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FlexPLI - Round Robin Tests (Update And Additions To Results Presented With Documents TF-RUCC-3-05 and TF-RUCC-4-03)

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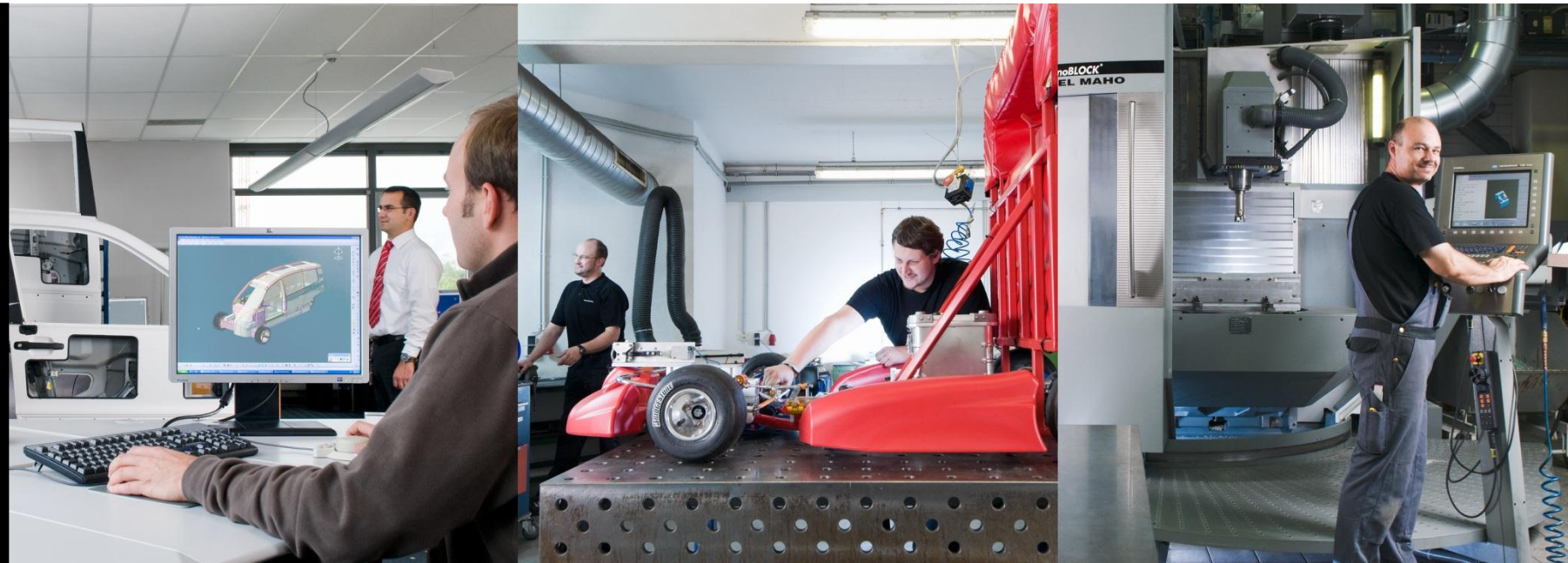
Daniel Folcini, Bertrandt
Sebastian Rieger, Bertrandt
Thomas Kinsky, GM Europe/Opel (representing the ACEA Task Force Pedestrians)

Ingolstadt, November 2012



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Agenda

1. **Test Series**
2. Legforms
3. Inverse Certification Test Results
4. Pendulum Certification Test Results
5. Summary
6. Discussion

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Test Series

European Automobile Manufacturers Association

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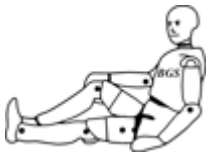

- Test series sponsored by ACEA, the European Automobile Manufacturers' Association
- Tests conducted by Bertrandt in Ingolstadt and by BGS Boehme and Gehring in Bergisch Gladbach
- Both labs are considered to be well experienced with FlexPLI testing
- 5 serial production impactors were tested:
  - 3 inverse certification tests in each lab (Σ: 29 tests, 203 values – the values of one test are still missing)
  - 3 pendulum certification tests in each lab (Σ: 30 tests, 210 values)
- Test scenario according to the scenario proposed for inclusion into gtr No 9 (see document UNECE/TRANS/WP.29/GRSP/2011/13)
- Test results are intended to support the discussion on the possible need to modify the proposed certification corridors
- Results of the test series had been reported partly to "Task Force Review and Update of (FlexPLI) Certification Corridors"

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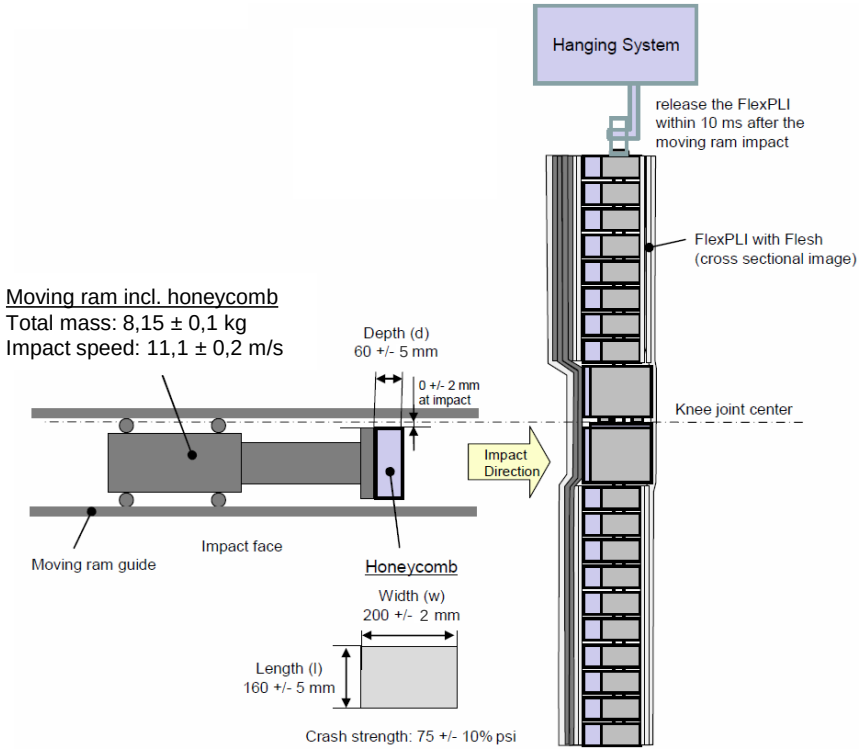
Inverse Certification Procedure



- Setup with flesh and skin
- Hanging system
  - Released within 10 ms after first contact
- Impact with guided moving ram
  - 11,1 ± 0,2 m/s
  - 8,15 ± 0,1 kg
- Aluminium honeycomb impactor, covered by a thin paper cloth
  - Data analysed till 50 ms after first contact

Certification corridors (as agreed on by IG GTR9-PH2 in Sep. 2012)

	Tibia 1	Tibia 2	Tibia 3	Tibia 4	MCL	ACL	PCL
Max	272,0	252,0	192,0	108,0	21,0	10,0	6,0
Min	230,0	210,0	166,0	93,0	17,0	8,0	4,0

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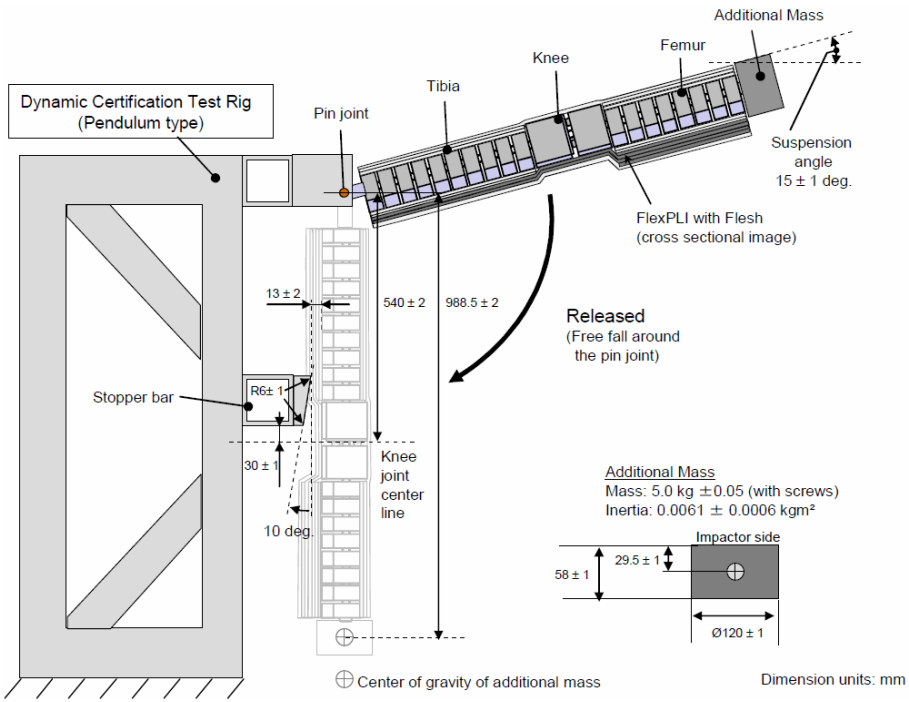
Pendulum Certification Procedure



- Setup with flesh and skin
- Impactor hangs upside down
- Additional mass at the upper end
  - 5,0 kg ± 0,05 kg
- 15° suspension angle
- Free fall around pin joint
- Sensors set to zero before first contact

Certification corridors (as agreed on by IG GTR9-PH2 in Sep. 2012)

	Tibia 1	Tibia 2	Tibia 3	Tibia 4	MCL	ACL	PCL
Max	272,0	219,0	166,0	111,0	24,0	10,5	5,0
Min	235,0	187,0	139,0	90,0	20,5	8,0	3,5

