Computational Simulation for Head Impact on Vehicle Hoods Using the Precise Finite Element Model

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ABSTRACT

This paper will describe head impact studies on hood of vehicles using headform impactors and engine compartment Finite Element (FE) models. A commercial FE code PAM-CRASH™ was used to conduct the computational simulation. Head Injury Criteria (HIC), which is obtained by post-processing the computed acceleration history, is used in this prediction method. Several numerical examples are demonstrated where close agreement between the test and the calculated values of the acceleration history is obtained. Additionally, the numerical scattering analysis is implemented to clarify the importance of each parameter.

INTRODUCTION

The objective of this study is to develop a computational evaluation method for head impact onto vehicle hoods considering several small parts in the engine compartment, in connection with proposed pedestrian safety regulations to be introduced in 2005 in Japan. In the early phase of car design, cost effective pedestrian protection measures should also be considered to avoid changes later in the development process. In this case design decisions for the hood and engine compartment structures have to be made using reliable predictive analysis methods. Also, several examples of numerical simulation are presented which describe impactors and isolated hood contacts [1][2][3].

This paper will describe actual head impact studies on hoods of vehicles. It explains the structures of a headform Finite Element (FE) model and construction of a front end FE model including the engine compartment with component parts. An explicit FE code, PAM-CRASH™, is used to implement the computation. Head Injury Criteria (HIC) is used in this prediction method by post-processing the computed time history of the acceleration. Close agreement between the test and the calculated values of the acceleration history is obtained. We can predict the deformed modes and energy absorption characteristics of engine compartment parts beneath the hood using the presented computational evaluation, although, the experimental method cannot obtain these modes, energy and the other quantities beneath the hood.

Additionally, the numerical scattering analysis is conducted in order to clarify the importance of each parameter.

Although there are still remaining possibilities for improvement of this method, there is good correlation at majority of the evaluating points. Thus, we are adopting this method for the practical design of hoods and engine compartment components beneath the hood.

FINITE ELEMENT MODELING

Headform Impactors

The first step in the head impact study is to develop a FE model of headform impactor (head dummy).

<u>Outline of Structure</u>

Finite Element model is presented, as shown in figure 1. The headform consists of two main parts, the outer skin (PVC) and the inner semi-sphere (aluminum). The outer skin was represented by elastic solid elements. The inner metal body was described by discrete rigid body elements, because the stiffness is much higher than that of the outer skin. Total mass and the moment of inertia were adjusted by concentrated masses, as expressed in table 1 [4][5].

