	9,20	4,36	22,73
SN01@Bertrandt, 120612-02	251,20	202,05	152,09	101,75	9,44	4,13	22,87
SN01@Bertrandt, 120612-03	251,29	202,16	152,05	101,85	9,56	4,02	22,82
SN03@Bertrandt, 120606-01	252,21	202,56	153,98	102,49	9,22	3,96	21,68
SN03@Bertrandt, 120606-02	251,90	202,48	153,56	101,95	9,49	3,83	21,82
SN03@Bertrandt, 120606-03	253,41	203,86	154,59	102,62	9,52	3,89	22,00
E-leg@Bertrandt, 120606-01	258,26	207,25	156,24	104,72	9,45	4,22	22,07
E-leg@Bertrandt, 120606-02	259,71	208,36	156,93	104,86	9,59	4,24	22,32
E-leg@Bertrandt, 120606-03	259,33	208,11	156,84	104,91	9,65	4,25	22,45
Maximum	259,94	208,81	158,31	106,39	9,90	4,61	23,10
Minimum	247,30	195,80	146,10	94,70	8,75	3,80	21,68
Max * 1,05 (Consideration of scatter)	272,94	219,25	166,22	111,71	10,40	4,84	24,26
Min * 0,95 (Consideration of scatter)	234,94	186,01	138,80	89,97	8,31	3,61	20,60
Certification Corridor Upper Limit	272	219	166	111	10,5	5	24
Certification Corridor Lower Limit	235	187	139	90	8	3,5	20,5

Calculated tibia values have been rounded in a way such that the corridors are kept tight.

For feasibility reasons, the ligament corridors have been widened slightly.

Revision of pendulum corridors

Verification of certification corridors (Application to 27 Flex-GTR tests):

