THE STUDY for DYNAMIC EVALUATION METOHD FOR ASSESSING WHIPLASH-ASSOSIATED DISODER IN REAR IMPACT

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ABSTRACT

FMVSS 202a and the head restraint gtr specify a dynamic sled test with Hybrid III dummy as an alternative to static tests. However, the poor biofidelity of Hybrid III dummy and the evaluation method based on the neck rearward rotational angle of the dummy during rear impact are urgent issues. To solve these issues, a dynamic evaluation of OC-T1 displacement, corrected for the seat back rearward inclination (hereinafter called "dynamic backset"), using BioRID II which has superior biofidelity, was studied to establish a test method with higher effectiveness, repeatability and reproducibility.

From dynamic Backset evaluations by dynamic tests and simulations using IIWPG crash pulse on various types of seats and analysis of real world minor neck injuries involving such seats in Japan, the following new facts were found. (1) Dynamic backset can evaluate the effectiveness of various types of seats with whiplash mitigation features, such as reactive, passive, and WHIPS, more accurately than neck rearward rotation of Hybrid III. Since the seat effectiveness increases as dynamic backset decreases, it is appropriate for a dynamic evaluation parameter as an alternative of static backset tests. (2) By setting each seat back to its design torso angle, instead of 25 degrees for every seat, the variation in BioRID II installation is decreased, resulting in higher repeatability and reproducibility. (3) According to the correlation analysis among real world accidents, minor neck injury phenomena, and various evaluation indicators, reduction of dynamic backset has an inhibitory effect on occurrence of minor neck injuries. (4) Confirming the relationship between other injury criteria

BACKGROUND

As a result of the Global Technical Regulation for Head Restraints, ("head restraint gtr"), which was established at the UN ECE-WP29 meeting in March 2008, it became necessary to evaluate the effect of static backset between head and head restraint as part of the evaluation of the head restraint's protection performance from minor neck injury in rear-end collision. In view of the technical difficulty of properly evaluating the static backset of reactive and other non-static head restraints, discussion had to be directed to the possible development of a dynamic evaluation method alternative to the static evaluation method. However, it was difficult to get all contracting parties consensus for selecting one common dummy for dynamic evaluation. Therefore, it was decided that each contracting party could select FMVSS202a dynamic evaluation method by using Hybrid-III dummy or could develop unique evaluation method by using BioRID II dummy. In Japan, although the number of road accident fatalities has been on the decrease, the number of rear-end accidents is on a marked rise (See Figure 1) and there is an urgent need to establish an appropriate method of evaluating the vehicle's occupant protection performance against the minor neck injury. Consequently the Japan Automobile Manufacturers Association ("JAMA") and the Japan Automobile Research Institute ("JARI") are conducting a joint study on the dynamic evaluation method using BioRID II to help the Japanese government introduce measures to protect vehicle occupants in rear-end collisions, because we have already studied that BioRID II has more better biofidelity than Hybrid III.

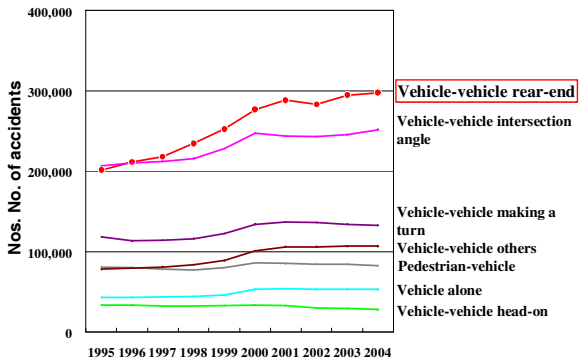


Figure 1. No. of accidents by accident configuration (as of end of December each year)

Alternative evaluation method

The dynamic evaluation method using BioRID II has been practiced by IIWPG, Folksam and ADAC. EuroNCAP is scheduled to apply it to neck injury assessment from 2009. However, in its study report on

neck injury, EEVC stated that there were still many questions remaining unanswered about actual whiplash associated disorders and that, to identify the neck injury mechanism involved, it would be necessary to determine appropriate injury parameters through the statistical analysis of both real world accident data and accident simulation data[1]. Similarly, Japanese researchers reported that the reproducibility of measurement values obtained by BioRID II was questionable at a time when measurement data by BioRID II are serving as the basis for the currently proposed injury parameters[2].

