Study on Impact Response (Injury Value) Variation Factors for BioRID-II Dummies

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ABSTRACT

The study aims to contribute to discussions for the standardization of BioRID-II dummies as an evaluation test tool, which is underway at the UN ECE/WP29/GRSP Head Restraint gtr Informal Meeting. Since it is important that as a test tool, BioRID-II be able to ensure a high repeatability and reproducibility, BioRID-II's response variations in calibration and sled tests be examined using the following simulation techniques: First, to identify variation factors, a calibration test simulation model (MADYMO 7.2) was developed. In the simulation, three parameters (i.e., bumper characteristics, cable-spring characteristics, and damper characteristics) were varied in such a way that the prescribed corridor was satisfied and the resultant variations in acceleration, load, moment and other readings of BioRID-II were examined. Next, a sled test simulation model was developed, and using this simulation model, a similar parameter study was conducted for sled testing. The dummies' head acceleration, T1 acceleration, neck force and neck moment were measured. In addition, rotations of the head, neck and torso were also measured and analyzed. According to the simulation results, the calibration test generated the following variations in terms of CV values: 2~20% for rotation angle and 2~10% for acceleration, load and moment. On the other hand the sled test generated variations of: 2~15% for rotation angle and 2~15% for acceleration, load and moment. The data proves that the bumper, the cable spring, and the damper influence the impact response of the dummy's rotation angle and injury value. Moreover, injury value variations proved practically identical between calibration and sled tests. Nevertheless clear differences between the two tests were found in the impact responses of respective rotation angles and injury values, also in the peak values and peak times. It was also found that these injury value variations can be minimized by approximation of impact responses and peak values, and by the synchronization of peak times between the two tests. Consequently it was considered necessary to introduce a calibration test method requiring seatback and head restraint conditions closely resembling that of the actual vehicle. This research compares the results of a calibration test and a ΔV16km/h sled test. The problem of determining what factors are affected by the calibration method of the BioRID-II dummy can now be defined. Moreover, the variation factor of the test conditions (dummy set, pulse, etc.) was also eliminated, and therefore only the cause of the variation of the dummy was studied. This analysis have yet to be reported until now, which makes such reports indispensable to the study of HR dynamic examination method of the UN ECE/WP29/GRSP.

1. Background

At the UN ECE/WP29/GRSP, an Informal Working Group on development of Global technical regulation No.7 ("Head Restraint gtr Informal Meeting") has been held since February 2005. Phase1 (it regulates as a standard requirement to the headrest about static backset (distance between the back of the head of a seated 3D mannequin and the head restraint)) was manufactured in March, 2008. Then, from December 2009, Phase2 of the Head Restraint gtr Informal Meeting (evaluation by dynamic test) was initiated. At the meeting, established was the evaluation by non geometric requirements called static backset but with a dummy injury value as a target. What was discussed was a target injury, a test method, etc. This currently, study focuses on dummy repeatability and reproducibility for use in regulation.

Japan Automobile Research Institute (JARI) and Japan Automobile Manufacturers Association (JAMA) has been studying [(1) - (3)] the test evaluation method which can reduce the neck injury generated during vehicle accident, and this testing method is to be proposed to Japan or other countries. As part of the research, injury value variation generated in evaluation test is examined. Various factors, such as variations in test conditions (impact acceleration, a dummy arrangement, etc.) and the individual differences of dummies or sheet, are included in injury value variation. This research particularly focused on whether or not injury value variation in calibration testing affects dummy responses in rear impact sled test. More specifically, analysis of the simulation of calibration test and Sled test was

similarly performed on the test condition, and the influence of the variation given to a dummy injury value was examined.

2. BioRID-II Dummies

2.1 Issues concerning BioRID-II Dummies

Dummies such as BioRID-II, RID3D and Hybrid-III have been proposed as rear impact dummies. Past research(4) indicated that BioRID-II (Fig.1) is proven to be the most biofidelic dummy, and test methods using BioRID-II have been adopted by the JNCAP and EuroNCAP. BioRID-II has a spine comprising of 24 vertebrae including not only the cervical but also the thoracic and lumbar vertebrae. With such a structure, BioRID-II now has the characteristic that enables it to reproduce the human spine movements. In additionally, the various body parts of BioRID-II have been given mechanical characteristics that resemble the responses of human body parts in volunteer sled tests. These merits have contributed to the high biofidelity of BioRID-II. On the other hand, because of its having a more structure compared to other dummies, BioRID-II has been reported to have issues of test reproducibility and differences in individual dummies(6). The major factors responsible for injury value variations have been thought of as (a) individual differences of dummies, (b) dummy adjustment, and (c) dummy setting at the sled test.

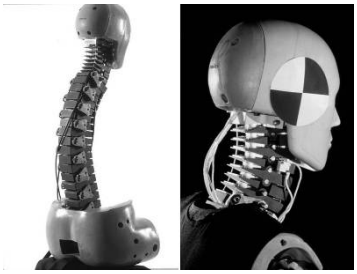

Fig.1 BioRID-II

2.2 Calibration Test Method for BioRID-II

To make sure that a dummy secures its dynamic response characteristics, BioRID-II calibration tests provide corridors(5) for each of the measurement items listed in Table 1. Regarding the three rotation angles shown in Fig.3, corridors have been set for each head rotation of the occipital condyle (Pot.A), neck link rotation about the first thoracic vertebra (Pot.B), and T1 rotation (Pot.C). In order to place the dummy’s response in the corridors at calibration test, various body parts of the dummy need to be adjusted. According to the users’ manual on BioRID-II, the bumper, cable spring and damper are mainly what need to be adjusted to put the three rotation angles into their respective corridors(7) in a calibration test. Moreover, the new calibration test method of BioRID-II is also proposed, but this research applied the existing method of calibration testing.