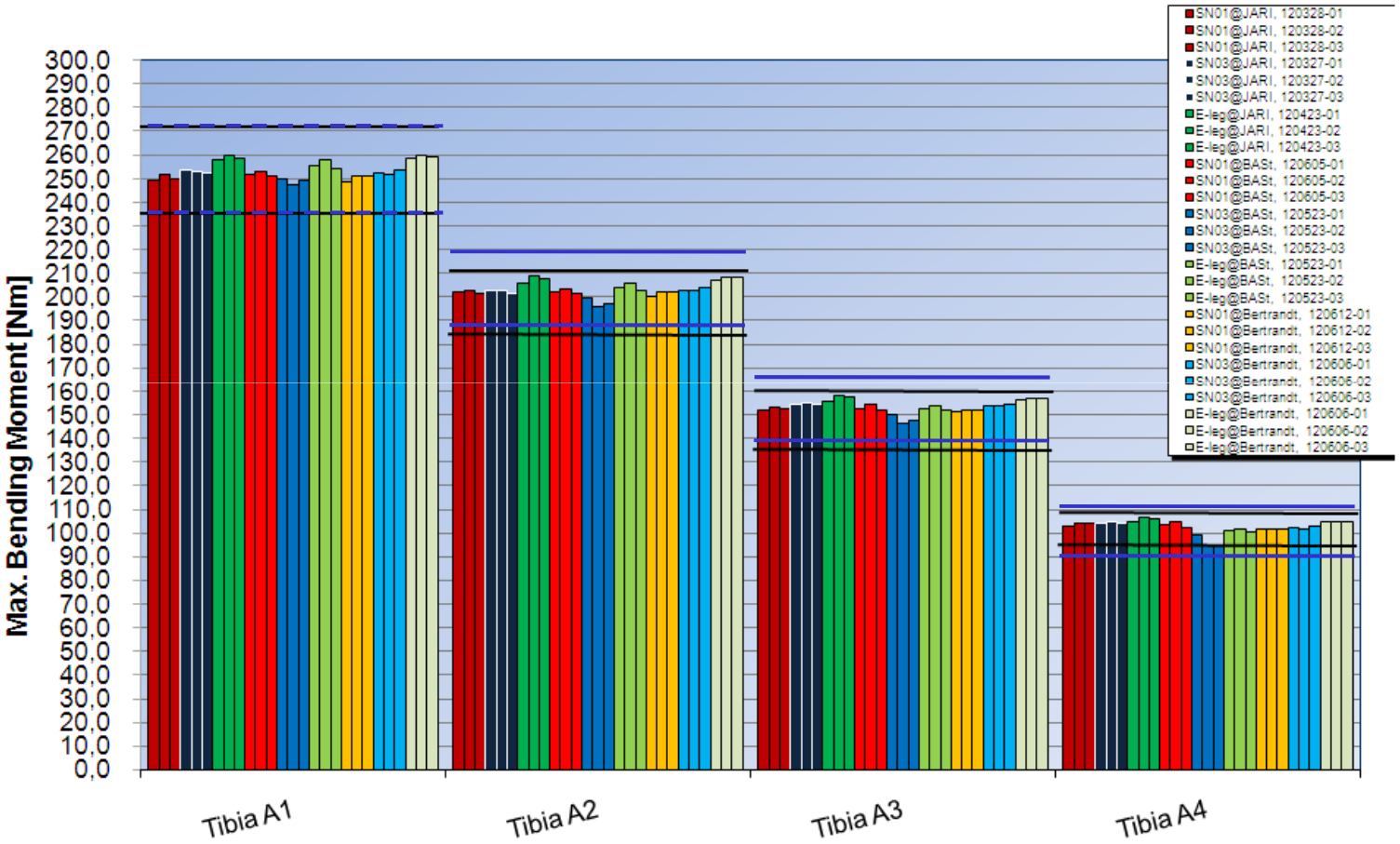
Test #	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
SN01@JARI, 120328-01	249,4	201,8	151,7	102,6	8,9	4,4	22,6
SN01@JARI, 120328-02	251,6	202,9	152,9	103,9	8,9	4,5	22,8
SN01@JARI, 120328-03	249,8	201,2	152,3	103,9	8,8	4,5	22,5
SN03@JARI, 120327-01	253,4	202,6	154,2	104,4	9,0	4,4	22,1
SN03@JARI, 120327-02	252,8	202,9	155,0	104,6	9,0	4,4	22,2
SN03@JARI, 120327-03	252,0	201,5	154,3	104,3	9,0	4,4	22,3
E-leg@JARI, 120423-01	258,0	205,6	155,6	105,0	9,2	4,6	22,4
E-leg@JARI, 120423-02	259,9	208,8	158,3	106,4	9,2	4,8	22,8
E-leg@JARI, 120423-03	258,7	207,6	157,5	106,1	9,4	4,4	22,4
SN01@BASt, 120605-01	251,8	202,1	152,7	103,6	9,6	4,0	23,0
SN01@BASt, 120605-02	252,7	203,2	154,1	104,8	9,4	4,3	23,1
SN01@BASt, 120605-03	251,2	201,6	151,9	102,4	9,4	4,3	23,0
SN03@BASt, 120523-01	250,0	199,4	150,1	99,2	9,7	3,8	22,1
SN03@BASt, 120523-02	247,3	195,8	146,1	94,7	9,7	3,7	22,0
