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RELATIONSHIP BETWEEN OCCUPANT INJURY AND THE PERTURBATION MARK ON THE VELOCITY INDICATOR ON A CLUSTER PANEL

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ABSTRACT−A perturbation mark is occasionally produced on the velocity indicator of the cluster panel of a vehicle during a vehicle collision. This mark can be used to estimate the velocity of the vehicle at the moment of the vehicle's impact. In this study, the effect of the impact velocity and the deceleration of the vehicle on the perturbation mark were investigated, and an analysis of the driver's injury was also conducted through a numerical pulse representation and computer simulations. Sled and pendulum tests were used to replicate the conditions that produce a perturbation mark on the velocity indicator of a cluster panel. It was verified that a higher peak acceleration is more likely than the impact velocity to cause a perturbation mark. According to the computer simulation results, a driver's injury could be more severe at higher peak accelerations with a constant impact velocity. If a perturbation mark, which can be used to estimate the impact velocity, is found while investigating a vehicle accident, this mark reveals that the acceleration was higher than that listed in the related crash report. Therefore, the injuries of the occupants could be more serious than those expected at the reported impact velocity.

KEY WORDS : Perturbation mark, Vehicle accident, Cluster panel, Velocity indicator, Frontal impact, Occupant injury

1. INTRODUCTION

In a vehicle accident investigation, investigators aim to gather all possible evidence at the accident site. Using the collected information, various analyses are conducted to determine the critical causes by reconstructing the accident.

The vehicle impact velocity is an important component necessary for reconstructing a vehicle accident in vehicle-to-vehicle and vehicle-to-pedestrian collisions. The impact velocity can be estimated from the skid marks on the road, the deformed regions and condition of the vehicle, film from closed-circuit television, and so forth. Occasionally, a perturbation mark is produced on the velocity indicator of the cluster panel of a vehicle, and it can be used to predict the velocity of the vehicle at the moment of impact (Baker and Fricke, 1986).

A perturbation mark is assumed to occur at a high impact velocity, which causes a higher oscillation amplitude on the velocity indicator. Moreover, the stiffness of the vehicle also seems to affect the mark because the mark is often found in truck type vehicles, which do not have a large crumble zone like the passenger type.

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This study investigates how the deceleration of a vehicle with a high stiffness affects the occurrence of a perturbation mark on the cluster panel. The effect of the high peak deceleration at a constant impact velocity is also discussed with respect to the occupant injuries.

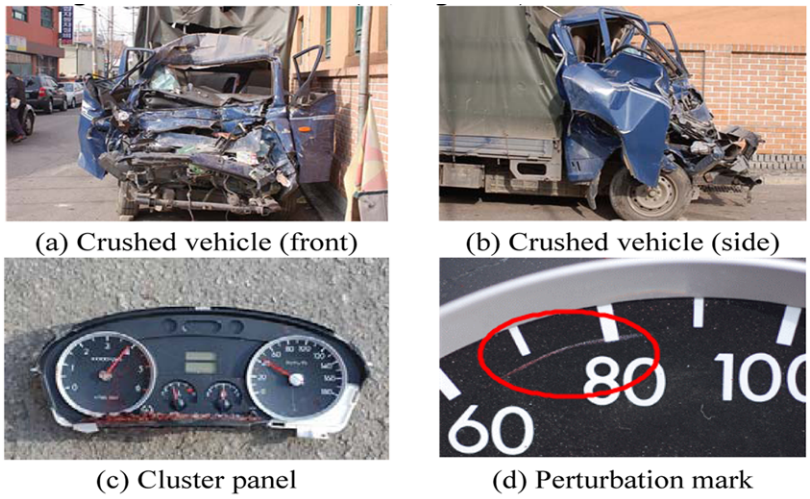
2. PERTURBATION MARK

There are several types of accidents: car-to-car collisions, car-to-pedestrian collisions, car-barrier collisions, and so forth. With car-to-car and car-to-barrier collisions, the vehicle deformation, before-and-after vehicle conditions, and skid and gouge marks can provide valuable evidence for the car accident investigation.

