Progress Report on Neck Injury Criteria Works for Discussion

Collaboration works with NHTSA(VRTC)

Part I

JAPAN
JMLIT/JASIC/JARI
<Contents>

1. Calculation of NDC from 20 cases FE Simulation
   - Investigation for calculation method of NDC
   - Calculation of NDC
   - Correlation between NDC and Strain(rate)
   - Correlation between NDC and IV-NIC(R)
   - Creation and Comparison of NDC Risk Curve

2. Re-analysis of PMHS test data with the Production Seat
   - Re-analysis of PMHS test data
   - Creating of NDC and IV-NIC(R) Risk Curve
   - Correlation between NDC/IV-NIC(R) and Neck Force/Moment

3. Study on Neck Injury Parameters and Injury Criteria
   - Injury Evaluation Parameters
   - Selection of Neck Injury Criteria (Consideration of BioRID-II R&R)
Calculation method of NDC (defined by NHTSA/VRTC)

One example of the time histories for NDCr, NDCx and NDCz deduced by the 20 cases of the FE simulation is shown in the next page.
Time history of NDCr

NDCr is the rotation angle (RA) for the Head O.C. relative to the T1 as shown in the figure. In the figure, the relative angles of each cervical vertebrae (CV) are also shown.

- As for the RA on NDCr and each CV, the extension by the simulation was not so apparent, but the flexion typically appeared.
- As for the FMVSS202a, the head backward rotational motion relative to the T1 (extension) is set as the regulation (12 degrees).
- On the other hand, the head flexion motion by the simulation typically appeared.
- As for the Head backward rotational motion relative to the T1 (during the interaction between the head and the headrest), it should be pointed out that there is the more important issue as to which phase (flexion or extension) will influence the occurrence of the neck injury.
Time history of NDCx

NDCx is the x-axis displacement for the Head O.C. relative to the T1 as shown in the figure. In the figure, the X axis displacements of each CV are also shown.

- As for the displacement on NDCx and each CV by the simulation, the head rearward motion (HRM) was not so apparent, but the head forward motion typically appeared.
- The peak value of the head rearward and the head forward motion were also calculated.
Time history of NDCz

NDCz is the z-axis displacement for the Head O.C. relative to the T1 as shown in the figure. In the figure, the z-axis displacement of each CV are also shown.

As for the displacement on NDCz and each CV by the simulation, the compression was not apparent, but the tension typically appeared.

The peak value of the compression and the tension were also calculated.

The peak value of NDCr, NDCx, and NDCz are summarized in next page.
Calculation Results of NDCr, NDCx and NDCz

The peak value of NDCr, NDCx and NDCz by the FE simulation are as follows:

<table>
<thead>
<tr>
<th>ID No.</th>
<th>$\Delta v$ [km/h]</th>
<th>Mean Acc. [g]</th>
<th>Peak Acc. [g]</th>
<th>WAD</th>
<th>NDCr (Ext.) [deg]</th>
<th>NDCr (Fix.) [deg]</th>
<th>NDCx (Head-R) [mm]</th>
<th>NDCx (Head-F) [mm]</th>
<th>NDCz (Comp.) [mm]</th>
<th>NDCz (Ten.) [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1_D</td>
<td>28.2</td>
<td>5.8</td>
<td>10.6</td>
<td>2</td>
<td>2.09</td>
<td>8.06</td>
<td>5.56</td>
<td>20.04</td>
<td>0.01</td>
<td>6.54</td>
</tr>
<tr>
<td>4_D</td>
<td>26.0</td>
<td>5.6</td>
<td>12.6</td>
<td>3</td>
<td>0.00</td>
<td>6.60</td>
<td>0.00</td>
<td>13.12</td>
<td>0.11</td>
<td>7.64</td>
</tr>
<tr>
<td>4_P</td>
<td>26.0</td>
<td>5.6</td>
<td>12.6</td>
<td>3</td>
<td>2.31</td>
<td>6.47</td>
<td>3.87</td>
<td>12.75</td>
<td>0.02</td>
<td>6.52</td>
</tr>
<tr>
<td>2_D</td>
<td>23.3</td>
<td>6.7</td>
<td>14.7</td>
<td>2</td>
<td>3.29</td>
<td>6.75</td>
<td>0.00</td>
<td>20.03</td>
<td>0.00</td>
<td>5.10</td>
</tr>
<tr>
<td>8_D</td>
<td>20.4</td>
<td>5.2</td>
<td>12.8</td>
<td>1</td>
<td>0.41</td>
<td>8.00</td>
<td>0.00</td>
<td>24.83</td>
<td>0.07</td>
<td>2.54</td>
</tr>
<tr>
<td>8_P</td>
<td>20.4</td>
<td>5.2</td>
<td>12.8</td>
<td>2</td>
<td>0.00</td>
<td>8.44</td>
<td>0.00</td>
<td>23.94</td>
<td>0.02</td>
<td>4.82</td>
</tr>
<tr>
<td>7_D</td>
<td>19.5</td>
<td>4.0</td>
<td>9.2</td>
<td>0</td>
<td>3.11</td>
<td>5.02</td>
<td>4.59</td>
<td>8.05</td>
<td>0.01</td>
<td>4.93</td>
</tr>
<tr>
<td>7_P</td>
<td>19.5</td>
<td>4.0</td>
<td>9.2</td>
<td>1</td>
<td>2.92</td>
<td>5.92</td>
<td>0.18</td>
<td>15.11</td>
<td>0.32</td>
<td>2.53</td>
</tr>
<tr>
<td>10_D</td>
<td>17.6</td>
<td>5.0</td>
<td>12.4</td>
<td>1</td>
<td>0.83</td>
<td>9.31</td>
<td>0.00</td>
<td>27.15</td>
<td>0.06</td>
<td>3.46</td>
</tr>
<tr>
<td>10_P</td>
<td>17.6</td>
<td>5.0</td>
<td>12.4</td>
<td>2</td>
<td>2.66</td>
<td>6.29</td>
<td>0.15</td>
<td>17.54</td>
<td>0.04</td>
<td>3.55</td>
</tr>
<tr>
<td>6_D</td>
<td>16.3</td>
<td>4.9</td>
<td>12.1</td>
<td>0</td>
<td>1.88</td>
<td>5.45</td>
<td>0.22</td>
<td>13.66</td>
<td>0.04</td>
<td>3.03</td>
</tr>
<tr>
<td>6_P</td>
<td>16.3</td>
<td>4.9</td>
<td>12.1</td>
<td>1</td>
<td>0.00</td>
<td>6.47</td>
<td>0.00</td>
<td>21.27</td>
<td>0.06</td>
<td>2.61</td>
</tr>
<tr>
<td>11_D</td>
<td>16.3</td>
<td>6.5</td>
<td>15.2</td>
<td>0</td>
<td>0.00</td>
<td>10.51</td>
<td>0.00</td>
<td>25.86</td>
<td>0.01</td>
<td>3.58</td>
</tr>
<tr>
<td>11_P</td>
<td>16.3</td>
<td>6.5</td>
<td>15.2</td>
<td>0</td>
<td>4.02</td>
<td>6.18</td>
<td>0.00</td>
<td>9.47</td>
<td>0.00</td>
<td>3.81</td>
</tr>
<tr>
<td>21_D</td>
<td>14.3</td>
<td>4.5</td>
<td>10.6</td>
<td>0</td>
<td>0.68</td>
<td>6.28</td>
<td>0.00</td>
<td>12.63</td>
<td>0.07</td>
<td>3.52</td>
</tr>
<tr>
<td>23_D</td>
<td>11.1</td>
<td>3.7</td>
<td>8.9</td>
<td>1</td>
<td>0.22</td>
<td>6.06</td>
<td>0.00</td>
<td>18.92</td>
<td>0.07</td>
<td>2.33</td>
</tr>
<tr>
<td>20_D</td>
<td>10.8</td>
<td>3.7</td>
<td>7.1</td>
<td>1</td>
<td>0.63</td>
<td>6.53</td>
<td>0.00</td>
<td>14.31</td>
<td>0.03</td>
<td>3.10</td>
</tr>
<tr>
<td>20_P</td>
<td>10.8</td>
<td>3.7</td>
<td>7.1</td>
<td>0</td>
<td>0.43</td>
<td>6.09</td>
<td>0.00</td>
<td>16.37</td>
<td>0.16</td>
<td>2.63</td>
</tr>
<tr>
<td>24_D</td>
<td>8.8</td>
<td>3.5</td>
<td>7.5</td>
<td>1</td>
<td>0.78</td>
<td>2.79</td>
<td>0.14</td>
<td>7.49</td>
<td>0.07</td>
<td>2.45</td>
</tr>
<tr>
<td>3_D</td>
<td>14.7</td>
<td>5.2</td>
<td>7.5</td>
<td>2</td>
<td>1.63</td>
<td>4.19</td>
<td>0.04</td>
<td>14.53</td>
<td>0.10</td>
<td>3.18</td>
</tr>
</tbody>
</table>
Summary of relationships between NDCr/NDCx/NDCz and WAD

NDCr:
The correlation coefficient between NDCr (Extension and Flexion) and WAD was quite low (0.1).

NDCx:
The correlation coefficient between NDCx (Head-Rearward and Head-Forward) and WAD was also quite low (around 0.1).

NDCz:
The correlation coefficient between NDCz (Compression) and WAD was quite inverted. However, the relationship between the Tension and the WAD had a higher correlation (0.632).

As shown in these results, there is only findings of correlation between NDCz·Tension and WAD.

