Development of a Biofidelic Flexible Pedestrian Legform Impactor Type GT (FLEX-GT)

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Background
Background

• The flexible pedestrian legform impactor type GT prototype (Flex-GT-prototype (called as Flex-GTα in the previous report\(^1\), \(^2\)) was developed in Spring 2006.
• In this version, 1) the range of motion of the knee region, 2) the light weight of the bone parts, as well as 3) the biofidelity under assembly level (Thigh-Knee-Leg connected level) are improved.
• However, a validation of the biofidelity under assembly level was not completely conducted, so it still needs to be validated.
• Thus, further validation study on the biofidelity of this impactor, detailed computer simulation analysis was performed.
**Computer simulation models**

**Simplified Car Model Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
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</thead>
<tbody>
<tr>
<td>$K_1$ (BLE stiffness)</td>
<td>mm</td>
<td>0.4</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>$K_2$ (BP stiffness)</td>
<td>JC</td>
<td>0.7</td>
<td>0.8</td>
<td>1.0</td>
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<tr>
<td>$K_3$ (SP stiffness)</td>
<td>JC</td>
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<td>0.8</td>
<td>1.0</td>
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<tr>
<td>$H_1$ (BLE height)</td>
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<td>650</td>
<td>700</td>
<td>750</td>
</tr>
<tr>
<td>$H_2$ (BP height)</td>
<td>mm</td>
<td>450</td>
<td>490</td>
<td>530</td>
</tr>
<tr>
<td>$H_3$ (SP height)</td>
<td>mm</td>
<td>250</td>
<td>270</td>
<td>300</td>
</tr>
<tr>
<td>$L_1$ (BLE lead)</td>
<td>mm</td>
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<td>200</td>
<td>275</td>
</tr>
<tr>
<td>$L_2$ (SP lead)</td>
<td>mm</td>
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<td>0</td>
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</tbody>
</table>

* Stiffness is changed by steel plate thickness.

**Explanation of Simplified Car Model**

**Over view – oblique front projection drawing**

As for the Flex-GT-prototype model, Impact height ($H_I$) base + 50 mm and base + 75 mm is also calculated.
**Explanation of Simplified Car Model**

**Frontal view of the car**

- **BLE elements** (Shell elements, Deformable)
- **BP elements** (Shell elements, Rigid)
- **SP elements** (Shell elements, Rigid)

**Fixed part**

- 50 mm
- 500 mm
- 50 mm

**BP joint** (Y translation)

**SP joint** (Y translation)

**Explanation of Simplified Car Model**

**Side view of the car**

- **BLE elements** (Shell elements, Deformable)
- **BP elements** (Shell elements, Rigid)
- **SP elements** (Shell elements, Rigid)

**BP joint** (Y translation)

**SP joint** (Y translation)

BLE: Bonnet leading edge
BP: Bumper
SP: Spoiler
Explanation of Simplified Car Model
BP and/or SP joint properties of the simplified car model

![Graph showing force versus displacement with JC 1.0, JC 0.8, JC 0.7, JC 0.6 curves.]

Specifications of the simplified car models (total 18 types)
Based on design of experiment method, L18 orthogonal table is utilized

<table>
<thead>
<tr>
<th>Simplified Car Model ID</th>
<th>K1 (BLE stiffness*)</th>
<th>K2 (BP stiffness**)</th>
<th>K3 (SP stiffness**)</th>
<th>H1 (BLE height)</th>
<th>H2 (BP height)</th>
<th>H3 (SP height)</th>
<th>L1 (BLE lead)</th>
<th>L2 (SP lead)</th>
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<td>700</td>
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<td>-20</td>
</tr>
</tbody>
</table>

* Stiffness is changed by steel plate thickness.
** Stiffness is changed by joint characteristics.
*** JC: Joint characteristics
# BLE: Bonnet leading edge, BP: Bumper, SP: Spoiler
Posture of the human model

a) Back view of HM  
b) Side view of HM  
HM: Human Model

Setting of the simplified car model for the human model

BP, SP for initial impact side of leg  
BP, SP for opposite side of leg  
BP, SP for non-initial impact side of leg
Front placement position of the Flex-GT-prototype model to the simplified car model

In this study, tibia bending moment of Flex-GT-prototype is estimated from each part of bone core strain using bone core 3 point bending test results not using conventional dynamic 3 point leg bending test like before (dynamic 3 point bending test include high inertia force of leg then difficult obtain appropriate conversion values).

