A STUDY ON PEDESTRIAN IMPACT TEST PROCEDURE BY COMPUTER SIMULATION

- The Upper Legform to Bonnet Leading Edge Test -

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ABSTRACT

EEVC/WG10 proposed three component pedestrian subsystem tests. Pedestrian subsystem impact tests with production cars have been conducted in Euro-NCAP according to the EEVC test method. From the Euro-NCAP the upper legform impact test has the most difficulty fulfilling the current injury criteria. However, recent accident analyses indicate that the priority of the upper legform test seems to be the lowest in the three EEVC subsystem tests.

The objective of this research is to validate the test conditions of the EEVC upper legform impact test using computer simulation models.

There is a possibility that the impact energy defined from the EEVC look-up graph may include significant errors. The values of the EEVC impact energy can be decreased about 30% for cars with a 650mm to 750mm bonnet leading edge height.

It is not necessary to use an impact velocity look-up graph which should be calculated directly using a specific impactor mass and an impact energy defined from an impact energy look-up graph.

INTRODUCTION

The European Experimental Vehicles Committee (EEVC/WG10) has proposed three component pedestrian subsystem tests for evaluating the vehicle safety performance in car-pedestrian accident. The three subsystem tests are headform impact to bonnet top, upper legform impact to bonnet leading edge, and legform impact to bumper.

Recently pedestrian impact tests with production cars have been conducted in the Euro-NCAP test program according to the current EEVC subsystem test method. The test results indicate that the upper legform impact test has the most difficulty fulfilling the current injury criteria. However, recent accident analyses indicate that the priority of the upper legform impact test seems to be the lowest in the three EEVC subsystem tests. This contradiction raised questions of whether the current upper legform impact test reflects the real world pedestrian accidents.

Accordingly, we validated the EEVC upper legform impact test conditions using computer simulation models. Both the car-pedestrian impact tests and the upper legform impact tests were simulated.

This paper outlines the computer simulation models and summarizes the parameter study concerning the EEVC test conditions of the upper legform impact test.

DEVELOPMENT OF COMPUTER SIMULATION MODELS

Car-Pedestrian Impact Model (Model A)

A car-pedestrian impact model was developed as shown in Figure 1 to understand the impact conditions at the bonnet leading edge when a car hits a pedestrian. MADYMO-5.3 was used in this study.

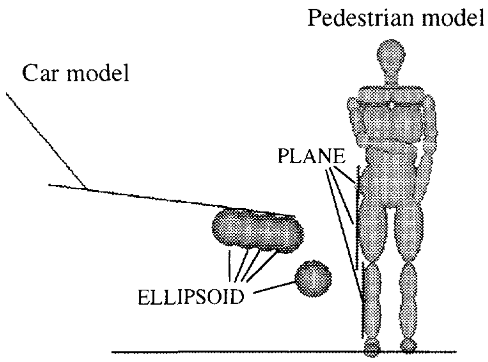


Figure 1. Computer simulation model of car-pedestrian impact (Model A).

To simplify the contact condition between car and pedestrian, the car-pedestrian impact model uses only two types of elements (ELLIPSOID and PLANE), and only ELLIPSOID-PLANE contact is defined. ELLIPSOID is used to represent the bumper and the bonnet leading edge. The pedestrian model is made by ELLIPSOID, however PLANEs are attached to the ELLIPSOIDs representing the pelvis, the upper leg, and the lower leg.

The model was validated by comparing the trajectories of the body segments in computer simulations and those from full-scale tests with PMHS (Post Mortem Human Subject)(1). The trajectories of the PMHS were normalized by their height. Their trajectory corridor was then made as shown in Figure 2. The trajectories obtained from the computer simulations were within the corridor. Accordingly, the car-pedestrian impact model can be used for this study.