SN03@BASt, 120523-03	249,1	196,8	147,5	95,0	9,7	3,7	22,1
E-leg@BASt, 120523-01	255,1	203,8	152,5	101,1	9,9	4,1	22,3
E-leg@BASt, 120523-02	257,6	206,0	153,8	101,9	9,8	4,2	22,4
E-leg@BASt, 120523-03	254,0	202,9	151,7	100,3	9,6	4,0	21,9
SN01@Bertrandt, 120612-01	248,5	200,0	151,1	101,6	9,2	4,4	22,7
SN01@Bertrandt, 120612-02	251,2	202,1	152,1	101,8	9,4	4,1	22,9
SN01@Bertrandt, 120612-03	251,3	202,2	152,1	101,9	9,6	4,0	22,8
SN03@Bertrandt, 120606-01	252,2	202,6	154,0	102,5	9,2	4,0	21,7
SN03@Bertrandt, 120606-02	251,9	202,5	153,6	102,0	9,5	3,8	21,8
SN03@Bertrandt, 120606-03	253,4	203,9	154,6	102,6	9,5	3,9	22,0
E-leg@Bertrandt, 120606-01	258,3	207,3	156,2	104,7	9,5	4,2	22,1
E-leg@Bertrandt, 120606-02	259,7	208,4	156,9	104,9	9,6	4,2	22,3
E-leg@Bertrandt, 120606-03	259,3	208,1	156,8	104,9	9,7	4,3	22,5
Upper Limit	**272**	**219**	**166**	**111**	**10,5**	**5**	**24**
Lower Limit	**235**	**187**	**139**	**90**	**8**	**3,5**	**20,5**

