JAMA-JARI Study for the Inverse Test
**Back Grounds**

- Up to now, **two different calibration test methods** for Flex-PLI were proposed.
- One is **Pendulum Test Method**, and the other is **Inverse Test Method**.
- **BASt/BGS strongly supported the Inverse Test Method**, because 1) it can detect **additional mass effect very well** and 2) its **loading speed** to the impactor is **comparable** with that of **during a car test**.
- However, **non of the other organizations had any experiences** to conduct the inverses test, so it is **difficult to judge** the inverse test method is **better than the pendulum test without conducting any inverse tests**.
- **JAMA-JARI** therefore **conducted the Inverse Tests** by themselves at JARI.

![Pendulum Test](image1.png)

![Inverse Test](image2.png)
Materials and Methodology
Inverse Test
Schematic Diagram of the Test Conditions

Hanging System
BAS/BGS Special Made

release the FlexPLI within [5] ms after the moving ram impact

FlexPLI with Flesh (cross sectional image)

Knee joint center

Modified Upper Legform Impactor

Moving ram
Total Mass: 8.1 +/- 0.1 kg
Impact speed: 11.1 +/- 0.2 m/s

Impact face
0 +/- 3 mm at impact

Honeycomb
Width
225 +/- 25 mm
Height
160 +/- 2 mm
Crash strength: 75 psi +/- 10%
Comparison of the Test Equipments
Inverse Test and Pendulum Test

Inverse Test Equipments

- Hanging System
- Moving Stopper
- Flex-GTR-proto (or Flex-GT)
- Moving Ram Guide
- Impact Speed Measurement System

Pendulum Test Equipment

- Hanging System
- Moving Ram
- Moving Ram with Honeycomb
- Propelling System
Test Equipments
Inverse Test: Overall

Flex-GTR-proto (or Flex-GT)
Moving Stopper
Hanging System
Moving Ram with Honeycomb
Impact Speed Measurement System
Moving Ram Guide
Test Equipments
Inverse Test: Hanging System

Hanging System

Hanging Position Adjuster
Vertical direction

Hanging Position Adjuster
Horizontal direction

Spring

Hook
Test Equipments
Inverse Test: Moving Ram with Honeycomb

Moving Ram with Honeycomb

Honeycomb: Cellbond Special Made
(Width 200 x Height 160 x Thickness 60)

Moving Ram Body

Moving Ram Guide
Test Equipments
Inverse Test: Honeycomb

Honeycomb: Cellbond Special Made
(Width 200 x Height 160 x Thickness 60)

How to hold the blue paper

Outlook
Back side
Front/Impact side

Blue Paper Sheet to Cover the Honeycomb
Test Equipments
Inverse Test: Moving Ram Body and Guide System
Test Equipments
Inverse Test: Honeycomb Deformation

After the Inverse Test example
With blue paper sheet

Frontal view

Without blue paper sheet

Frontal view

Top view

Top-Frontal view
<table>
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<th>Test ID</th>
<th>Flex-PLI Type</th>
<th>SN</th>
<th>Modification</th>
<th>Impact Speed (m/s)</th>
<th>Impact Speed (km/h)</th>
<th>Temperature (degrees C)</th>
<th>Relative Humidity (%)</th>
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* SN: Serial Number, Add Mass: Added 100g mass at the top and bottom of the impactor
## Pendulum Test

### Test Conditions

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<th>Flex-PLI type</th>
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<th>Modification</th>
<th>Temperature (degrees C)</th>
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* SN: Serial Number, Add Mass: Added 100g mass at the top and bottom of the impactor
Flex-GTR-prototype (SN03)  
Additional Mass  
Additional Mass in this study  
+ 100 g for femur top  
+ 100 g for tibia bottom  

Current gtr 9 tolerance:  
Femur Mass Tolerance  
+/- 100g  
Tibia Mass Tolerance  
+/- 100g  

BAS/BGS Add Mass  
+ 680g for femur top  
+ 680 g for tibia bottom  

Can not be allowed to attach the 680 g masses  

+ 100 g (Femur Top)  
+100 g (Tibia Bottom)
Results
Inverse Test Results
Kinematics (example)

- The **hanging part** was **released immediately** after the impact.
**Inverse Test Results**
**Waveforms (example)**

- Tibia-1
- Tibia-2
- Tibia-3
- Tibia-4

- Knee-ACL
- Knee-PCL
- Knee-MCL
Inverse Test Results

Waveforms (example)

- Femur-1
- Femur-2
- Femur-3
- Knee (tibia side) - Acc
Inverse Test Results
Comparability with BASt Test Results (Flex-GT)

- Based on the Flex-GT test results, **BASt and JARI test results** were **looked as comparable**.
**Inverse Test Results**

**Additional Mass Effect**

- Additional mass (+100 g for femur top and tibia bottom) effect was insignificant in the Inverse Test.