Consequently Japan and EEVC made a joint proposal at the UN/ECE/WP29/GRSP meeting in May 2008 to introduce into the ECE Regulation an alternative dynamic head restraint evaluation method using static backset and BioRID II as Phase 1 and to introduce into the gtr a dynamic evaluation method based on injury parameters as Phase 2. At the same meeting, Japan and EEVC proposed as Phase 1 evaluation method the OC-T1 displacement (" dynamic backset") evaluation incorporating the seatback angle correction by the ΔV=16km/h triangular pulse applied by IIWPG (refer to 3.3.1 for more details). Both proposals were accepted by UN/ECE/WP29/GRSP.

In the present study, therefore, simulation and testing analysis of dynamic backset and also other evaluation criteria employed in neck injury assessment were conducted to examine the relation to static backset and the suitability of the proposed alternative dynamic evaluation method.

Analytical Method

A simulation and sled tests for the rear-end collision proposed by Japan and EEVC was applied to analyze following items.

(1) Whether dynamic backset correlates with static backset, and can evaluate the effectiveness of various types of seats with whiplash mitigation features, such as reactive, passive, and WHIPS more properly.
(2) Whether repeatability and reproducibility can be ensured.
(3) Whether decrease in dynamic backset has an effect on decrease in occurrence of real-world minor neck injuries.

Simulation Model of the Rear-end Collision Sled

With MADYMO 6.4 employed as the solver, a simulation model of the rear-end collision sled was produced. The simulation model consisted of a dummy model and a seat model. Then, tests on parameters were carried out.

Dummy Model - A BioRID II Facet Ver.2.2[3] developed by TASS (TNO Automotive Safety Solutions) was used as the dummy model of the present simulation study. In the preliminary test the dummy model data were compared with the experimental results of rear-end collision sled tests at ΔV = 8km/h and ΔV = 16km/h (Dummy test)[4] to examine the dummy's behaviors and impact responses (acceleration, neck load, moment). From the differences found between the dummy model's behavior and the experimental results, the stiffness of the joint between the dummy's seventh cervical vertebra ("C7") and first thoracic vertebra ("T1") was reduced by 50% from that of the initial dummy model (See Figure 2). Figure 3 shows the comparisons of post-improvement behavior.

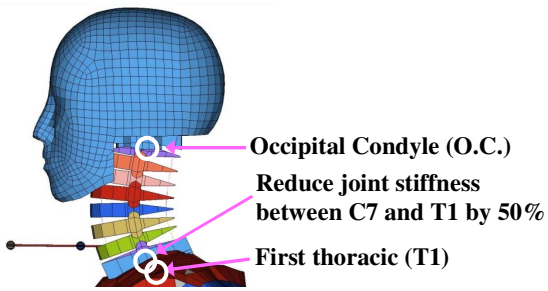
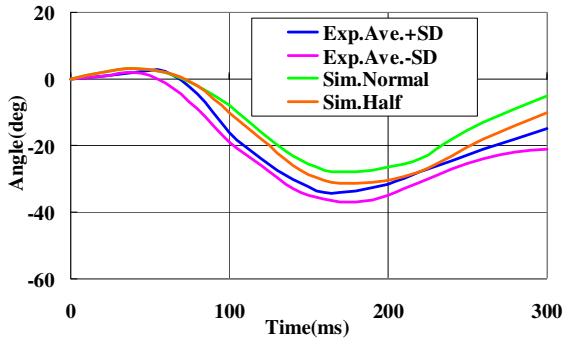
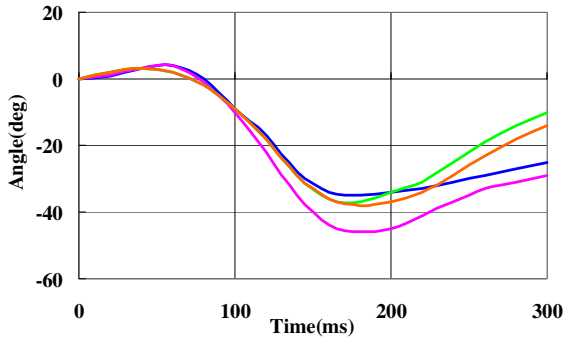


Figure 2. Spine of BioRID II facet dummy model



(a) Neck angle relative to T1



(b) Head angle relative to T1

Figure 3. Movement of BioRID II dummy model

Seat Model - The seat model was a simple model consisting of a head restraint, seatback, seat cushion and footrest. The contact stiffness of the seatback and head restraint and the joint stiffness of the seat and head restraint were calculated in advance from the results of static evaluation tests, and were adjusted to the results of the present rear-end collision simulation test at ΔV = 16km/h. Figure 4 shows the adjusted values for the seat and the head restraint.