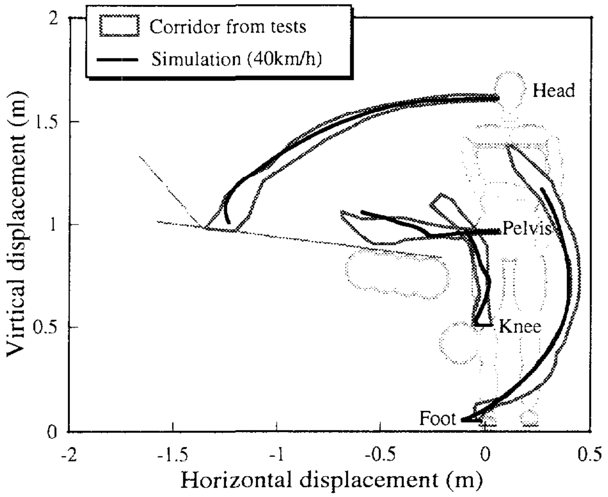


Figure 2. Validation of car-pedestrian impact model.

Upper Legform to Bonnet Leading Edge Test Model (Model B)

In order to understand the correlation between pedestrian full-scale tests and subsystem tests, an upper legform to bonnet leading edge test model was developed as shown in Figure 3. The impactor model has a translational joint to simulate the guiding system of the EEVC upper legform impactor. ELLIPSOID-PLANE contact is used to simplify the contact condition.

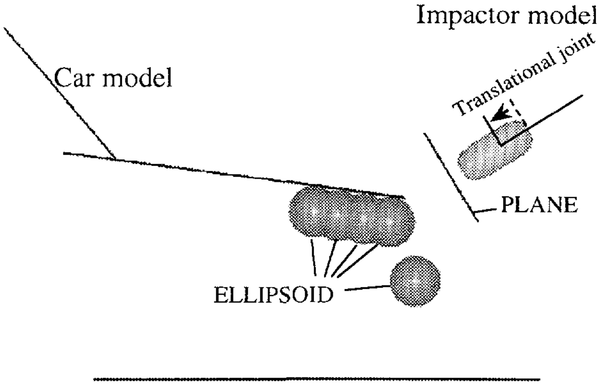


Figure 3. Computer simulation model of upper legform impact test (Model B).

PARAMETER STUDY

Parameter

In order to understand how the car front shape affects the test conditions of the EEVC upper legform test, simulations were performed for 42 cases. Figure 4 shows the definition of the car front shape. Table 1 shows the parameters used for the 42 simulations. Bumper center height is 390mm in all cases, since the bumper height doesn't cause significant differences on the test conditions. The EEVC upper legform test does not consider the bumper height in deciding its test conditions either.

The car impact speed is 40km/h. The car exterior stiffness is constant in all cases as shown in Figure 5. This stiffness is derived from the previous study using MADYMO-2D(2).

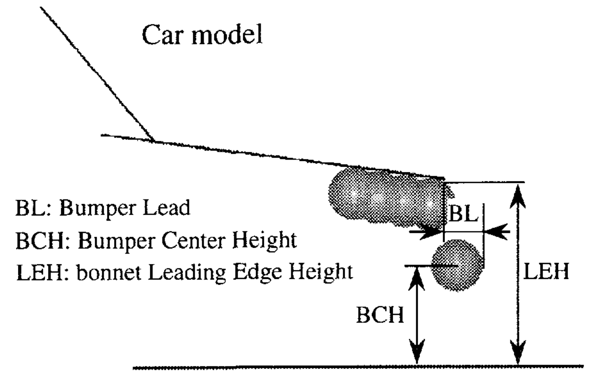


Figure 4. Definition of car front shape (BL, BCH, LEH).

Table 1. Parameters for 42 Simulations.

		BL (mm)					
		0	50	100	150	225	350
LEH (mm)	600	○	○	○	○	○	○
	650	○	○	○	○	○	○
	700	○	○	○	○	○	○
	750	○	○	○	○	○	○
	800	○	○	○	○	○	○
	850	○	○	○	○	○	○
	900	○	○	○	○	○	○

BCH: 390 mm

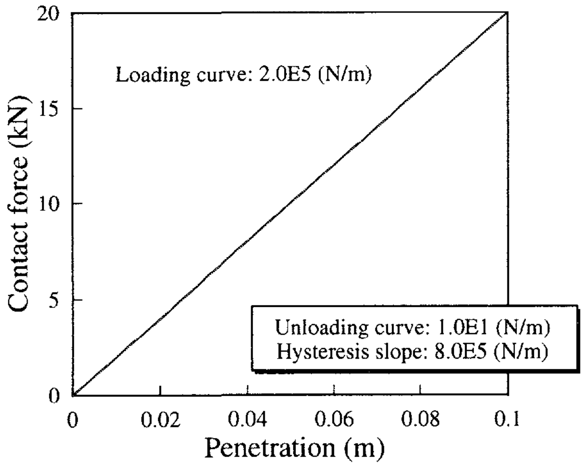


Figure 5. Car exterior stiffness used in all simulations.

