PEDESTRIAN HEAD IMPACT CONDITIONS DEPENDING ON THE VEHICLE FRONT SHAPE AND ITS CONSTRUCTION - FULL MODEL SIMULATION

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ABSTRACT

The recent pedestrian accident data show the injury source for head changes from former ones. The head contact points to the vehicle and contact conditions are thought to be influenced by the vehicle front shape, its construction (rigidity) and pedestrian size. In this study, 32 simulation models are calculated and the full dummy , developing in HONDA, sled tests are conducted. The result shows that not only vehicle front shape but also its rigidity much influences the head contact point and the impact conditions are influenced by the pedestrian height.

key words: ACCIDENT ANALYSIS, EEVC, PEDESTRIANS, SIMULATION, SLED TESTS

FOR THE EVALUATION of Pedestrian Protection in Europe, the European Enhanced Vehicle Committee (EEVC) - WG17-report[4] is mainly used now. For the evaluation of pedestrian head injuries, the report only takes the hood area of the vehicle into account. But from the recent Pedestrian Accident Research it was found that, the windshield has a bigger effect on head injuries than the hood area. One of the reasons for this phenomenon is the change of the front shape in recent vehicle models. The head contact point and contact conditions are thought to be influenced by the construction (rigidity), too. So in this study the Full Model Simulation is conducted to analyze the correlation between the contact points, contact conditions and the front shape, its rigidity. The pedestrian models are impacted not only at the center of the vehicle, like in many former studies, but also at the outer side of the vehicle where the construction is different from the center part. Four different size pedestrian models, two kinds of vehicle 3-D models and four impact positions are simulated. A full-scale dummy test is conducted to confirm the results of the simulation. In this test the pedestrian dummy which HONDA R&D is developing, is used. This study shows that the head contact point is much influenced by the front construction (rigidity) of the vehicle and that the head contact point is more backward than the Wrap Around Distance (W.A.D.) which is measured from the front shape of the vehicle. Furthermore the impact condition, head velocity and angle, are influenced by the pedestrian size.

NHTSA CONDUCTED a Pedestrian Injury Causation Study (PICS) from 1977 to 1980. They were interested in the influence of the vehicle front shape of recent models, and conducted another pedestrian accident research, Pedestrian Crash Data Study (PCDS) from 1994 to 1998 where only recent model year vehicles were inspected [5]. Kristie L. Jarrett et al (1998) [6] analyzed the data from both studies and the items found to be influenced by the change of front shape are the vehicle - pedestrian interaction, the increase in injury because of the windshield and A-pillar, and the decrease of thorax, abdomen and pelvis injuries. But it must be remembered that the vehicle speed of AIS 5&6 injury cases on windshield or A-pillar is more than 40km/h. Under 40km/h, the hood is still the main injury source for those cases. Dietmar Otte (1999) [3] indicated similar results using the accident data of Hannover Medical University. NHTSA released the PCDS data and Fig 1, Fig.2 shows one example of the analysis.

In PCDS they try to interview the drivers or pedestrians and investigate the pedestrian orientation to