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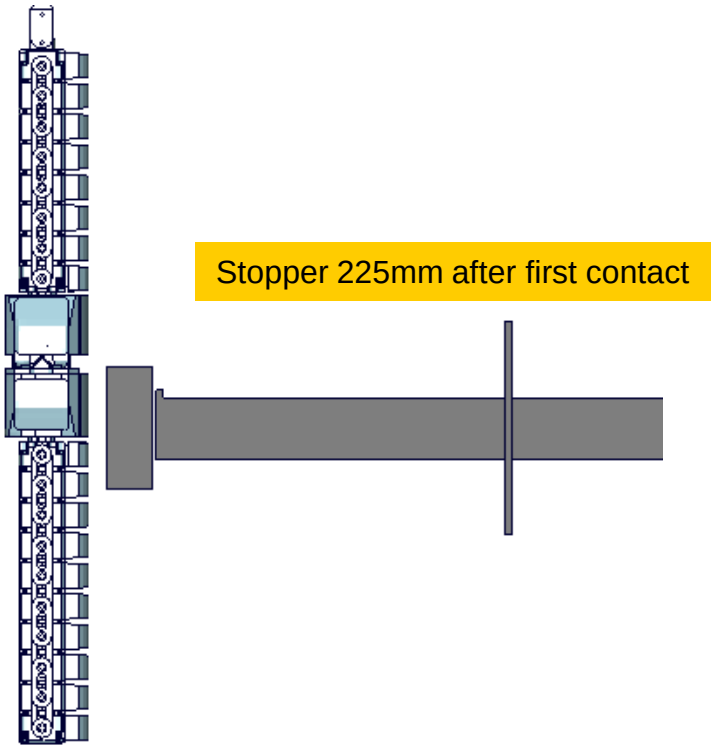
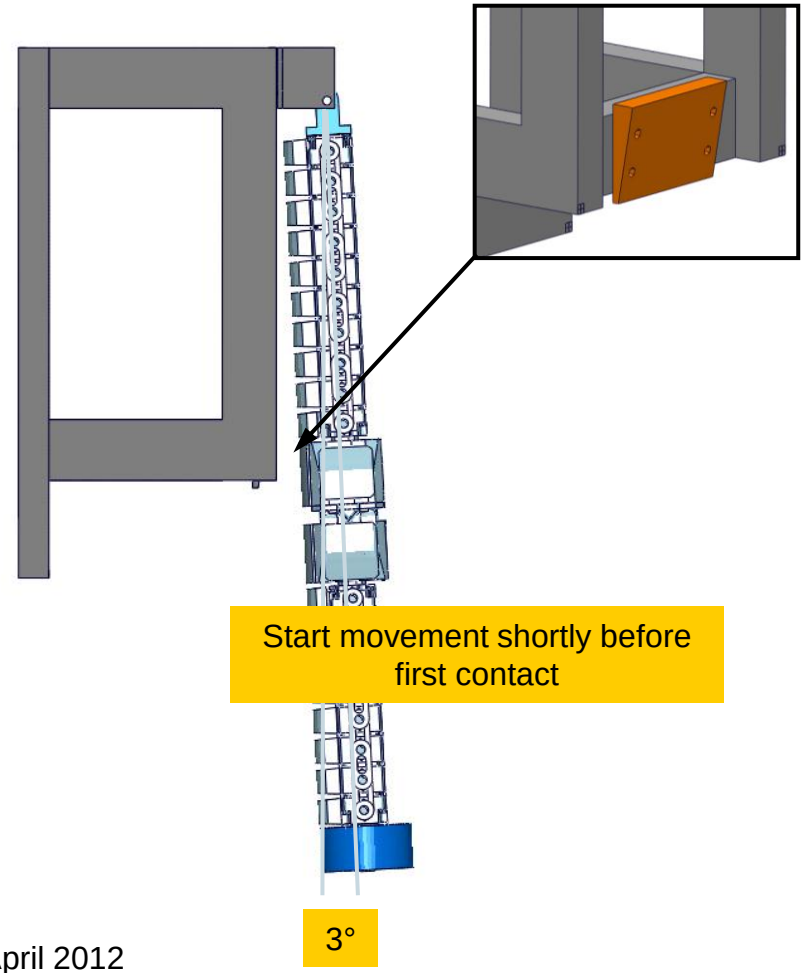
Simulation* of Certification Tests

Inverse Certification



Pendulum Certification



* All pictures of simulations are for information purpose only
Humanetics FlexPLI simulation model V2.0, solver PamCrash, April 2012

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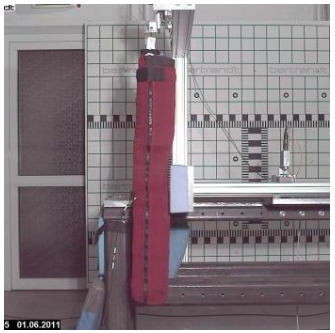
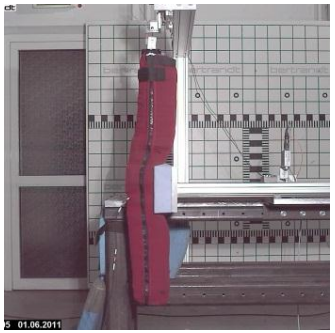
Movement during Inverse Certification

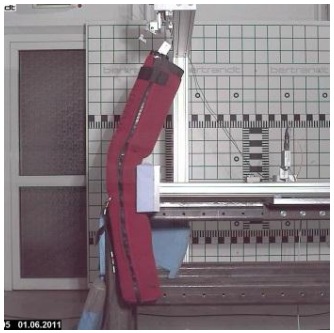
0 ms



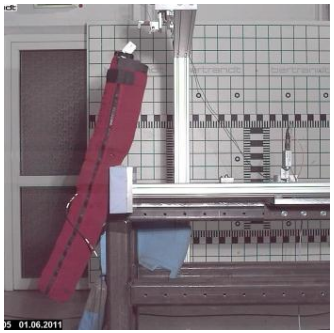
7 ms



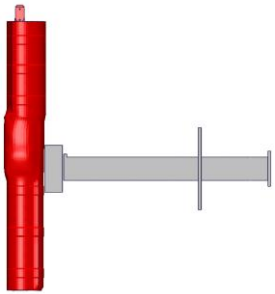
20 ms



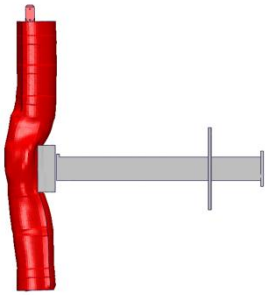
50 ms



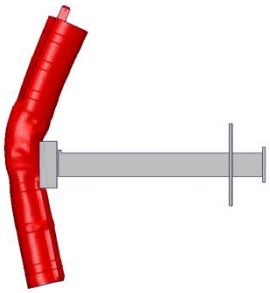
0 ms



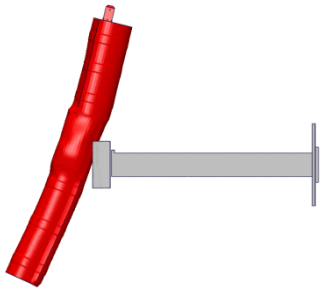
7 ms



20 ms



50 ms



All pictures of simulations are for information purpose only
Humanetics FlexPLI simulation model V2.0, solver PamCrash, April 2012

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Movement during Pendulum Certification

0 ms

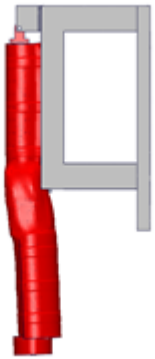
17 ms

90 ms

200 ms

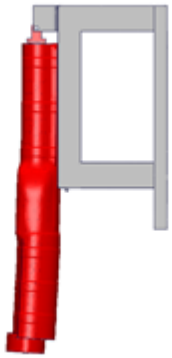
0 ms

17 ms



90 ms

200 ms



All pictures of simulation are for information purpose only
Humanetics FlexPLI simulation model V2.0, solver PamCrash, April 2012

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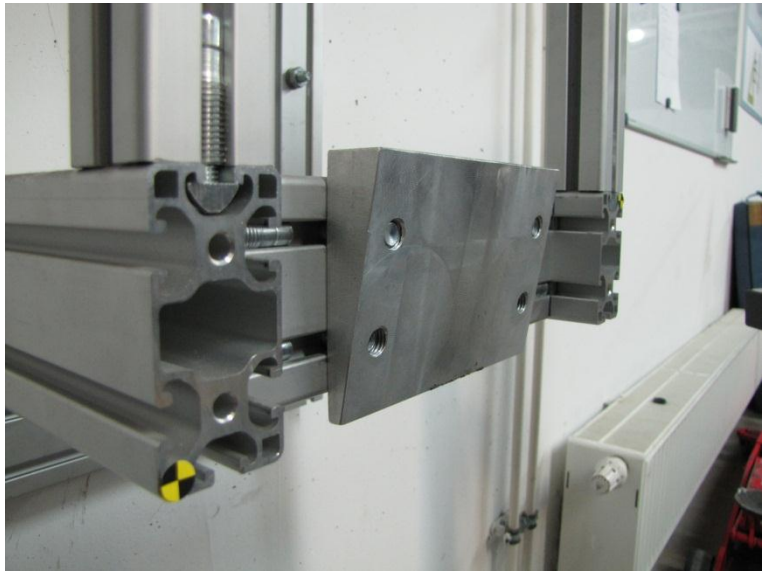
Inverse Certification – Stopper Bar



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Legforms

- All legform impactors used for the test series are FlexPLI version GTR, manufactured by Humanetics
- Legforms are of different build levels:
  - Legform 1 assembled in June 2010 / major repair in May 2011
    - Messring M=BUS
  - Legform 2 assembled in Sept. 2010 / major repair in Jan. 2012
    - Messring M=BUS
  - Legform 3 assembled in March 2012
    - Messring M=BUS
  - Legform 4 assembled in March 2012
    - Hentschel
  - Legform 5 assembled around April 2012 (build level of “master legs”?)
    - Kistler KT-System

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Test Schedule

	LAB 1		LAB 2		
	Date	Test	Date	Test	
Leg 1	14.03.2012	Pendulum	08.03.2012	Pendulum	March 2012
Leg 1	14.03.2012	Inverse	08.03.2012	Inverse	
Leg 2	15.03.2012	Pendulum	27.02.2012	Pendulum	March 2012
Leg 2	15.03.2012	Inverse	24.02.2012	Inverse	
Leg 3	05.04.2012	Pendulum	02.04.2012	Pendulum	April 2012
Leg 3	04.04.2012	Inverse	30.03.2012	Inverse	
Leg 4	11.06.2012	Pendulum	27.04.2012	Pendulum	June / April 2012*
Leg 4	11.06.2012	Inverse	11.05.2012	Inverse	
Leg 5	10.09.2012	Pendulum	11.05.2012	Pendulum	May / September 2012**
Leg 5	10.09.2012	Inverse	20.09.2012	Inverse	

* Interruption between the tests by Lab 1 and Lab 2;
no information available about further testing activities during this time

** Interruption between pendulum certification tests in Lab 2 and further tests;
12 vehicle tests after first set of pendulum certification tests with test results below the criteria proposed for gtr No. 9

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Certification Corridors

INVERSE CORRIDORS							
Draft GTR9-PH2 since Sept. 2012	Tibia 1 (Nm)	Tibia 2 (Nm)	Tibia 3 (Nm)	Tibia 4 (Nm)	MCL (mm)	ACL (mm)	PCL (mm)
lower limit	272	252	192	108	21	10	6
upper limit	230	210	166	93	17	8	4
Draft GTR9-PH2 till Sept. 2012	Tibia 1 (Nm)	Tibia 2 (Nm)	Tibia 3 (Nm)	Tibia 4 (Nm)	MCL (mm)	ACL (mm)	PCL (mm)
lower limit	277	269	204	120	23	10,5	6
upper limit	237	223	176	98	18	8,5	4,5

The green marked corridors were agreed on during the 4th meeting of the Informal Group on GTR No. 9 - Phase 2 (IG GTR9-PH2), held from 17 - 19 September 2012 in Washington DC.

The corridors are based on the results of certification tests carried out in a round robin test series using so called “master legs” that were specifically prepared for those purposes by the legform manufacturer. The master legs represent the latest build level as agreed within the work of the IG GTR9-PH2.

The legforms used in the round robin test series on behalf of ACEA – of which the results are shown in this presentation – may differ from the master legs despite they were delivered as FlexPLI version GTR. The legs are serial production legs representing the build levels at the date of their assembly for the customer and therefore do not necessarily represent the master legs’ build level.