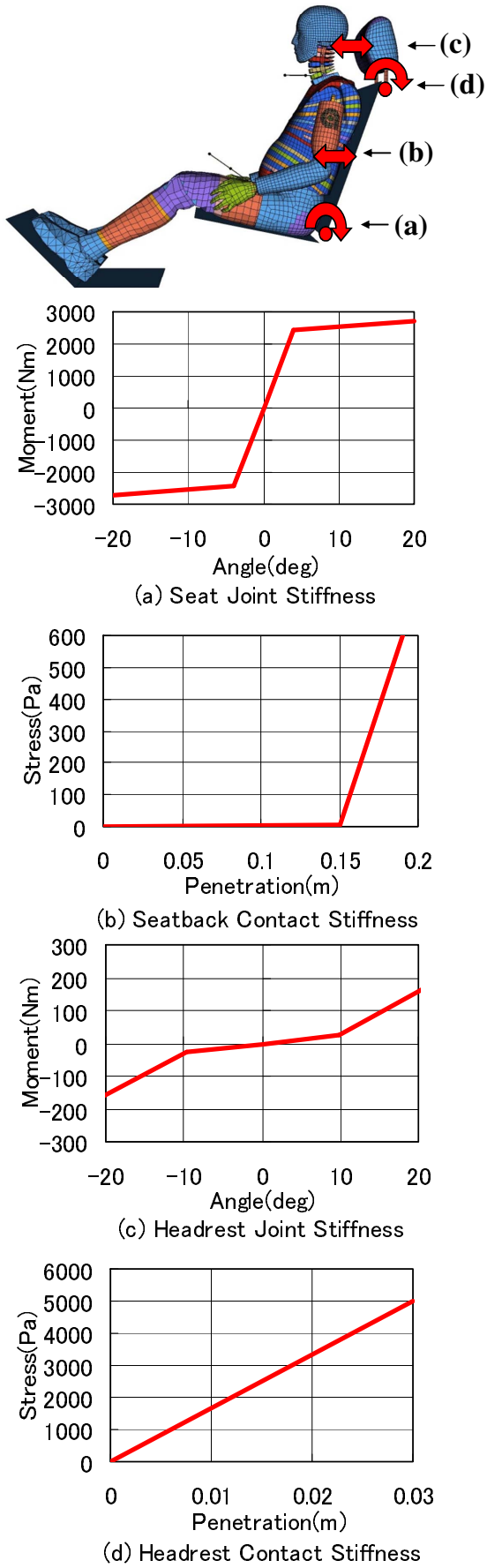


Figure 4. Property of seat and head restraint

Sled test

To examine the appropriateness of dynamic backset, repeatability of the test and reproducibility with different dummies, sled test was conducted using seats for mass production vehicles. Sled acceleration pulse is the same as that used in Euro NCAP "medium severity pulse" or IIWPG Delta-V of 16kph pulse, as shown in Figure 5. 3 types of seats with different mechanisms used in the test are: "A" for normal seat, "B" for passive seat, and "C" for reactive seat. Setting condition of seats and dummies is the same as that used in Euro NCAP, except that the seatback angle was adjusted at the design reference angle.[5] For each seat, reproducibility due to the use of different dummies was evaluated using 3 BioRID II (Level G) dummies. In addition, test was conducted 3 times for each seat using one of these dummies to evaluate repeatability of the test.

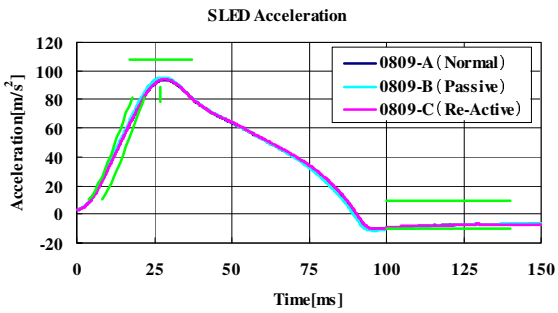


Figure 5. Sled Pulse

Evaluation Method

Evaluation of Dynamic Backset - Dynamic backset is defined as the maximum relative displacement of BioRID II's occipital condyle ("O.C.") and T1 in the vehicle longitudinal direction. To derive the value of dynamic backset, coordinates are converted in relation to the rearward inclination angle of the seatback and the following calculations were performed: a) Calculate the seatback angle from equation (1). b) Determine the angle variation from the original angle according to equation (2). c) Perform coordinate conversions in equation (3) and (4), and rotate the coordinate system in keeping with the variation of seatback angle. d) Subtract T1 from OC in equation (5). e) According to equation (6), subtract the OC-T1 reminder of the original dummy position from the OC-T1 reminder derived by formula (5). The final value thus obtained represents the amount of relative displacement. Figure 6 shows the conceptual drawing of dynamic backset measurement.

