

Development of Test Method to Evaluate Aggressiveness Focusing on Stiffness and Interaction: Part 2

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ABSTRACT

Test methods to evaluate vehicle compatibility are being studied worldwide. Compatibility performance is central in securing mutual protection in collisions between large and small vehicles. To consider compatibility performance, good structural interaction and stiffness matching are important. A test method using a novel moving deformable barrier (MDB) was developed to evaluate compatibility performance that includes consideration of both structural interaction and stiffness matching.

This new barrier has the following features to represent an offset vehicle-to-vehicle collision with a compact car.

- The barrier width is divided at the lower rail position of the compact car, and the layer that simulates the characteristics of vehicle sections toward the interior is harder than the outward layer. This varying stiffness of the MDB helps simulate the horizontal interaction performance that occurs in real-world crashes.
- A bumper structure and a wheel proxy layer are installed at heights corresponding to similar structures of the compact car. These layers are harder than the surrounding layers to evaluate the vertical interaction performance of the evaluated vehicle.
- The energy absorption characteristic of this barrier is equivalent to the engine compartment of a compact car to evaluate the stiffness characteristic of the evaluated vehicle.

Vehicle-to-MDB tests were conducted using two large vehicles that have different vertical interaction performance, and the test results were compared to vehicle-to-vehicle test results between prototype SUVs and compact cars.

The correlation was verified between the vehicle-to-MDB test and the vehicle-to-compact car test. This MDB test shows promise for the simultaneous evaluation of both the structural interaction and stiffness of vehicles.

INTRODUCTION

Vehicle occupant protection performance is currently evaluated through front collision tests implemented in countries worldwide as part of regulations and assessments. These evaluations mainly assume collisions with fixed objects or with vehicles of the same weight as the evaluated vehicle. However, in the real world, vehicles have various weights and the majority of collisions are with vehicles of differing weight. The technology for addressing this type of collision is called “compatibility,” and much research has been conducted in this field. In real world collisions between compact vehicles and larger vehicles, the compact vehicle usually experiences more severe cabin deformation. To improve compatibility, both the self-protection performance of compact vehicles must be improved and the capability of large vehicles to protect the other vehicle in the collision (referred to as the “opposing vehicle” below) must be improved. The main factors utilized to determine opposing vehicle protection performance are vehicle weight, load interaction and stiffness. Research is being carried out to assess how these factors should be evaluated.¹

In the previous paper, an offset MDB test method was proposed as a possible method for evaluating all these factors simultaneously. For this method, to explain offset vehicle-to-vehicle (V-to-V) collisions, the vehicle was divided along the horizontal axis into 2 vertical sections to show the importance of taking into consideration localized stiffness. This deformable barrier (DB) was manufactured with 2 vertical section, divided

along the horizontal axis, with different stiffness (Fig. 1). Consequently, this DB showed that it was possible to reproduce the force characteristics of a V-to-V collision with a compact vehicle and the behavior of structural components that intrude into the opposing vehicle.²

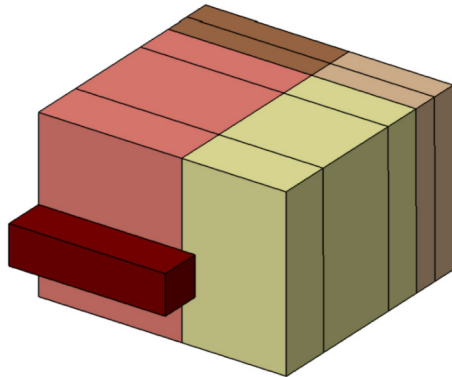


Fig. 1. Isometric View of Deformable Barrier (Proposed in Previous Paper⁽²⁾)

The next step in this research was to examine load interaction in the height-direction during V-to-V collisions.^{3,4} Here, the necessity of dividing the DB in the height-direction was clarified and changes were made to the DB. In addition, MDB tests using differing height SUVs were carried out with this DB to confirm that height-direction load interaction differences could be produced.

HEIGHT-DIRECTION LOAD INTERACTION

COMPARISON OF LOAD PATHS DURING DIFFERING VEHICLE HEIGHT V-TO-V TESTS

Initially, two SUV prototype vehicles (i.e. SUV-A and SUV-B) of different heights were used and the phenomena resulting from V-to-V collision tests with a compact passenger car (hereafter referred to as the “small-PC”) were recorded. Figure 2 shows a side view of the vehicle height settings. The lower rail center height of SUV-A was adjusted to be in line with the lower rail center height of the small-PC (V-to-V-A). The lower rail center height of SUV-B was adjusted to be 150 mm higher than the lower rail center height of the small-PC (V-to-V-B).

