



FlexPLI

Biofidelic Assessment Interval (BAI):

Open Issues

8th Meeting of Informal Group GTR9 Phase 2
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Oliver Zander

Bundesanstalt für Straßenwesen

Bundesanstalt für Straßenwesen

(Federal Highway Research Institute)

Background

Femur Corridors for Inverse Tests

Femur Zero Crossing

Discussion

Wording

Content



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- **At the 7th meeting of the IG GTR9-PH2, several issues were raised regarding the biofidelic assessment interval (BAI) for the FlexPLI proposed by BAST.**
- **As the BAI is determined, amongst other things, by the common zero crossing of the FlexPLI femur readings subsequent to their first local maximum, the establishment of femur corridors to ensure the femur segment working properly during the test were requested.**
- **Finally, several proposals for a modification of the BAI wording were made.**
- **This document is aiming at addressing the above mentioned issues.**

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Femur corridors for inverse test



For the determination of inverse femur corridors, the TEG method as used for the tibia segments and ligament elongations, was applied:

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 $\pm 10\%$)

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

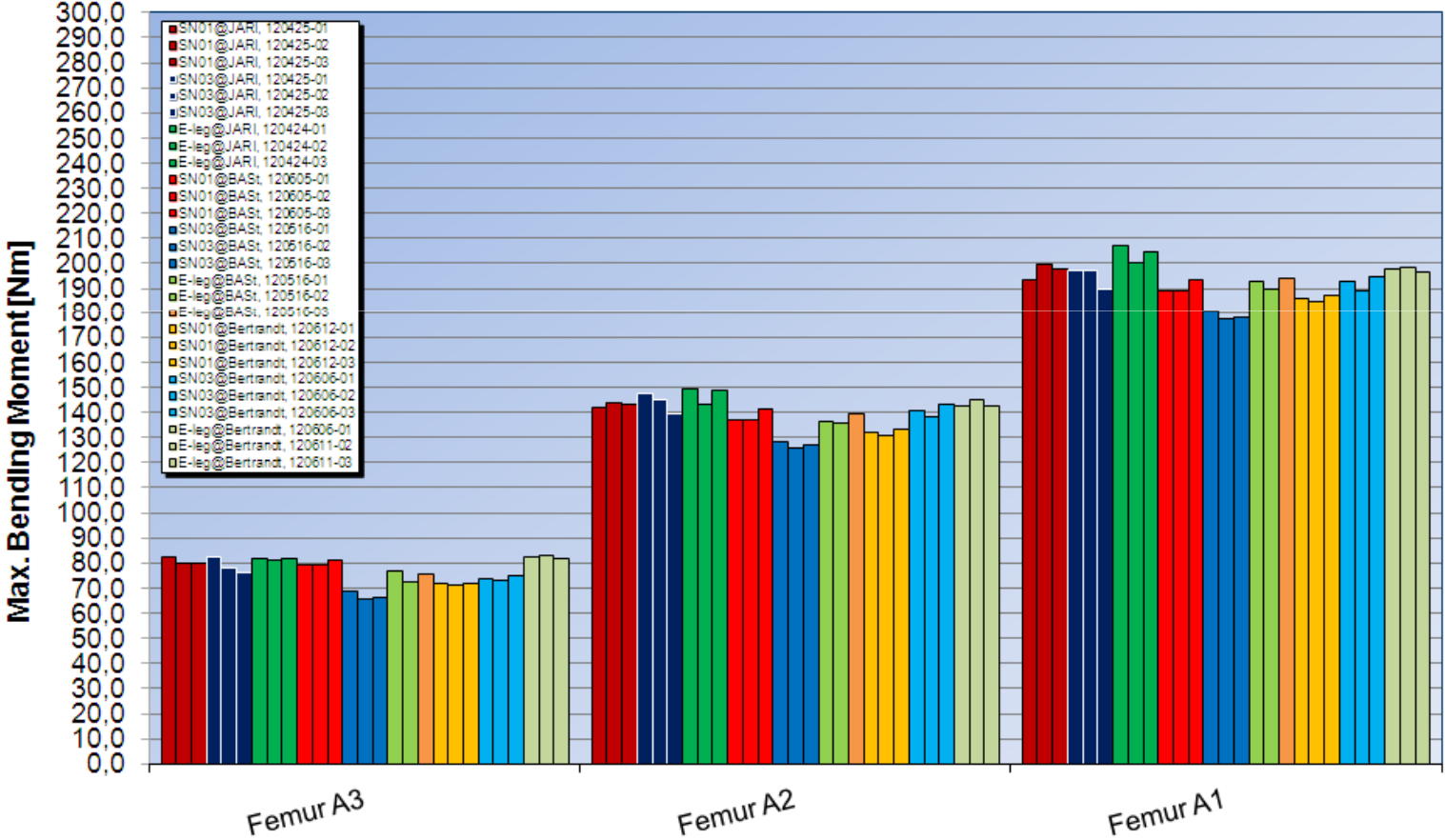
Determination of corridor limits

Consideration of scatter: maxima $+ 5\%$ / minima -5%

Inverse test results & analysis



- Three Flex-GTR impactors (Master Legs) have been inverse tested at JARI, BAST and Bertrandt (SN01, SN03 and E-Leg) between April and May, 2012
- Femur test results overview:



Revision of **inverse** corridors



Coefficients of variation:

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

Segment	Femur A3	Femur A2	Femur A1
Setup 1 - SN01 - JARI	1,78	0,53	1,66
Setup 2 - SN03 - JARI	4,05	2,92	2,20
Setup 3 - E-leg - JARI	0,39	2,32	1,79
Setup 4 - SN01 - BASt	1,25	1,82	1,30
Setup 5 - SN03 - BASt	2,57	1,15	0,95
Setup 6 - E-leg - BASt	2,60	1,61	1,15
Setup 7 - SN01 - Bertrandt	0,48	0,77	0,77
Setup 8 - SN03 - Bertrandt	1,43	1,73	1,49
Setup 9 - E-leg - Bertrandt	0,70	0,91	0,44

All segments with good repeatability (CV < 5%)

Thus, all segments could 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	Femur A3	Femur A2	Femur A1
Setups for Reproducibility Corridor [CV < 5%]	1-9	1-9	1-9
Pooled Mean with CV < 5%	76,70	139,23	192,53
Upper Limit	84,37	153,15	211,79
Lower Limit	69,03	125,30	173,28

Determination of reproducible test results:

Test #	Femur A3	Femur A2	Femur A1
SN01@JARI, 120425-01	82,41	142,25	193,42
SN01@JARI, 120425-02	79,95	143,68	199,87
SN01@JARI, 120425-03	79,89	143,37	197,57
SN03@JARI, 120425-01	82,35	147,71	197,29
SN03@JARI, 120425-02	77,95	145,30	197,33
SN03@JARI, 120425-03	76,15	139,53	189,87
E-leg@JARI, 120424-01	81,60	149,36	207,31
E-leg@JARI, 120424-02	81,09	143,17	200,10
E-leg@JARI, 120424-03	81,67	148,74	204,77
SN01@BAST, 120605-01	79,50	136,80	189,10
SN01@BAST, 120605-02	79,10	137,30	189,10
SN01@BAST, 120605-03	81,00	141,40	193,40
SN03@BAST, 120516-01	68,90	128,60	180,30
SN03@BAST, 120516-02	65,70	125,70	177,10
SN03@BAST, 120516-03	66,20	126,90	177,70
E-leg@BAST, 120516-01	76,50	136,10	193,10
E-leg@BAST, 120516-02	72,70	135,70	190,00
E-leg@BAST, 120516-03	75,30	139,70	194,30
SN01@Bertrandt, 120612-01	71,63	131,85	185,92
SN01@Bertrandt, 120612-02	71,29	131,05	184,65
SN01@Bertrandt, 120612-03	71,98	133,06	187,51
SN03@Bertrandt, 120606-01	73,48	140,50	192,94
SN03@Bertrandt, 120606-02	72,89	138,33	188,95
SN03@Bertrandt, 120606-03	74,94	143,20	194,48
E-leg@Bertrandt, 120606-01	82,35	142,41	197,61
E-leg@Bertrandt, 120611-02	82,76	144,78	198,22
E-leg@Bertrandt, 120611-03	81,62	142,65	196,51

Revision of **inverse** corridors



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

Test #	Femur A3	Femur A2	Femur A1
SN01@JARI, 120425-01	82,41	142,25	193,42
SN01@JARI, 120425-02	79,95	143,68	199,87
SN01@JARI, 120425-03	79,89	143,37	197,57
SN03@JARI, 120425-01	82,35	147,71	197,29
SN03@JARI, 120425-02	77,95	145,30	197,33
SN03@JARI, 120425-03	76,15	139,53	189,87
E-leg@JARI, 120424-01	81,60	149,36	207,31
E-leg@JARI, 120424-02	81,09	143,17	200,10
E-leg@JARI, 120424-03	81,67	148,74	204,77
SN01@BAsT, 120605-01	79,50	136,80	189,10
SN01@BAsT, 120605-02	79,10	137,30	189,10
SN01@BAsT, 120605-03	81,00	141,40	193,40
SN03@BAsT, 120516-01		128,60	180,30
SN03@BAsT, 120516-02		125,70	177,10
SN03@BAsT, 120516-03		126,90	177,70
E-leg@BAsT, 120516-01	76,50	136,10	193,10
E-leg@BAsT, 120516-02	72,70	135,70	190,00
E-leg@BAsT, 120516-03	75,30	139,70	194,30
SN01@Bertrandt, 120612-01	71,63	131,85	185,92
SN01@Bertrandt, 120612-02	71,29	131,05	184,65
SN01@Bertrandt, 120612-03	71,98	133,06	187,51
SN03@Bertrandt, 120606-01	73,48	140,50	192,94
SN03@Bertrandt, 120606-02	72,89	138,33	188,95
SN03@Bertrandt, 120606-03	74,94	143,20	194,48
E-leg@Bertrandt, 120606-01	82,35	142,41	197,61
E-leg@Bertrandt, 120611-02	82,76	144,78	198,22
E-leg@Bertrandt, 120611-03	81,62	142,65	196,51
Maximum	82,76	149,36	207,31
Minimum	71,29	125,70	177,10
Max * 1,05 (Consideration of scatter)	86,90	156,82	217,67
Min * 0,95 (Consideration of scatter)	67,73	119,42	168,25
Certification Corridor Upper Limit	86	156	217
Certification Corridor Lower Limit	68	120	169