$$\theta(t) = \tan^{-1}\frac{SBUz(t) - SBLz(t)}{SBUx(t) - SBLx(t)} \quad \cdots\cdots (1)$$

$$\Delta\theta(t) = \theta(t) - \theta(0) \quad \cdots\cdots (2)$$

$$T1x'(t) = T1x(t)\cos\Delta\theta(t) + T1z(t)\sin\Delta\theta(t) \quad \cdots\cdots(3)$$

$$OCx'(t) = OCx(t)\cos\Delta\theta(t) + OCz(t)\sin\Delta\theta(t) \quad \cdots\cdots(4)$$

$$D_{(OC\text{-}T1)}(t) = OCx'(t) - T1x'(t) \quad \cdots\cdots(5)$$

$$\Delta D_{(OC\text{-}T1)}(t) = D_{(OC\text{-}T1)}(t) - D_{(OC\text{-}T1)}(0) \quad \cdots\cdots(6)$$

The symbols in the above equations denote the following meanings:

SBU: Target mark position in the upper part of seatback
SBL: Target mark position in the lower part of seatback
OC: Position of the dummy's occipital condyle
Tl: Position of the dummy's first thoracic vertebra

Note: The equations represent the visual observation of the dummy from its right side. The OC-T1 value obtained by dummy observation from its left side is derived by multiplying the OC-T1 value from the right side by a conversion value of -1.

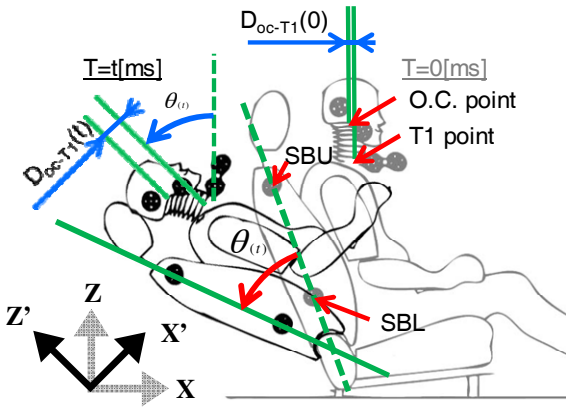


Figure 6. How to measure dynamic backset

Parameter Study

Discussion of Dynamic Backset - To determine the relation between static backset and dynamic backset, a simulation analysis was conducted with the amount of backset set at 5, 25, 45, 65 and 85mm. The ΔV = 16km/h acceleration waveform proposed by IIWPG[6] was used as sled pulse. To analyze the effects of various seat design parameter on dynamic backset, the horizontal distance between head and head restraint (static backset +15mm), and distance from top of head (vertical distance between head and head restraint), seat hinge stiffness and contact stiffness of the seatback were varied from base model to 80, 90, 110, and 120%. Figure 7 illustrates the definitions of the static backset and the distance from top of head.

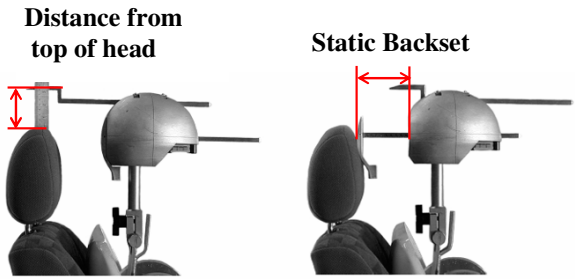


Figure 7. Static backset measuring position

Comparative Assessment of Other Evaluation Criteria - The neck evaluation criteria which will be included in the EuroNCAP assessment are NIC, Nkm, T1G (T1 x acceleration), UNFX (upper neck shear force), UNFZ (upper neck axial force), T-HRC (head restraint contact time), and Rebound V (head rebound velocity). In the present simulation study the amount of backset in relation to these parameters were calculated.

RESULTS

Relation between Backset and Dynamic Backset

Simulation analyses - Figure 8 shows the simulation result of relation between static backset and dynamic backset, NIC and Nkm. It was found that every 3 indictors increased with the increase of static backset practically in a nearly linear proportion. However, in case of coefficient of determination between evaluation criteria and static backset point of view, dynamic backset shows the highest coefficient rate (R^2) among all indicators as shown in Figure 9.