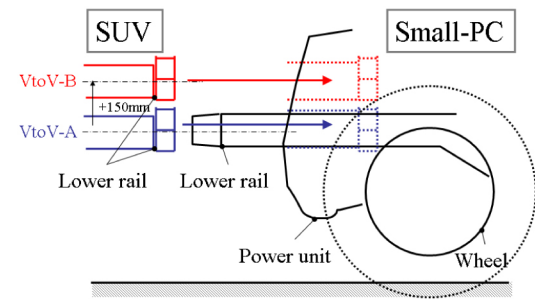


Fig. 2. Height Setting of V-to-V Tests (Side View)

Figure 3 shows a plan view of the collision positions. The bumper beam fitted at the end of the SUV lower rail was positioned using the plan view to contact the small-PC power unit.

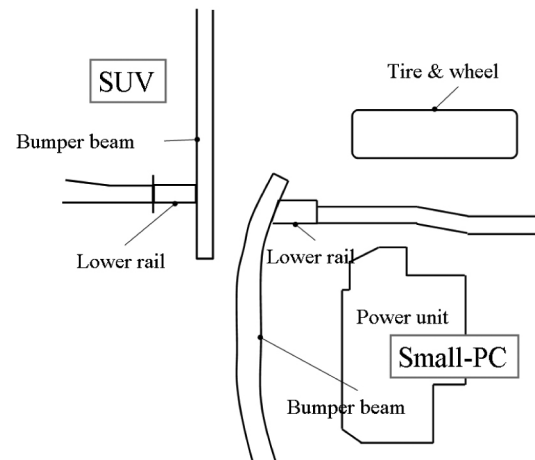


Fig. 3. Width Setting of V-to-V Tests (Plan View)

Other conditions were as follows.

- Vehicle speed: 55 km/h for both vehicles (closing speed of 110 km/h)
- Collision format: 50% offset of small-PC
- Weight of small-PC: 1156 kg
- Weight of SUV: 2,000 kg

Firstly, each load interaction was assessed using high speed video (Fig. 4). The following occurred in V-to-V-A.