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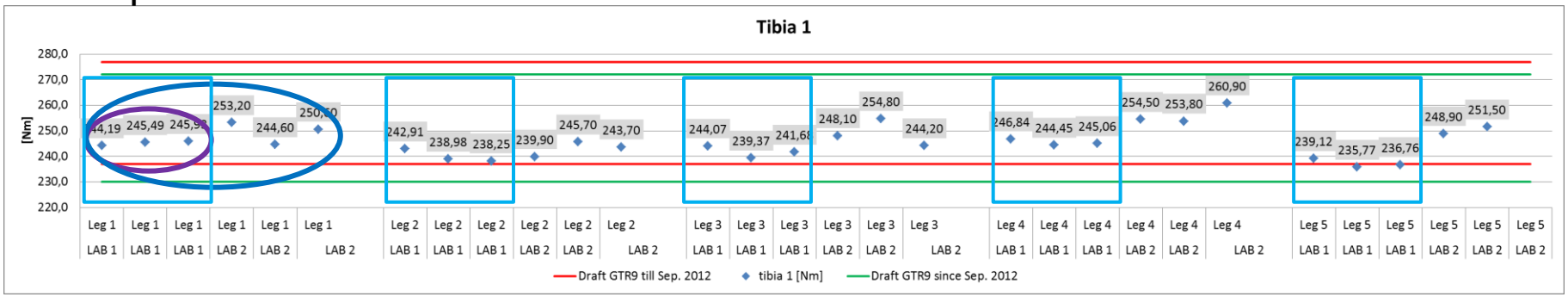
Explanation Chart - Table



$$\frac{\sum x1 + x2 + \cdots + xn}{n}$$

$$\sqrt{\frac{\sum (x - \bar{x})^2}{n}}$$

$$\frac{standard\ deviation}{arithmetic\ mean}$$

relevant limits		Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	LAB 1	LAB 2	Overall
min:	230								
max:	272								
LAB 1 + 2	arithmetic mean [Nm]	247,34	241,57	245,37	250,93	242,41	241,92	249,60	245,63
	standard deviation [Nm]	3,36	2,71	4,98	5,97	6,51	3,47	5,44	5,94
	coefficient of variation	1,36%	1,12%	2,03%	2,38%	2,68%	1,44%	2,18%	2,42%
LAB 1	arithmetic mean [Nm]	245,20	240,05	241,71	245,45	237,22			
	standard deviation [Nm]	0,74	2,05	1,92	1,01	1,41			
	coefficient of variation	0,30%	0,85%	0,79%	0,41%	0,59%			
LAB 2	arithmetic mean [Nm]	249,47	243,10	249,03	256,40	250,20			
	standard deviation [Nm]	3,60	2,41	4,38	3,19	1,30			
	coefficient of variation	1,44%	0,99%	1,76%	1,25%	0,52%			

Coefficient of variation
≤ 3% = good

Coefficient of variation
3% < cov < 7% = acceptable

Coefficient of variation
7% < cov < 10% = marginal

Coefficient of variation
≥ 10% = not acceptable

Classification shown in document TEG-075 (O. Zander)

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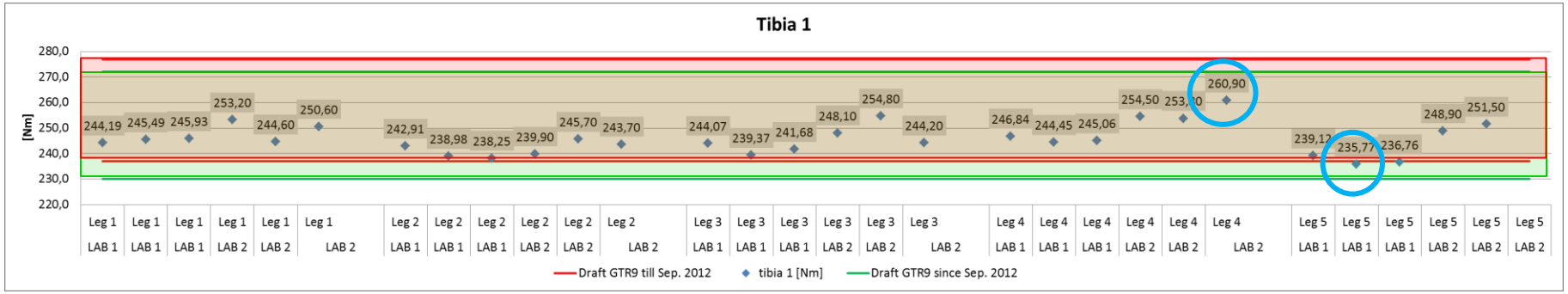
Inverse Certification Test Results – Tibia 1

Draft GTR9-PH2 till Sep. 2012 (237 – 277 Nm)

- All test results meet the corridor except the legform 5 in lab 1

Draft GTR9-PH2 since Sep. 2012 (230 – 272 Nm)

- All test results meet the corridor



relevant limits		Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	LAB 1	LAB 2	Overall
min:	230								
max:	272								
LAB 1 + 2	arithmetic mean [Nm]	247,34	241,57	245,37	250,93	242,41	241,92	249,60	245,63
	standard deviation [Nm]	3,36	2,71	4,98	5,97	6,51	3,47	5,44	5,94
	coefficient of variation	1,36%	1,12%	2,03%	2,38%	2,68%	1,44%	2,18%	2,42%
LAB 1	arithmetic mean [Nm]	245,20	240,05	241,71	245,45	237,22			
	standard deviation [Nm]	0,74	2,05	1,92	1,01	1,41			
	coefficient of variation	0,30%	0,85%	0,79%	0,41%	0,59%			
LAB 2	arithmetic mean [Nm]	249,47	243,10	249,03	256,40	250,20			
	standard deviation [Nm]	3,60	2,41	4,38	3,19	1,30			
	coefficient of variation	1,44%	0,99%	1,76%	1,25%	0,52%			

highest and lowest value

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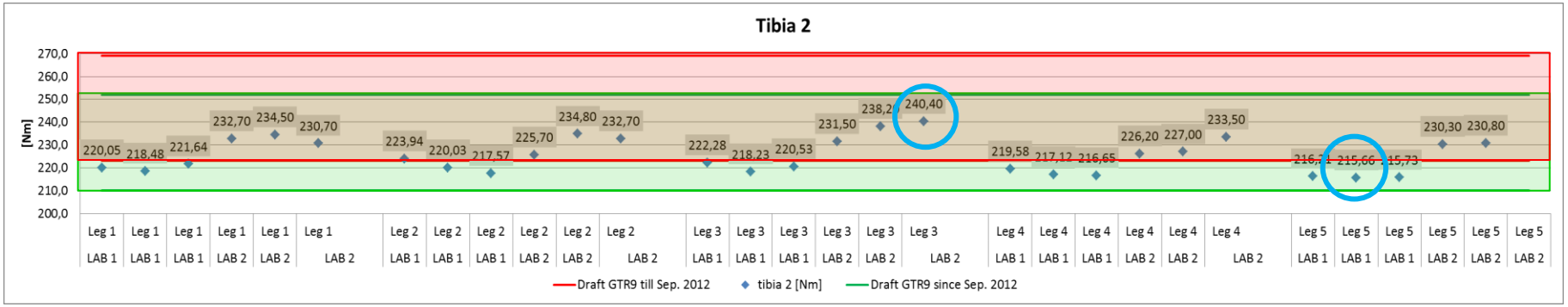
Inverse Certification Test Results – Tibia 2

Draft GTR9-PH2 till Sep. 2012 (223 – 269 Nm)

- In lab 1, most test results are below the lower limit value of the corridor
- In lab 2, test results meet the corridor but all are in the lower half of the corridor

Draft GTR9-PH2 since Sep. 2012 (210 – 252 Nm)

- All test results meet the corridor



relevant limits		Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	LAB 1	LAB 2	Overall
min:	210								
max:	252								
LAB 1 + 2	arithmetic mean [Nm]	226,35	225,79	228,52	223,34	221,74	218,91	232,07	225,27
	standard deviation [Nm]	6,45	6,23	8,68	6,09	7,20	2,43	4,06	7,36
	coefficient of variation	2,85%	2,76%	3,80%	2,73%	3,25%	1,11%	1,75%	3,27%
LAB 1	arithmetic mean [Nm]	220,06	220,51	220,35	217,78	215,87			
	standard deviation [Nm]	6,45	2,62	1,66	1,28	0,24			
	coefficient of variation	2,93%	1,19%	0,75%	0,59%	0,11%			
LAB 2	arithmetic mean [Nm]	232,63	231,07	236,70	228,90	230,55			
	standard deviation [Nm]	1,55	3,89	3,79	3,27	0,25			
	coefficient of variation	0,67%	1,68%	1,60%	1,43%	0,11%			

highest and lowest value

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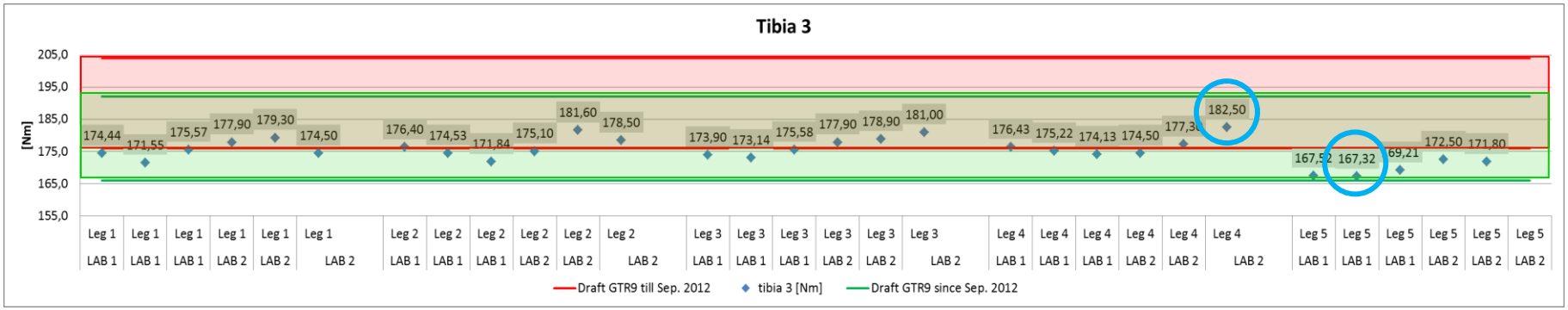
Inverse Certification Test Results – Tibia 3

Draft GTR9-PH2 till Sep. 2012 (176– 204Nm)

- All test results are around the lower limit value but regularly miss to meet the corridor

Draft GTR9-PH2 since Sep. 2012 (166 – 192 Nm)