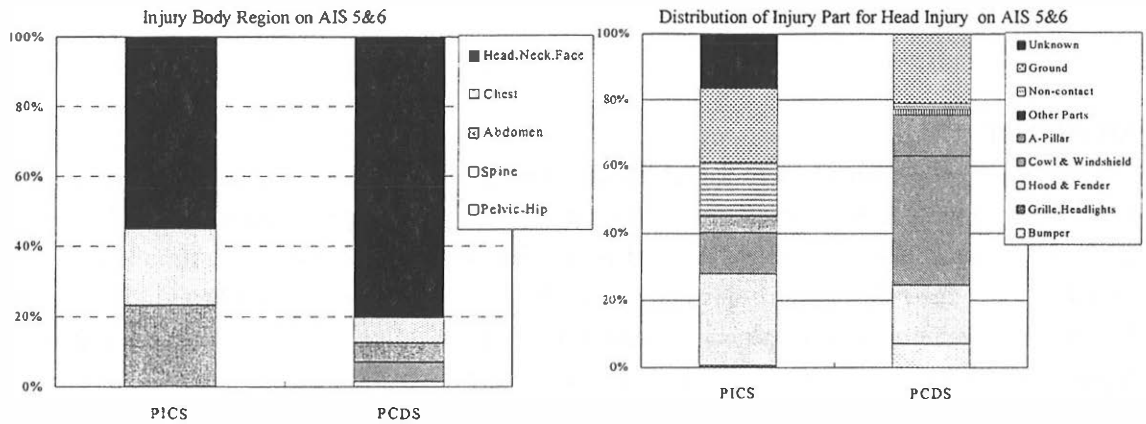


Fig. 1 Injury Body Region and Injury Part Distribution for PICS and PCDS

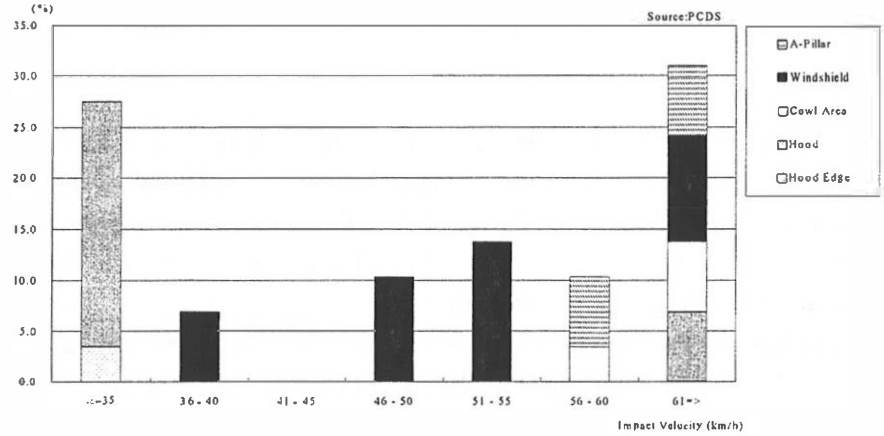


Fig.2 Distribution of Injury Source for Head Injury (AIS 5&6) by Impact Velocity

the vehicle at the accidents (Fig. 3). From these data the pedestrian orientation was determined for use in the simulation model in this study.

SIMULATION MODEL

PEDESTRIAN MODEL - HONDA R&D developed the Pedestrian Create program (HONDA Pedestrian Dummy Creator) [8]. The origin of this program is GEBOD (GEnerator of BODy), Joints properties data are improved by using the former PMHS (Post Mortem Human Subject) test results and are transferred to PAM-CRASH data format. This model is constituted by 15 segments and 14 joints. All segments are made of rigid body and have mesh on the surfaces. The joint properties have the same value for each model size. Here the joint properties for child is said to be different from adult ones, softer, but there are few child PMHS test data for model validation. So in this study adult joint

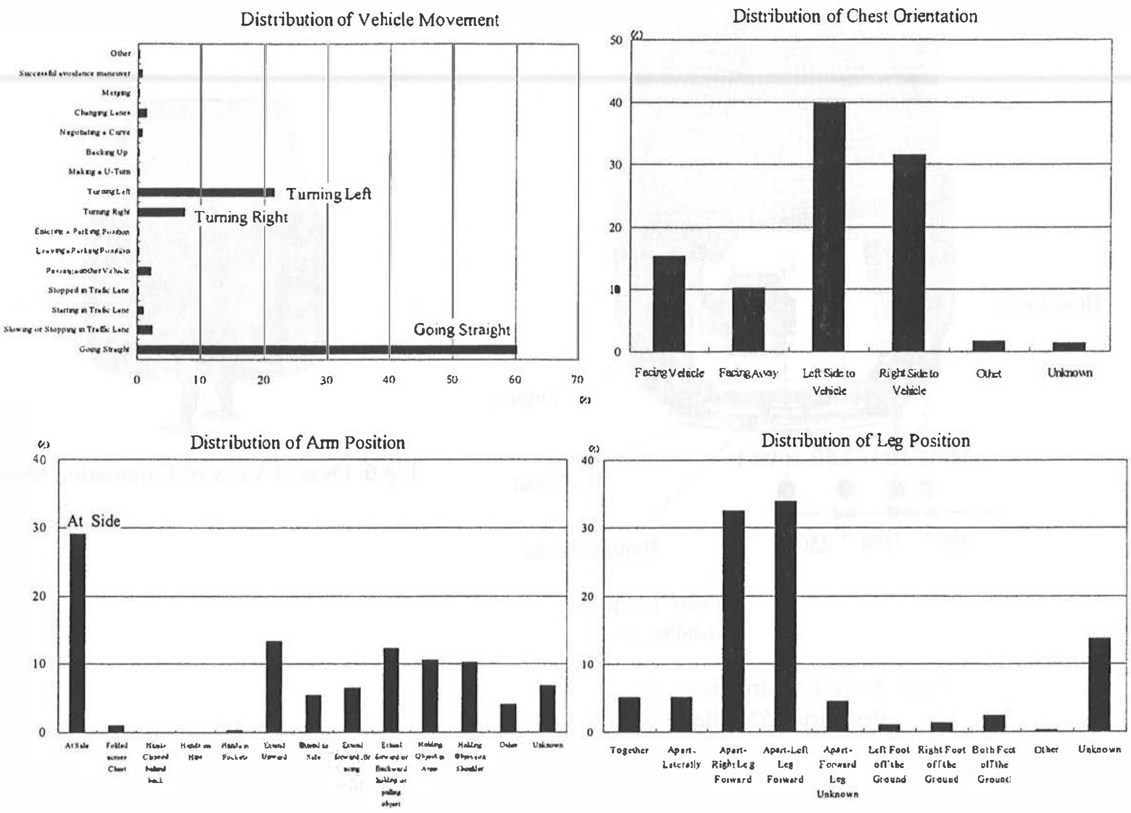


Fig.3 Vehicle Movement and Pedestrian Orientation at Pre-Crash

properties was taken for child model, too. Accordingly the results should be considered for only qualitative one (trend). Four kinds of pedestrian sizes (Fig. 4) are used in this study. The friction between foot and ground is neglected because in the full-scale dummy test the dummy is hanging at the time of contact. In the simulation the pedestrian model is put as close as possible to the vehicle making sure that initial penetration does not occur. Therefore the dropping distance by the gravity before the crash is negligible.