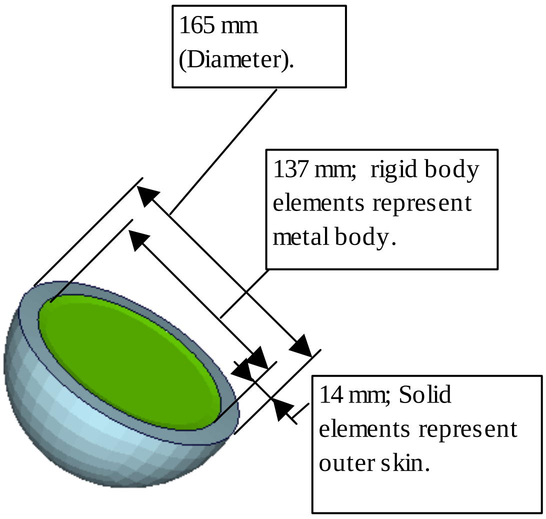

Figure 1. Outline of finite element model of headform impactor

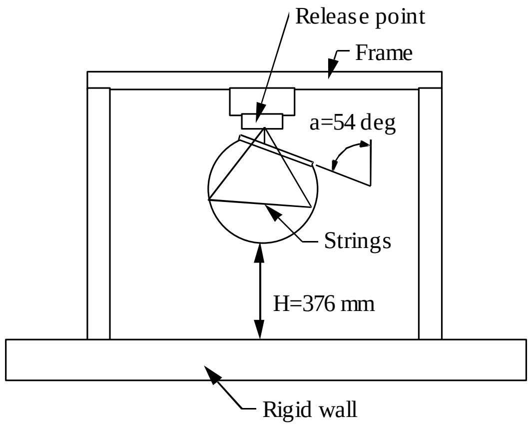

Figure 2. Drop test of head form impactors

Table 1.
Finite element models of the headform impactors

	Mass	Diameter	Moment of Inertia		
			Ixx	Iyy	Izz
	Kg	mm	Kg mm^2	Kg mm^2	Kg mm^2
Adult	4.8	165	12500	12500	12350
Child (JPN)	3.5	165	10470	10470	10150
Child (EURO)	2.5	130	3600	3568	3632

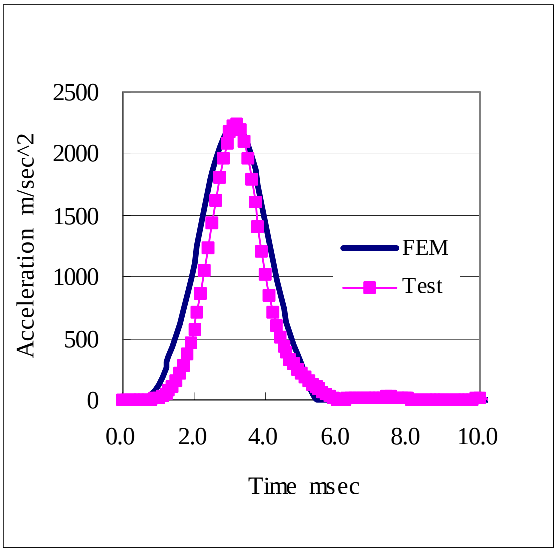

Figure 3. Time history of acceleration of adult headform impactors.

__**Young's modulus of the outer skin**__

The Young's modulus of the outer skin model is determined by drop test, as depicted in figure 2. Maximal acceleration was correlated, as shown in table 2 and figure 3. Although, there are possibilities of improvement of outer skin modeling, especially in large strain and strain rate effects, this factor is not significant for the overall analysis. Because of small sensitivity of material properties of outer skin, the error effect will be discussed later.

Table 2.
Young's modulus of outer skin and maximal acceleration

	Max. Acceleration		Young's Modulus
	FE Model	Test	FE Model
	m/sec^2	m/sec^2	MPa
Adult	2232.7	2232.67	6.8
Domestic Child	2311.7	2311.67	5.85
Euro Child	2204.9	2204.9	10.5

Vehicle Structures

The second step is to make the front structure of vehicle body by FE modeling. Figure 4 depicts the FE model with boundary conditions. More precise meshes are required for Hood, Fenders, Head Lamps, because local stiffness and strength have significant effect on the acceleration of impactors. Whereas, solid elements were employed for Hood Mastic modeling. Concentrated masses were adopted to represent NV-Insulator on the reverse side of the Hood.

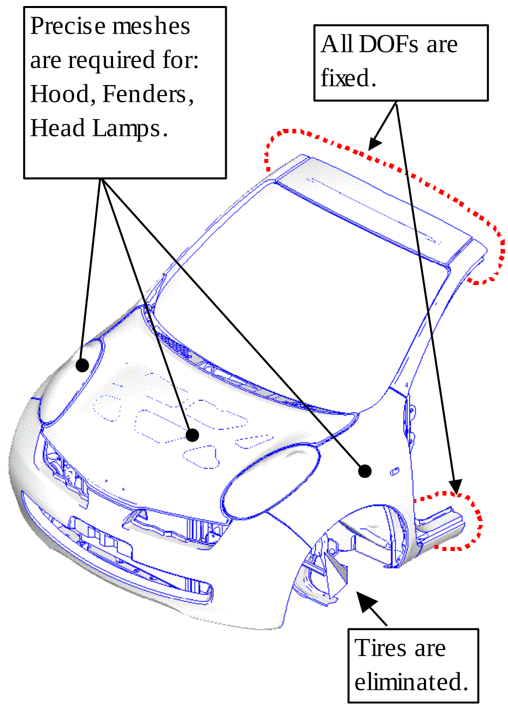

Figure 4. Finite element model of front vehicle structure with boundary conditions.