A perturbation mark occasionally is produced on the velocity indicator of the cluster panel of a vehicle during a vehicle collision (Figure 1).

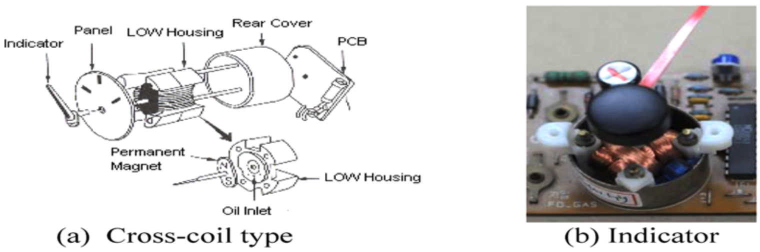
2.1. Impact Velocity Estimation

Perturbation marks usually appear on the cluster panel. It is assumed that the velocity indicator, which may be scratched on the cluster panel, and the paint substance on the rear side of velocity indicator are simultaneously smeared. Thus, a perturbation mark can be used to estimate



(a) Crushed vehicle (front) (b) Crushed vehicle (side)
(c) Cluster panel (d) Perturbation mark

Figure 1. Vehicle accident left a perturbation mark on the velocity indicator on the cluster panel.



(a) Cross-coil type (b) Indicator

Figure 2. Structure of a cross-coil type indicator and a sample of an indicator.

a car's velocity at the moment of impact. Traffic accident data indicate that perturbation marks tend to occur more frequently with truck type vehicles than in passenger type ones.

2.2. Structure of the Velocity Indicator

Instrument panels provide drivers with the status of the vehicle driving systems. Instrument panels may be of two types: digital and analogue. Analogue panels may contain three types of instruments: bimetal, cross-coil and step motor.

Cross-coil instruments are widely used for vehicle velocity indicators. An example of a velocity indicator is illustrated in Figure 2 (Kim *et al.*, 2007). An electric current flows through the cross coil so that the magnetic field may be created around the low-housing. The indicator is located on the axis of a permanent magnet and is rotated by the magnetic field.

Gaps exist among the low-housing, the spindle axis, the rear cover, and so forth. The gaps and masses of these components cause an oscillation from the external disturbance. The flexibility of the velocity indicator and the panel also cause an oscillation from the disturbance. The gaps and masses of the components and the flexibility affect the occurrence of perturbation marks under high acceleration conditions.

3. HAVERSINE PULSE MODEL

There are four well-recognized shapes of a vehicle crash pulse: Haversine ($\sin^2$), sine, square wave, and symmetric triangular. In this study, the haversine pulse model was selected to represent the vehicle frontal barrier impact pulse (Varat and Husher, 2003).

Figure 3 is a graphical representation of the vehicle acceleration, which can be written as follows:

$$a = P\sin^2\left(\frac{\pi \cdot t}{T}\right) \quad (1)$$

The computer simulation and sled test often require the generation of suitable acceleration-time histories with a proper set of shape, amplitude and duration characteristics. Previous research have demonstrated the usefulness of analytical techniques such as the haversine representation for