Table.1 Measurement Item of Calibration Test

Measurement Item	
Pendulum Force	N
Sled Acceleration	m/s^2
Sled Velocity	m/s
T1 Acceleration	m/s^2
Head Rotation about Occipital Condyle	deg
Neck Link Rotation about T1	deg
T1 Rotation	deg

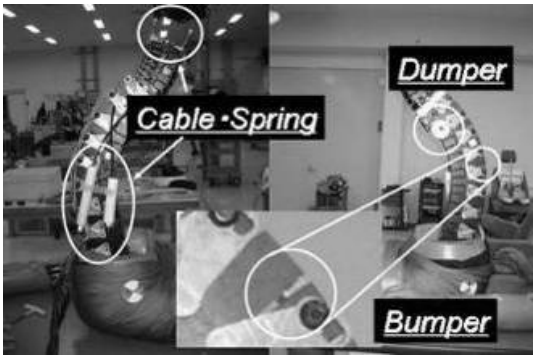

Fig.2 Adjustment Item of Calibration Test

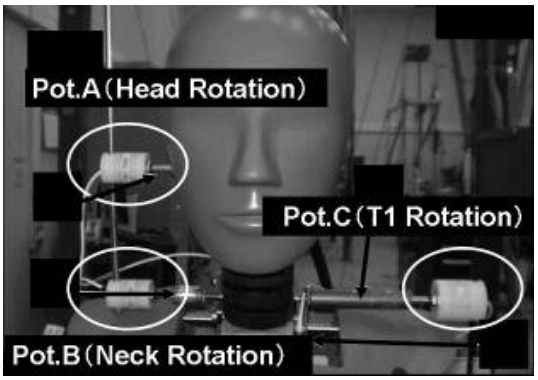

Fig.3 Rotation Angle of Calibration Test

3. Simulation Analysis of Calibration Test

In order to examine the variation in the dummy in a calibration test, it is necessary to ensure the reproducibility of a test. So, it is able to perform comparatively easily and its reproducibility examined using good simulation. The simulation used MADYMO7.2 for the solver while BioRID-II Facet Ver3.0 developed by TASS (TNO Automotive Safety Solutions) was used as the dummy model.

3.1 Simulation Model for Calibration Tests

A simulation model consisting of a dummy model and a mini sled model was produced in accordance with the existing method of calibration test of a BioRID-II dummy. Then parameter study was performed so that the corridor specified at the time of a calibration test might be satisfied. While in actual

calibration tests, impact is applied to the mini sled by using a probe, sled accelerations were provided as an input condition in the simulation. The results of the parameter study are showed in Fig.5, Fig.6 and Fig.7. Although Pot.C has failed from the corridor, in the present simulation model, Fig.7 is limited in the condition where each rotation angle becomes the closest to a corridor. So, the simulation was effected by this condition.

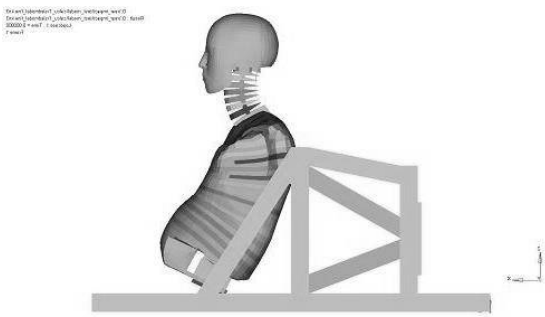

Fig.4 Simulation Model of Calibration Test

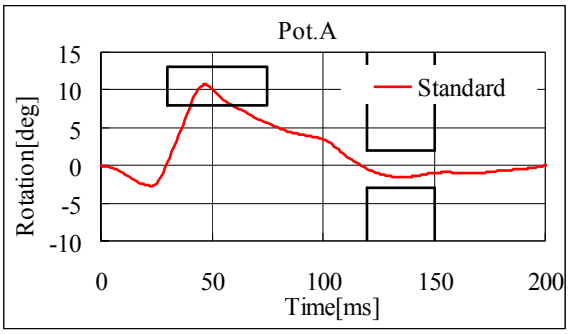

Fig.5 Pot.A (Standard Model)

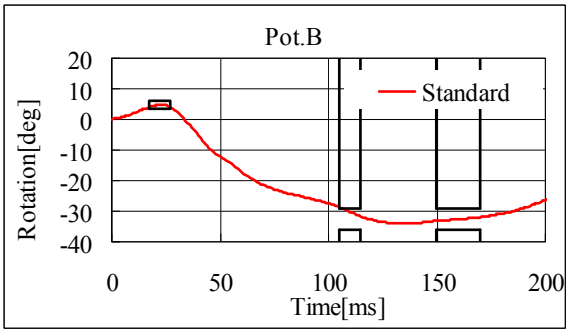

Fig.6 Pot.B (Standard Model)

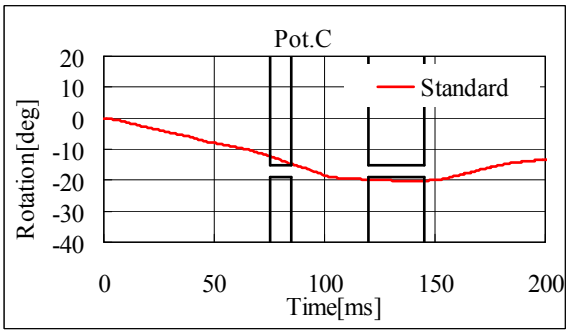

Fig.7 Pot.C (Standard Model)

3.2 Simulation Conditions

As calibration test conditions in the simulation, the input acceleration of the mini sled was used, shown in Fig.8. In addition to the item specified in the calibration test, the measurement items were made up of the head acceleration, neck load, and neck moment [8].

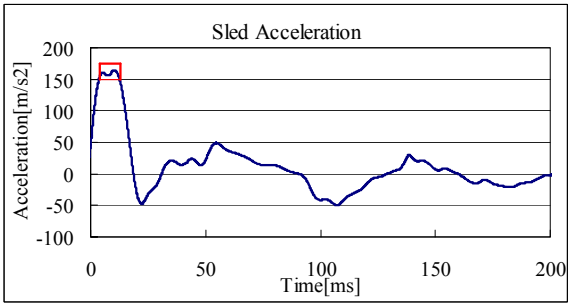

Fig.8 Sled Acceleration for Calibration Test

3.3 Simulation Parameters

This research has applied the existing method of calibration testing. And the factors of the variation in the dummy contained in a calibration test are varied. In those factors, the present study was focused on the corridor widths of Pot.A, Pot.B, and Pot.C. Even though the corridors passed and the calibration test was satisfactory, the injury values would vary if the passing values within each corridor differed. So, simulation models were produced for the cases of passing the upper, middle and lower portions of each corridor for Pot.A, Pot.B, and Pot.C. Note that among the plural number of corridors provided for Pot.A, Pot.B and Pot.C, only one corridor was selected. When a corridor in Pot.A was divided into upper, middle and lower portions, conditions were made so that all the other corridors in Pot.B and Pot.C would, as much as possible, is satisfied. The same method was also used when a setup for Pot.B and Pot.C was performed.