Parts in the Engine Compartments

The final step is to develop the models of several parts in the engine compartment. Figure 5 shows examples of these FE models. Precise modeling is required for: Air Cleaner, Air Duct, Battery, Engine Cover, Radiator, Condenser, Reservoir Tank, Relay Box, Hood Hinge, Hood Lock, etc. These parts have significant effect on the acceleration profile of the impactor where there is limited space below the hood. Bumper Rubber and Hood Seal Rubber were modeled by springs. Cowl Top Cover is also important for impact at the rear end of the Hood.

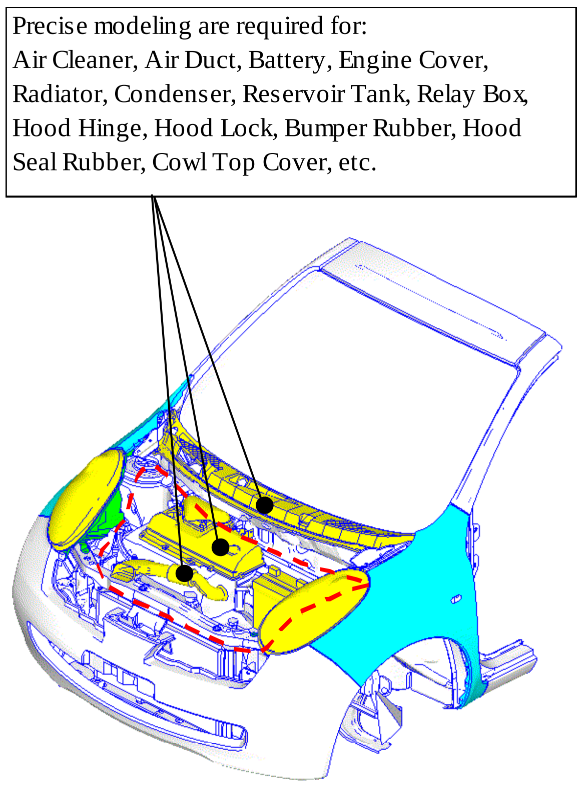

Figure 5. Finite element model of parts in the engine compartment.

NUMERICAL EXAMPLES

Impact Conditions

Several numerical examples are presented in order to demonstrate the validity of this method. Table. 3 and figure 6 show impact conditions of headform impactors where target quantities are listed [4][5]. Because of gravity effect, the release angle χ is slightly smaller than the incident (impact) angle α, where $\chi = 90 - \beta$ (See figure 6). In FE calculation, same impact speed as test is employed whereas the other quantities are the exact values in the table.

Table 3.
Impact conditions of headforms.

	Adults	Child (JPN)	Child (EURO)
Mass kg	4.8	3.5	2.5
Speed km/h	35	35	40
Incident angle α deg	65	50	50
Inclined angle β deg	25.8	41.2	41.2
Diameter mm	165	165	130

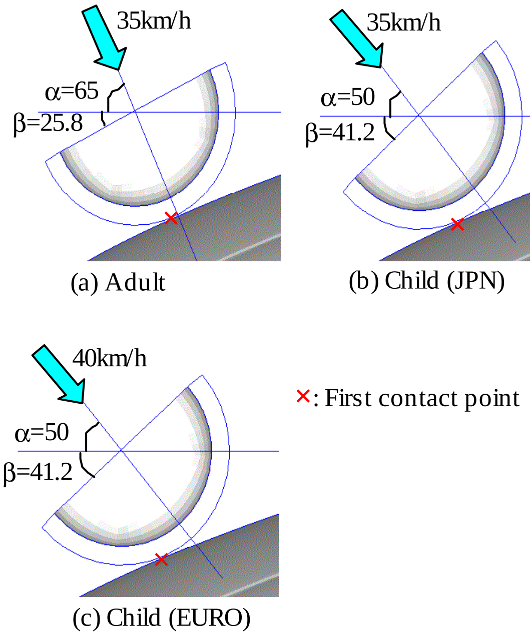

Figure 6. Impact conditions of headforms.