- **All certification tests passed the complete set of defined draft pendulum criteria**

100 % passed
0 % failed

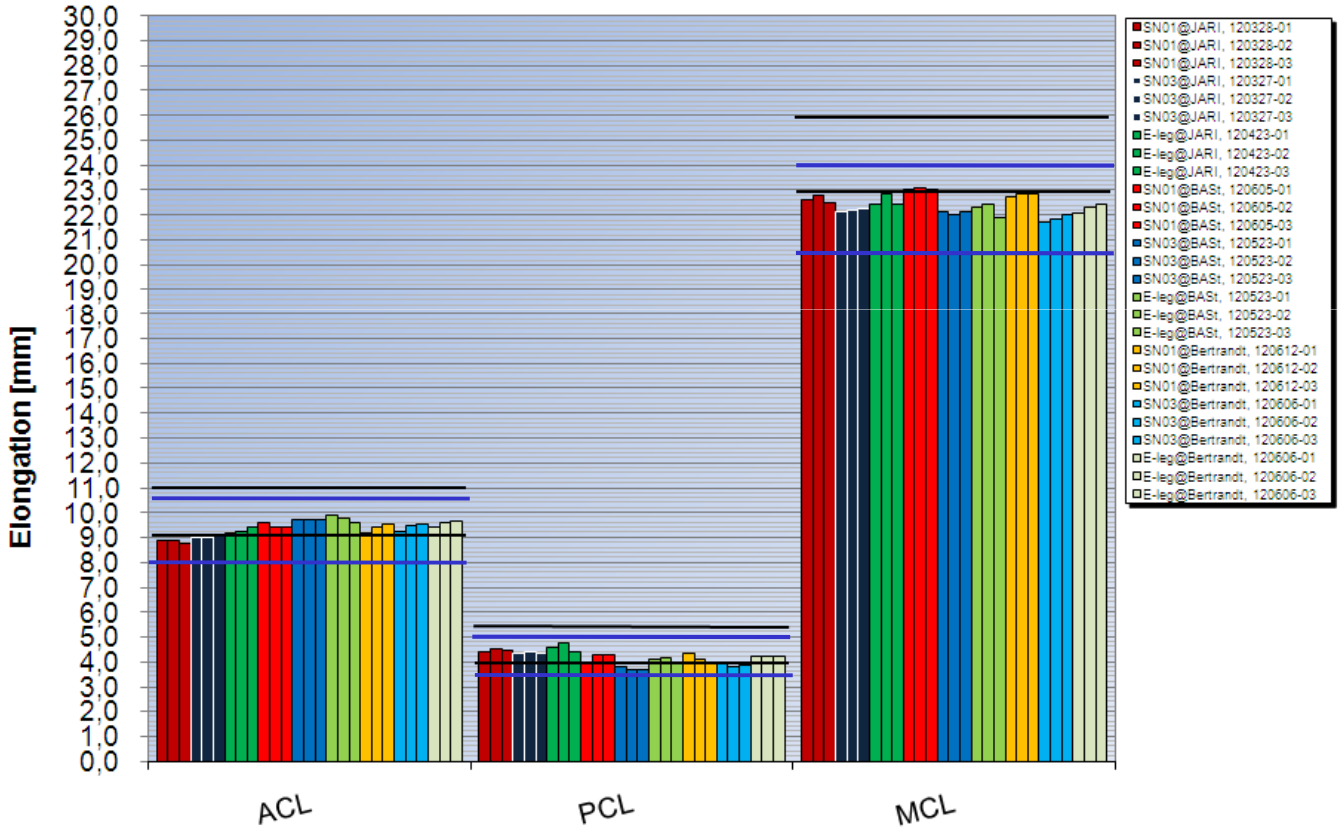
Revision of pendulum corridors

Verification of certification corridors (Application to 27 Flex-GTR tests):



Revision of pendulum corridors

Verification of certification corridors (Application to 27 Flex-GTR tests):



Comparison of pendulum corridors

Old draft pendulum certification corridors:

	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
upper	272	211	160	108	11	5,4	26
lower	235	185	135	94	9	4	23
average	253,5	198	147,5	101	10	4,7	24,5
range	37	26	25	14	2	1,4	3

Revised draft pendulum certification corridors:

	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
upper	272	219	166	111	10,5	5	24
lower	235	187	139	90	8	3,5	20,5
average	253,5	203	152,5	100,5	9,25	4,25	22,25
range	37	32	27	21	2,5	1,5	3,5

Average shift old ➔ new:

	Tibia A1	Tibia A2	Tibia A3	Tibia A4	ACL	PCL	MCL
Average shift [abs]:	0	5	5	-0,5	-0,75	-0,45	-2,25
Average shift [%]:	0,00	2,53	3,39	-0,50	-7,50	-9,57	-9,18

Draft GTR text:

Draft proposal for modification of ECE/TRANS/WP.29/GRSP/2011/13:

8.2.2.3.1 When the Lower legform II is used for a test as specified in paragraph 8.2.2.4., the maximum bending moment of the tibia at tibia-1 shall be not more than 272 Nm and not less than 235 Nm, the maximum bending moment at tibia-2 shall be not more than 219 Nm and not less than 187 Nm, the maximum bending moment at tibia-3 shall be not more than 166 Nm and not less than 139 Nm, and the maximum bending moment at tibia-4 shall be not more than 111 Nm and not less than 90 Nm. The maximum elongation of MCL shall be not more than 24 mm and not less than 20.5 mm, the maximum elongation of ACL shall be not more than 10.5 mm and not less than 8 mm, and the maximum elongation of PCL shall be not more than 5 mm and not less than 3.5 mm […]

Summary

- **The inverse and pendulum certification corridors have been revised, taking into account all available and provided test data (3 impactors * 3 labs * 3 repetitions * 2 test setups)**
- **As a method of updating the corridors, the established method as agreed by TEG was used**
- **Based on the available test data, the revised draft inverse corridors have been further tightened for tibia 2,3,4 and MCL and slightly widened for tibia 1 and PCL. ACL width remained unchanged.**
- **Based on the available test data, the revised draft pendulum corridors had to widened for all segments except tibia 1**
- **Based on the available tests, the inverse mid corridor for all segments was shifted downwards (between 2,3 and 7,8 percent)**
- **Based on the available tests, the pendulum mid corridor for all ligaments was shifted downwards (between 7,5 and 9,5 percent), for two tibia segments upwards (2,5 and 3,4 percent), for two tibia segments almost unchanged**
- **Revision of all previously built impactors though equipped with vinylester bones as well as long rubbers (such as SN04) strongly recommended**

Thank you !