Simulation Results

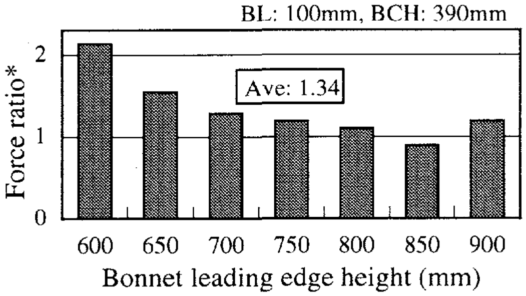
Impact Energy by EEVC Method

Impact energy was calculated by using two methods (EEVC method and new method). The first method or EEVC method was developed by EEVC to obtain the impact energy from their full-scale dummy tests(3). EEVC calculated values of horizontal energy from the measured forces and the relative displacements of the leg into the bonnet leading edge in the full-scale tests. They admit that accurate calculations of the deformation energy of the bonnet leading edge contact from full-scale tests is difficult.

There is a major problem in the EEVC method. Specifically, it should be noted that the direction of the relative displacement is not comparable to the direction of the resultant force vector in the EEVC method. The EEVC method assumes this difference is small. This assumption may be acceptable in calculating the impact energy for higher bonnet leading edge. However, this assumption cannot be used for the lower bonnet leading edge since there is significant sliding between the upper leg and the bonnet leading edge, and the directions of the relative displacement and the force vector are completely different.

The previously mentioned two computer simulation models were used in order to validate the EEVC method. The impact energy calculated from the car-pedestrian impact model was used to reconstruct the equivalent bonnet leading edge impact using the upper legform to bonnet leading edge test model.

The impactor force was divided by the femur/pelvis contact force to obtain the impact force ratio. If the subsystem test is equivalent to the full-scale test, the impact force ratio should become one. Figure 6 shows the impact force ratio obtained from the computer simulations using model A and model B at different bonnet leading edge



$$\text{* Force ratio} = \frac{\text{Impactor force}}{\text{Femur/pelvis contact force}}$$

Figure 6. Impact force ratio from EEVC method.

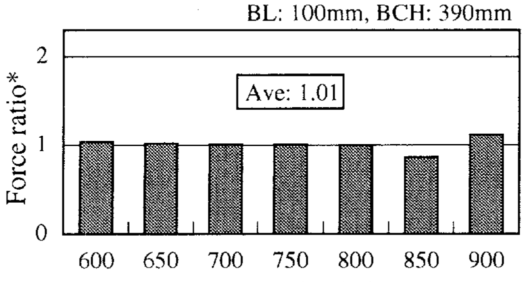
heights. Most of the ratios exceed one. The average impact force ratio is 1.34. Note that the force ratio becomes nearly one when the bonnet leading edge height becomes higher. In contrast, the force ratio becomes more than 1.5 when the bonnet leading edge height becomes lower. This result suggests that the EEVC method may cause significant errors in calculating the impact energy, especially when the bonnet leading edge height becomes lower.

Impact Energy by New Method

Impact energy was also calculated by the new method. The new method uses normal impact force and penetration excluding tangential friction force to calculate the impact energy. This means that the friction energy is excluded in the new method. The friction energy should be excluded in the current EEVC upper legform impact test since the upper legform is guided and it is positioned perpendicular to the impact direction. The guided upper legform impactor cannot reconstruct the sliding mechanism at the contact surface.

Note that the direction of the penetration coincides with the direction of the normal impact force in the new method. This method can accurately calculate the impact energy in the normal direction even if there is significant sliding between the upper leg and the bonnet leading edge, although the energy due to the tangential sliding is not available.