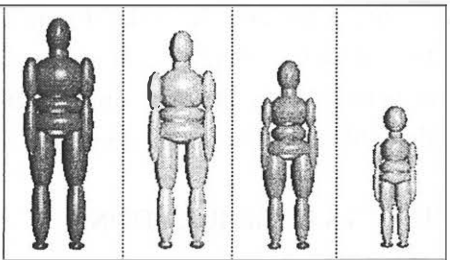
Pedestrian Size				
	Large Male	Average Male	Small Female	Child
Height(m)	1.87	1.76	1.52	1.14
Weight(Kgf)	99.0	78.0	46.0	23.0
Similar Dummy	AM95	AM50	AF05	C6Y

Fig.4 Pedestrian Model Size on Simulation

VEHICLE MODEL - Two kinds of vehicle models with different hood edge height are used, a passenger car and a utility vehicle. They are the 3D half body models based on the mass production vehicles. The vehicle weight is equal to the catalogue value and the added mass is put at the aft end for supplementing the shortage in the model weight. The vehicle parts in the frontal area are made in detail but in the engine room only the engine is modeled and other parts have only weight at their center of gravity. Vehicle speed is 40km/h and braking after the crash is not considered.

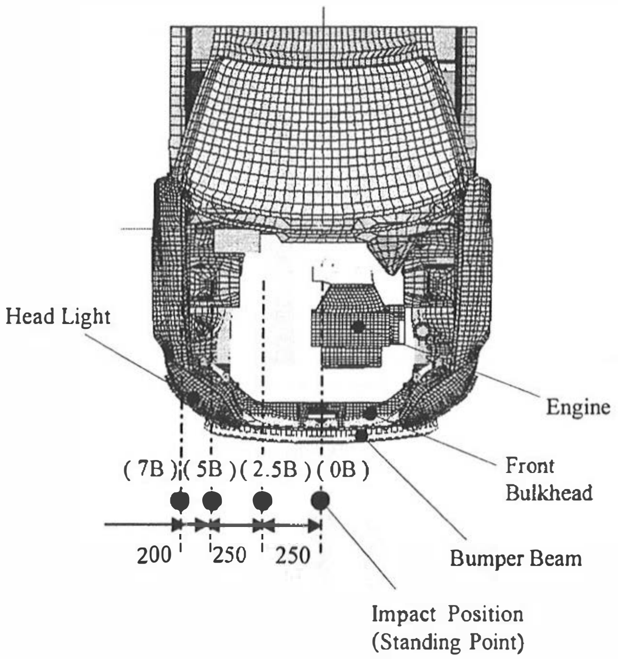


Fig.5 Front Construction and Pedestrian Standing Points

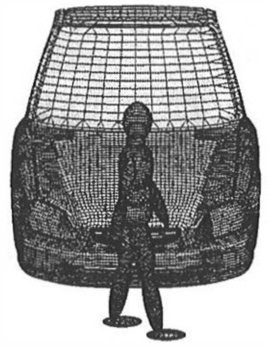


Fig.6 Overall View of Calculation Model

CALCULATION MODEL – In this study, head contact points and impact conditions are considered. Items influencing them are not only the front shape but also its construction (rigidity), so the pedestrians are impacted at the outer position too. Fig. 5 shows the impact positions with the lateral measurements indicating the distance between the pelvis center of gravity and the vehicle center line. The pedestrian orientation at pre-crash is decided from the PCDS analysis, thorax and face is lateral to the vehicle, legs are fore and aft and arms are fore and aft at the side. Fig. 6 shows one of the calculation models. Totally 32 cases are calculated in this study.

RESULTS OF SIMULATION

HEAD CONTACT POINTS are decided through the animation. For the head contact velocity, first a time analysis of the head tri-axial combined velocity at the center of gravity is made determining the timing when the velocity changes rapidly. The head velocity is decided as the value at the above timing. For the head contact angle, the head trajectory curve is established and it is defined as dz/dx at the contact timing (with z the vertical displacement and x the horizontal displacement). Fig. 7 shows the head contact points for each condition. It shows that for the center area of the vehicle, contact points are parallel to the