- All test results meet the corridor
- Legform 5 is close to the lower limit



relevant limits		Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	LAB 1	LAB 2	Overall
min:	166								
max:	192								
LAB 1 + 2	arithmetic mean [Nm]	175,54	176,33	176,74	176,68	169,67	173,12	177,38	175,18
	standard deviation [Nm]	2,51	3,09	2,78	2,82	2,14	2,92	3,18	3,72
	coefficient of variation	1,43%	1,75%	1,58%	1,60%	1,26%	1,69%	1,79%	2,12%
LAB 1	arithmetic mean [Nm]	173,85	174,26	174,21	175,26	168,02			
	standard deviation [Nm]	1,69	1,87	1,02	0,94	0,85			
	coefficient of variation	0,97%	1,07%	0,59%	0,54%	0,50%			
LAB 2	arithmetic mean [Nm]	177,23	178,40	179,27	178,10	172,15			
	standard deviation [Nm]	2,02	2,65	1,29	3,31	0,35			
	coefficient of variation	1,14%	1,49%	0,72%	1,86%	0,20%			

highest and lowest value

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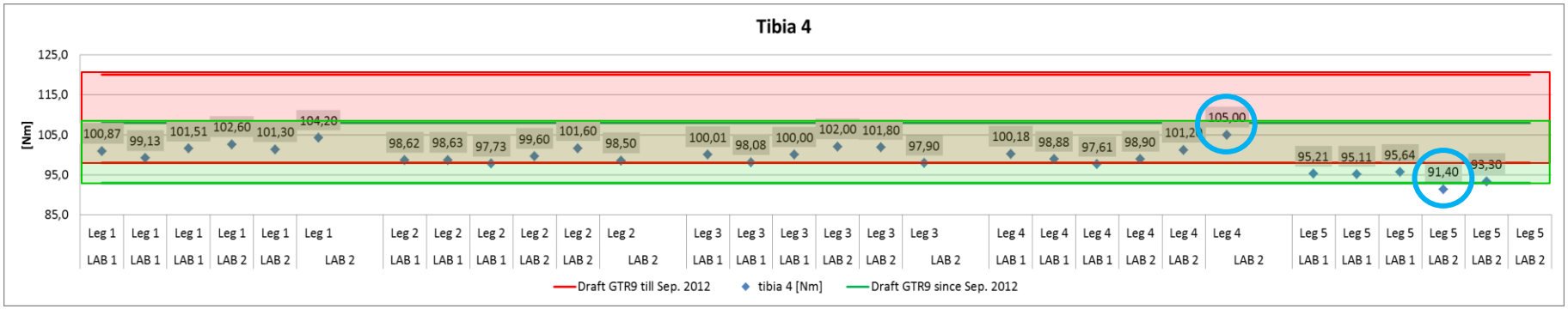
Inverse Certification Test Results – Tibia 4

Draft GTR9-PH2 till Sep. 2012 (98 – 120 Nm)

- Test results are around the lower limit value
- All tests with legform 5 miss the corridor

Draft GTR9-PH2 since Sep. 2012 (93 – 108 Nm)

- All test results meet the corridor except in one test with legform 5



relevant limits		Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	LAB 1	LAB 2	Overall
min:	93								
max:	108								
LAB 1 + 2	arithmetic mean [Nm]	101,60	99,11	99,97	100,30	94,13	98,48	99,95	99,19
	standard deviation [Nm]	1,55	1,24	1,60	2,38	1,58	1,91	3,68	2,99
	coefficient of variation	1,53%	1,25%	1,60%	2,38%	1,68%	1,94%	3,68%	3,02%
LAB 1	arithmetic mean [Nm]	100,50	100,51	99,36	98,89	95,32			
	standard deviation [Nm]	1,01	0,42	0,91	1,05	0,23			
	coefficient of variation	1,00%	0,42%	0,91%	1,06%	0,24%			
LAB 2	arithmetic mean [Nm]	102,70	99,90	100,57	101,70	92,35			
	standard deviation [Nm]	1,19	1,28	1,89	2,52	0,95			
	coefficient of variation	1,15%	1,28%	1,88%	2,47%	1,03%			

highest and lowest value

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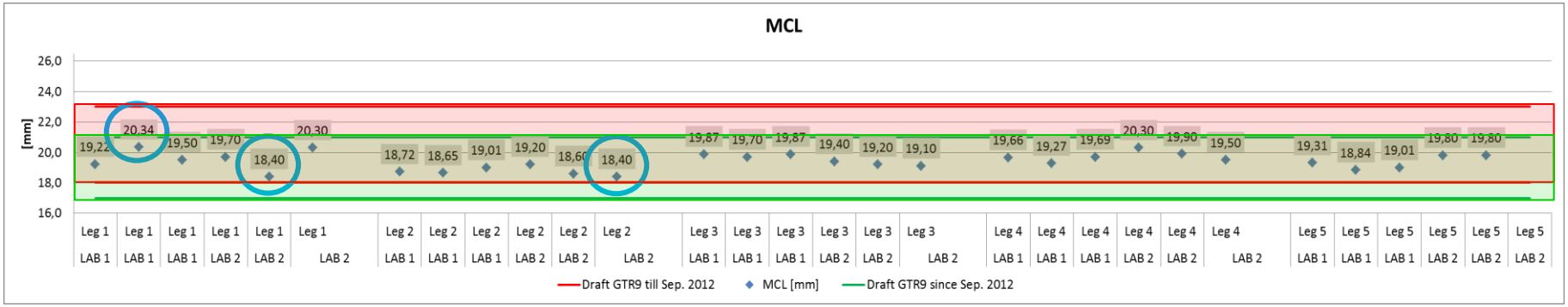
Inverse Certification Test Results – MCL

Draft GTR9-PH2 till Sep. 2012 (18 – 23 mm)

- All test results meet the corridor
- For legform 1, test results significantly scatter

Draft GTR9-PH2 since Sep. 2012 (17 – 21 mm)

- Test results are mainly in the upper half of the corridor



relevant limits		Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	LAB 1	LAB 2	Overall
min:	17								
max:	21								
LAB 1 + 2	arithmetic mean [mm]	19,58	18,76	19,52	19,72	19,35	19,38	19,40	12,40
	standard deviation [mm]	0,66	0,13	0,31	0,32	0,40	0,47	0,60	0,54
	coefficient of variation	3,39%	0,68%	1,58%	1,64%	2,04%	2,41%	3,11%	4,33%
LAB 1	arithmetic mean [mm]	19,69	18,79	19,81	19,54	19,05			
	standard deviation [mm]	0,48	0,11	0,08	0,19	0,19			
	coefficient of variation	2,42%	0,60%	0,40%	0,98%	1,02%			
LAB 2	arithmetic mean [mm]	19,47	18,73	19,23	19,90	19,80			
	standard deviation [mm]	0,79	0,14	0,12	0,33	0,00			
	coefficient of variation	4,07%	0,75%	0,65%	1,64%	0,00%			

highest and lowest value

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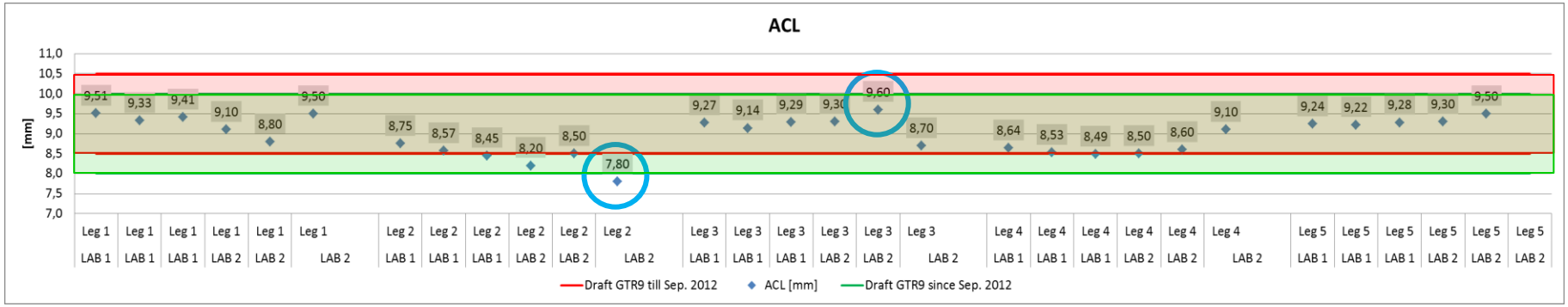
Inverse Certification Test Results – ACL

Draft GTR9-PH2 till Sep. 2012 (8,5 – 10,5 mm)

- For legforms 1, 3 and 5, test results are in the middle of the corridor
- For legforms 2 and 4, test results are around the lower limit value but do not all meet the corridor

Draft GTR9-PH2 since Sep. 2012 (8 – 10 mm)

- All test results meet the corridor except one test with legform 2



relevant limits		Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	LAB 1	LAB 2	Overall
min:	8								
max:	10								
LAB 1 + 2	arithmetic mean [mm]	9,28	8,38	9,22	8,64	9,31	9,01	8,89	8,95
	standard deviation [mm]	0,25	0,31	0,27	0,21	0,10	0,37	0,52	0,45
	coefficient of variation	2,73%	3,65%	2,92%	2,44%	1,08%	4,11%	5,83%	5,05%
LAB 1	arithmetic mean [mm]	9,42	8,59	9,23	8,55	9,25			
	standard deviation [mm]	0,07	0,12	0,07	0,06	0,02			
	coefficient of variation	0,78%	1,44%	0,72%	0,74%	0,27%			
LAB 2	arithmetic mean [mm]	9,13	8,17	9,20	8,73	9,40			
	standard deviation [mm]	0,29	0,29	0,37	0,26	0,10			
	coefficient of variation	3,14%	3,51%	4,07%	3,01%	1,06%			

highest and lowest value

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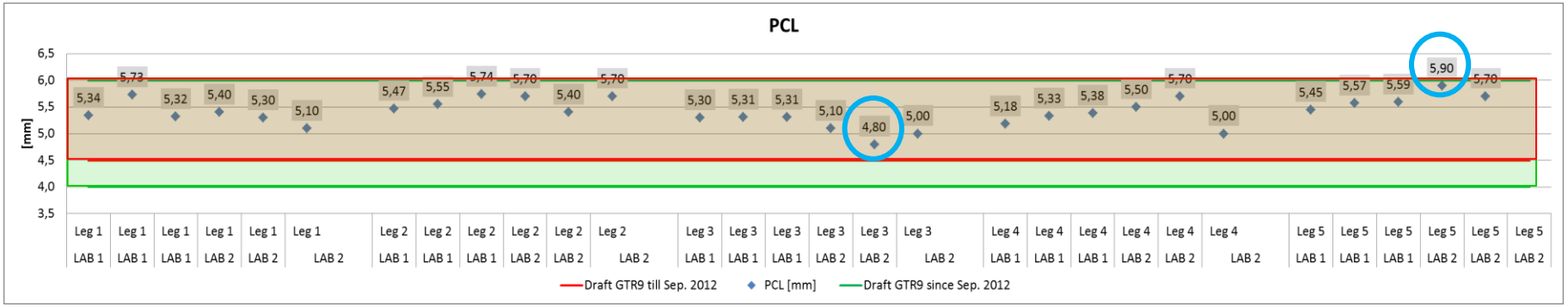
Inverse Certification Test Results – PCL

Draft GTR9-PH2 till Sep. 2012 (4,5 – 6 mm)

- All test results are around the middle or in the upper half of the corridor

Draft GTR9-PH2 since Sep. 2012 (4 – 6 mm)