The new method was also validated in the same way previously introduced for the EEVC method. Figure 7 shows the impact force ratio obtained from the computer simulations. Most of the ratios are close to one. The average impact force ratio is 1.01. This result clearly indicates that the impactor force in the subsystem test may become identical to the femur/pelvis contact force in the full-scale test if we use the impact energy defined by the new method.



$$\text{* Force ratio} = \frac{\text{Impactor force}}{\text{Femur/pelvis contact force}}$$

Figure 7. Impact force ratio from new method.

Accordingly, the new method can be more realistic than the EEVC method in obtaining the impact energy look-up graph for the upper legform impact test.

Figure 8 shows the impact energy curves obtained from the computer simulations using the new method. When we compare the new impact energy curves with the EEVC look-up graph, the influence of bumper lead on the impact energy becomes less significant for lower bonnet leading edges. However, for higher bonnet leading edge, the bumper lead varies the impact energy significantly.

The impact velocity decreases inversely to the increase of bumper lead (see Figure 13). When the bumper lead increases, the contacting point may sift from femur to pelvis as shown in Figure 9. The effective mass at the contacting point may then increase accordingly. The decrease of impact velocity due to the increase of bumper lead does not necessarily decrease the impact energy, since the impact energy is decided from the combination of the impact velocity and the effective mass. The values of impact energy

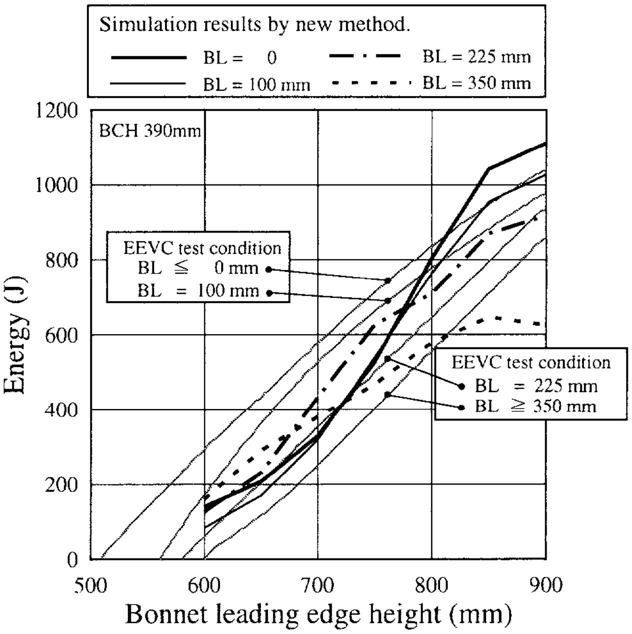
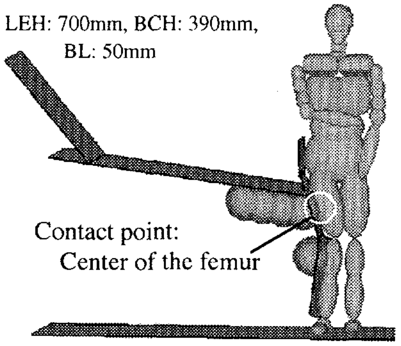
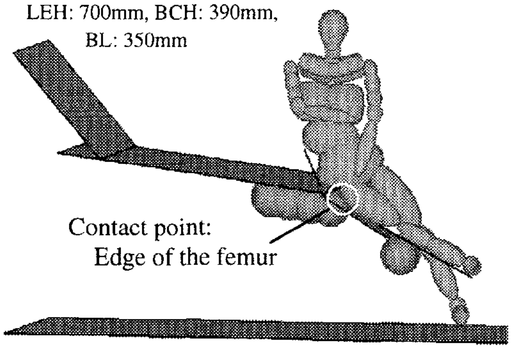


Figure 8. Impact energy curves by new method with the EEVC look-up graph.



1) Contact at femur center. (BL:50mm)



2) Contact near hip joint. (BL:350mm)

Figure 9. Contact point by bumper lead.

in the EEVC look-up graph always increase when the bumper lead decreases. This tendency is not seen in the new impact energy curves from the new method.