3.3.1 Corridors for Pot.A (Head Rotation Angle)

Pot.A of the simulation model represents the angle of head rotation against neck rotation and has two corridors. The present study was focused on the first corridor which corresponded with time of the first contact of the head to the head restraint. Pot.A was adjusted by modifying the characteristics of the simulation model's cervical spine joint covering C1-C2. Specifically, as torque characteristics against the angle were defined into the cervical spine joint, adjustment of the cervical spine joint was made by scaling its torque characteristics. The characteristics of the cervical spine joint corresponded with the characteristics of bumpers that were inserted between the cervical vertebrae of BioRID-II in the calibration test.

Table 2 shows the adjustment volumes of the cervical spine joint characteristics. Fig.9 shows the

results of the parameter study on Pot.A. Fig.10 and Fig.11 show changes in rotation angles in Pot.B and Pot.C as a result of adjustments in Pot.A.

Table.2 Volume of adjustment
(cervical spine joint No.1 - No.2)

Upper	0.7
Middle	0.3
Lower	0.15

unit : times

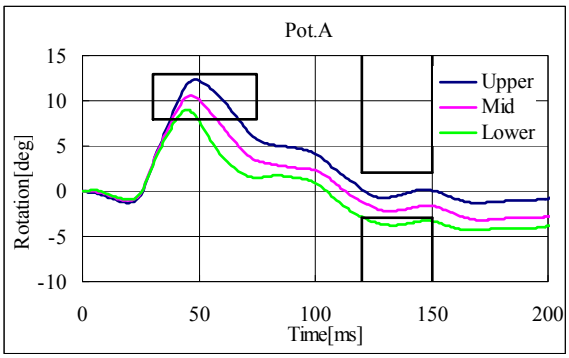

Fig.9 Pot.A

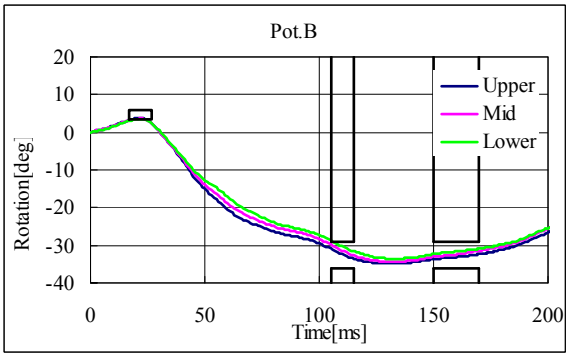

Fig.10 Pot.B

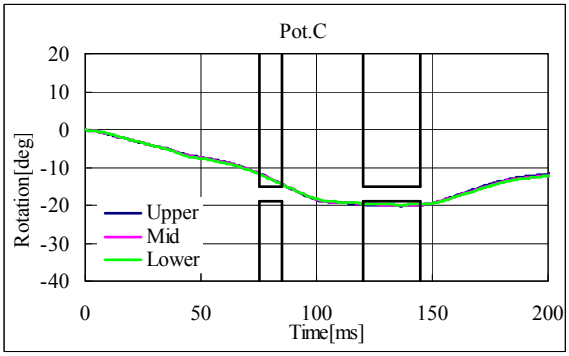

Fig.11 Pot.C

3.3.2 Corridors for Pot.B (Neck Rotation Angle)

Pot.B of the simulation model represents the angle of neck rotation against T1 rotation and has three corridors. The present study focused on the second corridor which among the three had the greatest width. As in Pot.A, Pot.B was likewise adjusted by modifying the characteristics of the simulation model's cervical spine joint covering C1-C2. In addition, adjustment of the two thoracic spine joints covering C7-T1 and T1-T12, respectively, were performed by scaling of their torque characteristics against the angle. The characteristics of these joints corresponded with the characteristics of bumpers inserted between the cervical and thoracic vertebrae of BioRID-II in the calibration test.

Table 3 shows the adjustment volumes of cervical spine joint characteristics. Table 4 shows the adjustment volumes of the characteristics of the two thoracic spine joints. Fig.12 shows the results of the parameter study on Pot.B. Fig.13 and Fig.14 show changes in rotation angles at Pot.A and Pot.C as a result of Pot.B adjustments.

Table.3 Volume of adjustment
(cervical spine joint No.1 - No.2)

Upper	0.005
Middle	0.1
Lower	0.25

unit : times

Table.4 Volume of adjustment
(cervical spine joint No.7 - thorax spine joint No.1 and thorax spine joint No.1 - No.12)