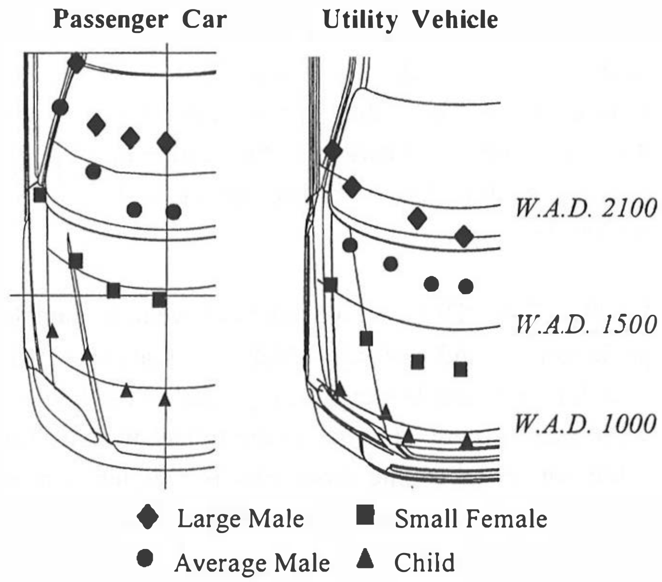


Fig. 7 Head Contact Points

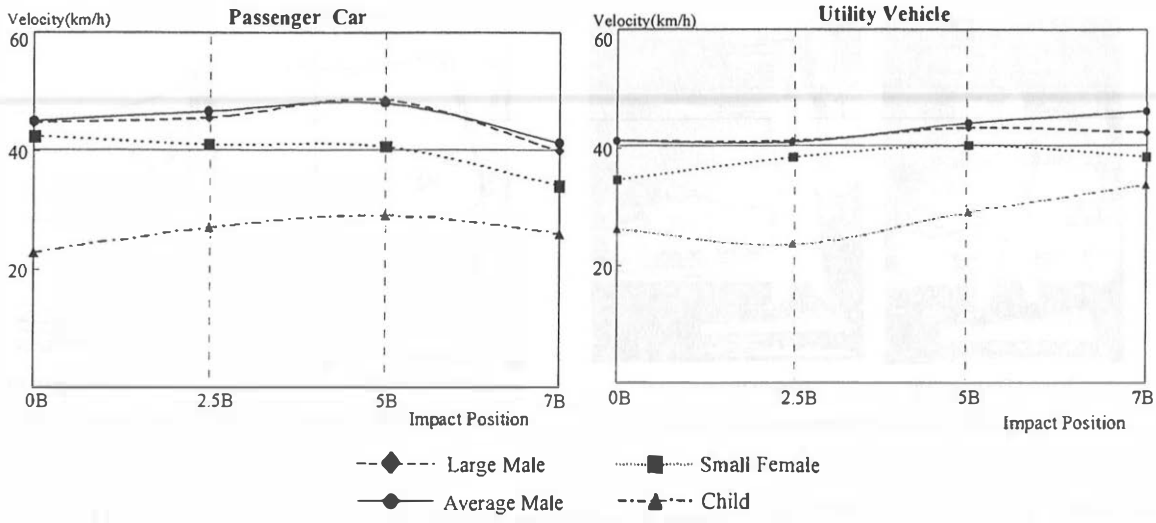


Fig. 8 Head Contact Velocity by Impact Position

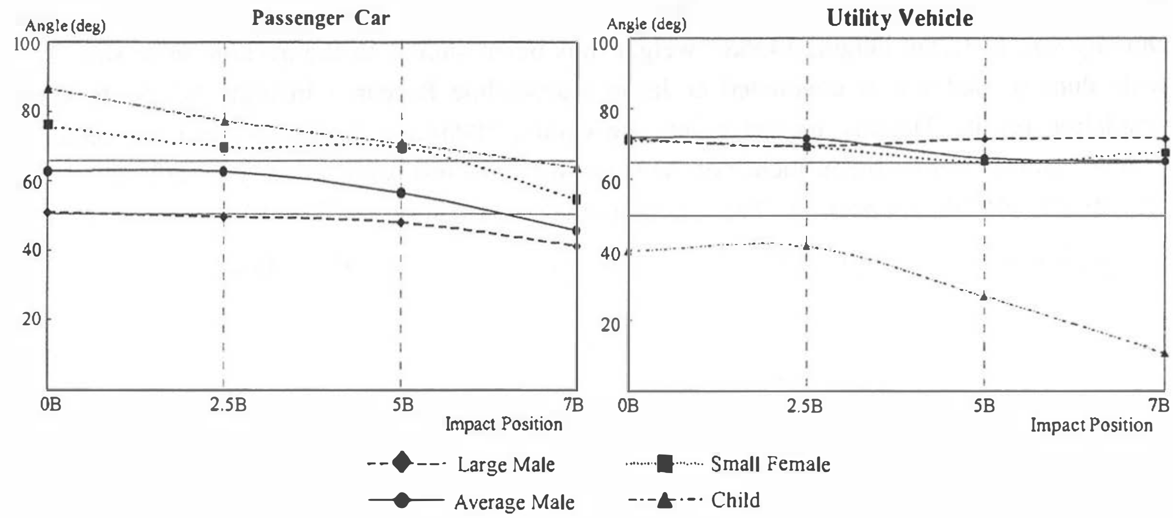


Fig. 9 Head Contact Angle by Impact Position

front shape, but for outer side impacts they are more backward than the W.A.D. which is dependent from the front shape. This phenomenon is found on each pedestrian size and vehicle type, and for the passenger car it is remarkable. Fig. 8 shows the head contact velocity and in this figure the abscissa means the pedestrian impact position. The head velocity of the child in all positions is lower than the vehicle speed. This result is similar to Wismans et al (1999) [7] result and lower than the velocity in the EEVC report. It is increasing along the pedestrian height but the head velocity of the large male is the same as that for the average male. Fig. 9 shows the head contact angle. The bigger the pedestrian size, the smaller the angle is, for the passenger car. This result is not in line with the EEVC report. On the other hand for the utility vehicle, the angle of the child head is the smallest with the angle for the other pedestrian sizes being similar to each other.

	Passenger Car		Utility Vehicle	
Left Leg Position / Impact Position	Fore	Aft	Fore	Aft
0B	◻	◻	◻	◻
4B			◻	
5B	◻	◻	◻	
6B		◻	◻	