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

Revision of **inverse** corridors



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

Test #	Femur A3	Femur A2	Femur A1
SN01@JARI, 120425-01	82,41	142,25	193,42
SN01@JARI, 120425-02	79,95	143,68	199,87
SN01@JARI, 120425-03	79,89	143,37	197,57
SN03@JARI, 120425-01	82,35	147,71	197,29
SN03@JARI, 120425-02	77,95	145,30	197,33
SN03@JARI, 120425-03	76,15	139,53	189,87
E-leg@JARI, 120424-01	81,60	149,36	207,31
E-leg@JARI, 120424-02	81,09	143,17	200,10
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SN01@BAST, 120605-02	79,10	137,30	189,10
SN01@BAST, 120605-03	81,00	141,40	193,40
SN03@BAST, 120516-01	68,90	128,60	180,30
SN03@BAST, 120516-02	65,70	125,70	177,10
SN03@BAST, 120516-03	66,20	126,90	177,70
E-leg@BAST, 120516-01	76,50	136,10	193,10
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E-leg@Bertrandt, 120611-02	82,76	144,78	198,22
E-leg@Bertrandt, 120611-03	81,62	142,65	196,51
Upper Limit	86	156	217
Lower Limit	68	120	169

- Two certification tests failed the complete set of defined draft inverse femur criteria