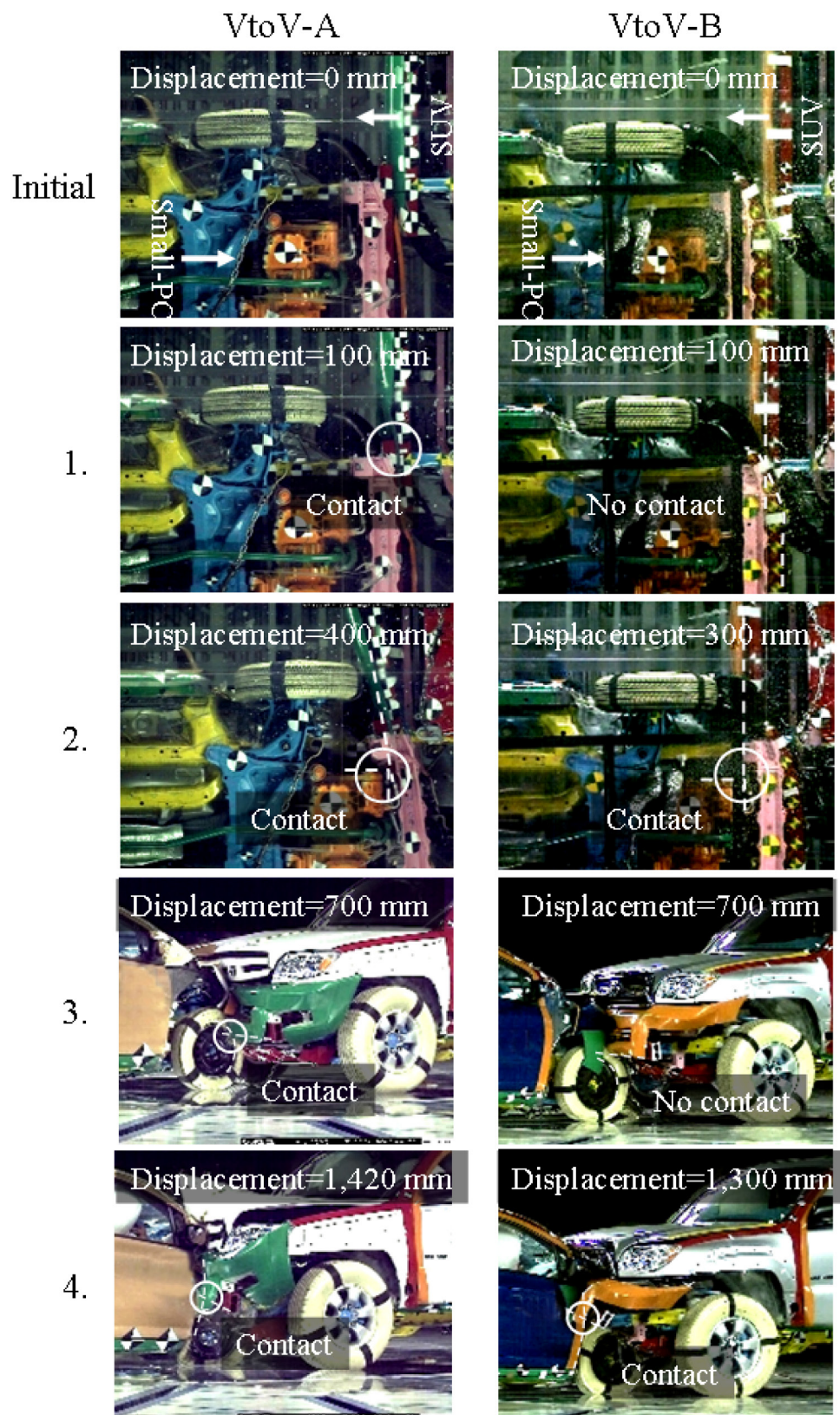


Fig. 4. Comparison of High Speed Video

1. The end of the SUV lower rail contacted with the small-PC lower rail, causing deformation.
2. The end of the SUV lower rail contacted with the small-PC power unit, causing deformation.
3. The end of the SUV lower rail contacted with the small-PC wheel, causing deformation.
4. At a displacement of 1,420 mm, the end of the SUV lower rail reached the small-PC cabin and any greater displacement caused small-PC cabin deformation.

The above results confirmed the three load paths of the SUV lower rail impact on the opposing small-PC power unit, lower rail, and wheel. Conversely, the following occurred in V-to-V-B.

1. The end of the SUV lower rail passed above the small-PC lower rail.
2. The end of the SUV lower rail contacted with the small-PC power unit, causing deformation. The small-PC lower rail also functions as a load path from this point due to the connection of the power unit to the lower rail.
3. The end of the SUV lower rail passed above the small-PC wheel.
4. At a displacement of 1,300 mm, the end of the SUV lower rail reached the small-PC cabin and any greater displacement caused small-PC cabin deformation.

Based on the above, V-to-V-B test, it was understood that the force on the small-PC lower rail is delayed and the wheel does not function as a load path.

Next, the forces generated in these tests were compared. Figure 5 shows the force-displacement characteristics. Displacement values were calculated based on the combined value of the double integral values from the accelerometers positioned at the side sills on both sides (relative displacement). The force values used the mean values of both vehicles based on calculating the inertia force by multiplying mass and deceleration for each vehicle.⁵ The V-to-V-B test showed that the force was lower than in V-to-V-A at the point in time when load path differences occur.

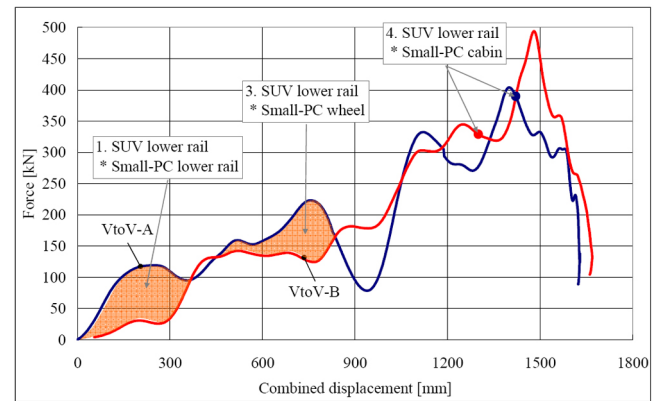


Fig. 5. Comparison of Force-Displacement Characteristics

Figure 6 shows the position of the edge of the SUV relative to the small-PC during the V-to-V tests. Based on this diagram, the amount that the SUV edge intrudes into the small-PC was plotted in Fig. 7. Based on Figs. 6 and 7, it was understood that intrusion to the small-PC in V-to-V-B was greater than in A due to the lack of initial load interaction between both lower rails and load interaction between the SUV lower rail and small-PC wheel in V-to-V-B. In particular, the displacement difference that occurs due to the wheel load interaction from 900 to 1200 mm is carried through the rest of the collision and manifests as intrusion into the small-PC cabin.