- All test results are in the upper half of the corridor



relevant limits		Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	LAB 1	LAB 2	Overall
min:	4								
max:	6								
LAB 1 + 2	arithmetic mean [mm]	5,37	5,59	5,14	5,35	5,64	5,44	5,38	5,41
	standard deviation [mm]	0,19	0,13	0,19	0,22	0,15	0,16	0,33	0,26
	coefficient of variation	3,50%	2,29%	3,73%	4,16%	2,68%	2,96%	6,05%	4,73%
LAB 1	arithmetic mean [mm]	5,46	5,59	5,31	5,30	5,54			
	standard deviation [mm]	0,19	0,11	0,00	0,08	0,06			
	coefficient of variation	3,45%	2,03%	0,09%	1,60%	1,12%			
LAB 2	arithmetic mean [mm]	5,27	5,60	4,97	5,40	5,80			
	standard deviation [mm]	0,12	0,14	0,12	0,29	0,10			
	coefficient of variation	2,37%	2,53%	2,51%	5,45%	1,72%			

highest and lowest value

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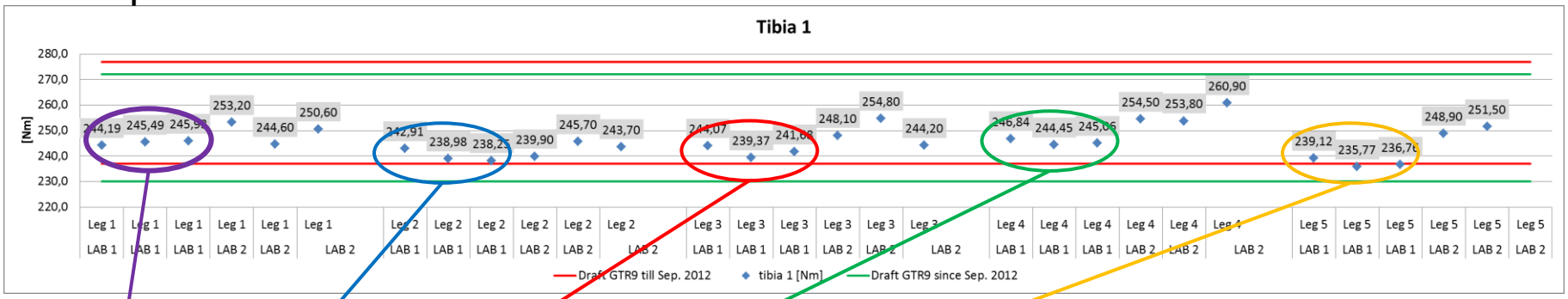
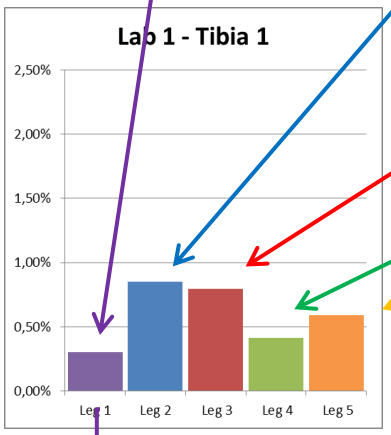
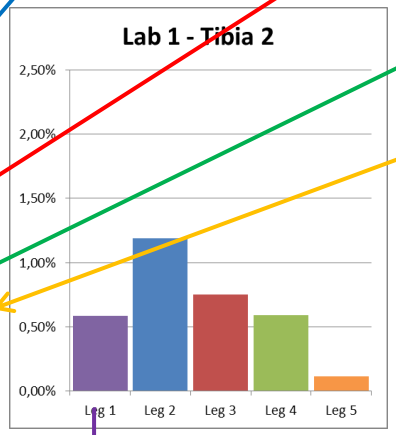
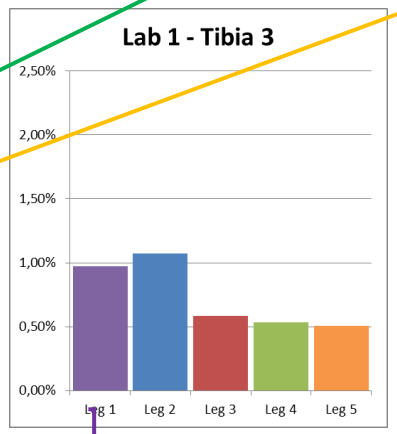
Explanation Chart - Table

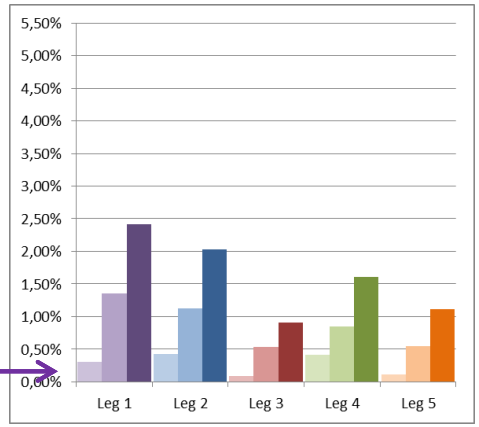








. . .



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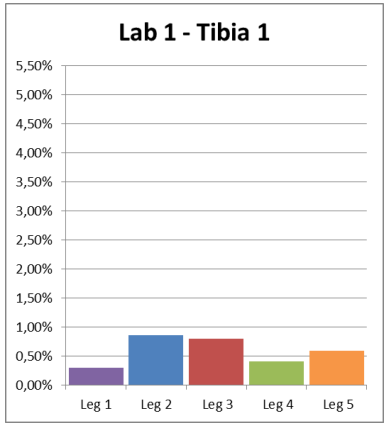
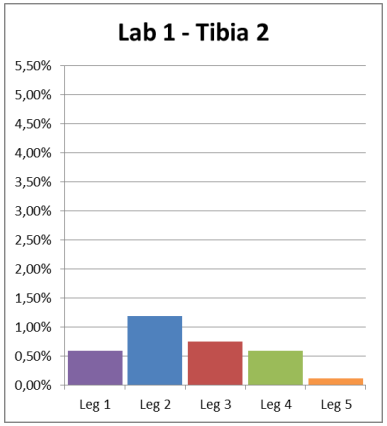
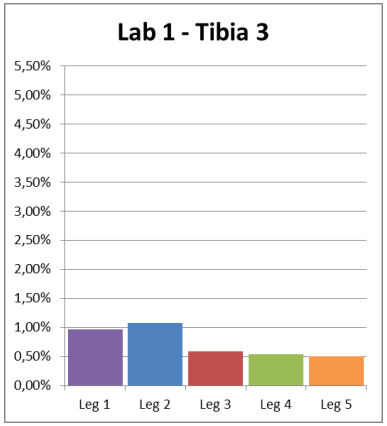
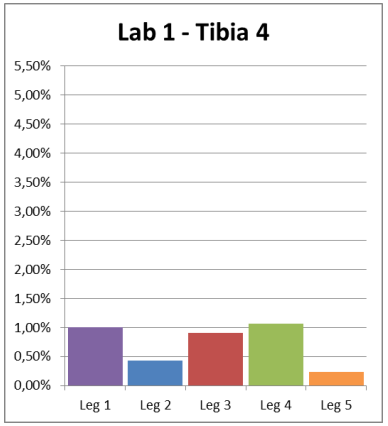
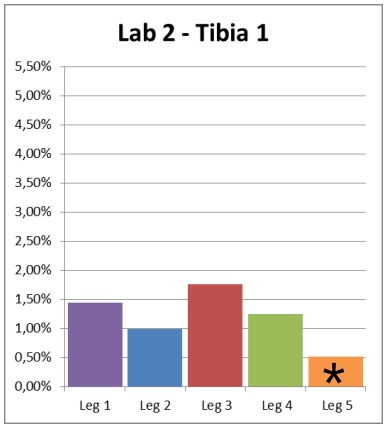
Inverse Certification: Comparison of CoV (1/2)

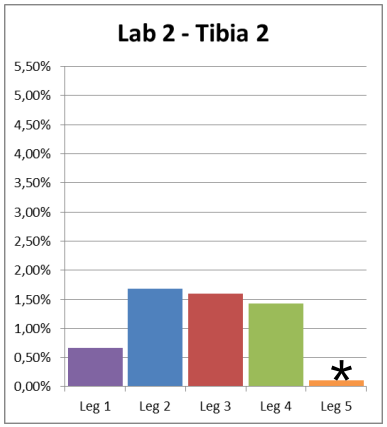


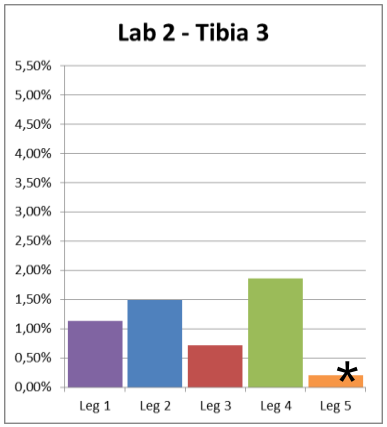


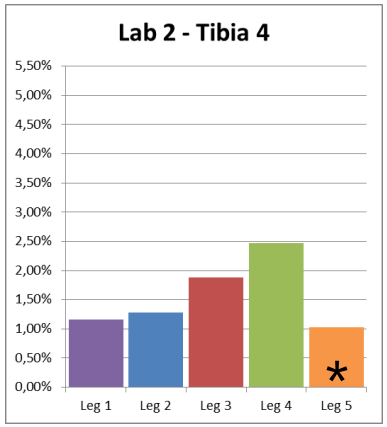












* Only two (instead of three) values for used legform 5!

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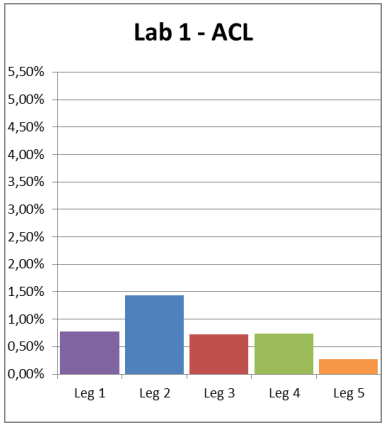
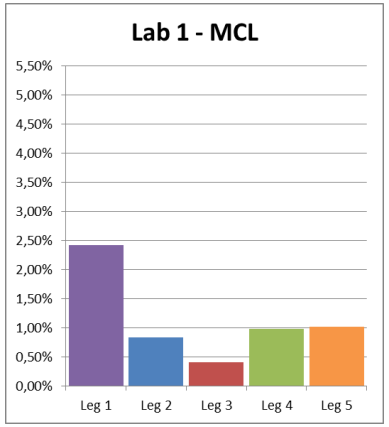
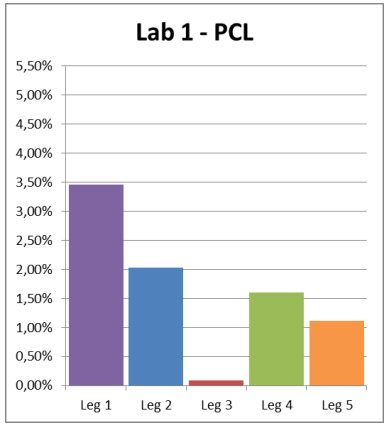
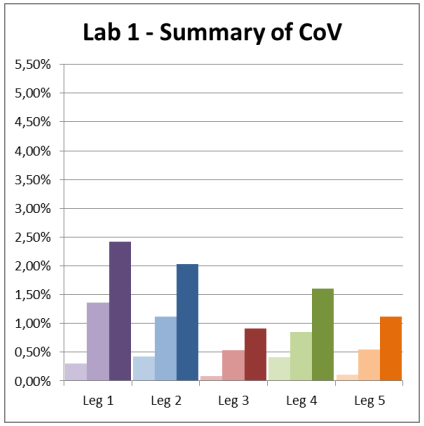
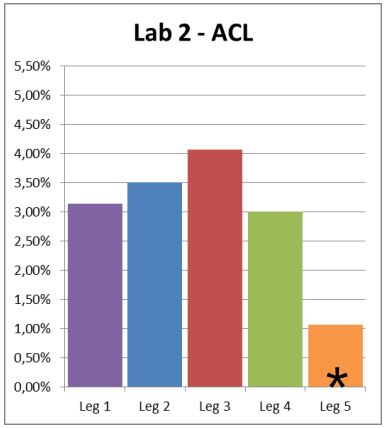
Inverse Certification: Comparison of CoV (2/2)