Impact on the Center Position of Hood

Figure 7 depicts the time history of acceleration of the child (JPN) headform on the center of the hood. Solid blue line expresses the FE simulation while red dotted line denotes impactor test results. Close agreement was obtained in this case.

Two vertical lines at 0.9 and 4.0 m sec are the time period, t_1 and t_2, for calculating the Head Injury Criteria (HIC). Head Injury Criteria is obtained by post-processing the acceleration history using the following equation:

$$HIC = \left[(t_2 - t_1) \left(\frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} a\, dt \right)^{2.5} \right]_{MAX}$$

$$(t_2 - t_1) \leq 15\, m\,\text{sec}, \qquad (1)$$

where a is resultant acceleration.

The FE obtained HIC is slightly higher than that of test by 6.8 %.

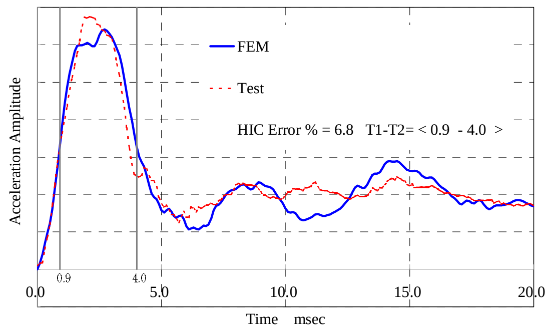

Figure 7. Time history of acceleration of the child (JPN) headform on the center of the hood.

Impact on Hinge Area

Figure 8 shows the time history of acceleration of the adult headform on hood hinge area. The first peak, marked as (A) in the figure 8, was obtained by local buckling of the outer hood, which can be observed in figure 9. Figure 9 depicts the energy density with deformed mode at 2 m sec. The second peak (B) in figure 8 was made by deformation of inner hood, as shown in figure 10. The highest peak (C) in figure 8 was caused by contact between the inner hood, the hinge arm and the hood ledge, as depicted in figure 11. One of the main reason of the discrepancy of acceleration between FE simulation and the impactor test can be assumed as scattering of the impact point. Figure 12 shows the outer hood deformation comparing the test result at 10 m sec. Similar deformations were observed between two models.

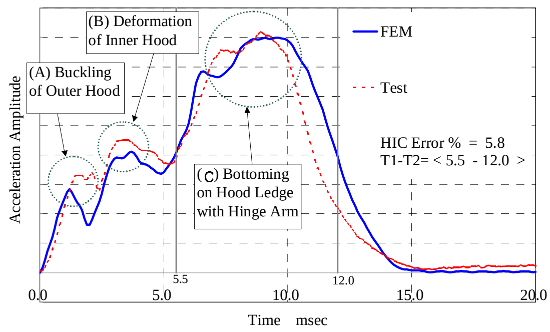

Figure 8. Time history of acceleration of the adult headform on the hood hinge area.

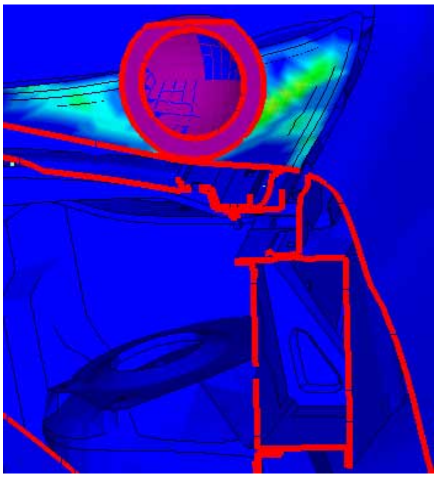

Figure 9. Energy density with deformed mode at 2 m sec.