97,5 % passed

2,5 % failed

Inverse corridors & Draft GTR9 Text

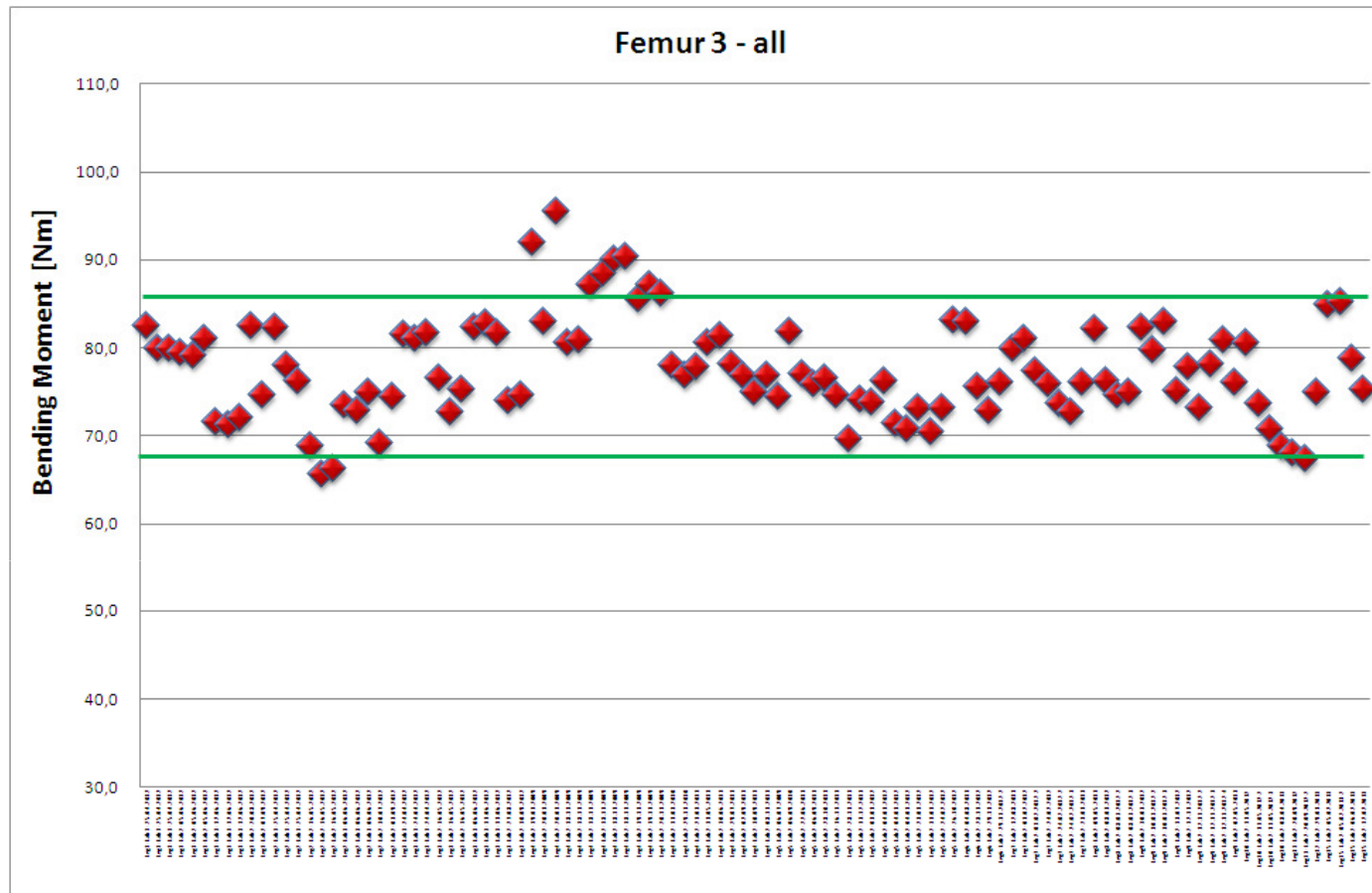


Draft femur inverse certification corridors:

	Femur A3	Femur A2	Femur A1
upper	86	156	217
lower	68	120	169
average	77	138	193
range	18	36	48

- 8.1.3.3.1.** When the flexible lower legform impactor is used for the test specified in paragraph 8.1.3.4., the absolute value of the maximum bending moment of the femur at femur-3 shall be not more than 86 Nm and not less than 68 Nm, the absolute value of the maximum bending moment at femur-2 shall be not more than 156 Nm and not less than 120 Nm, and the absolute value of the maximum bending moment at femur-1 shall be not more than 217 Nm and not less than 169 Nm. [...]

Verification of inverse corridors



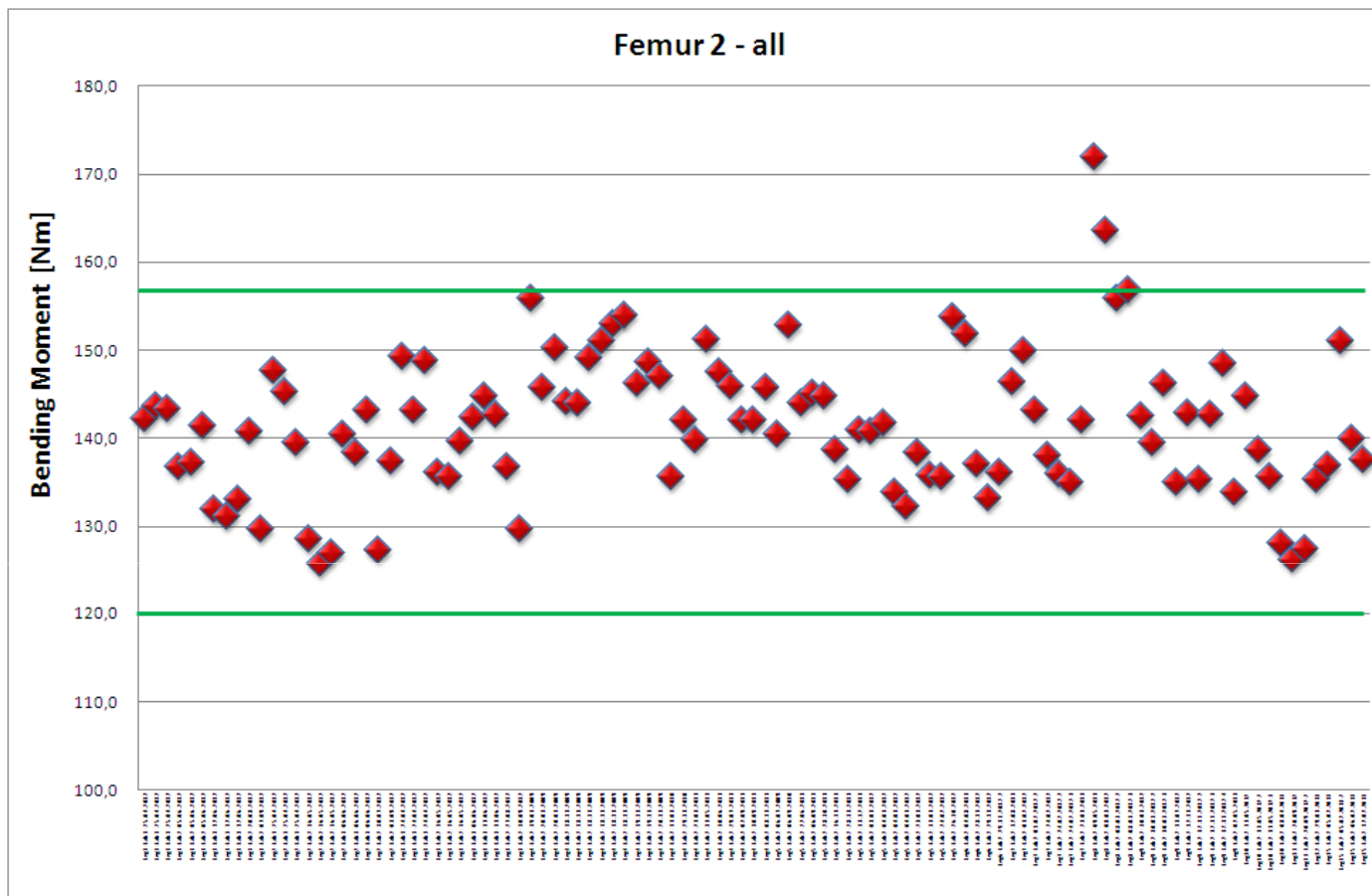
105 inverse tests w/ known femur peak results:

68 * serial production legs
37 * prototypes

11 * not met – 94 * met

➤ Serial production legs: 3 * not met (thereof 2 * master leg)

Verification of inverse corridors



105 inverse tests w/ known femur peak results:

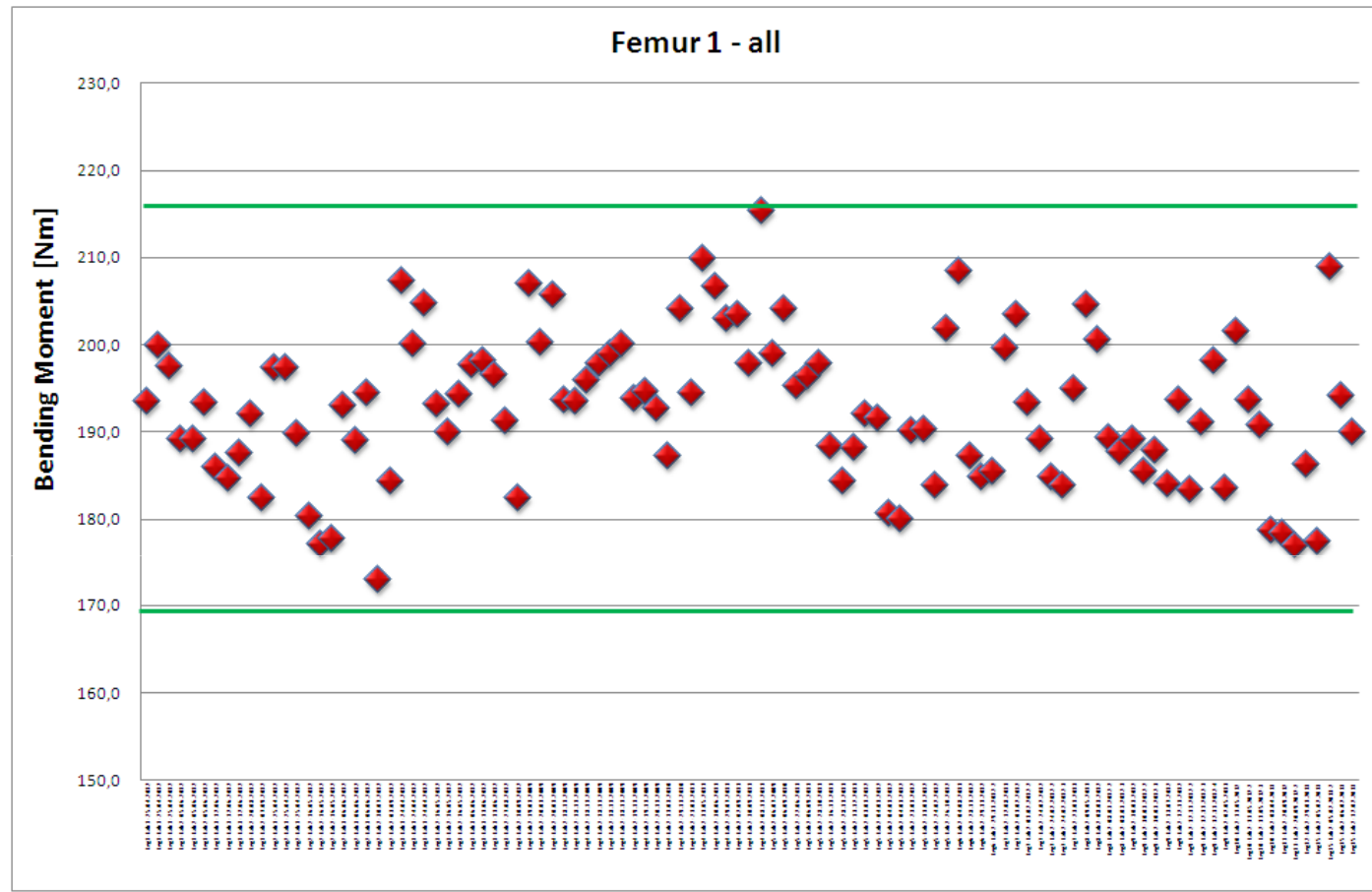
68 * serial production legs
37 * prototypes