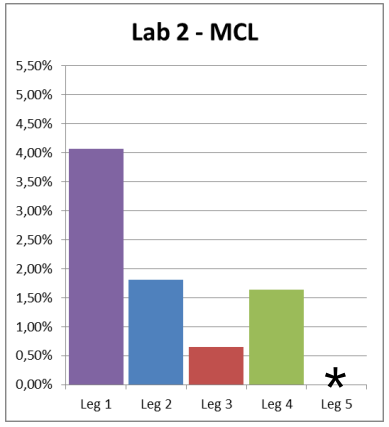


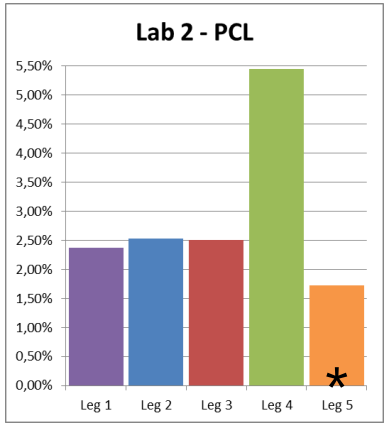


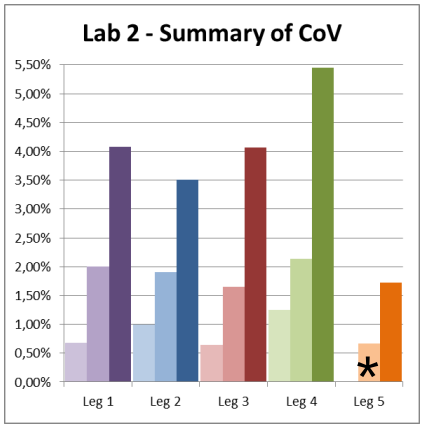












Left: minimum value
Center: average
Right: maximum value

* Only two (instead of three) values for used legform 5!

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Agenda

1. Test Series
2. Legforms
3. Inverse Certification Test Results
4. **Pendulum Certification Test Results**
5. Summary
6. Discussion

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Calibrations Corridors

PENDULUM CORRIDORS							
Draft GTR9-PH2 since Sept. 2012	Tibia 1 (Nm)	Tibia 2 (Nm)	Tibia 3 (Nm)	Tibia 4 (Nm)	MCL (mm)	ACL (mm)	PCL (mm)
lower limit	272	219	166	111	24	10,5	5
upper limit	235	187	139	90	20,5	8	3,5
Draft GTR9-PH2 till Sept. 2012	Tibia 1 (Nm)	Tibia 2 (Nm)	Tibia 3 (Nm)	Tibia 4 (Nm)	MCL (mm)	ACL (mm)	PCL (mm)
lower limit	272	211	160	108	26	11	5,4
upper limit	235	185	135	94	23	9	4

The green marked corridors were agreed on during the 4th meeting of the Informal Group on GTR No. 9 - Phase 2 (IG GTR9-PH2), held from 17 - 19 September 2012 in Washington DC.

The corridors are based on the results of certification tests carried out in a round robin test series using so called “master legs” that were specifically prepared for those purposes by the legform manufacturer. The master legs represent the latest build level as agreed within the work of the IG GTR9-PH2.

The legforms used in the round robin test series on behalf of ACEA – of which the results are shown in this presentation – may differ from the master legs despite they were delivered as FlexPLI version GTR. The legs are serial production legs representing the build levels at the date of their assembly for the customer and therefore do not necessarily represent the master legs’ build level.

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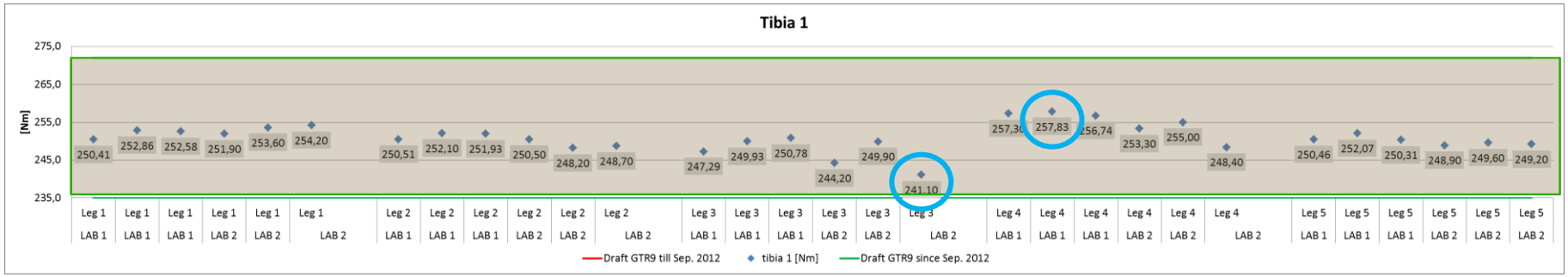
Pendulum Certification Test Results – Tibia 1

Draft GTR9-PH2 till Sep. 2012 (235 – 272 Nm)

- All test results meet the corridor, most test results are in the lower half
- For tests of legforms 3 and 4 tested in lab 2, test results significantly scatter

Draft GTR9-PH2 since Sep. 2012 (235 – 272 Nm)

- (No shifting of the corridor)



relevant limits		Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	LAB 1	LAB 2	Overall
min:	235								
max:	272								
LAB 1 + 2	arithmetic mean [Nm]	252,59	250,32	247,20	254,76	250,09	252,21	249,78	250,99
	standard deviation [Nm]	1,22	1,47	3,51	3,23	1,05	2,86	3,58	3,46
	coefficient of variation	0,48%	0,59%	1,42%	1,27%	0,42%	1,14%	1,43%	1,38%
LAB 1	arithmetic mean [Nm]	251,95	251,51	249,33	257,29	250,95			
	standard deviation [Nm]	1,09	0,71	1,49	0,45	0,80			
	coefficient of variation	0,43%	0,28%	0,60%	0,17%	0,32%			
LAB 2	arithmetic mean [Nm]	253,23	249,13	245,07	252,23	249,23			
	standard deviation [Nm]	0,97	0,99	3,64	2,80	0,29			
	coefficient of variation	0,38%	0,40%	1,49%	1,11%	0,12%			

highest and lowest value

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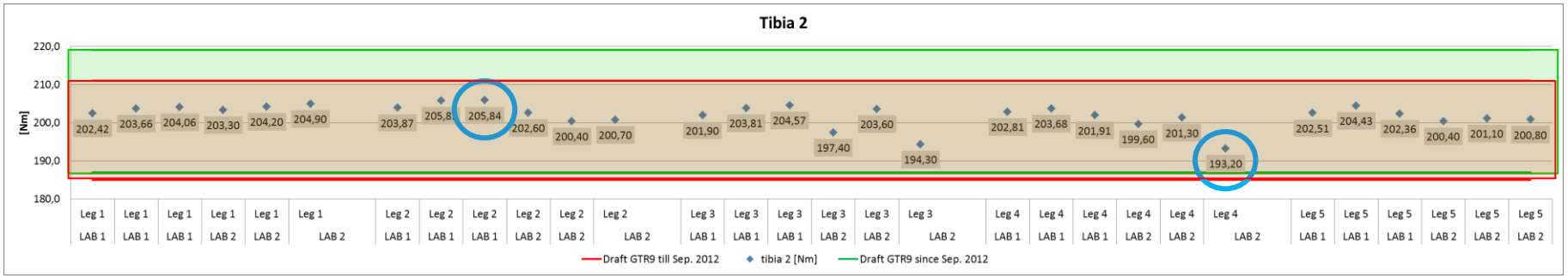
Pendulum Certification Test Results – Tibia 2

Draft GTR9-PH2 till Sep. 2012 (185 – 211 Nm)

- All test results meet the corridor
- Again, for legforms 3 and 4 test results significantly scatter during tests in lab 2

Draft GTR9-PH2 since Sep. 2012 (187 – 219 Nm)

- All test results meet the corridor



relevant limits		Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	LAB 1	LAB 2	Overall
min:	187								
max:	219								
LAB 1 + 2	arithmetic mean [Nm]	203,76	203,21	200,93	200,42	201,93	203,58	200,52	202,05
	standard deviation [Nm]	0,77	2,19	3,79	3,47	1,36	1,22	3,25	2,89
	coefficient of variation	0,38%	1,08%	1,88%	1,73%	0,67%	0,60%	1,62%	1,43%
LAB 1	arithmetic mean [Nm]	203,38	205,18	203,43	202,80	203,10			
	standard deviation [Nm]	0,70	0,92	1,12	0,72	0,94			
	coefficient of variation	0,34%	0,45%	0,55%	0,36%	0,46%			
LAB 2	arithmetic mean [Nm]	204,13	201,23	198,43	198,03	200,77			
	standard deviation [Nm]	0,65	0,97	3,87	3,49	0,29			
	coefficient of variation	0,32%	0,48%	1,95%	1,76%	0,14%			

highest and lowest value

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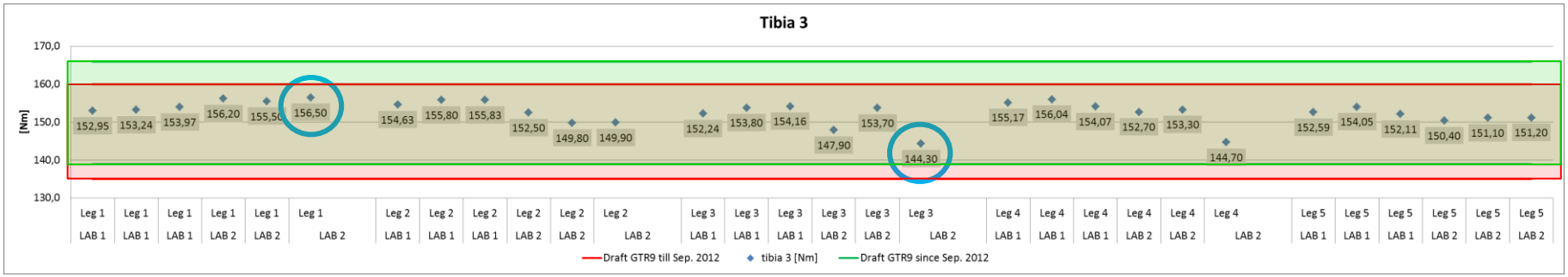
Pendulum Certification Test Results – Tibia 3

Draft GTR9-PH2 till Sep. 2012 (135 – 160 Nm)

- All test results are in the corridor
- Again, for legform 3 test results significantly scatter during tests in lab 2

Draft GTR9-PH2 since Sep. 2012 (139 – 166 Nm)