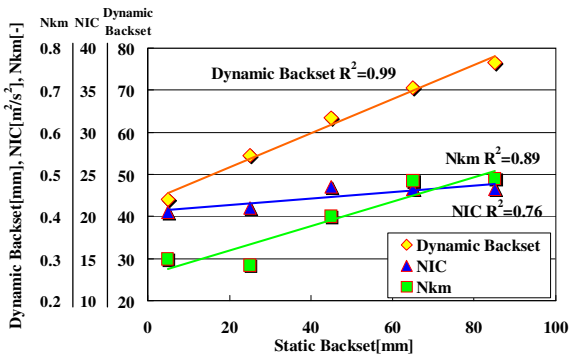


Figure 8. Relation between backset and dynamic backset etc.

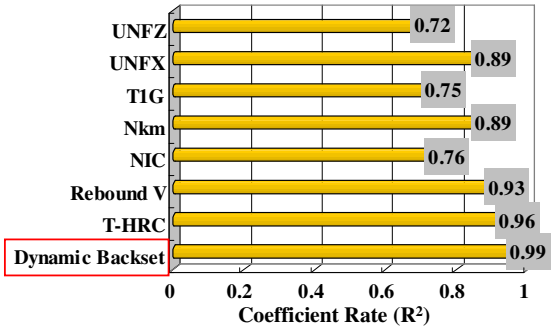


Figure 9. Coefficient of determination between evaluation criteria and static backset

Figures 10 shows the relation between dynamic backset and seat design parameters such as distance from top of head, seat hinge stiffness and seatback contact stiffness, respectively. When these seat design parameters are changed +/- 20% from base seat model, the static backset and seat hinge stiffness show higher influence to dynamic backset than others, and the seatback contact stiffness show lower influence to dynamic backset.
Decrease in "horizontal distance between head and head restraint" simulates the effectiveness of active and reactive head restraints, decrease in "seat hinge stiffness" simulates the effectiveness of WHIPS seats, and decrease in "seatback contact stiffness" simulates the effectiveness of passive seats. As the dynamic backset decreases in each of these cases, it was found that the effectiveness of various types of seats with whiplash mitigation features in the market can be reflected.

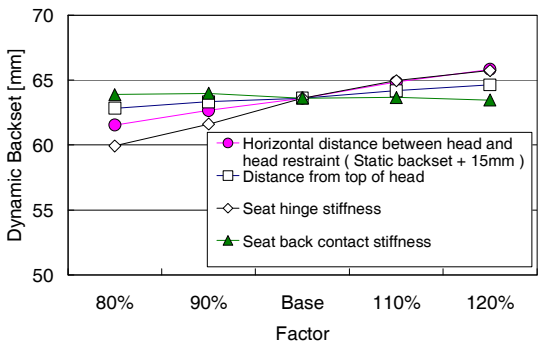


Figure 10. Sensitivity analysis to Dynamic Backset

Sled test analyses - In order to examine the simulated correlation with static backset for various types of seats with whiplash mitigation features in the market, either sled test was conducted or EEVC test data was used for 33 types of seats shown in Table 1.
The result shows that for normal seat, there is a correlation with static backset as shown in Figure 11. And for both passive and reactive type of seats with whiplash mitigation features, there is a tendency to show smaller dynamic backset than a normal seat with the same static backset.

Table 1 Sled Test Seat Specifications

IIHS Ranking	Seat Type	Number (*:EEVC data)
Good	Normal	4
	Reactive	2(3*)
	Passive	2
	WHIPS	(1*)
Acceptable	Normal	1
	Reactive	(1*)
	Passive	2
Marginal	Normal	1
	Reactive	1
	Passive	4
Poor	Normal	5
	Reactive	5
	Passive	1
Total		33

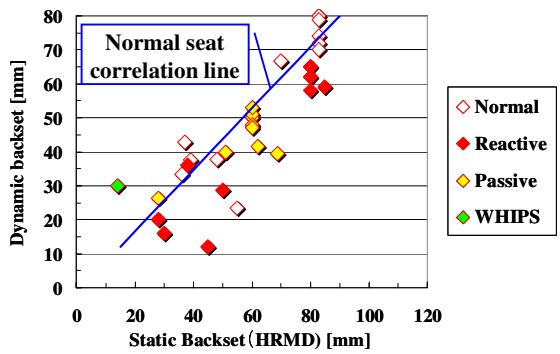


Figure 11. Relation between static backset and dynamic backset

Repeatability and Reproducibility study

Seating condition - As it was found that the dynamic backset is relatively sensitive to static backset based on the above simulation result, the dummy seating procedure used by Euro NCAP was modified as follows in order to decrease variation.