3 * not met – 102 * met

➤ Serial production legs: 3 * not met



Verification of inverse corridors



all met

Verification of inverse corridors



Summary:

Femur requirements only:

- **91 tests passed inverse femur draft requirements**
 - 62 w/ serial production legs
 - 29 w/ prototypes
- **14 tests failed inverse femur draft requirements**
(due to one or more segments not meeting the corresponding corridor)
 - 6 w/ serial production legs
 - 8 w/ prototypes
- **Pass / fail ratio for femur requirements**
 - 87 % for all legforms
 - 91 % for serial production legs
 - 78 % for prototypes

Femur, tibia and ligament requirements:

- **59 tests passed complete inverse requirements**
 - 51 w/ serial production legs
 - 8 w/ prototypes
- **46 tests failed complete inverse requirements if femur requirements are included**
 - 17 w/ serial production legs
 - 29 w/ prototypes
- **9 tests failed complete inverse requirements due to femur requirements**
 - 6 w/ serial production legs
 - 3 w/ prototypes
- **Pass / fail ratio for complete requirements**
 - 56 % for all legforms
 - 75 % for serial production legs
 - 22 % for prototypes
 - 9 % due to femur requirements

Content



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Femur Zero Crossing

Discussion

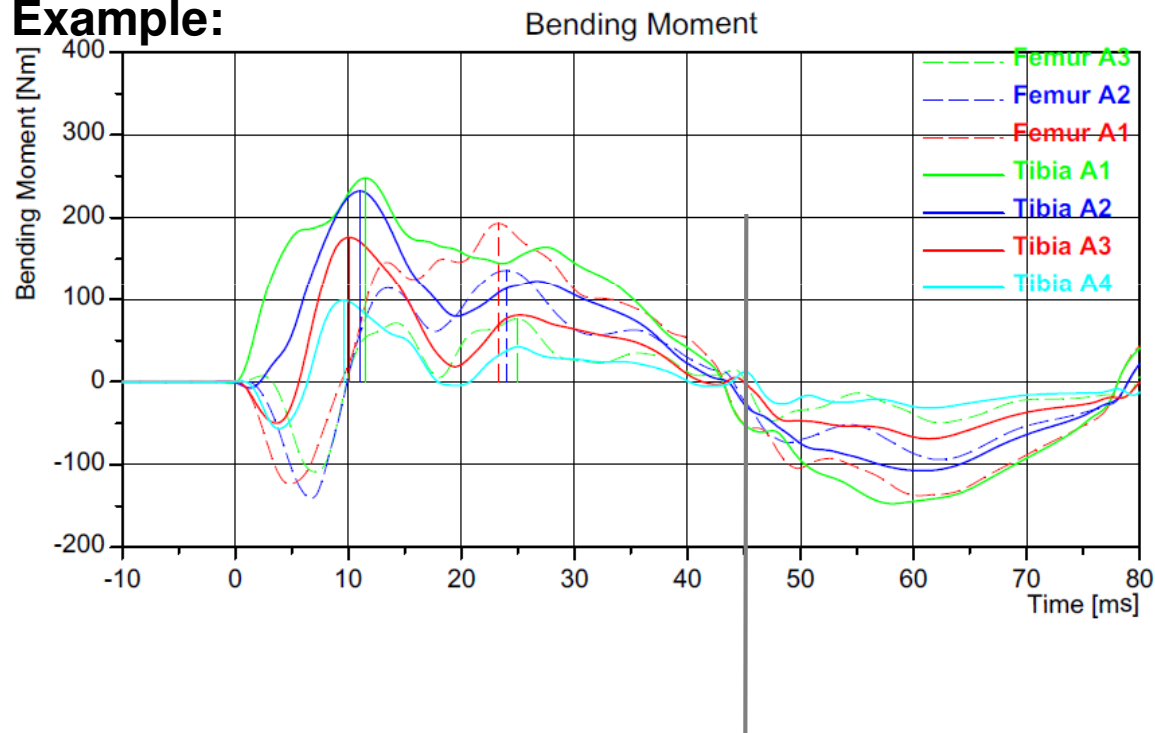
Wording

Femur zero crossing



Examination of the time history curves of the nine inverse certification tests with master legs at BAST used for the establishment of the inverse certification corridors:

Example:



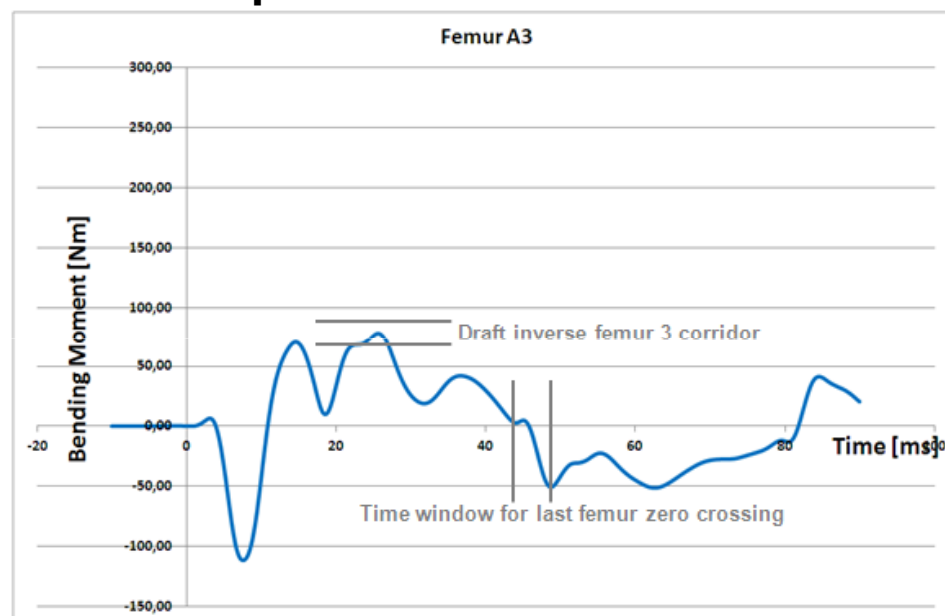
Last zero crossing of femur @ approx. 45 ms

Femur zero crossing



Results:

Timing of last zero crossing of femur segments within the nine inverse certification tests with the three master legs at BAST was between 46 and 48,5 ms after the time of first impact.



Due to the high repeatability of the time window for the femur zero crossing, it is suggested to limit the femur requirements to the draft femur corridors for the peak loadings.

Content



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Discussion

In principal, several scenarios in terms of additional femur (and tibia) corridors:

a) corridors for the femur maxima

a11) for inverse test only (1 set of new corridors)

a12) for pendulum test only (1 set of new corridors)

a13) for inverse and pendulum test (2 sets of new corridors)

b) corridors for the zero crossing

b1) for femur only

b11) for inverse test only (1 set of new corridors)

b12) for pendulum test only (1 set of new corridors)

b13) for inverse and pendulum test (2 sets of new corridors)

b2) for femur and tibia

b11) for inverse test only (2 sets of new corridors)

b12) for pendulum test only (2 sets of new corridors)

b13) for inverse and pendulum test (4 sets of new corridors)

c) corridors for both, femur and tibia, pendulum and inverse test, maxima and zero crossing (6 sets of new corridors)

Discussion

1. Inverse test is well representing / simulating vehicle tests.
2. The zero crossing is always taking place after the occurrence of the maxima, regardless of the exact zero crossing timing.
→ I.e. the zero crossing timing has no influence on the maximum tibia results.
3. If corridors for the zero crossing are requested, those are needed for the tibia as well, because the tibia results are also used to define the BAI.
4. Maximum femur corridors are in line with already established (maximum tibia) corridors (most coherent, most consistent, most understandable)
5. Further requirements should be limited to what is really necessary → one further set of corridors sufficient
6. Further potential conflicts between the different types of tests (as observed for tibia and ligament maxima regarding pendulum and inverse test) should be avoided.

Conclusion:

BAST is clearly in favour of option a11, i.e. the establishment of corridors for the femur maxima for the inverse test only (1 set of new corridors).

Content



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Femur Corridors for Inverse Tests

Femur Zero Crossing

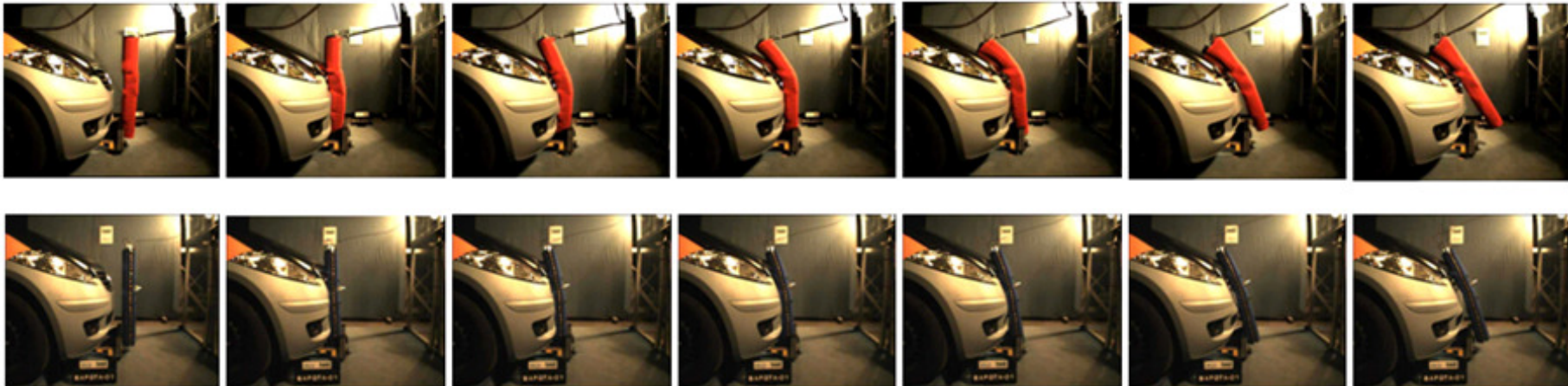
Discussion

Wording

Wording (I)