- All test results meet the middle of the corridor



relevant limits		Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	LAB 1	LAB 2	Overall
min:	139								
max:	166								
LAB 1 + 2	arithmetic mean [Nm]	154,73	153,08	151,02	152,66	151,91	154,04	151,31	152,68
	standard deviation [Nm]	1,41	2,54	3,68	3,73	1,19	1,24	3,57	3,00
	coefficient of variation	0,91%	1,66%	2,44%	2,44%	0,78%	0,80%	2,36%	1,96%
LAB 1	arithmetic mean [Nm]	153,39	155,42	153,40	155,09	152,92			
	standard deviation [Nm]	0,43	0,56	0,83	0,81	0,82			
	coefficient of variation	0,28%	0,36%	0,54%	0,52%	0,54%			
LAB 2	arithmetic mean [Nm]	156,07	150,73	148,63	150,23	150,90			
	standard deviation [Nm]	0,42	1,25	3,87	3,92	0,36			
	coefficient of variation	0,27%	0,83%	2,61%	2,61%	0,24%			

highest and lowest value

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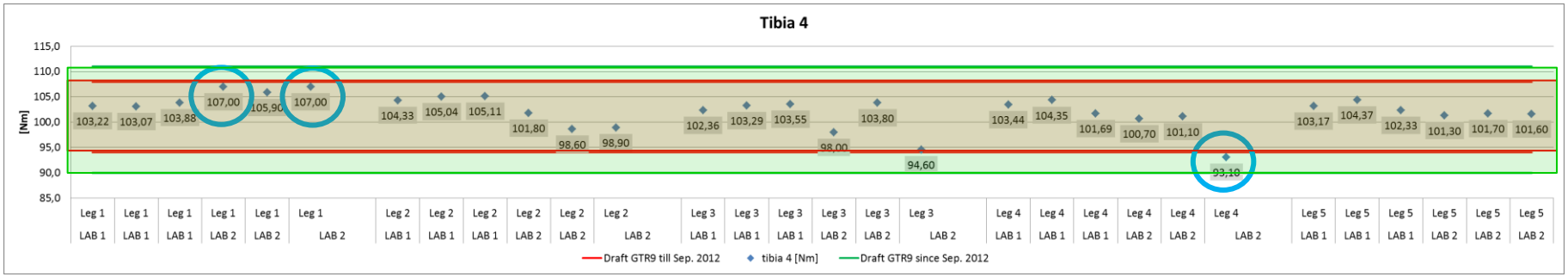
Pendulum Certification Test Results – Tibia 4

Draft GTR9-PH2 till Sep. 2012 (94 – 108 Nm)

- For all legforms, significant scatter of the test results can be noted
- For tests of legforms 2 and 3 in lab 2, test results significantly scatter

Draft GTR9-PH2 since Sep. 2012 (90 – 111 Nm)

- All test results well meet the corridor



relevant limits		Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	LAB 1	LAB 2	Overall
min:	90								
max:	111								
LAB 1 + 2	arithmetic mean [Nm]	105,01	102,30	100,93	100,73	102,41	103,55	101,01	102,28
	standard deviation [Nm]	1,68	2,74	3,45	3,65	1,07	0,95	3,90	3,11
	coefficient of variation	1,60%	2,68%	3,42%	3,62%	1,04%	0,92%	3,86%	3,04%
LAB 1	arithmetic mean [Nm]	103,39	104,83	103,07	103,16	103,29			
	standard deviation [Nm]	0,35	0,35	0,51	1,10	0,84			
	coefficient of variation	0,34%	0,34%	0,50%	1,07%	0,81%			
LAB 2	arithmetic mean [Nm]	106,63	99,77	98,80	98,30	101,53			
	standard deviation [Nm]	0,52	1,44	3,80	3,68	0,17			
	coefficient of variation	0,49%	1,45%	3,84%	3,74%	0,17%			

highest and lowest value

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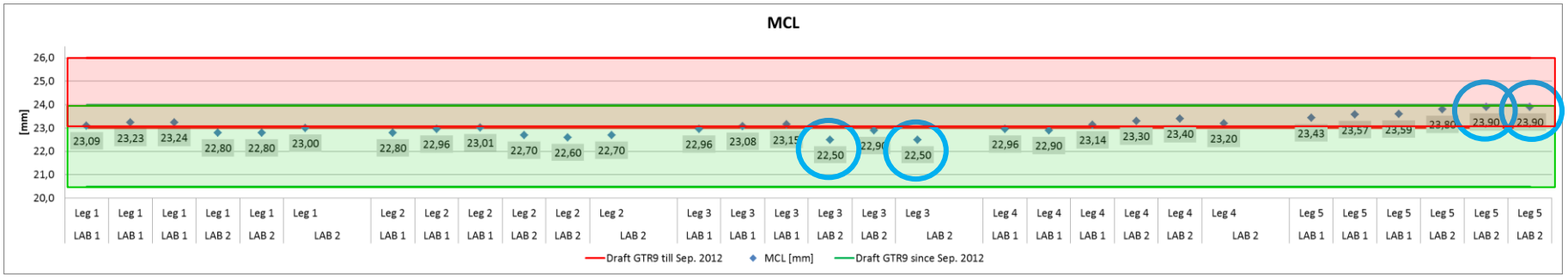
Pendulum Certification Test Results – MCL

Draft GTR9-PH2 till Sep. 2012 (23 – 26 mm)

- All test results are around the lower limit value but miss to meet the corridor regularly

Draft GTR9-PH2 since Sep. 2012 (20,5 – 24 mm)

- All test results are in the upper half of the corridor



relevant limits		Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	LAB 1	LAB 2	Overall
min:	20,5								
max:	24								
LAB 1 + 2	arithmetic mean [mm]	23,03	22,80	22,85	23,15	23,70	23,14	23,07	23,10
	standard deviation [mm]	0,18	0,15	0,26	0,18	0,18	0,23	0,48	0,38
	coefficient of variation	0,78%	0,64%	1,13%	0,76%	0,75%	0,99%	2,07%	1,63%
LAB 1	arithmetic mean [mm]	23,19	22,92	23,06	23,00	23,53			
	standard deviation [mm]	0,07	0,09	0,08	0,10	0,07			
	coefficient of variation	0,30%	0,39%	0,34%	0,44%	0,30%			
LAB 2	arithmetic mean [mm]	22,87	22,67	22,63	23,30	23,87			
	standard deviation [mm]	0,09	0,05	0,14	0,08	0,05			
	coefficient of variation	0,41%	0,21%	0,62%	0,35%	0,20%			

highest and lowest value

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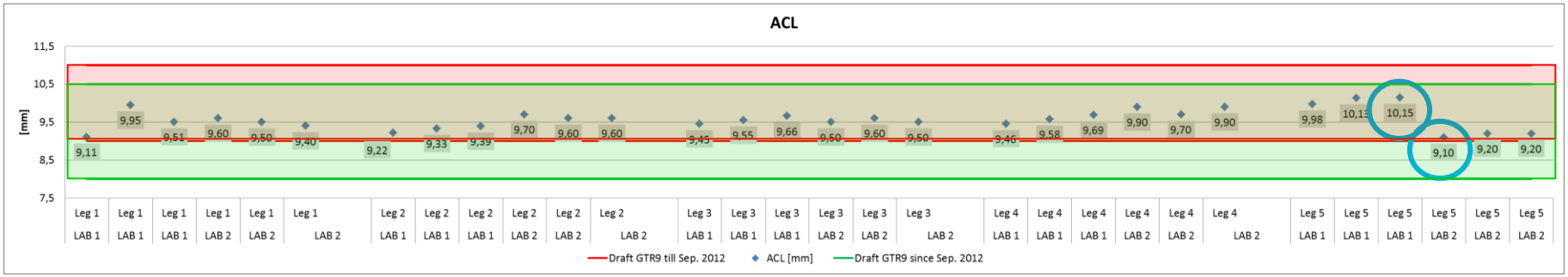
Pendulum Certification Test Results – ACL

Draft GTR9-PH2 till Sep. 2012 (9 – 11 mm)

- Most test results are in the lower half of the corridor

Draft GTR9-PH2 since Sep. 2012 (8 - 10,5 mm)

- Test results are mainly around the middle of the corridor



relevant limits		Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	LAB 1	LAB 2	Overall
min:	8								
max:	10,5								
LAB 1 + 2	arithmetic mean [mm]	9,51	9,47	9,54	9,71	9,63	9,61	9,53	9,57
	standard deviation [mm]	0,25	0,17	0,07	0,16	0,46	0,31	0,23	0,27
	coefficient of variation	2,62%	1,80%	0,73%	1,64%	4,82%	3,20%	2,38%	2,85%
LAB 1	arithmetic mean [mm]	9,52	9,31	9,55	9,58	10,09			
	standard deviation [mm]	0,34	0,07	0,09	0,09	0,08			
	coefficient of variation	3,60%	0,76%	0,90%	0,98%	0,75%			
LAB 2	arithmetic mean [mm]	9,50	9,63	9,53	9,83	9,17			
	standard deviation [mm]	0,08	0,05	0,05	0,09	0,05			
	coefficient of variation	0,86%	0,49%	0,49%	0,96%	0,51%			

highest and lowest value

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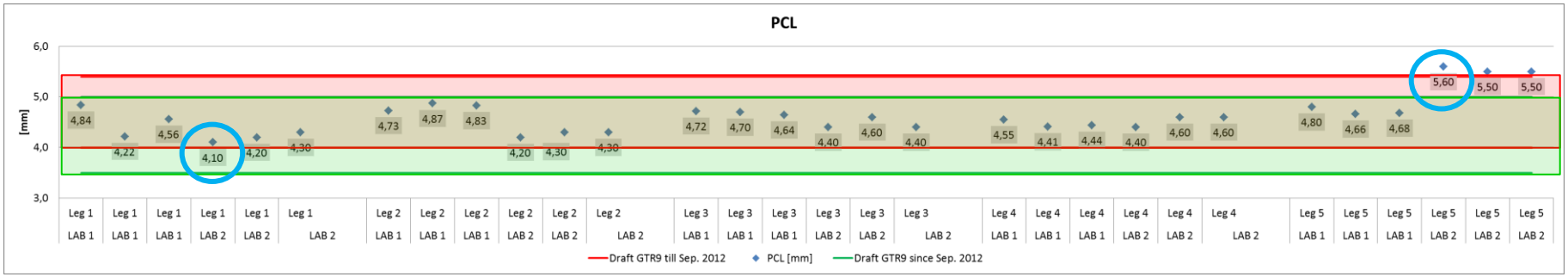
Pendulum Certification Test Results – PCL

Draft GTR9-PH2 till Sep. 2012 (4 – 5.4 mm)

- All test results except of the legform 5 of Lab 2 are in the corridor but show significant scatter

Draft GTR9-PH2 since Sep. 2012 (3,5 – 5 mm)

