Comparison of FlexPLI Performance in Vehicle Tests with Prototype and Series Production Legforms

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At the 3rd meeting of the Informal Group GTR9 Phase 2 a draft proposal for a future work plan regarding the further FlexPLI evaluation by means of vehicle tests was presented by BASt (Doc GTR9-3-06).

This draft work plan suggested testing vehicles from different categories with ideally the series production legforms (SN01, SN03 and E-Leg) whose test results had been previously used for the definition of updated full assembly inverse and pendulum certification corridors (Doc TF-RUCC-4-04).

BASt contributed to the round robin vehicle tests carrying out tests on frontends that had been previously tested against prototype impactors (SN01, SN02 and SN03).

To ensure the impactors being in appropriate conditions, inverse and pendulum certification tests were carried out with the threes series production impactors before and after each vehicle test series.

The test results were afterwards compared to prototype test results that had been carried out on identical impact locations (ESV paper 09-0277).
Impactor evaluation:
E-Leg, SN01, SN03
(serial production level)

Full assy certification (inverse & pendulum):
E-Leg, SN01, SN03
before and after each vehicle test series
7 inverse and pendulum certifications each

Sedan #1:
SN03 (and SN04)
Two impact locations
8 tests

Comparison w/ prototypes:
SN02
Two impact locations
6 tests

Sedan #2:
E-Leg, SN01, SN03
Two impact locations
10 tests

Comparison w/ prototypes:
SN01, SN02, SN03
Two impact locations
12 tests

Comparison rubber length:
SN02
One impact location
2 tests
Inverse certification test results

• All tibia results within new TF-RUCC draft corridors

• Tibia 4 results partly low in corridor

• All knee results well within new TF-RUCC draft corridors
Pendulum certification test results

- All tibia results well within new TF-RUCC draft corridors

- All knee results within new TF-RUCC draft corridors
Sedan #1 test results - Overview

• Two impact locations
• One prototype impactor (SN02) – 6 tests
• One serial production impactor (SN03) – 6 tests
• Comparative tests with SN04 – 2 tests
• All requirements (tentative tibia and knee threshold values) met in all tests
Sedan #1 test results - Repeatability

- Scatter of prototype test results partly marginal or even unacceptable
- Serial production leg shows an improved repeatability
- All coefficients of variation of the serial production leg in an acceptable range

Coefficients of variation – Sedan #1 tests:

<table>
<thead>
<tr>
<th>Setup</th>
<th>Tibia 1</th>
<th>Tibia 2</th>
<th>Tibia 3</th>
<th>Tibia 4</th>
<th>ACL</th>
<th>PCL</th>
<th>MCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedan #1 P1 SN02 Proto</td>
<td>5.05</td>
<td>0.34</td>
<td>1.43</td>
<td>7.43</td>
<td>10.97</td>
<td>4.81</td>
<td>2.89</td>
</tr>
<tr>
<td>Sedan #1 P2 SN02 Proto</td>
<td>2.45</td>
<td>1.75</td>
<td>2.10</td>
<td>7.08</td>
<td>2.66</td>
<td>8.72</td>
<td>2.35</td>
</tr>
<tr>
<td>Sedan #1 P1 SN03 Serial</td>
<td>1.76</td>
<td>1.55</td>
<td>2.24</td>
<td>2.51</td>
<td>6.35</td>
<td>3.61</td>
<td>2.86</td>
</tr>
<tr>
<td>Sedan #1 P2 SN03 Serial</td>
<td>3.28</td>
<td>1.33</td>
<td>0.69</td>
<td>0.44</td>
<td>2.52</td>
<td>6.80</td>
<td>3.72</td>
</tr>
</tbody>
</table>
Sedan #1 test results - Ser. Prod.