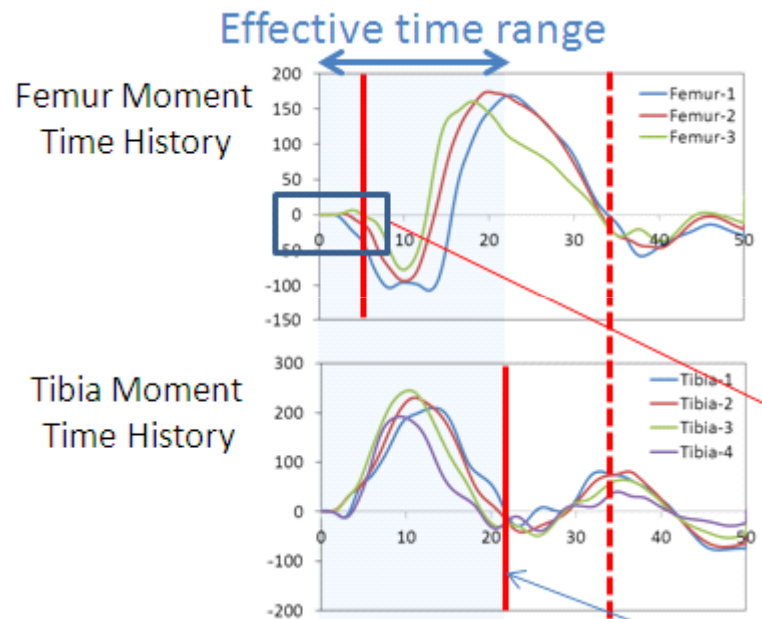
- It was suggested by members of the IG to remove the word „biofidelic“ from the definition of the (biofidelic) assessment interval (BAI).
- One of the major advantages of the FlexPLI in comparison to the EEVC lower legform impactor was understood as its superior biofidelic properties.
- Therefore, the elimination of the word „biofidelic“ within the BAI definition is not comprehensible.
- The limited biofidelic properties of the FlexPLI in some rare cases during short time periods should not overlay the altogether very humanlike behaviour.
- Thus, it is recommended to keep the word „biofidelic“ within the definition.



Wording (II)



- It was requested to modify the BAI definition taking into account that the timings of the common zero crossing of the tibia and of the common zero crossing of the femur bending moments are not always coincident, as suggested in GTR9-7-13:



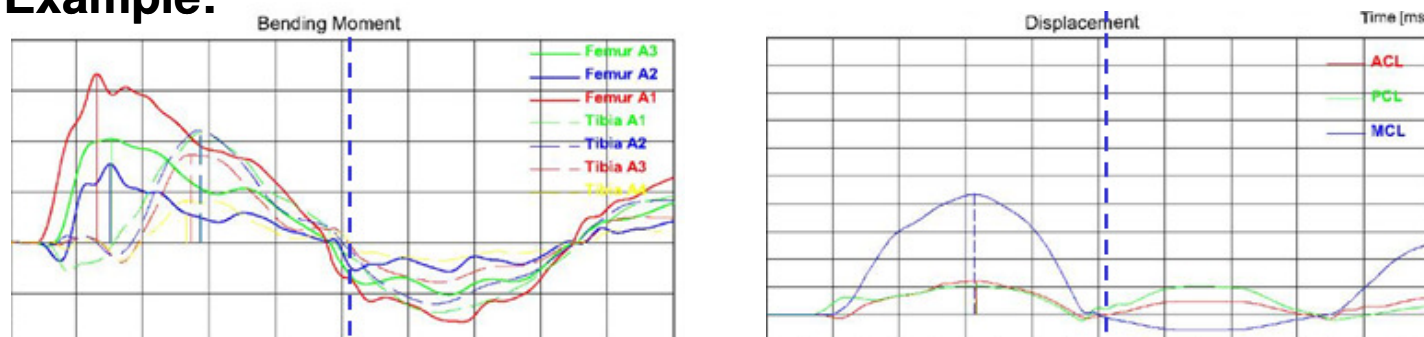
- To address this phenomenon, a modified definition is proposed

Wording (II)



- 3.3** The biofidelic assessment interval (BAI) of the flexible lower legform impactor is defined and limited by the time of first contact of the flexible lower legform impactor with the vehicle and the timing of the last zero crossing of all femur segments and tibia segments after their first local maxima subsequent to any marginal value of 15 Nm, within their particular common zero crossing phases. The BAI is identical for all bone segments and knee ligaments. In case of not all tibia and/or femur bending moments having a zero crossing during their common zero crossing phases, the time history curves are shifted downwards until all bending moments are crossing zero. The downwards shift is to be applied for the determination of the BAI only.

Example:



Thank you !

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