- All test results except of the legform 5 of Lab 2 are in the corridor



relevant limits		Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	LAB 1	LAB 2	Overall
min:	3,5								
max:	5								
LAB 1 + 2	arithmetic mean [mm]	4,37	4,54	4,58	4,50	5,12	4,64	4,60	4,62
	standard deviation [mm]	0,25	0,28	0,13	0,09	0,41	0,17	0,49	0,37
	coefficient of variation	5,81%	6,10%	2,86%	1,91%	8,07%	3,00%	10,62%	7,95%
LAB 1	arithmetic mean [mm]	4,54	4,81	4,69	4,47	4,71			
	standard deviation [mm]	0,25	0,06	0,03	0,06	0,06			
	coefficient of variation	5,58%	1,22%	0,73%	1,35%	1,31%			
LAB 2	arithmetic mean [mm]	4,20	4,27	4,47	4,53	5,53			
	standard deviation [mm]	0,08	0,05	0,09	0,09	0,05			
	coefficient of variation	1,94%	1,10%	2,11%	2,08%	0,85%			

highest and lowest value

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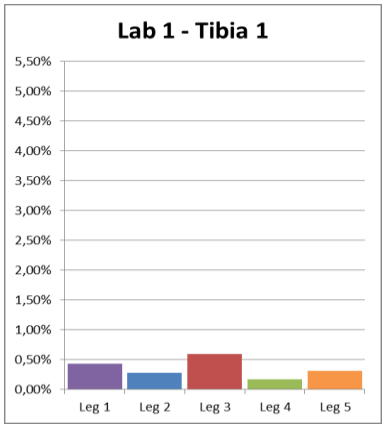
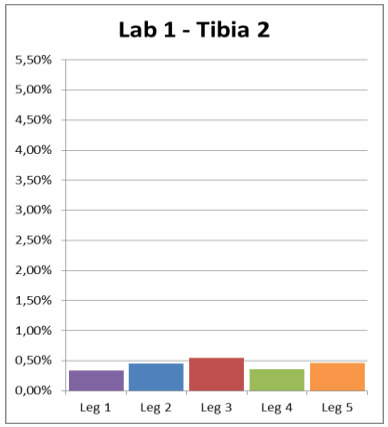
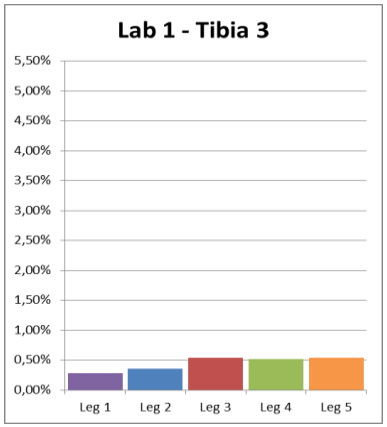
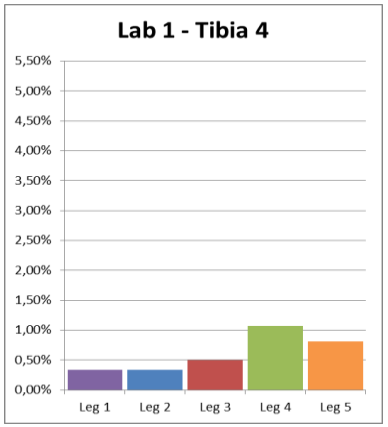
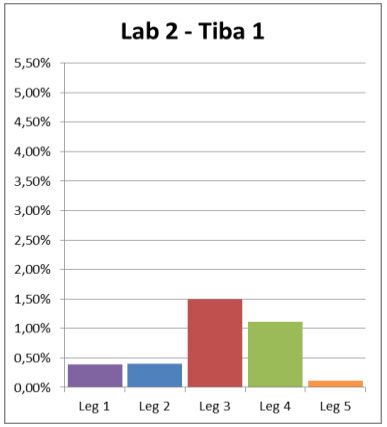
Pendulum Certification: Comparison of CoV (1/2)

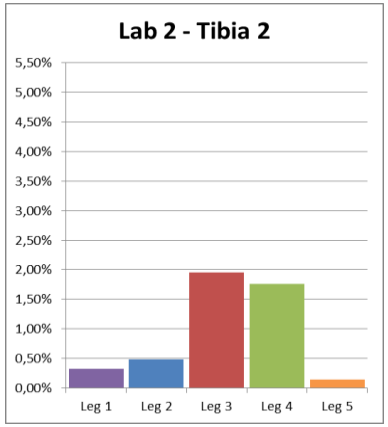


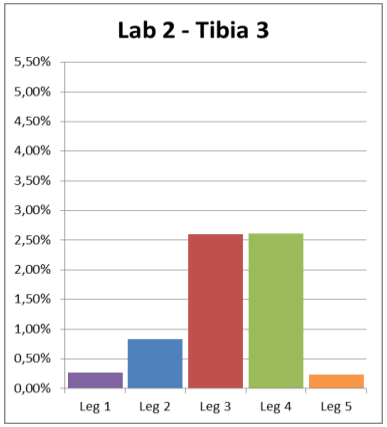


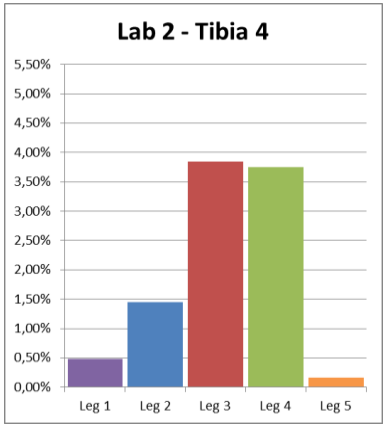












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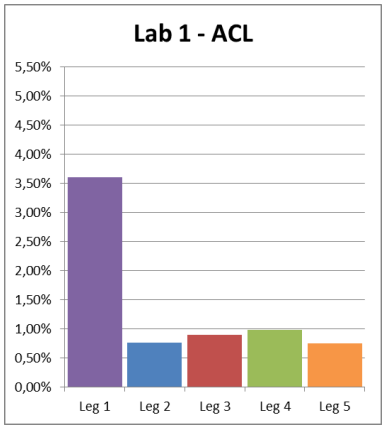
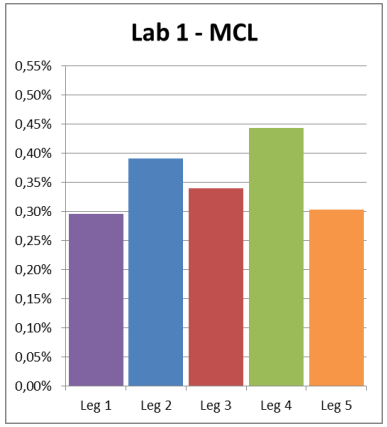
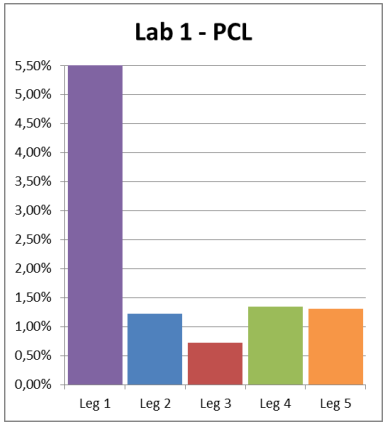
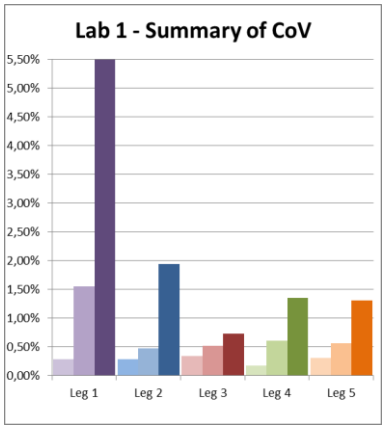
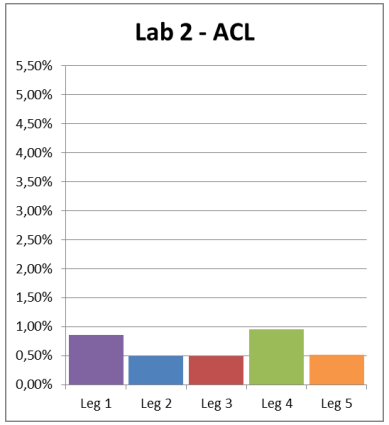
Pendulum Certification: Comparison of CoV (1/2)

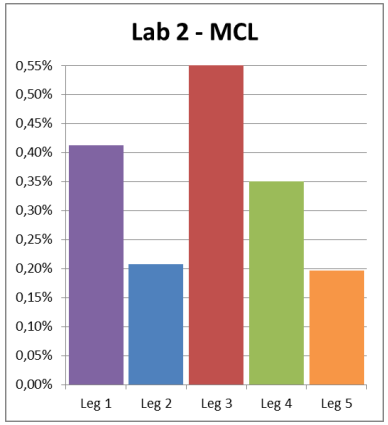


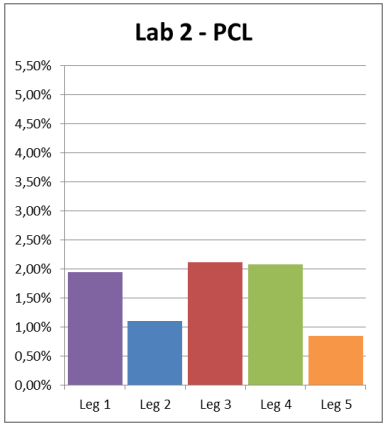


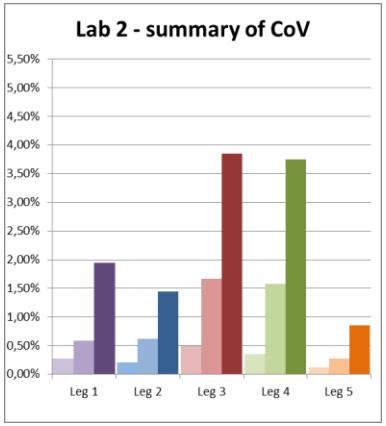












Left: minimum value
Center: average
Right: maximum value

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Agenda

1. Test Series
2. Legforms
3. Inverse Certification Test Results
4. Pendulum Certification Test Results
5. **Summary**
6. Discussion

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Summary (1/3)

- Corridors
  - Corridors agreed in September 2012 fit better than the corridors based on the tests of the prototype legs
  - With the old corridors, 58 of 413 test results fail (41x inverse test, 17x pendulum test)
  - With the new corridors, 5 of test results fail (2x inverse test, 3x pendulum test)

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Summary (2/3)

- Legforms
  - The highest coefficient of variation (CoV) for all inverse tests is 4,16% (PCL)
    - All other CoV values are below 4%
  - Considering the singl labs, the highest CoV for the inverse tests is 5,45% (PCL)
    - 80% of the CoV values are below 2%
    - 90% of the CoV-values are below 3%
  - The highest CoV for all pendulum tests is 8,07% (PCL)
    - All other CoV values are mainly below 3%
  - Considering the single labs, the highest CoV for the pendulum tests is 5,58% (PCL)
    - 89% of the CoV values are below 2%
    - 94% of the CoV values are below 3%

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Summary (3/3)

- Labs
  - Lab 1 generally has a higher arithmetic mean of all criteria for the pendulum tests
    - The highest differences are ≈ 3 Nm at tibia 2 and tibia 3 and 0,08 mm at ACL
  - Lab 2 generally has a higher arithmetic mean of all tibia values for the inverse tests
    - The highest differences are ≈ 13 Nm at tibia 2 and 0,08 mm at ACL
  - The highest coefficient of variation (CoV) for the inverse tests is 6,05% (PCL)
    - All other CoV values are mainly below 3%
  - The highest CoV within the pendulum tests is 10,62% (PCL)
    - All other CoV values are mainly below 3%

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Agenda

1. Test Series
2. Legforms
3. Inverse Certification Test Results
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5. Summary
6. **Discussion**

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Discussion

- The redefinitions of the corridors were based on the test results with the three “master legforms” but it is unclear whether the sensor capabilities (allowed scatter of single sensors) also were considered
- Further tests to confirm the test results and to assess the longtime performance of impactors are carried out at the moment
- Lack of clarity remains for the root causes for the scatter of different legforms, for the question of what can be done if a legform constantly fails meeting the corridors and how a fine tuning of the respective legforms could be done

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Thanks.