Table 1 SLED Test Condition

RESULT OF FULL DUMMY TEST

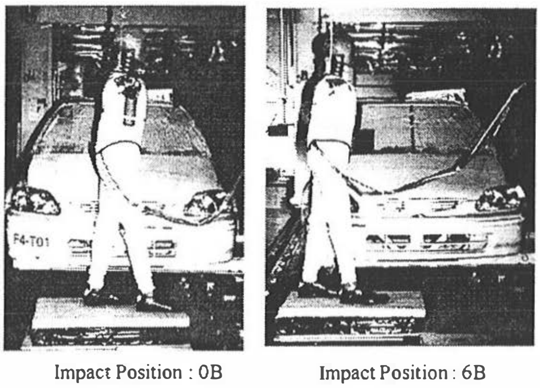


Fig. 10 Standing Posture at Pre-Crash

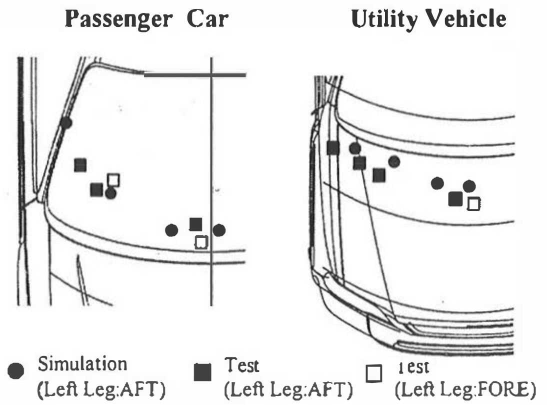


Fig. 11 Head Contact Points (Simulation & TEST)

HONDA R&D IS since 1997, developing a pedestrian dummy for pedestrian protection [1], [2]. In this study the Phase 1 dummy is used. The goal of Phase 1 dummy was to make the motion similar to PMHS. So this dummy is enough for this study to confirm the head contact points and conditions. Dummy size is 1.76m height, 74.9kgf weight thus being similar to the average male size. The full-scale dummy sled test is conducted at Japan Automobile Research Institute (JARI) to check the simulation results. Dummy impact points are center, 500mm and 600mm from the center of the vehicle. And to confirm the influence of the leg position the test is conducted both left leg forward and aft at center and 500mm position. Table 1 shows the test condition and Fig. 10 shows the dummy

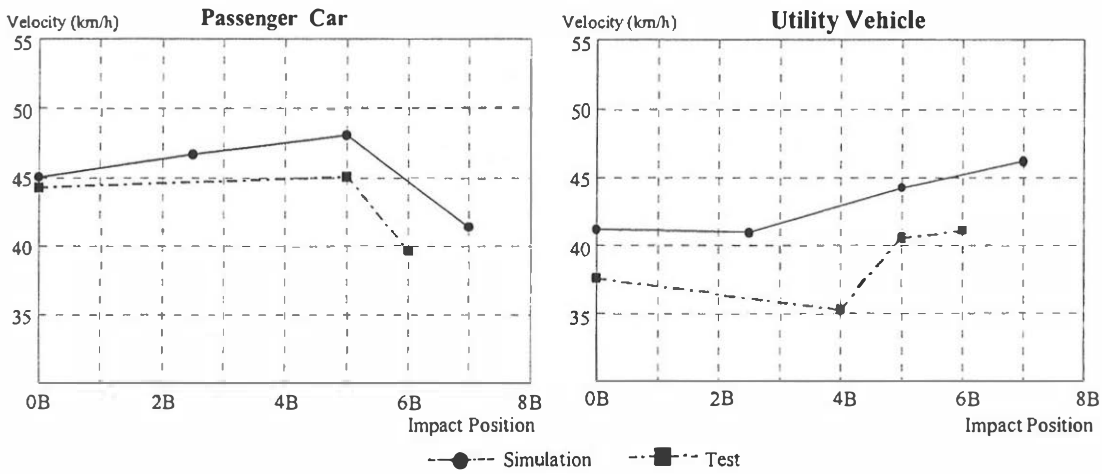


Fig.12 Head Contact Velocity (Simulation & TEST)

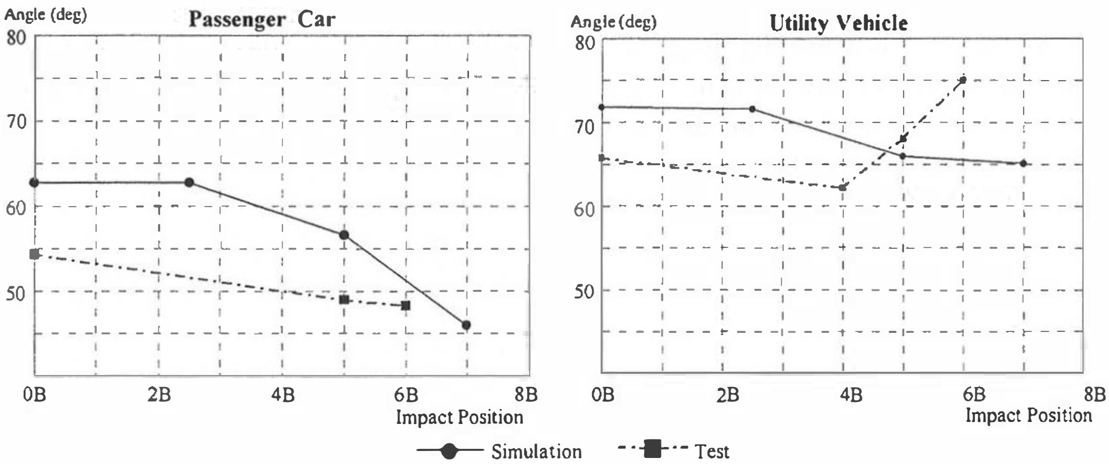


Fig. 13 Head Contact Angle (Simulation & TEST)