(1) Seatback design angle: from 25 degrees for every seat to design reference angle.
(2) Backset tolerance: from +/-5mm to +/- 2mm.

For seatback design angle, one of the studies reports that 25 degrees for every seat does not reflect the real-world usage, and the static backset, serving as a reference for installation of the BioRID II dummy, varies due to considerable variation during adjustment.[7]

Repeatability - Test was conducted 3 times for each of the 3 types of seats, and repeatability was evaluated using CV value as shown below.

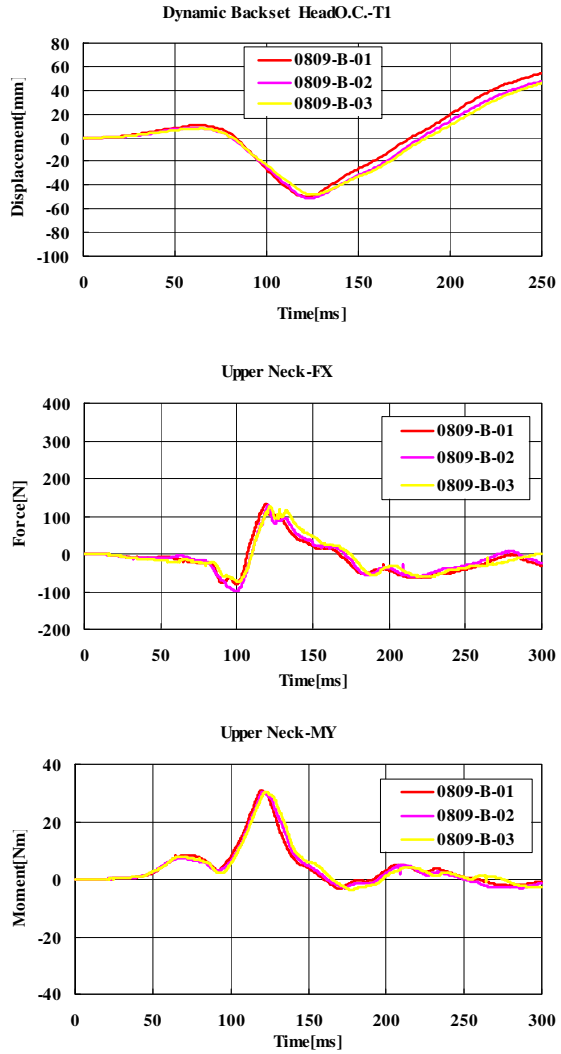
$$Repeatability\ C.V = \left[\frac{S_d}{\overline{X}} \right] 100\ (\%)$$

$\overline{X}$ = Average value of each dummy

S_d = Standard deviation of each dummy

Admissible level: C.V $\leq$ 10%

The evaluation result shows that dynamic backset represents CV values at a practical level and is lower compared to other assessment parameters, as shown in Figure 12.



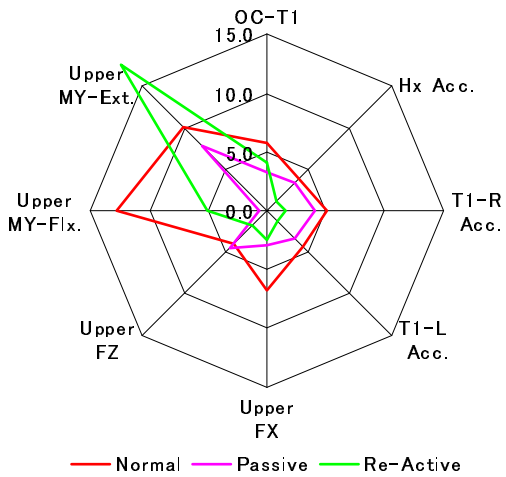


Figure 12. Repeatability Evaluation

<u>Reproducibility</u> – Test was conducted 3 times with 3 dummies for each of the 3 types of seats, and repeatability was evaluated using CV value as shown below.

$$Reproducibility\ C.V = \left[\frac{S_b}{\overline{X_G}} \right] 100(\%)$$

$\overline{X_G}$ = Average value of 3 dummies

$$S_B = \left[\frac{MSB - MSW}{n} \right]^{1/2}$$

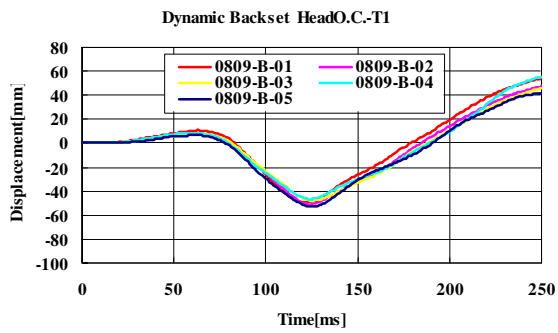
MSB: Average square between dummies

MSW: Average square within a dummy

n: Number of repetitions of test

Admissible level: C.V $\leq$ 10%

The evaluation result shows that dynamic backset represents CV values at a practical level and is lower compared to other assessment parameters, as shown in Figure 13.