Measurement points of the human model and the Flex-GT-prototype model

Tibia bending moment of human model can be obtained directory.
Results

Results: Relationship between the Human model and Flex-GT prototype model

- To lift up the impact height of the Flex-GT can be obtained better correlation to the human one.
Discussions

Upper body effect (1): Lifting up the lower limb

Upper body tend to stay at the initial position because of its high inertia, as a result, upper body tend to lift up the knee joint and leg positions vertically.

Impactor lift up motions of knee joint and leg position are relatively small.

a) Human model, H: base
b) Flex-GT-prototype model, H: base
**Upper body effect (2): Inhibition of thigh behavior**

Upper body tend to stay at the initial position because of its high inertia, as a result, the thigh behavior is disturbed.

The thigh can move easily compared to the human one, as a result, tend to generate large bending angle at the knee joint position.

In order to sift up the impact height, leg rotation is facilitated, as a result, the knee bending angle can be comparable to the human one.

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**Upper body effect (2): Angle of the thigh, leg, and knee (S11, example)**

<table>
<thead>
<tr>
<th>Time (ms)</th>
<th>Angle (deg)</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
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<tr>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

**Knee angle of human model**

- Knee angle is bigger than the human one
- Knee angle is comparable to the human one
Discussions and Conclusions

- From the results of this analysis, an impact height 50-75 mm higher than the base (25 mm) more correlated with the human model. One of the reasons for this is seemed as to be the effect of the presence or absence of the human upper body.
- The human upper body has great inertia force because of its size in mass relative to the leg, which tends to stay relatively at the initial position even after the leg crashes into a car. Therefore, during impact with a car, the upper body tends to lift up the leg overall.
- It is highly possible that these differences cause the difference in the loading condition on the tibia and the knee medial collateral ligament, and it is suggested that changing the impact height of the pedestrian legform impactor have effects to correct these differences.
- Moreover, the human upper body has the effect of inhibiting thigh movement due to its great inertia force.
- As mentioned above, the human upper body has great inertia force because of its size in mass relative to the leg, which tends to stay relatively at the initial position even after the leg crashes into a car. Therefore, during impact into a car, it inhibits thigh behavior to prevent the thigh from falling against the car.
- It is considered that shifting the impact position of the pedestrian legform impactor upwards especially facilitates rotation of the leg region of the pedestrian legform impactor, and as a result, the load occurring on the knee part has the same effect as in the human body.

Discussions and Conclusions, contd.

- Additionally, it has a chance that the difference in distribution of mass between the human body and the pedestrian legform impactor, while in the human body the bone part is very light in weight and a flesh part covers most of the mass, affects to the human and impactor differences.
- In the regulatory purpose pedestrian legform impactor, it is difficult to reduce the mass of the bone part to be equivalent to that of the human body because of various limitations such as incorporation of measuring censors, endurance, and testability.
- Moreover, to change the current impactor specification has a high risk for the developments itself (unexpected issue will be happened, that’s from our a lot of experiments).
- To keep the current specification of the impactor and to select best impact heights is therefore one of a good practical method we believe.
References

1) UN/ECE/WP29/GRSP/INF-GR-PS/Flex-TEG: Information on the Flexible Pedestrian Legform Impactor GT Alpha (Flex-GT-alpha), TEG-021 (2006)
2) UN/ECE/WP29/GRSP/INF-GR-PS/Flex-TEG: Evaluation Activities on Injury Assessment Ability of the Flexible Pedestrian Legform Impactor GT Alpha (Flex-GT-alpha), TEG-022 (2006)

Thank you for your attentions!