Impact Position : 0B

Impact Position : 5B

0ms

30ms

60ms

90ms

120ms

150ms

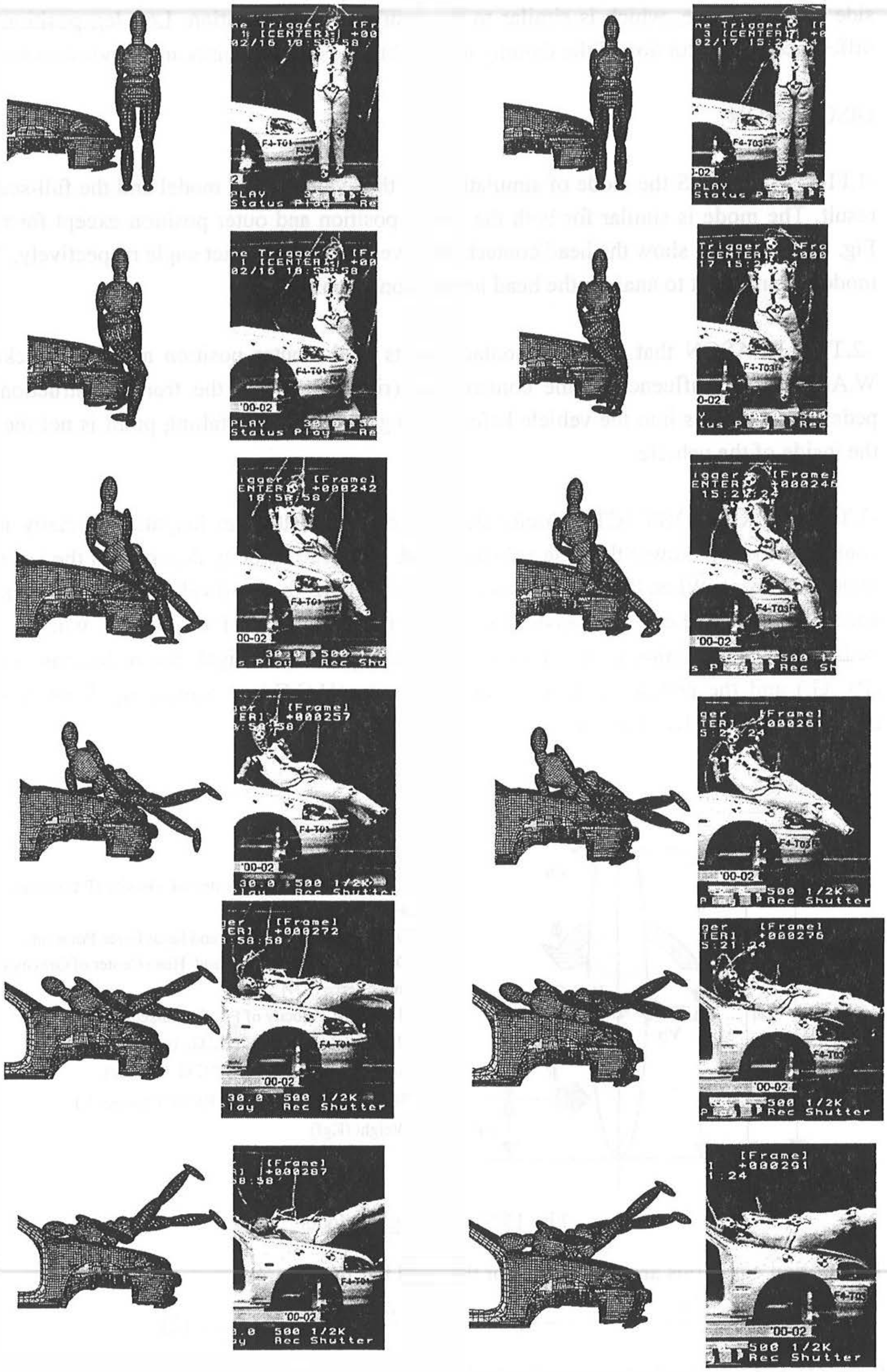


Fig. 14 Mode Comparison between Simulation and Sled Test for passenger car
(Simulation Model : Average Male Pedestrian)

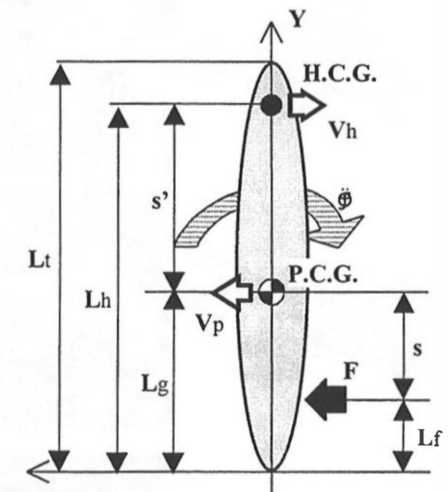
setting photos. Sled velocity is 40km/h. Fig. 11, 12 and 13 show the resulting, head contact point, contact velocity, and contact angle. Head contact point is more backward than the W.A.D. at the outer side of the vehicle, which is similar to the result of the simulation. Left leg position makes a little difference for the torsion of the dummy motion but the contact points and conditions are similar.

DISCUSSION

-1.FIG. 14 SHOWS the mode of simulation for the average male model and the full-scale dummy test result. The mode is similar for both the center position and outer position except for the leg motion. Fig. 11, 12 and 13 show the head contact, head velocity and contact angle respectively. The simulation model is sufficient to analyze the head impact conditions.