Upper	12
Middle	6
Lower	1

unit : times

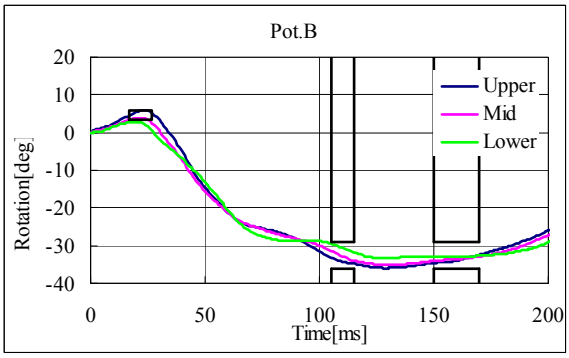

Fig.12 Pot.B

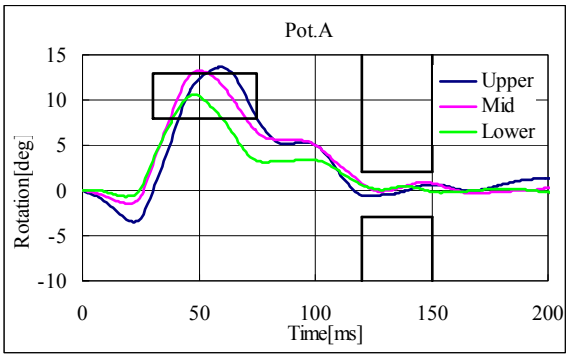

Fig.13 Pot.A

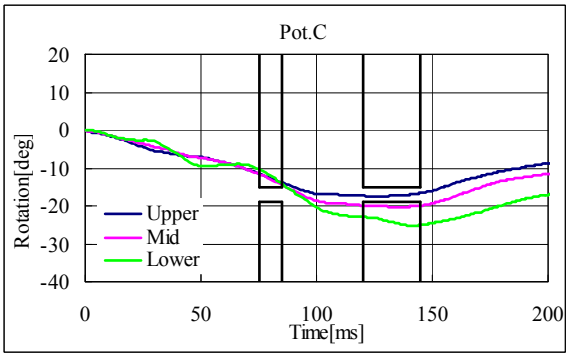

Fig.14 Pot.C

3.3.3 Corridors for Pot.C (T1 Rotation Angle)

Pot.C of the simulation model represents the angle of T1 rotation against the mini sled and has two corridors. The present study focused on the second corridor with a greater width. As in Pot.A and PotB, Pot.C was also adjusted by modifying the characteristics of the simulation model's cervical spine joint covering, C1-C2. In addition as in Pot.B, adjustment of the two thoracic spine joints covering C7-T1 and T1-T12, respectively, were performed by changing their characteristics. The characteristics of these joints corresponded with the characteristics of bumpers inserted between the cervical and thoracic vertebrae of BioRID-II in the calibration test.

Table 5 shows the adjustment volumes of cervical spine joint characteristics. Similarly Table 6 shows the adjustment volumes of the characteristics of the thoracic spine joint covering C7-T1, while Table 7 shows those of the thoracic spine joint covering T1-T12. Fig.15 shows the results of the parameter study on Pot.C. Fig.16 and Fig.17 show changes in rotation angles at Pot.A and Pot.B as a result of Pot.C adjustments.

Table.5 Volume of adjustment
(cervical spine joint No.1 - No.2)

Upper	0.025
Middle	0.08
Lower	0.1

unit : times

Table.6 Volume of adjustment
(cervical spine joint No.7 - thorax spine joint No.1)

Upper	12
Middle	6
Lower	6

unit : times

Table.7 Volume of adjustment
(thorax spine joint No.1 - No.12)

Upper	18
Middle	12
Lower	9

unit : times

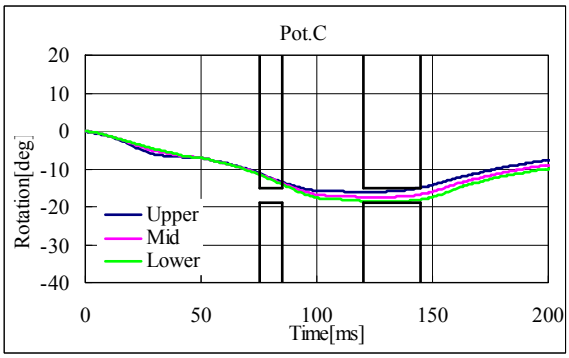

Fig.15 Pot.C

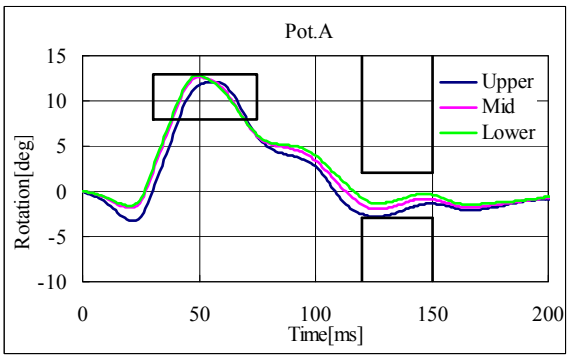

Fig.16 Pot.A

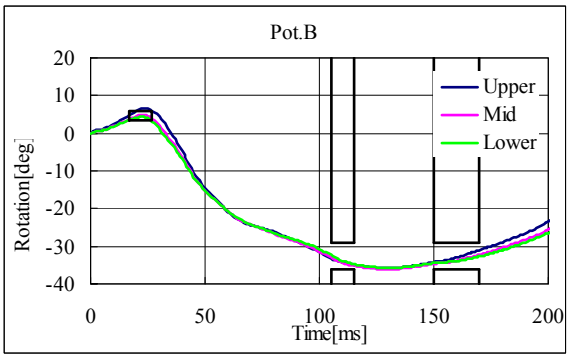

Fig.17 Pot.B

3.4 Results of the Simulation

Simulation was conducted under various test conditions, and injury values were determined in relation to changes made in Pot.A, Pot.B and Pot.C. For each injury value, the coefficient of variation (C.V.) and the standard deviation were calculated in order to evaluate injury value variations.

3.4.1 Pot.A

Table 8 shows injury value results when the conditions for Pot.A were changed. UpperNeck-MY(Flx) was the only injury value with a C.V. that exceeded 10%. All the other injury value items recorded a C.V. of less than 10%.

Table.8 Injury value of Pot.A

Result	NIC [m^2/s^2]	UpperNeck FX [N]	FZ [N]	MY-Flx. [Nm]	MY-Ext. [Nm]
Upper	51.1	235.4	220.5	11.8	-16.4
Mid	50.3	228.9	210.7	13.4	-15.0
Lower	49.3	224.6	237.2	15.0	-14.0
Average	50.2	229.6	222.8	13.4	-15.1
S.D.	0.9	5.5	13.4	1.6	1.2
C.V.[%]	1.8	2.4	6.0	12.0	7.7

Result	LowerNeck FX [N]	FZ [N]	MY-Flx. [Nm]	MY-Ext. [Nm]
Upper	280.7	230.9	2.0	-35.2
Mid	272.0	218.3	2.1	-33.4
Lower	263.2	242.0	1.9	-32.5
Average	272.0	230.4	2.0	-33.7
S.D.	8.8	11.9	0.1	1.4
C.V.[%]	3.2	5.2	5.8	4.1

3.4.2 Pot.B

Table 9 shows injury value results when the conditions for Pot.B were changed. The injury values with a C.V. that exceeded 10% were the UpperNeck-FX, UpperNeck-MY(Flx), LowerNeck-FX, LowerNeck-MY(Flx), and LowerNeck-MY(Ext). All the other injury value items recorded a C.V. of less than 10%.