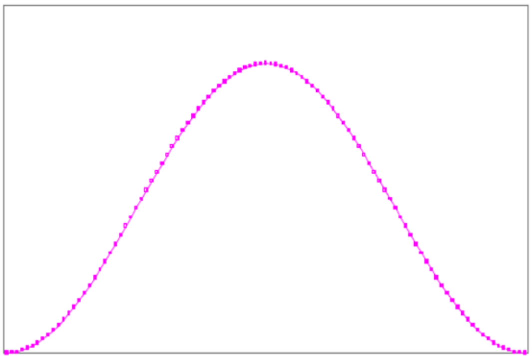
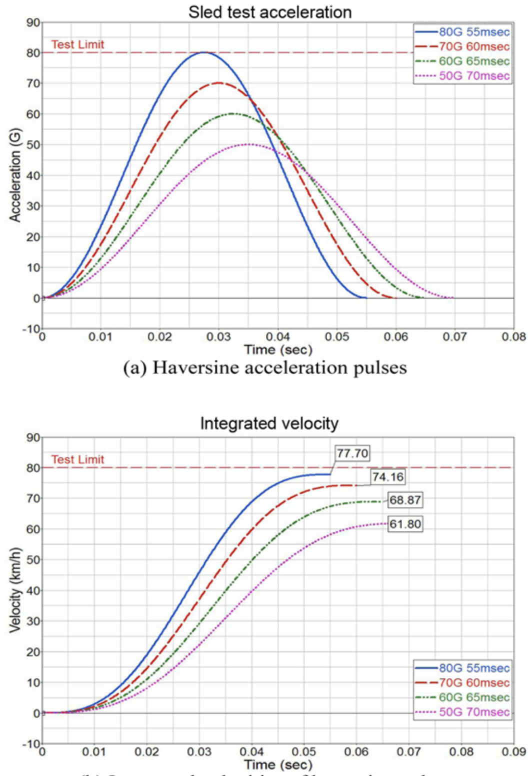


Figure 3. Graphical representation of the haversine function.



(a) Haversine acceleration pulses

(b) Integrated velocities of haversine pulses

Figure 4. Haversine acceleration pulses and their integrated velocities.

studying the severity of collisions (Varat and Husher, 2000).

4. SLED TEST

4.1. Sled Test Pulse Generation

To reproduce a perturbation mark, sled tests were performed at the first stage of this study. From the vehicle frontal barrier impact test reports of NHTSA (National Highway Traffic Safety Administration), in accordance with FMVSS208 and NCAP protocols, the peak vehicle accelerations were found to be around 30–60 G at the impact velocity of 56 km/h.

For the sled test, the highest peak accelerations pulses within sled equipment capacity were chosen. A perturbation mark was assumed to occur in a more severe impact condition than those of the regulations and NCAP tests.

At first, the haversine pulses were generated for four peak accelerations of 50, 60, 70 and 80 G as shown in Figure 4. The time duration for each pulse was adjusted according to the limit velocity of the equipment. The haversine pulses were used as the reference input pulses for the sled tests. The applied sled test pulses are illustrated in Figure 5. During the pulse generation on the sled test equipment, the haversine pulse of 80 G peak acceleration was excluded because of the limit of the equipment capacity.

4.2. Motion of Velocity Indicator

Two instrument panels were selected for the sled tests and were reworked to mount them on the test jig, as shown in Figure 6. Color paint was pasted on the rear sides of the indicators to aid the determination of whether the velocity indicators contact the cluster panels.

From the sled tests with three different peak accelerations, no contact marks were checked out identically on the cluster panels. The oscillating indicator motions at the 70 G peak acceleration pulse are illustrated in Figure 7. While examining the high speed camera film, it was observed that the velocity indicators were oscillating without contacting the cluster panels. The indicator center also oscillated significantly along the low-housing axis.