- Two impact locations
- One serial production impactor (SN03) - 6 tests
- Comparative tests with SN04 - 2 tests
- All requirements (tentative tibia and knee threshold values) clearly met in all tests
Sedan #1 test results – Proto vs Ser. Prod. #1

- Impact location #1
- Prototype impactor SN02 & Serial production impactor SN03
- 6 tests
- Tibia 1-3 and PCL results lower with serial production impactor
- Tibia 4 and ACL results slightly higher with serial production impactor

<table>
<thead>
<tr>
<th></th>
<th>Tibia A1</th>
<th>Tibia A2</th>
<th>Tibia A3</th>
<th>Tibia A4</th>
<th>ACL</th>
<th>PCL</th>
<th>MCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>UDV SN02</td>
<td>311.33</td>
<td>326.22</td>
<td>244.37</td>
<td>177.54</td>
<td>8.47</td>
<td>7.91</td>
<td>19.67</td>
</tr>
<tr>
<td>UDV SN03</td>
<td>265.37</td>
<td>277.43</td>
<td>218.83</td>
<td>188.67</td>
<td>9.25</td>
<td>5.77</td>
<td>19.50</td>
</tr>
<tr>
<td>Dev. [%]</td>
<td>8.76</td>
<td>14.51</td>
<td>9.30</td>
<td>6.40</td>
<td>9.06</td>
<td>23.11</td>
<td>4.85</td>
</tr>
</tbody>
</table>

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Sedan #1 test results – Proto vs Ser. Prod. #2

- Impact location #2
- Prototype impactor SN02 & Serial production impactor SN03
- 6 tests
- All results lower with serial production impactor

<table>
<thead>
<tr>
<th></th>
<th>Tibia A1</th>
<th>Tibia A2</th>
<th>Tibia A3</th>
<th>Tibia A4</th>
<th>ACL</th>
<th>PCL</th>
<th>MCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>SN02</td>
<td>239.07</td>
<td>282.27</td>
<td>241.50</td>
<td>164.97</td>
<td>6.50</td>
<td>6.43</td>
<td>21.26</td>
</tr>
<tr>
<td>SN03</td>
<td>212.20</td>
<td>260.69</td>
<td>227.03</td>
<td>143.77</td>
<td>6.07</td>
<td>5.30</td>
<td>13.42</td>
</tr>
<tr>
<td>Dev. [%]</td>
<td>-11.24</td>
<td>-5.89</td>
<td>-5.76</td>
<td>-5.21</td>
<td>-6.67</td>
<td>-18.62</td>
<td>-8.75</td>
</tr>
</tbody>
</table>

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Sedan #2 test results - Overview

- Two impact locations
- Three "original" prototype impactors (SN01, SN02 and SN03) – 12 tests
- One "modified" prototype impactor (SN02), i.e. with long rubber sheets – 2 tests
- Three serial production impactors (E-Leg, SN01 and SN03) – 10 tests

- All (except one prototype) tests passed the tentative tibia and knee threshold values
- Only MCL requirement failed once with SN02 prototype
Sedan #2 test results - Repeatability

Comparison of repeatability between prototype and serial production impactors shows inconsistent results.

Repeatability of ACL/PCL partly still unacceptable.

Tibia repeatability improved (all CV’s acceptable).

Increased scatter in knee results.

Coefficients of variation – Sedan #2 tests:

<table>
<thead>
<tr>
<th>Setup</th>
<th>Tibia 1</th>
<th>Tibia 2</th>
<th>Tibia 3</th>
<th>Tibia 4</th>
<th>ACL</th>
<th>PCL</th>
<th>MCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedan #2 P1 SN01</td>
<td>2.18</td>
<td>2.78</td>
<td>4.18</td>
<td>1.59</td>
<td>2.74</td>
<td>4.14</td>
<td>2.68</td>
</tr>
<tr>
<td>Sedan #2 P1 SN02</td>
<td>1.40</td>
<td>1.82</td>
<td>4.01</td>
<td>3.69</td>
<td>1.16</td>
<td>11.68</td>
<td>1.79</td>
</tr>
<tr>
<td>Sedan #2 P1 SN03</td>
<td>8.74</td>
<td>8.83</td>
<td>3.57</td>
<td>7.09</td>
<td>11.88</td>
<td>7.51</td>
<td>10.98</td>
</tr>
<tr>
<td>Sedan #2 P2 SN01</td>
<td>3.36</td>
<td>4.23</td>
<td>2.38</td>
<td>4.87</td>
<td>0.77</td>
<td>4.33</td>
<td>1.38</td>
</tr>
<tr>
<td>Sedan #2 P1 Eleg</td>
<td>1.28</td>
<td>2.78</td>
<td>3.36</td>
<td>4.64</td>
<td>3.14</td>
<td>12.87</td>
<td>4.06</td>
</tr>
<tr>
<td>Sedan #2 P1 SN01</td>
<td>1.74</td>
<td>6.33</td>
<td>6.45</td>
<td>2.10</td>
<td>11.17</td>
<td>10.42</td>
<td>8.32</td>
</tr>
<tr>
<td>Sedan #2 P1 SN03</td>
<td>2.99</td>
<td>4.47</td>
<td>2.64</td>
<td>5.83</td>
<td>4.26</td>
<td>7.10</td>
<td>3.33</td>
</tr>
</tbody>
</table>
Sedan #2 test results – Ser. Prod.

• Two impact locations

• Three serial production impactors (E-Leg, SN01 and SN03) – 10 tests

• All requirements (tentative tibia and knee threshold values) clearly met in all tests
Sedan #2 test results – Proto vs Ser. Prod. #1

- Impact location #1
- Prototype impactors SN01, SN02 and SN03
- Serial production impactors E-Leg, SN01 and SN03
- 18 tests
- Again, test results lower with serial production impactors
Sedan #2 test results – Proto vs Ser. Prod. #2

- Impact location #2
- Prototype impactor SN02
- Serial production impactor SN03
- Only one test performed with serial production impactor
- 4 tests
- Most results (except PCL) lower with serial production impactor

<table>
<thead>
<tr>
<th>Location</th>
<th>Tibia A1</th>
<th>Tibia A2</th>
<th>Tibia A3</th>
<th>Tibia A4</th>
<th>ACL</th>
<th>PCL</th>
<th>MCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>SN02</td>
<td>201.40</td>
<td>194.17</td>
<td>222.57</td>
<td>154.87</td>
<td>7.31</td>
<td>6.67</td>
<td>21.00</td>
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<tr>
<td>Single Test</td>
<td>170.30</td>
<td>155.49</td>
<td>205.20</td>
<td>153.20</td>
<td>6.20</td>
<td>7.00</td>
<td>15.00</td>
</tr>
<tr>
<td>Dev. [%]</td>
<td>-15.44</td>
<td>-9.69</td>
<td>-11.00</td>
<td>-17.00</td>
<td>5.00</td>
<td>-12.64</td>
<td></td>
</tr>
</tbody>
</table>

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Influence of rubber length

- Sedan #2 vehicle tests
- Impact location #1
- Prototype impactor SN02
- 3 tests with long rubber sheets
- 2 tests with short rubber sheets
- Inconsistent influence of rubber length depending on location of particular load paths
• 18 impactor tests with three different serial production impactors (E-Leg, SN01 and SN03) on two different vehicles were carried out at BASt.

• The impactors have been successfully inverse and pendulum certified according to the TF-RUCC corridor proposal before and after each vehicle test series.

• All test results entirely met the tentative FlexPLI thresholds for tibia bending moments as well as ligament elongations according to ECE-TRANS-WP29-GRSP-2011-13e.

• A comparison of the serial production impactor test results with prototype results on identical impact locations shows that the serial production impactors are producing in most cases lower output values than the prototypes. This observation is in line with the inverse certification tests (Doc TF-RUCC-4-04).

• The repeatability of vehicle test results shows an improvement regarding the tibia segments while the scatter in the knee is partly increased.

• The influence of the length of the rubber sheet on the test results is inconsistent and seems to depend on the location of the particularly impacted load paths.
Thank you!