Table.9 Injury value of Pot.B

Result	NIC [m^2/s^2]	UpperNeck FX [N]	FZ [N]	MY-Flx. [Nm]	MY-Ext. [Nm]
Upper	49.3	306.7	209.3	8.8	-20.1
Mid	51.4	245.1	222.8	10.9	-17.2
Lower	48.9	173.9	222.6	13.6	-18.0
Average	49.8	241.9	218.2	11.1	-18.5
S.D.	1.3	66.5	7.7	2.4	1.5
C.V.[%]	2.7	27.5	3.5	21.5	8.1

Result	LowerNeck FX [N]	FZ [N]	MY-Flx. [Nm]	MY-Ext. [Nm]
Upper	318.5	234.3	1.8	-41.2
Mid	285.2	235.1	2.0	-36.2
Lower	247.9	226.6	1.6	-23.0
Average	283.9	232.0	1.8	-33.4
S.D.	35.3	4.7	0.2	9.4
C.V.[%]	12.4	2.0	13.6	28.1

3.4.3 Pot.C

Table 10 shows injury value results when the conditions for Pot.C were changed. The injury values with a C.V. that exceeded 10% were UpperNeck-FX and LowerNeck-MY(Flx). All the other injury value items recorded a C.V. of less than 10%.

Table.10 Injury value of Pot.C

Result	NIC [m^2/s^2]	UpperNeck FX [N]	FZ [N]	MY-Flx. [Nm]	MY-Ext. [Nm]
Upper	47.0	331.0	222.8	10.7	-17.6
Mid	49.5	268.6	243.5	11.5	-17.4
Lower	50.3	259.9	231.0	11.3	-17.8
Average	48.9	286.5	232.4	11.2	-17.6
S.D.	1.7	38.8	10.4	0.4	0.2
C.V.[%]	3.6	13.5	4.5	3.7	1.0

Result	LowerNeck FX [N]	FZ [N]	MY-Flx. [Nm]	MY-Ext. [Nm]
Upper	340.4	249.9	2.3	-44.0
Mid	318.4	266.1	1.6	-39.8
Lower	308.9	246.5	1.6	-38.3
Average	322.5	254.2	1.9	-40.7
S.D.	16.2	10.4	0.4	2.9
C.V.[%]	5.0	4.1	21.7	7.2

3.5 Conclusions of simulation analysis of calibration test

To examine the injury value variations in the calibration test, the effect of the rotation angle corridors was analyzed. It was found that the rotation angle that had the most effect on injury value variations was Pot.B, On the other hand, the rotation angle that had the least effect on the variation was Pot.A.

4. Simulation Analysis of Sled Test

An examination was made to determine the effect of injury value variations in calibration test on the corresponding variation in the sled test.

4.1 Simulation Model for Rear Impact Sled Tests

A rear impact sled simulation model consisting of a dummy model and a seat model was produced. For the dummy model, the one produced for the preceding section (Section 3) was used. For the seat model, a simple model consisting of a head restraint, a seatback and a seat cushion was produced. For the compression characteristics of the seatback and head restraint, the results obtained in the static test were applied. The value of each characteristic was adjusted in the simulation of a rear impact sled test with an impact speed of ΔV16 km/h. Fig.18 shows the simulation model, Fig.19 shows the mechanical characteristics of the seat model, and Fig.20 shows the derived values and validation results.

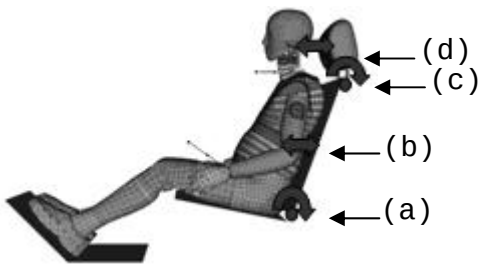

Fig.18 Simulation Model of Sled Test

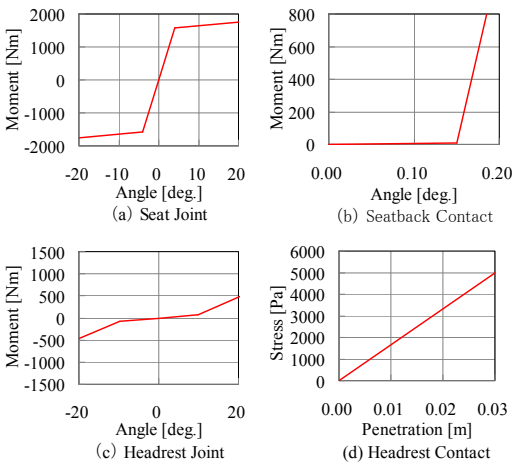

Fig.19 Property of seat and headrest

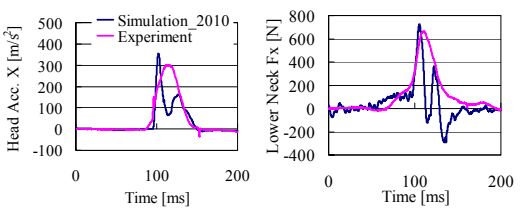

Fig.20 Validation of Simulation Model

4.2 Simulation Conditions

As a rear impact sled test simulation condition, a triangular pulse used in the EuroNCAP rear impact test and the medium waveform were employed (Fig.21). The test speed (speed change) was set at ΔV16 km/h. Measured were head acceleration, T1 acceleration, neck load and neck moment. The setting values used for the seated dummy are as shown in Table 11.