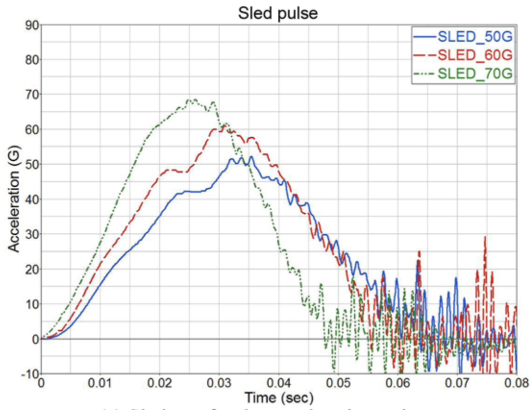
5. PENDULUM TEST

5.1. Truck Barrier Test Review

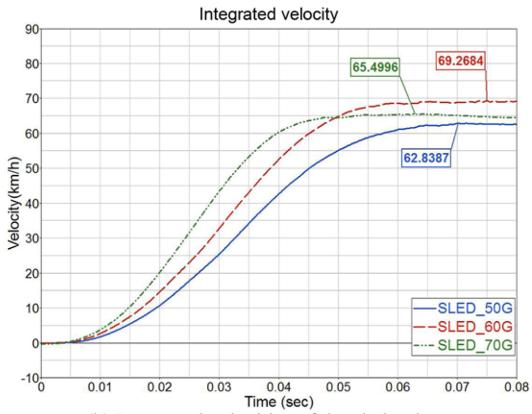
From traffic accident investigations, it is recognized that the perturbation marks appear at a relatively high impact velocity in truck type vehicle accidents. The data in Figure 8, which are from a truck manufacturer and not open to the public in detail, show an example of an A-pillar pulse from the frontal rigid barrier test of a truck type vehicle at the 48 km/h impact velocity. The peak acceleration from the A-pillar was higher than 120 G, and the time duration was about 40 msec. The axis scales were removed because of a confidential issue. Contrary to the structure of passenger cars, the front structures of truck type vehicles do not have a large enough crumble zone to absorb the impact energy.

5.2. Pendulum Impact Test

After reviewing the truck vehicle impact test, supplemental pendulum impact tests were performed in addition to the previous sled tests. The pendulum test equipment was modified from the calibration test equipment for the thorax and the pelvis of the ATD (Anthropometric Test Device). The pendulum impact test configuration is illustrated in



(a) Sled test for the acceleration pulses



(b) Integrated velocities of the sled pulses

Figure 5. Sled acceleration pulses and their integrated velocities.

(a) Indicator motion of the upper cluster panel

(b) Indicator motion of the lower cluster panel

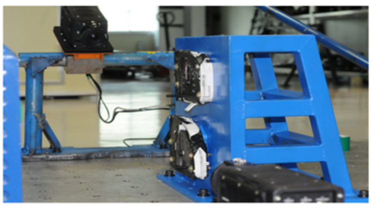
Figure 7. Oscillating indicator motions at the 70 G peak acceleration pulse.

Figure 9. A rubber pad was attached on the contact face of the pendulum to prevent the acceleration sensor from receiving extremely high noise signals.

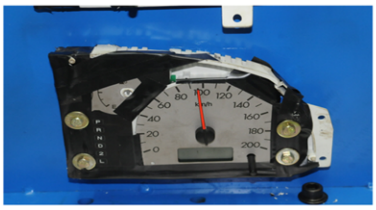
One of the test results is shown in Figure 10. The peak accelerations from the repeated tests with three different cluster panel samples exceeded 200 G. Perturbation marks occurred on the velocity indicators with all three samples. One of the test results is shown in the Figure 10. Therefore, it can be assumed that a higher peak acceleration produces a more noticeable perturbation mark. If a perturbation mark

(a) Sled test equipment

(c) Upper cluster panel



(b) Test jig setup



(d) Lower cluster panel

Figure 6. Sled test setup to reproduce the perturbation mark on velocity indicator.

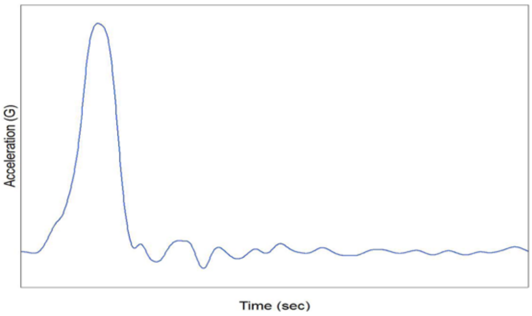
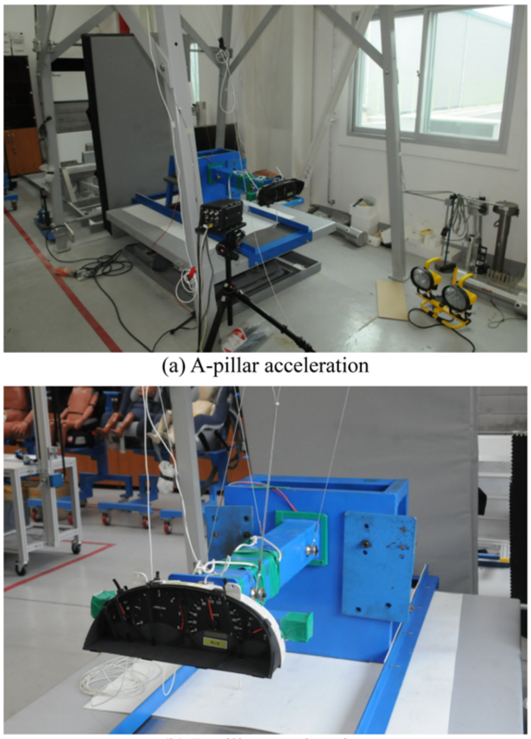