- **Flex-GTR,proto (SN03), JARI-Apr.09**
- **Flex-GTRPROTO (SN03)-Add Mass, JARI-Apr.09**

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**Impact Speed (m/s)** vs **Bending Moment (Nm)**

- **Tibia-1**
- **Tibia-2**
- **Tibia-3**
- **Tibia-4**

**Impact Speed (m/s)** vs **Elongation (mm)**

- **Knee-ACL**
- **Knee-PCL**
- **Knee-MCL**
Additional mass (+ 100 g for femur top and tibia bottom) effect was also insignificant in the pendulum test.
Discussions

- **JAMA-JARI conducted** the Inverse Tests at JARI in order to investigate its detail.
- **Efforts to conduct single certification test:**
  - Almost one day is needed to conduct the inverse test.
  - Especially, preparation of a lot of test equipments were took much time.
  - Expensive and Non-Reusable Special Honeycomb was required.
- **Impact Condition:**
  - Hard impact, around 250 g (CFC180) was observed at Knee joint level during the Inverse Test, compare to that of the pendulum test (around 80 g).
  - The Impactor was impacted to the stopper wall under a severe impact condition, therefore, it has a chance to be damage the impactor and/or measurement cables during the Inverse Test.
  - Moving Ram has to be stopped suddenly from the 11.1 m/s impact speed condition, therefore, it has a chance to be damaged the Moving Ram under the sudden stop condition.
- **Additional Mass Effect:**
  - Additional 100 g masses, at the top of Femur and at the bottom of Tibia, effect were insignificant in the Inverse Test.
  - Basically, to add 680 g masses, at the top of Femur and bottom of Tibia are not allowed by the gtr 9 mass tolerances (Flex-PLI can be used same tolerances).
  - Additional mass and/or inertia influences can be controlled by tolerances for the Mass, CoG and Moment of Inertia of the impactor.
  - We therefore need not concern these effects seriously by using the inverse test method.
Discussions, contd.

- **Loading Speed:**
  - Loading speed of the Inverse Test is close to that of a car impact test.
  - However, the main parts of the Flex-GTR, bone cores and knee springs, are made with low rate sensitive materials (see appendix).
  - Loading speed is therefore not essential items for the Flex-PLI certification test, whereas, applied loading level is important.
  - Applied loading level is comparable between the Inverse Test and Pendulum Test, therefore, no concerns on this issues for the Pendulum test.
## Conclusions

- **JAMA-JARI conducted** the Inverse Tests at JARI in order to investigate its detail.
- After the investigation, **JAMA-JARI recommend** to use Pendulum Test for a certification test of the Flex-PLI by following reasons,
  - Efforts to conduct single Inverse test is significant for the Inverse Test (much effort is needed to conduct a single test compare to the pendulum test, even if the test is needed per 20 car impact tests). **Pendulum Test** is much Easy and Simple.
  - Impact condition of Inverse test is severe (around 250 g, i.e. upper limit level of the current gtr 9), and the impactor impacted to a stopper wall directly, therefore, it has a chance to be damaged the impactor and/or measurement cables during the inverse test. **Pendulum Test** has no concerns on this issue.
  - Additional Masses Effect (add 100 g masses) was insignificant, therefore, we need not to check the additional effect by the inverse test per 20 car impact tests. (requirement of the tolerance of mass, CoG, moment of inertia are enough to control on this issues)
  - Loading Speed is not essential because the Flex-PLI main parts are made with low rate sensitive materials.
  - Applied load level is important and the loading level is comparable between the Inverse test and the Pendulum test.
  - Merits of the Inverse Test are not significant whereas it is required much efforts to conduct the test.


Appendix

- Low Rate Sensitivity of the Bone Cores of the Flex-PLI.

Tibia Bone Core
Quasi-static 3-Point Bending Test

Tibia Bone Core
Dynamic 3-Point Bending Test

Loading speed of the bone core during a car test: around 1.5 m/s

$F_c$: Force Center, $D_c$: Deflection Center

$M_c$: Moment Center (Nm) = $F_c/2 (N) \times 0.205 (m)$

Support Length: 410 mm

Support (Fixed)

Support (Fixed)

Support (Fixed)

Support (Fixed)

$V$: 80 mm/min

$V$: 0.83 m/s

Ram ($r = 25$ mm, mass= 65.2 kg)

Neoprene

Load transducer

Load transducer

$F_c/2$ $F_c/2$

$D_c$

$F_c$

$D_c$

$F_c$

$D_c$

Support base

Support base

Support base

Support base

$F_c$: Force Center, $D_c$: Deflection Center

$M_c$: Moment Center (Nm) = $F_c/2 (N) \times 0.205 (m)$

Quasi-static 3-Point Bending Test

Dynamic 3-Point Bending Test

0 5 10 15 20 25 30 0 50 100 150 200 250 300 350 400 450 500

Deflection center $D_c$ (mm)

Moment center $M_c$ (Nm)
Appendix

- Low Rate Sensitivity of the Bone Cores of the Flex-PLI.

Loading speed of the bone core during a car test: around 1.5 m/s

Direct impact to the bone cores
**Appendix**

- Low Rate Sensitivity of the Knee Springs of the Flex-PLI.

Loading speed during the dynamic compression test: 0.3 m/s
Loading speed of the knee spring during a car test: around 0.5 m/s