-2.THE REASON that the head contact points at the outer position are more backward than the W.A.D., is the influence of the construction (rigidity). When the front construction is weak, the pedestrian leg goes into the vehicle before falling down and the falling point is not the front face but the inside of the vehicle.

-3.THE HEAD CONTACT velocity depends on the pedestrian height. Especially the child head contact velocity is lower than the vehicle speed. The head velocity depends on the pedestrian rotation after the impact. When the head falls towards the vehicle, the head velocity will be higher than vehicle speed and when the head transfers in the vehicle direction of moving, it will be smaller. The pedestrian head rotation mode is decided by the input force height, the pedestrian center of gravity (P.C.G.) and the pedestrian head center of gravity (H.C.G.). A simple rigid bar model is used to confirm this mode like Fig. 15.



Lt : Overall Height (m)
Lh : Head Height(m)
Lg : Height of Pedestrian Center of Gravity (P.C.G.) (m)
Lf: Input Force Height (m)
s : Distance between P.C.G. and input Force Point (m)
s' : Distance between P.C.G. and Head Center of Gravity (H.C.G.) (m)
F : Input Force (KN)
Vp : Horizontal Velocity of P.C.G. (m/sec)
Vh : Horizontal Velocity of H.C.G. (m/sec)
$\ddot{\phi}$: Angular Velocity around P.C.G. (rad/sec)
J : Moment of Inertia around P.C.G. ($kgm\sec^2$)
W : Weight (Kgf)

Fig. 15 Simple Rigid Model

The motion equations around P.C.G. for the rigid bar model are

$$F = \frac{W}{g}\frac{d^2x}{d^2t} \text{ --------- (1)} \qquad T = J\frac{d\omega}{dt} \text{ ----------- (2)}$$

From (1) and (2), P.C.G. horizontal velocity(Vp) and angular velocity(ω) is

$$V_p(t) = \frac{g}{W}Ft \text{ --------- (3)} \qquad \omega(t) = \frac{T}{J}t \text{ ----------- (4)}$$

From (3) and (4), the dummy head horizontal velocity(Vh) is

$$Vh(t) = V_p(t) - s'\omega(t)$$
$$= (\frac{g}{W} - \frac{ss'}{J})Ft \text{------}(5)$$

(5) shows that head velocity and direction is found by

$$K = \frac{g}{W} - \frac{ss'}{J} \text{---------}(6)$$

When K is 0, then the s' is the imaginary rotation center (I.R.C.). If H.C.G. is above I.R.C., the head velocity is higher than the vehicle speed and if H.C.G. is below I.R.C., the head velocity is lower. For this model, the moment of inertia (J) is determined only by height (Lt) and weight (W)

$$J = \frac{W}{g}\frac{Lt^2}{12} \text{----------}(7)$$

In (6), W and s' will concern with Lt and s will concern with Lt and vehicle bumper height. The correlation between them is found for the simulation models in this study. Table2 shows the P.C.G. and H.C.G. for each pedestrian model. Fig. 16 shows the correlation between Lt and s, s' and Fig. 17 shows between Lt and W. The following approximates are adopted which are based on Lt.

From (7) to (11), (6) can be expressed by Lt only. Fig. 18 shows the correlation between Lt and K when impacting at the center of vehicle. From these figures, the child head velocity is lower than the vehicle speed and the head velocity is saturated around the average male height. This is similar to the

	Large Male	Average Male	Small Female	Child
Height (Lt / cm)	187.0	176.0	152.0	114.0
Mass (W/ Kgf)	99.0	78.0	46.0	23.0
Height of Pedestrian Center of Gravity (P.C.G. /cm)	103.6	96.3	81.8	61.4
Height of Head Center of Gravity (H.C.G. /cm)	172.9	162.4	140.1	101.3

Table2. Dimension for each pedestrian model

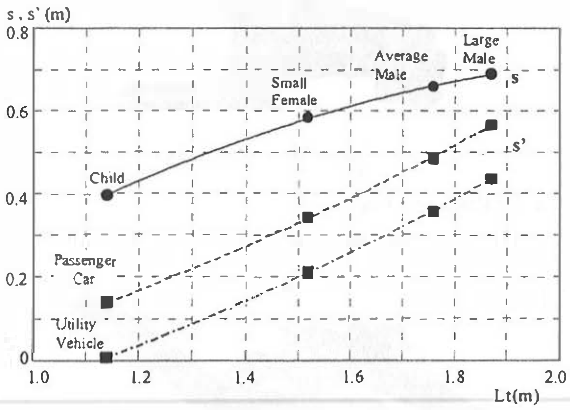


Fig.16 The Relation between s, s' and Lt

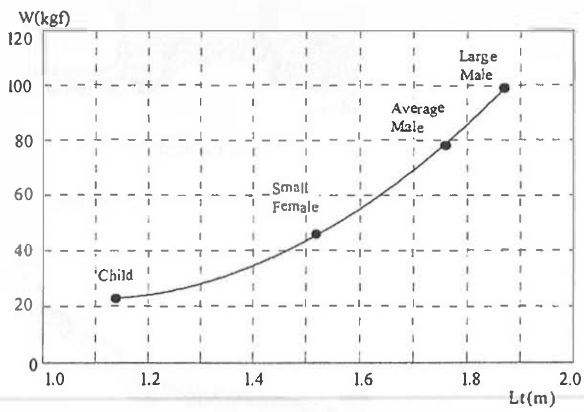


Fig. 17 The Relation between W and Lt

$$s' = -0.246Lt^2 + 1.138Lt - 0.581 \text{---------}(8)$$

$$s = 0.143Lt^2 + 0.154Lt - 0.223 \text{----------}(9) \quad \text{(for passenger car)}$$

$$= 0.143Lt^2 + 0.154Lt - 0.353 \text{----------}(10) \quad \text{(for utility vehicle)}$$

$$W = 125.98Lt^2 + 275.68Lt + 173.63 \text{--------}(11)$$

result of the simulation. Accordingly the head contact velocity for the child area of the vehicle is lower than the vehicle velocity, and that for the adult area is higher but the velocity for the average male height is the maximum necessary for consideration.