Figure 8. Pulse from the truck frontal barrier test (48 km/h).



(a) A-pillar acceleration

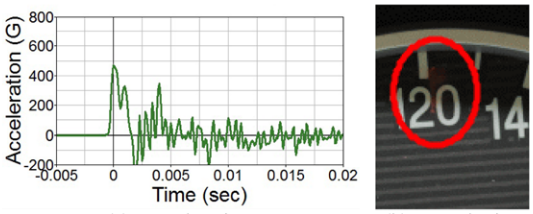
(b) B-pillar acceleration

Figure 9. Pendulum impact test configuration.

is found on the cluster panel in a vehicle accident investigation, a relatively high acceleration and a high impact velocity should be considered to reconstruct the conditions of the accident.

6. OCCUPANT INJURIES

If a perturbation mark occurs on the velocity indicator, a considerable peak acceleration was likely applied on both the vehicle structures and the occupants. The peak level of that acceleration could be higher than those from the regulations and the NCAP tests.



(a) Acceleration (b) Perturbation mark

Figure 10. Pendulum impact test results.

6.1. Simulation Model

In this study, the effect of a high peak acceleration on driver injuries was reviewed with a constant impact velocity. Figure 11 shows a frontal driver simulation model, which was constructed from the application database in MADYMO V.7.1 and was selected as the base model (TASS, 2009). The occupant restraint systems that was considered to consist of a single-stage airbag, retractor and buckle pretensioners; a single-stage seatbelt load limiter; and a non-collapsible steering column. The base model was customized on NCAP (Dec. 2004), and the 5-star rating score is summarized in Figure 12.

6.2. Simulation Pulses

The impact velocity was fixed at 56 km/h, which is at the same level as the regulations and the NCAP test. The acceleration pulses were generated using the haversine representation as defined in Eq. (1). Figure 13 shows the haversine pulses of 30, 50, 80, 100, 120 and 140 G together with the base pulse and the integrated velocities of those pulses. The acceleration pulses were applied for the frontal occupant simulation input.

6.3. Driver Kinematics and Injuries

The driver kinematics for the 30 and the 140 G models at 40 msec are illustrated in Figure 14. The driver position in the 140 G model moved forward earlier than that in the 30 G model. Thus, the driver position did not align with the

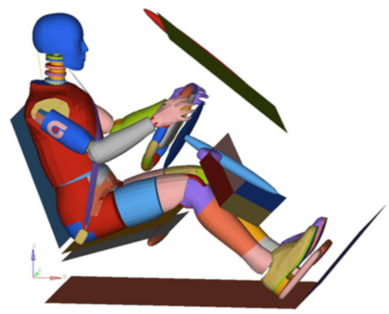


Figure 11. Frontal driver simulation model.