The femur/pelvis contact point can be determined geometrically considering the wrap around distance at the femur/pelvis contact point. If the bonnet leading edge is high or bumper lead is very long, the pelvis contacts the bonnet leading edge directly. The contact point shifts only on the pelvis, and the effective mass does not vary significantly, as compared to the femur-to-bonnet leading edge contact. If the contact point is on the pelvis, the variation of the impact energy can be mainly due to the variation of the impact velocity. If the contact point is on the femur, the variation of both the impact velocity and the effective mass cause the difference of the impact energy. Values of impact energy do not necessarily increase in relation to the decrease of bumper lead. However, the values of impact energy in the EEVC look-up graph always increase when bumper lead decreases.

The influence of bumper lead on the impact energy is insignificant when the bonnet leading edge is lower than 800mm and the bumper lead is less than 225mm. This zone may cover many production cars nowadays. Accordingly, one regression curve can be proposed to calculate the impact energy more simply as shown in Figure 10. This regression curve is expressed by Equation (1).

$$
\begin{aligned}
Energy(J) &= -5.111\times10^{-5}LEH^3 + 1.149\times10^{-1}LEH^2 \\
&\quad - 8.204\times10^{1}LEH + 1.901\times10^{4} \qquad (1)
\end{aligned}
$$

LEH: *Bonnet leading edge height (mm)*

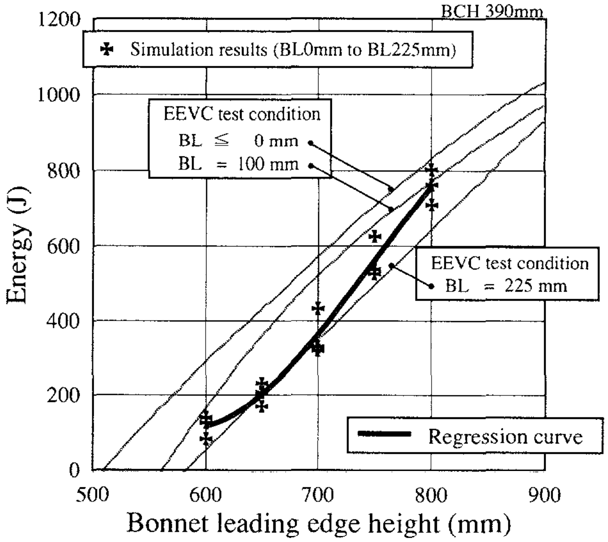


Figure 10. Impact energy regression curve by new method with the EEVC look-up graph.

Impact Angle by EEVC Method

Impact angle was calculated using two methods, the EEVC method and a new method. In the EEVC method, the horizontal and vertical contact forces relative to the ground coordinate system are integrated by time to obtain impulses in the horizontal and vertical directions(3). The impact angle is calculated from these horizontal and vertical impulses. The start and end angles are calculated from the horizontal and vertical impulses. Their average value is then used to produce an impact angle look-up graph. The start and end times are taken as the time at which the resultant force rises to 40% of the peak value and the time at which it *falls below 40%* of the peak force.

The horizontal and vertical contact forces include friction force caused by a sliding at the bonnet leading edge. The impact angle obtained from the EEVC method can be influenced by the friction force.

The impact angle curves from the computer simulations using the EEVC method are shown in Figure 11 with the EEVC impact angle look-up graph. The calculated values of the impact angle vary more significantly according to the bonnet leading edge height as compared to the EEVC impact angles. When the bonnet leading edge is higher than 800mm, the influence of the bumper lead on the impact angle becomes negligible. When the bonnet leading edge height is lower than 800mm, the extent of the bumper lead influence on the impact angle increases in relation to the decrease of the bonnet leading edge height.

Impact angle curves differ between the simulation results and the EEVC values as described previously. However, their general tendencies are comparable.

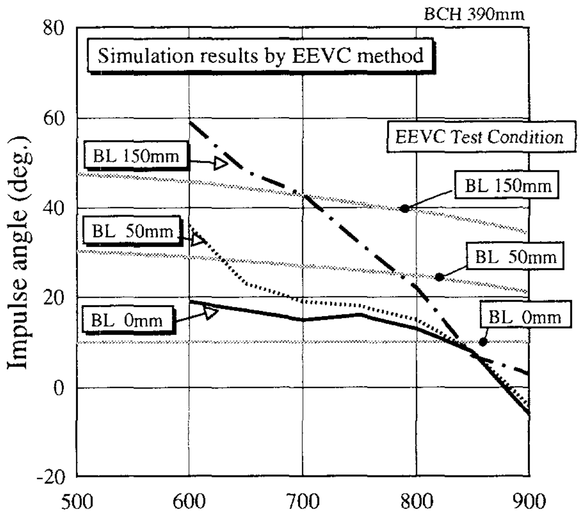


Figure 11. Impact angle curves by EEVC method with the EEVC look-up graph.