In order to verify the relationship between NDCr/NDCx/NDCz and Strain(Rate) the following survey was also done.
Correlation coefficient of Strain was around 0.7.
Correlation coefficient of Strain Rate exceeded 0.5.
### Relationship between NDCr/NDCx/NDCz and Strain(Rate) (Correlation Coefficient)

<table>
<thead>
<tr>
<th>Correlation Coefficient (R)</th>
<th>NDCr</th>
<th>NDCx</th>
<th>NDCz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Extension</td>
<td>Flexion</td>
<td>Head-Rear</td>
</tr>
<tr>
<td>Max Principal Strain</td>
<td>0.191</td>
<td>0.706</td>
<td>0.116</td>
</tr>
<tr>
<td>Max Shear Strain</td>
<td>0.166</td>
<td>0.699</td>
<td>0.133</td>
</tr>
<tr>
<td>Max Principal Strain Rate</td>
<td>0.044</td>
<td>0.604</td>
<td>0.300</td>
</tr>
<tr>
<td>Max Shear Strain Rate</td>
<td>0.036</td>
<td>0.529</td>
<td>0.323</td>
</tr>
</tbody>
</table>

#### NDCr:
Correlation coefficient of Flexion and Strain(Rate) was around 0.5 to 0.7.

#### NDCx:
Correlation coefficient of Head-Forward and Strain(Rate) exceeded 0.7.

#### NDCz:
Correlation coefficient of Tension and Strain was around 0.5.
Relationship between NDCr•Flexion/NDCx•Flxsion and IV-NIC(R)

- Correlation coefficient of IV-NIC(R)•Flexion was 0.708.
- Correlation coefficient of IV-NIC(R)•Flexion was 0.871
### Relationship between NDCr/NDCx/NDCz and IV-NIC(R) (Correlation Coefficient)

<table>
<thead>
<tr>
<th>Correlation Coefficient (R)</th>
<th>NDCr</th>
<th>NDCx</th>
<th>NDCz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Extension</td>
<td>Flexion</td>
<td>Head- Rear</td>
</tr>
<tr>
<td>IV- NIC_Extension_Mean</td>
<td>0.230</td>
<td>0.014</td>
<td>0.538</td>
</tr>
<tr>
<td>IV- NIC_Flexion_Mean</td>
<td>0.236</td>
<td>0.708</td>
<td>0.028</td>
</tr>
</tbody>
</table>

- **NDCr**: Correlation coefficient of NDCr - Flexion and IV-NIC(R) - Flexion was around 0.708.

- **NDCx**: Correlation coefficient of Head-Forward and IV-NIC(R) - Flexion was around 0.871.

- **NDCz**: Correlation coefficient of Tension and IV-NIC(R) - Flexion was quite low (0.254).
Summary of Relationship between NDCr/NDCx/NDCz and IV-NIC(R) (Correlation Coefficient)

- As for the relationship between NDC and WAD, only NDCz· Tension had correlation with WAD.

- As for the relationship between NDC and Strain(Rate), only NDCx· Head-Forward had correlation with Strain(Rate).

- As for the relationship between NDC and IV-NIC(R), NDCr· Flexion and NDCx· Head-Forward had correlation with IV-NIC(R)· Flexion.
Conclusion

◆ The correlation coefficient between WAD and IV-NIC is quite high. On the other hand, it is quite low for the correlation coefficient between WAD and NDC.

◆ The correlation among the Strain, the NDC, and the IV-NIC as predictors of the cervical vertebral motion is quite high.

◆ According to the significant correlation among those parameters shown as the cervical injury risks, it is possible to predict cervical injuries with the common indicator of IV-NIC based on the results among the human volunteer tests, the CAE (20 cases of accident reconstruction simulations), and the PMHS tests.

The injury risk curves on both of WAD and IV-NIC based on the CAE, and AIS and IV-NIC based on the PMHS tests are established. Although it is under review by NHTSA and JAPAN, the injury evaluation parameters and the injury criteria for informal GTR7 are tentatively reported as shown in Part II, for your consideration.
Further discussion (if needed)
Clarification of the concepts on the NDC and the neck injury parameters proposed by Japan

- Concept of the NDC
  Neck soft tissue injuries are induced by the energy accumulation of the whole relative motion between the Head O.C. and T1 during the head-headrest interaction.
  The total displacement of the cervical vertebrae come up with “the total motion of the Head O.C. relative to the T1”. In other words, it assumes that any minor neck injuries are possible to be evaluated by the entire neck motion.

- Concept of the neck injury parameters proposed by Japan
  Neck soft tissue injuries are caused by the relative motion of the cervical vertebrae, and also the soft tissues surrounding to cervical vertebrae as it is stretched by the relative motion of the cervical vertebrae.
  It assumes that the relative cervical vertebral motion is one main causation of minor neck injuries.