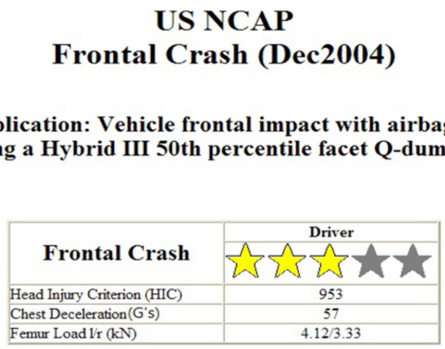
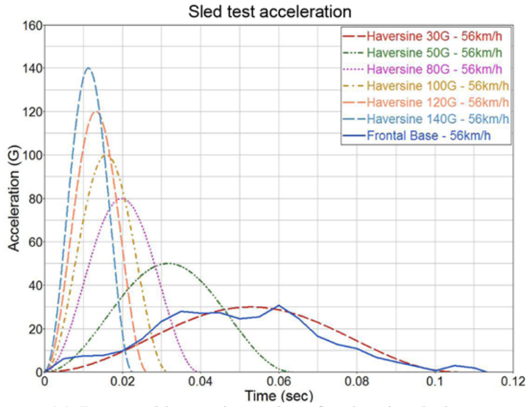
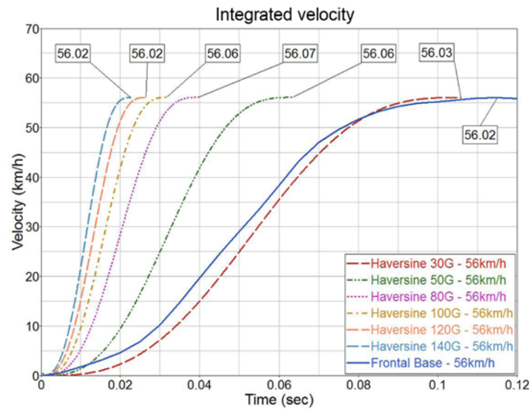


Figure 12. NCAP 5-star rating score for the frontal driver simulation model.



(a) Base and haversine pulses for the simulations



(b) Integrated velocities of the simulation pulses

Figure 13. Sled acceleration pulses and integrated velocities.

deployed airbag. Because the airbag firing times and the seatbelt were set to satisfy the regulations and NCAP protocols, such a close occupant position to the airbag might cause severe injuries to the head, neck and thorax. The peak vehicle accelerations on the NCAP frontal impact are expected to be approximately 30–50 G.

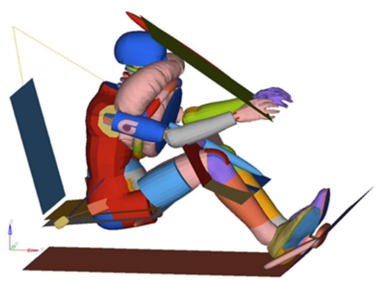
The injury index results presented in Table 1 and Figure 15 show that most injury index values increased as the peak acceleration was increased at a constant impact velocity. Gradual increases are observed in Figure 15(a), (b), (d) and (e). Meanwhile, rapid increases are observed in Figures 15(c) and (f) at the peak acceleration of 50 G. This results indicate that a higher peak acceleration should be avoided to reduce the level of occupant injuries.

7. CONCLUSIONS

The conditions to reproduce a perturbation mark on the velocity indicator on the cluster panel of a vehicle were studied through sled and pendulum tests. An analysis of the driver's injury was also conducted through a numerical pulse representation and computer simulations. The relationship between the perturbation mark and the occupant injury can be summarized as follows:

(1) The data, which are from a truck manufacturer and not open to the public in detail, demonstrated that a perturbation mark occurred at 48 km/h with an acceleration value higher than 120 G. To repeat the accident situation, a pendulum test was performed, and a perturbation mark was observed at an acceleration value exceeding 200 G.
(2) A high peak acceleration can cause more severe occupation injury than an impact velocity of 56 km/h, which is the frontal impact condition of the regulation and the NCAP test.
(3) When a perturbation mark is found during a vehicle

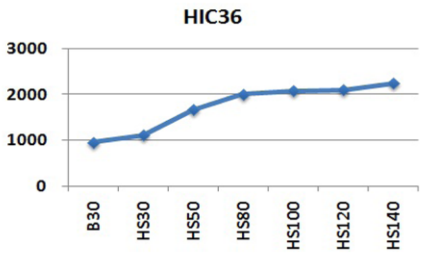
(a) Kinematics for 30 G model at 40 msec



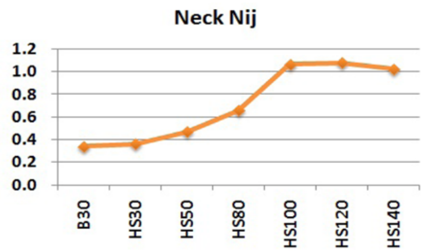
(b) Kinematics for 140 G model at 40 msec

Figure 14. Driver kinematics of the 30 G and the 140 G models.