Impact Angle by New Method

The new method is almost the same as the EEVC method, but it excludes the friction force component. The friction force may affect the car deformation, but may not contribute to the femur lateral deformation. The impactor test is conducted against the perpendicular direction of the front member, so the impact angle should be calculated using only the impact force perpendicular to the front member.

The impact angle curves obtained from the computer simulations using the new method are shown in Figure 12 with the EEVC impact angle look-up graph. The impact angle curves calculated by the new method are similar but shift about 10 degrees upward relative to those from the EEVC method because the friction force works to decrease the impact angle.

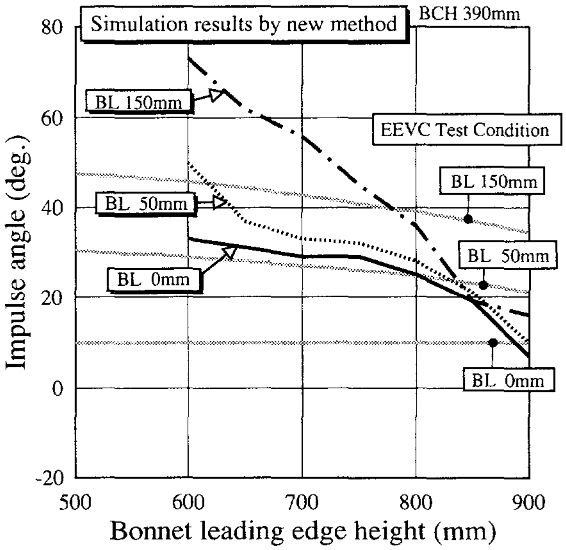


Figure 12. Impact angle curves by new method with the EEVC look-up graph.

Impact Velocity

Upper leg impact velocity against the bonnet leading edge depends strongly on the vehicle shape, especially the bonnet leading edge height and the bumper lead. Impact velocities calculated from the computer simulations of 42 cases are plotted in Figure 13 in which the EEVC impact velocity curves are also superimposed. The calculated impact velocities are nearly identical to the values in the EEVC look-up graph when a shaded zone is excluded.

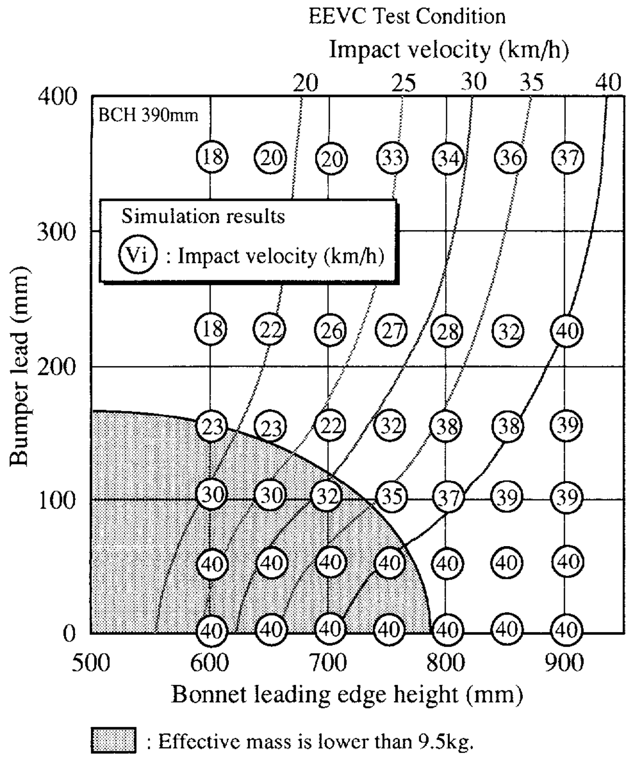


Figure 13. Calculated impact velocity with the EEVC look-up graph.