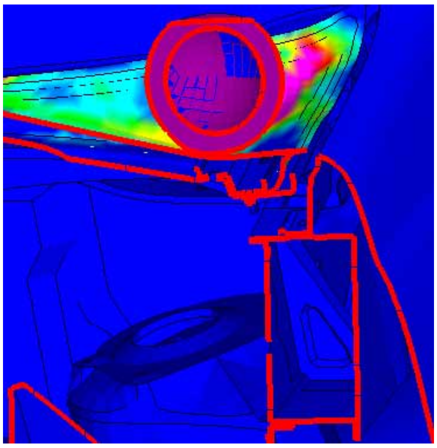

Figure 10. Energy density with deformed mode at 4 m sec.

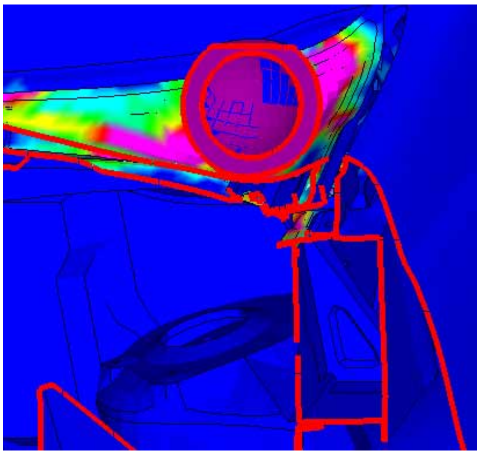

Figure 11. Energy density with deformed mode at 10 m sec.

(a) Test **(b) FEM**

Figure 12. Outer hood deformation with test result at 10 m sec.

Examples of the Scattering Analysis

Several scattering calculations were implemented by FE model in order to estimate the sensitivity of various parameters. Tables 4 (a) shows an example from the FE results. Tables 4 (b) explains the impact points. Scattered items through A to F in table 4 (a) are denoted in table 4 (c). The most significant factor is the clearance between hood and rigid component surface. Reduction of original clearance by 10 mm results in a HIC increase of 79 %. Impact speed is also important. A small increase in speed addition of 2% results in an increase in HIC of 6-7 %. Additionally, in the area near the fender, impact location has large influence, because buckling mode of the fender is strongly affected by the impact location. Finally, Young's modulus of outer skin model does not have large sensitivity. This means that the material properties of head impactor do not have a large effect on the resultant HIC.

Table 4.
Impact conditions of headforms.

(a) HIC deviation by scattering

Impact	HIC deviation %					
points	A	B	C	D	E	F
1	2.3	0.9		-4.5	-2.1	
2	0.8		7.3	-8.0	-0.8	79.0
3	4.1	11.0			-3.1	
4	0.6	-1.1	6.0	0.9	-2.5	
5	-2.2	-1.4		-6.7	-1.1	

(b) Explanation of impact points

No	Explanation of impact points
1	Front end
2	Center of the hood, on hood rib
3	Near the fender
4	Near the hinge
5	Center of the hood, separate from hood rib

(c) Scattered quantities

Items	Explanation	Base	Scattered
A	Young`s modulus of outer skin	6.8 Mpa	13.2 Mpa
B	Lateral position	Target	Target + 10 mm
C	Speed	35.0 km/h	35.0+0.72 km/h
D	Thickness of hood	Original	Original x 1.15
E	Yield stress and tangent modulus of hood	Original	Original x 1.15
F	Clearance between hood and stiff material	Original	Original - 10 mm

FUTURE STUDIES

There are possibilities of further improvement of the accuracy of this simulation especially at:
(1) parts with resin materials;
(2) vertical wall of fender and partitions of engine compartment.

CONCLUSIONS

This paper presented a practical computational simulation method employing FE modeling. As a basis of the assessment, Head Injury Criteria (HIC) was used by post-processing the time history of the calculated acceleration of headform impactor. Although there are possibilities for further improvement of this method, there is good correlation with majority of the evaluating points. The efficiency of design procedures of front structure has been improved by employing the presented method.

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