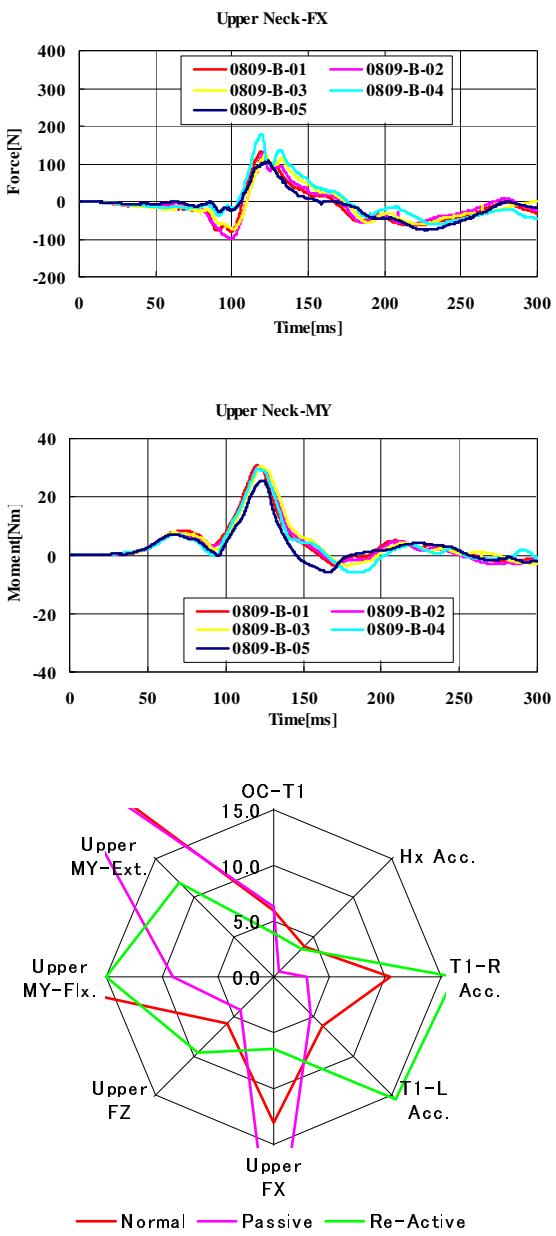


Figure 13. Reproducibility Evaluation

Correlation with Real-World Injury Rate

First, by both simulation and actual testing, we examined correlation with IIWPG assessment rating, which has been used for evaluation of a number of seats and is utilized by NHTSA for review of dynamic assessment procedure [8]. (See Figure 14, 15) It was found that dynamic backset decreased with higher IIWPG rating. The IIWPG rating and dynamic backset indicated practically a linear correlation.

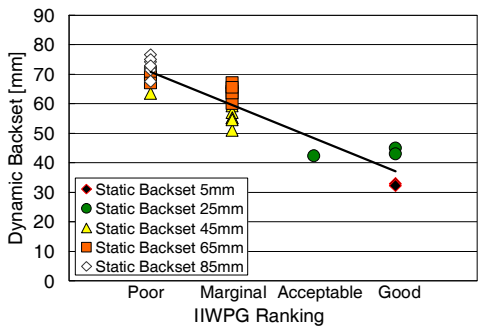


Figure 14. Correlation between IIWPG rating and dynamic backset based on simulation

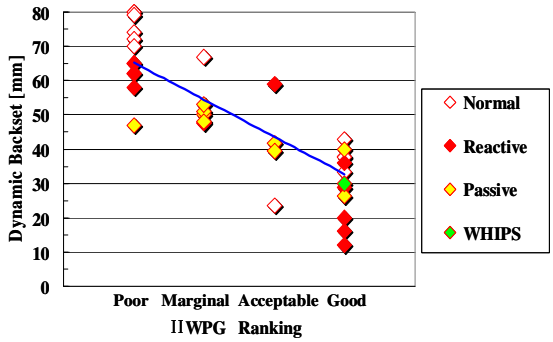


Figure 15. Correlation between IIWPG rating and dynamic backset based on sled test

Next, correlation was examined between dynamic backset and permanent disability ratio in neck due to rear-end collision in field, which is one of the major issues in real-world accidents in Japan (see Figure 16). The result shows that there is a decreasing tendency in dynamic backset with decrease in residual disability ratio.