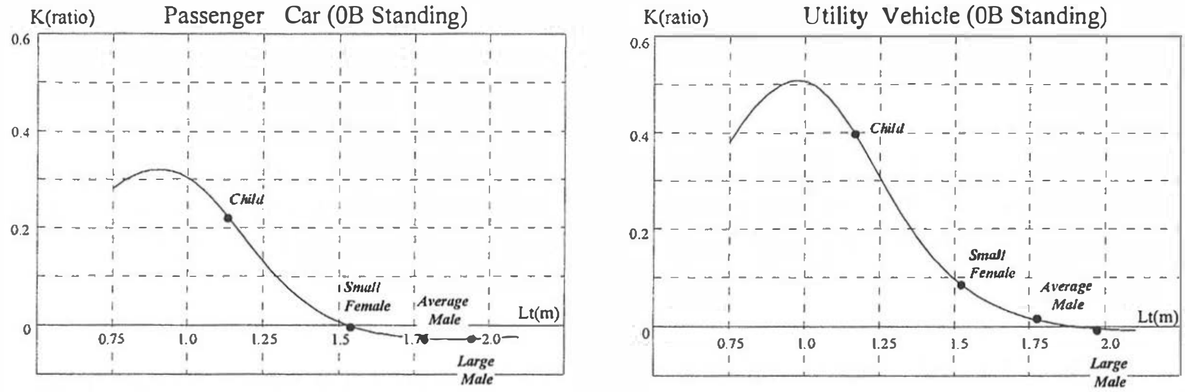
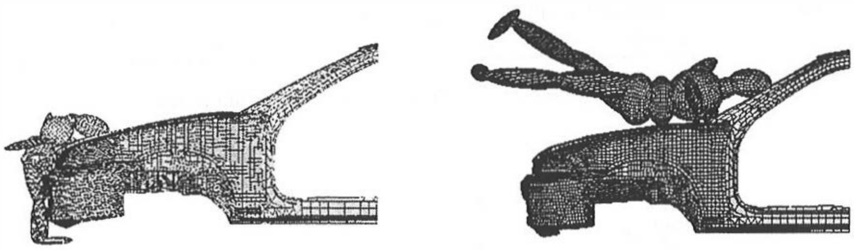


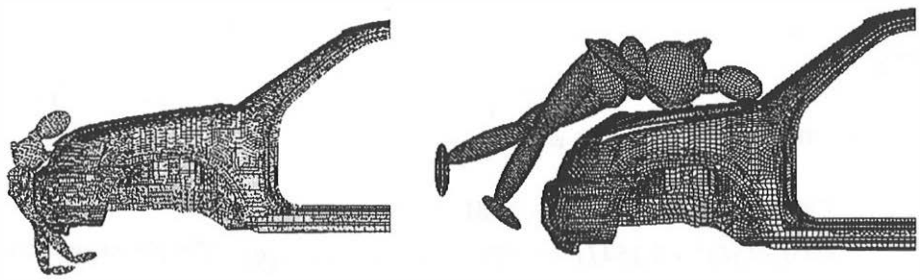
Fig. 18 Head Velocity Ratio(K) depending on the Pedestrian Height(Lt)

-4.THE HEAD CONTACT angle depends on the pedestrian height , too. Especially for the passenger car, the child head contact angle is the largest for all pedestrian sizes. This result is different from the EEVC test procedure. Fig. 19 shows the animation at the contact timing. The child is not carried over to the vehicle and only the neck is bent. Furthermore the contact object is the hood which is nearly horizontal and consequently the contact angle is large. On the other hand, the large male is carried over and the whole body wraps around the hood . The contact object is the windshield which has an initial angle so that the contact angle is small. For the utility vehicle, the child head contact angle is the smallest. In this case the head collides directly with the hood edge before there is any neck bending (Fig. 20). For other sizes, the contact object is below the windshield or on the hood and these areas are nearly horizontal.



Child Pedestrian　　　　Large Male Pedestrian

Fig. 19 Head Contact for Passenger Car



Child Pedestrian　　　　Large Male Pedestrian

Fig.20 Head Contact for Utility Vehicle

CONCLUSION

THE PEDESTRIAN FULL MODEL simulation is conducted to analyze the influence of the vehicle front shape and its construction (rigidity) on the head impact conditions. The conclusions are summarized below.

-1.The head contact point is influenced by the front construction (rigidity).

-2.The head contact velocity depends on the dummy height. The child head velocity is lower than the vehicle speed and the taller the pedestrian, the higher his head velocity is. But this increased ratio is saturating around that of the average male height.

-3.The contact angle for passenger car depends on the pedestrian height and child head contact angle is the largest.

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