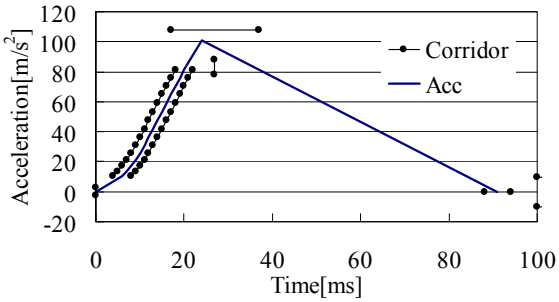

Fig.21 Sled Pulse

Table.11 Dummy Setting

Initial Position of Dummy		
Backset	60	mm
Head - HeadRestraint (Height)	42	mm
Head Angle	0	deg
Pelvis Angle	22	deg
SeatBack Angle	20	deg

4.3 Simulation Parameters

As the parameters to be changed in the simulation, the Upper, Middle and Lower corridor portions for Pot.A, Pot.B and Pot.C were employed. The same conditions as those applied to the simulation of the calibration test were applied to the simulation of the rear impact sled test.

4.4 Results of the Simulation

Simulation was conducted under varied conditions, and injury values were determined in relation to changes recorded in Pot.A, Pot.B and Pot.C. For each injury value the coefficient of variation (C.V.) and the standard deviation were calculated to evaluate injury value variations.

4.4.1 Pot.A

Table 12 shows injury value results when the conditions for Pot.A were changed. UpperNeck-MY indicated the largest injury value variation, and its waveforms are shown in Fig.22. As shown in Table 12, UpperNeck-MY(Flx) and LowerNeck-MY (Flx) recorded a C.V. that exceed 10%. All the other injury value items recorded a C.V. of less than 10%.

Table.12 Injury value of Pot.A

Result	NIC [m²/s²]	UpperNeck FX [N]	UpperNeck FZ [N]	UpperNeck MY-Flx. [Nm]	UpperNeck MY-Ext. [Nm]
Upper	24.0	152.3	1058.1	20.9	-12.0
Mid	24.0	150.7	1050.8	26.6	-12.7
Lower	23.4	149.4	1040.2	37.2	-12.5
Average	23.8	150.8	1049.7	28.2	-12.4
S.D.	0.3	1.4	9.0	8.2	0.4
C.V.[%]	1.3	1.0	0.9	29.2	3.0

Result	LowerNeck FX [N]	LowerNeck FZ [N]	LowerNeck MY-Flx. [Nm]	LowerNeck MY-Ext. [Nm]
Upper	672.0	711.9	11.8	-32.2
Mid	678.4	704.3	10.2	-32.4
Lower	665.5	693.5	9.2	-32.2
Average	672.0	703.3	10.4	-32.3
S.D.	6.4	9.2	1.3	0.1
C.V.[%]	1.0	1.3	12.6	0.3

Table.13 Injury value of Pot.B

Result	NIC [m²/s²]	UpperNeck FX [N]	UpperNeck FZ [N]	UpperNeck MY-Flx. [Nm]	UpperNeck MY-Ext. [Nm]
Upper	23.1	174.5	1035.1	20.0	-7.1
Mid	24.3	155.1	1066.9	19.3	-11.3
Lower	20.1	130.3	1071.4	32.7	-9.3
Average	22.5	153.3	1057.8	24.0	-9.2
S.D.	2.2	22.2	19.8	7.6	2.1
C.V.[%]	9.6	14.5	1.9	31.5	22.7

Result	LowerNeck FX [N]	LowerNeck FZ [N]	LowerNeck MY-Flx. [Nm]	LowerNeck MY-Ext. [Nm]
Upper	724.2	675.6	13.4	-34.9
Mid	671.9	715.8	13.0	-31.9
Lower	625.1	684.3	9.3	-27.5
Average	673.7	691.9	11.9	-31.4
S.D.	49.6	21.1	2.3	3.7
C.V.[%]	7.4	3.1	19.0	11.9

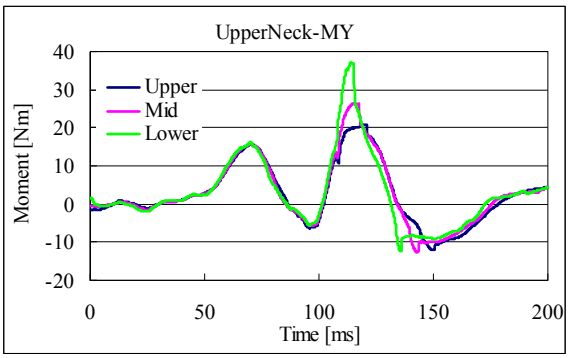

Fig.22 UpperNeck-MY

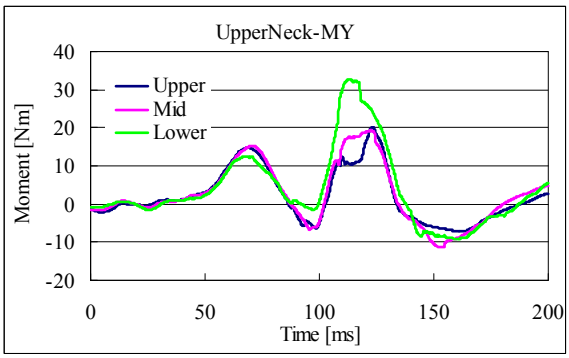

Fig.23 UpperNeck-MY

4.4.2 Pot.B

Table 13 shows injury value results when the conditions for Pot.B were changed. Fig.23 shows the waveforms of UpperNeck-MY which recorded the largest injury value variation. As shown in Table 13, the injury values with a C.V. that exceeded 10% were the UpperNeck-FX, UpperNeck-MY(Flx), UpperNeck-MY(Ext), LowerNeck-MY(Flx), and LowerNeck-MY(Ext). All the remaining injury value items recorded a C.V. of less than 10%.

4.4.3 Pot.C

Table 14 shows injury value results when the conditions for Pot.C were changed. Fig.24 shows the waveforms of UpperNeck-MY which recorded the largest injury value variation. As shown in Table 14, the injury values with a C.V. that exceeded 10% only the UpperNeck-MY(Ext). All the other injury value items recorded a C.V. less of than 10%.