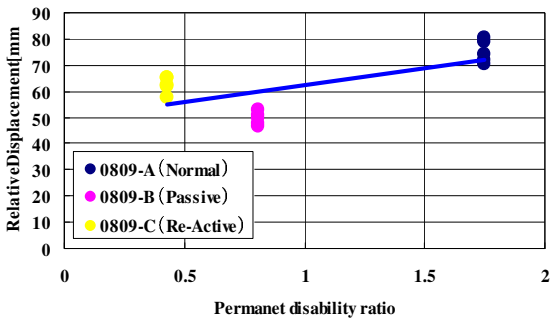


Figure 16. Correlation between Dynamic Backset and Permanent Disability Ratio

Comparison with Hybrid III Head Rearward Rotation Angle

We examined correlation with dynamic backset in BioRID II by performing sled test to assess head rearward rotation,

using Hybrid III specified in FMVSS 202a for 7 different types seats. The result shows that there is a general correlation with dynamic backset as shown in Figure 17. However, WHIPS, showing too large head rotation angle in the case of Hybrid III , showed relatively smaller value in the case of dynamic backset.

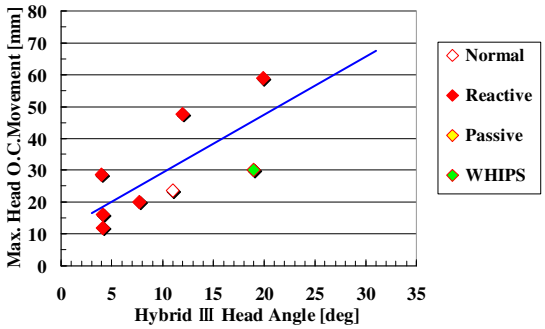


Figure 17. Correlation between Hybrid III head rearward rotation angle and dynamic backset

CONCLUSION

From dynamic backset evaluations by simulations and sled tests using IIWPG crash pulse on various types of seats and analysis of field minor neck injuries involving such seats in Japan, the following new facts were found.

(a) Relation between static backset and dynamic backset

i) As the amount of static backset increased, the dynamic backset increased in a linear proportion. In the various evaluation parameters (dynamic backset, NIC, Nkm, UNFX, UNFZ, T-HRC, Rebound V and T1-G), dynamic backset indicated the highest correlation with the amount of static backset.

ii) Dynamic backset can evaluate the effectiveness of various types of seats with whiplash mitigation features, such as reactive, passive, and WHIPS, more appropriately than head rearward rotation angle of Hybrid III.

iii) By setting each seat back to its design torso angle, instead of 25 degrees for every seat, the variation in BioRID II installation is decreased, resulting in higher repeatability and reproducibility.

iv) According to the correlation analysis with IIWPG assessment rating and filed accidents ratio, dynamic backset has an inhibitory effect on occurrence of minor neck injuries in real world.

DISCUSSION

Evaluation of dynamic backset found that assessment of seats with whiplash mitigation features is feasible, which is difficult to be assessed by static backset. However, assessment by dynamic backset is only possible for mainly Phase I in minor neck injury phenomenon as shown in Figure 18. For more proper evaluation of minor neck injury phenomenon, we believe it would be appropriate to evaluate by injury parameter taking Phase II and III also into account. Therefore, JAMA and JARI are working with Japanese Government and EEVC to promote head restraint gtr Phase 2 activities. And in the future, we are aiming to establish more appropriate minor neck injury assessment procedure through such activities.

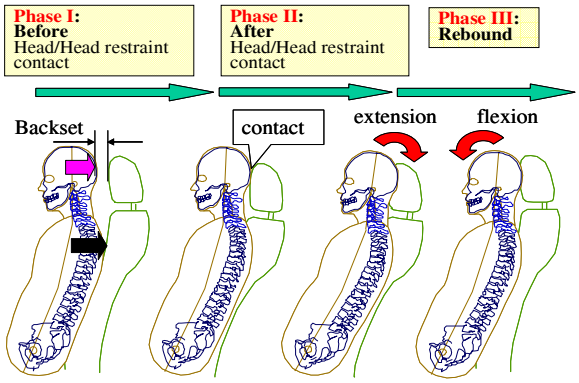


Figure 17. Minor Neck Injury Phenomenon

ACKNOWLEDGEMENTS

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