The effective mass at the bonnet leading edge contact was about 2kg to 25kg from the computer simulations. The effective mass is calculated from Equation (2).

$$M_{eff} = \frac{2E}{V_i^2} \qquad (2)$$

M_{eff} : Effective mass, E : Impact energy, V_i : Impact velocity

It is very difficult to develop a small impactor with the necessary instrumentation. EEVC selected a minimum impactor mass of 9.5kg to obtain the EEVC look-up graph(4). Accordingly, we modified our calculated values in the shaded zone by compensating for the mass ratio, using the minimum impactor mass of 9.5kg, under the same impact energy. Equation (3) explains this method.

$$V_{im} = \sqrt{\frac{M_{eff}}{9.5}} \times V_i \qquad (3)$$

(Effective mass < 9.5kg)

V_m : Modified impact velocity, M_{eff} : Effective mass (kg),

V_i : Impact velocity

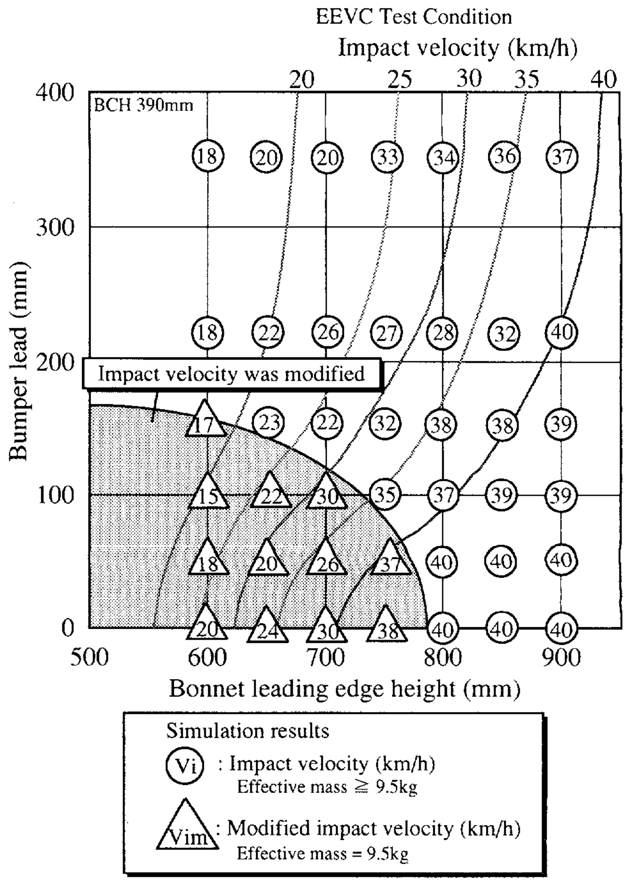


Figure 14. Calculated and modified impact velocities with the EEVC look-up graph.

Figure 14 shows the results of this modification. All values in the shaded zone are relatively smaller than those in the EEVC curves. Note that all cars included in the shaded zone are tested by the impactor mass of 9.5kg at the modified impact velocity.

Nowadays many cars with streamlined shape are included in the shaded zone. EEVC assumed that the modification of the impact velocity doesn't not affect the test results under the same impact energy. If this assumption is correct, the EEVC impact velocity look-up graph is not necessary. It should be noted that impactor mass can be constant in all tests. Impact velocity is calculated directly by Equation (2) with a specific impactor mass and an impact energy defined from the look-up graph.

Impact tests should be simple. It doesn't seem necessary to change the impactor mass in each test.

CONCLUSIONS

EEVC test conditions of the upper legform impact test were validated using computer simulation models. Conclusions are summarized below.

(1) Computer simulation results raised the possibility that the impact energy defined from the EEVC look-up graph may include significant errors, especially for cars with a lower bonnet leading edge. For example, the values of the EEVC impact energy can be decreased about 30% for passenger cars with a 650mm to 750mm bonnet leading edge height.

(2) It is not necessary to use an impact velocity look-up graph. Impact velocity should be calculated directly by Equation (2) using a specific impactor mass and an impact energy defined from an impact energy look-up graph.

(3) Impact angles from computer simulations vary more significantly according to the bonnet leading edge height and the bumper lead as compared to the values in the EEVC look-up graph. However, their general tendencies are comparable.

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