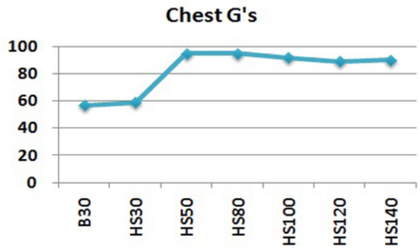
accident investigation, it can be used to estimate the impact velocity, and it reveals that the acceleration was higher than that listed in the related crash report. Therefore, the occupants' injuries could be more serious than those expected at that impact velocity.



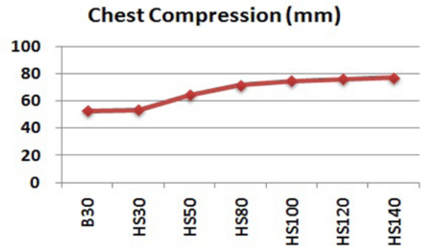
(a) HIC36



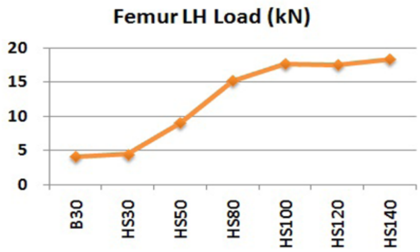
(b) Neck Nij



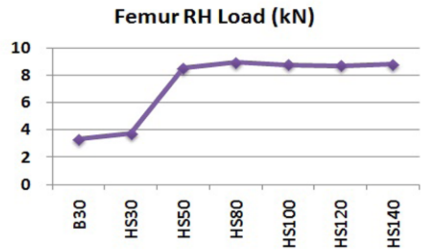
(c) Chest G's



(d) Chest compression



(e) Left femur load



(f) Right femur load

Figure 15. Simulation results of the injury index according to the acceleration peaks.

Table 1. Summary of injury indices for the frontal collision simulations.

Injury index	Base	Haversine pulse					
	B30	HS30	HS50	HS80	HS100	HS120	HS140
HIC15	835	996	1424	1746	2049	2068	2201
HIC36	953	1109	1662	2008	2078	2094	2244
Chest G's	57.00	59.00	95.00	95.00	92.00	89.00	90.00
Chest deflection (mm)	52.70	53.34	64.43	71.72	74.80	76.04	77.03
Left femur load (kN)	4.12	4.40	9.00	15.23	17.65	17.57	18.35
Right femur load (kN)	3.33	3.74	8.54	8.93	8.76	8.69	8.80
Neck Nij	0.339	0.362	0.466	0.657	1.063	1.076	1.022
Neck-tension (kN)	1.533	1.513	2.574	3.176	4.467	4.476	5.397
Neck-compression (kN)	0.003	0.019	0.003	0.034	0.004	0.004	0.004

REFERENCES

Baker, J. S. and Fricke, L. B. (1986). *The Traffic-Accident Investigation Manual*. 9th Edn Northwestern University Traffic Institute. Illinois.

Kim, M. B., Jang, H. S., Lee, J. I. and Jang, Y. H. (2007). *Vehicle Electricity.* 1st Edn. Golden Bell. Seoul. Korea.

TASS (2009). *MADYMO Manual*. Release 7.1. TASS. Netherlands.

Varat, M. S. and Husher, S. E. (2000). Vehicle impact response analysis through the use of accelerometer data. *SAE Paper No.* 2000-01-0850.

Varat, M. S. and Husher, S. E. (2003). Crash pulse modeling for vehicle safety research. *18th ESV*, *Paper No*. 501.