Table.14 Injury value of Pot.C

Result	NIC [m²/s²]	UpperNeck FX [N]	FZ [N]	MY-Flx. [Nm]	MY-Ext. [Nm]
Upper	23.0	146.1	1040.4	16.2	-8.0
Mid	23.4	167.6	1043.1	17.5	-10.2
Lower	24.2	159.4	1060.1	18.3	-11.3
Average	23.5	157.7	1047.9	17.3	-9.8
S.D.	0.6	10.9	10.7	1.1	1.7
C.V.[%]	2.6	6.9	1.0	6.3	17.1

Result	LowerNeck FX [N]	FZ [N]	MY-Flx. [Nm]	MY-Ext. [Nm]
Upper	721.2	638.7	14.4	-35.0
Mid	725.4	677.6	13.5	-35.3
Lower	685.0	710.3	13.6	-32.8
Average	710.5	675.5	13.8	-34.4
S.D.	22.2	35.8	0.5	1.4
C.V.[%]	3.1	5.3	3.6	4.0

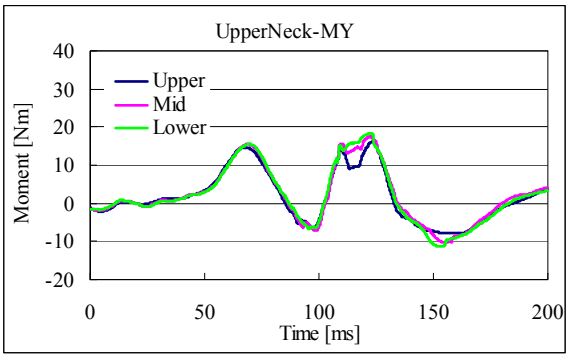

Fig.24 UpperNeck-MY

4.5 Conclusions of Simulation Analysis of Sled Test

Injury value variations in rear impact sled testing were examined. The same dummy sub-model as the one reported in Section 3 was used. The simulation results indicated that the rotation angle that had the most effect on injury value variations was Pot.B, while the rotation angle that had the least effect on the variation was Pot.C.

5. Comparison of Variations between Calibration Tests and Sled Tests

A comparison was made between the injury value variations observed in the calibration test and in the sled test.

5.1 Pot.A

Table 15 shows injury value results when the conditions for Pot.A were changed in both the calibration test and sled test. UpperNeck-MY(Flx) was the only injury value with a C.V. that exceeded 10% in both tests. LowerNeck-MY(Flx) indicated a C.V. of less than 10% in the calibration test but a C.V. that exceeded 10% in the sled test. All the other injury value items recorded a C.V. of less than 10%.

Fig.25 shows the time-history of UpperNeck-MY which registered the largest injury value variation in both the calibration test and the sled tests. The time-histories indicate differences in peak times and time-history shapes between the two tests. In addition, as shown in the time-history of the calibration test of Fig. 25, the minus-value is outputted at the time of Time=0. Since a dummy model has many joints in its backbone, it is difficult to set it up in posture wherein the loads to all the joints are removed completely, in early stages of calculation.

Table.15 Coefficient of variation of Pot.A

Result	NIC [m²/s²]	UpperNeck FX [N]	FZ [N]	MY-Flx. [Nm]	MY-Ext. [Nm]
Calibration	1.8	2.4	6.0	12.0	7.7
Sled	1.3	1.0	0.9	29.2	3.0

Result	LowerNeck FX [N]	FZ [N]	MY-Flx. [Nm]	MY-Ext. [Nm]
Calibration	3.2	5.2	5.8	4.1
Sled	1.0	1.3	12.6	0.3

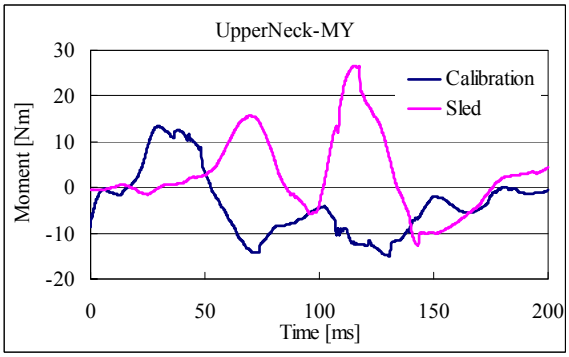

Fig.25 UpperNeck-MY

5.2 Pot.B

Table 16 shows injury value results when the conditions for Pot.B were changed in both the calibration test and the sled tests. UpperNeck-FX, UpperNeck-MY(Flx), LowerNeck-MY(Flx), and LowerNeck-MY(Ext) were the injury values with a C.V. that exceeded 10% in both the calibration test and the sled test. UpperNeck-MY(Ext) indicated a C.V. of less than 10% in the calibration test but had a C.V. that exceeded 10% in the sled test. On the other hand LowerNeck-FX recorded a C.V. that exceeded10% in the calibration test but had a C.V. of less than 10% in the sled test. NIC, UpperNeck-FZ, and LowerNeck-FZ indicated a C.V. of less than 10% in both tests.

Fig.26 shows the time-history of the UpperNeck-MY which registered the largest injury value variation in both the calibration test and the sled test. The time-histories indicate differences in peak times and in time-history shapes between the two tests.

Table.16 Coefficient of Variation of Pot.B

Result	NIC [m²/s²]	UpperNeck FX [N]	FZ [N]	MY-Flx. [Nm]	MY-Ext. [Nm]
Calibration	2.7	27.5	3.5	21.5	8.1
Sled	9.6	14.5	1.9	31.5	22.7
Result	LowerNeck FX [N]	FZ [N]	MY-Flx. [Nm]	MY-Ext. [Nm]	
Calibration	12.4	2.0	13.6	28.1	
Sled	7.4	3.1	19.0	11.9	

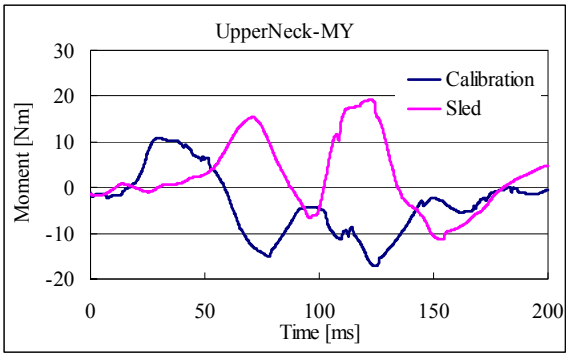

Fig.26 UpperNeck-MY

5.3 Pot.C

Table 17 shows injury value results when the conditions for Pot.C were changed. There were no injury value items with a C.V. that exceeded 10%. UpperNeck-MY(Ext) indicated a C.V. of less than 10% in the calibration test but had a C.V. that exceeded 10% in the sled test. On the other hand UpperNeck-FX and LowerNeck-MY(Flx) recorded a C.V. that exceeded 10% in the calibration test but had a C.V. of less than 10% in the sled test. All the other injury value items recorded a C.V. of less than 10%.

Fig.27 shows the time-history of UpperNeck-MY which registered the largest injury value variation in both the calibration test and the sled tests. The time-histories indicate differences in the peak times and the time-history shapes between the two tests.

Table.17 Coefficient of variation of Pot.C

Result	NIC [m²/s²]	UpperNeck FX [N]	FZ [N]	MY-Flx. [Nm]	MY-Ext. [Nm]
Calibration	3.6	13.5	4.5	3.7	1.0
Sled	2.6	6.9	1.0	6.3	17.1
Result	LowerNeck FX [N]	FZ [N]	MY-Flx. [Nm]	MY-Ext. [Nm]	
Calibration	5.0	4.1	21.7	7.2	
Sled	3.1	5.3	3.6	4.0	

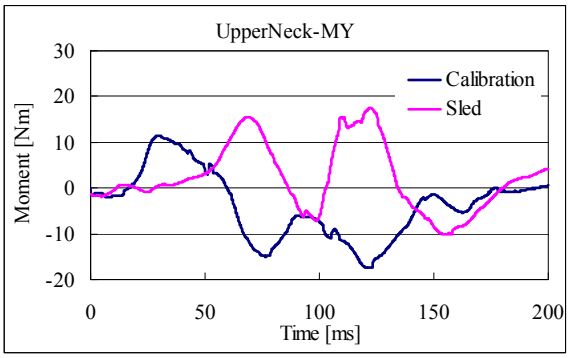

Fig.27 UpperNeck-MY

5.4 Discussions

The results of the present study indicated that injury values with a large C.V. in the calibration test also gave a large C.V. in the sled test. In addition, Pot.B was the rotation angle that gave the largest injury value variation in both the calibration test and the sled tests. On the other hand, Pot.A of the calibration test result, and Pot.C of the sled test result were the rotation angles that gave the least variation of injury values. It was found that the injury values that registered a C.V. of less than 10% at calibration test but registered a C.V. that exceeded 10% at the sled test were the LowerNeck-MY(Flx) of Pot.A, UpperNeck-MY(Ext) of Pot.B, and UpperNeck-MY(Ext) of Pot.C.

Initially, the reason why the variation of Pot.B became large was considered. Pot.B is the neck rotation angle, or the difference of head rotation angle and T1 rotation angle. Therefore, Pot.B is affected by the rotation angles of both Pot.A and Pot.C. In contrast, Pot.B influences the rotation angles of both Pot.A and Pot.C. So, from the result of the simulation, if it becomes possible to reduce the variation in Pot.B, it is thought that reducing the variation in Pot.A and Pot.C is also possible. Moreover, regarding Pot.B, cable adjustment and exchange of the bumper affects the actual dummy. So, when making those adjustments, caution is required.

Next, the reason why the injury values that registered a C.V. of less than 10% at calibration test but registered a C.V. that exceeded 10% at sled test was considered. In the current calibration test without headrest, the dummy motion and behavior differed from the sled test. So, a difference was found in the peak value of the injury value and the timing which became a peak value was also different. This was considered as one reason. Consequently it may be possible to reduce injury value variations by reproducing in the calibration test the same dummy behavior observed in the sled test. In other words, one way of reducing injury value variations may be to conduct a calibration test with a headrest. However, the kind and structure of the seat are varied. So, the motion of sled test, the peak value of an injury value, etc. varies depending on the seats. Therefore,

headrest, seat and other factors need to be considered in order to develop a new calibration test method. On the other hand, in considering a calibration test with a head restraint, it will be necessary to note that the range of motion of the dummy's head will be restricted by the headrest. Specifically, extension behavior will be restricted while flexion behavior will not be affected as much. Therefore, the range of motion by the side of expansion is not read correctly. In a calibration test, since evaluation of the range of motion of the neck is also needed, the calibration test without headrest is likewise needed. However, the current calibration test without headrest does not require the measurement of load and moment for UpperNeck and LowerNeck. And in contrast, the sled test shows variations in load and moment for UpperNeck and LowerNeck. It is therefore necessary to examine the possible addition of these measurement items into the calibration test.

6. Conclusions

In the present study the calibration test and the sled test were analyzed by simulation, and factors affecting the variation of dummy injury values were examined for both tests.

The results indicated that if injury value variations are generated in the calibration test, similar variations will be generated in the sled test. Consequently it will be possible to reduce injury value variations in sled test by reducing such variations in calibration test. To do so, it is thought that one method is by carrying out a more exact calibration test by narrowing the corridor of Pot.A, Pot.B, and Pot.C (especially Pot.B) of calibration test.

Another method of solving the variation problem is to reproduce in the calibration test the dummy behavior that is similar to the dummy behavior observed in sled test. For example, a calibration test with a headrest may be introduced. However, since the introduction of a headrest may also bring forth new problems (such as measurement of neck load and reduce the variation) in the calibration test, it is necessary to conduct calibration test both with and without a headrest.

As a future topic, the current calibration test without headrest needs to be reviewed, as a new calibration test method with headrest is developed. It will be necessary to find out these correspondences to immediately reduce the variation of dummy injury values. Moreover, in the current calibration test, measurement of the injury value of each part of a dummy is not effected. By evaluating neck load and neck moment, etc. in calibration test, we believe that this would lead to the reduction of the variation in the dummy.

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