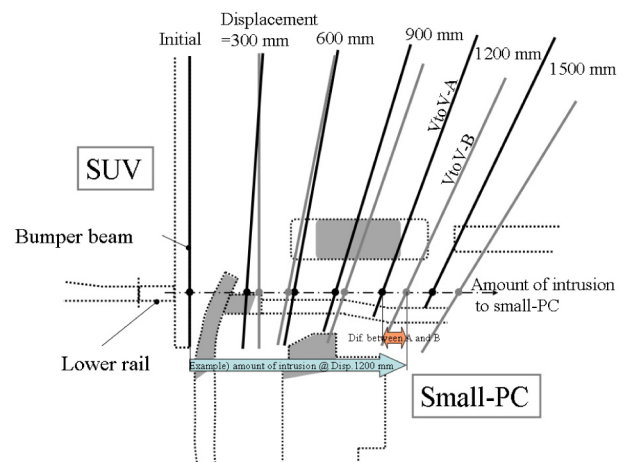


Fig. 6. Intrusion of SUV to Small-PC in V-to-V Tests

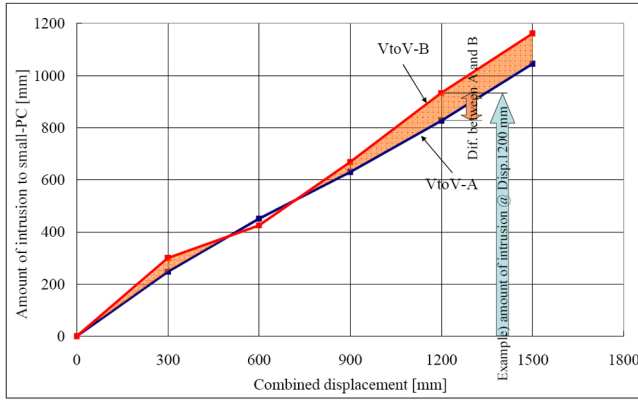


Fig. 7. Results of Intrusion of SUV to Small-PC in V-to-V Tests

Figure 8 shows diagrams of the final small-PC cabin deformation and Fig. 9 shows diagrams of the final SUV lower rail deformation. Based on these results, it was understood that the SUV lower rail end deformation in V-to-V-B was smaller than in V-to-V-A, and small-PC cabin deformation increased.

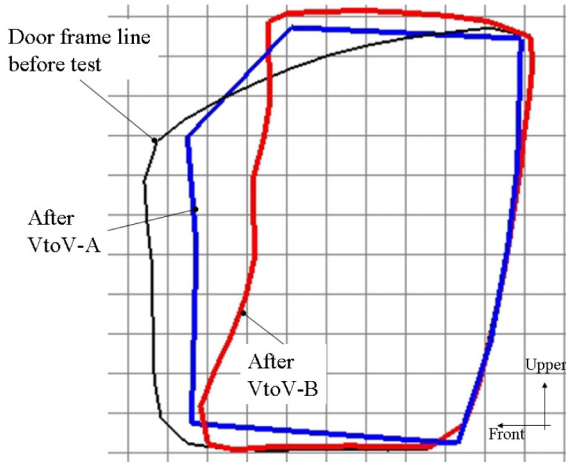


Fig. 8. Results of Cabin Deformation Measurement of Small-PC (Side View)

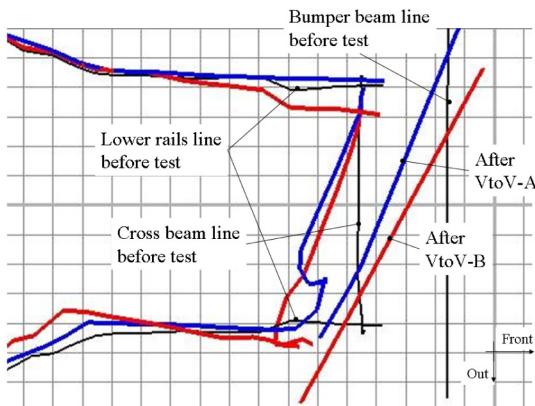


Fig. 9. Results of Lower Rail Deformation Measurement of SUV (Plan View)

MODELING USING SYNTHETIC SPRINGS

It can be shown that the following linear spring combinations and vehicle masses could be used to show differences in height-direction interaction performance caused by the load path differences understood in the previous section.

The following equation is obtained based on the conservation of momentum law between the time before the collision and at the time when combined displacement is at the maximum.

$$M_2 \cdot V_2 - M_1 \cdot V_1 = (M_1 + M_2) \cdot V' \quad (1)$$

And the following equation is obtained based on the energy conservation law.

$$\begin{aligned} \frac{1}{2} \cdot M_1 \cdot V_1^2 + \frac{1}{2} \cdot M_2 \cdot V_2^2 = \\ \frac{1}{2} \cdot (M_1 + M_2) \cdot V'^2 + \frac{1}{2} \cdot K_{comb} \cdot dis \max^2 \end{aligned} \quad (2)$$

M_1 :	Opposing vehicle (small-PC) mass
M_2 :	Evaluated vehicle (SUV) mass
V_1 :	Opposing vehicle initial velocity
V_2 :	Evaluated vehicle initial velocity
V' :	Velocity of both vehicles when combined deformation (displacement) value is the maximum
K_{comb} :	Combined spring constant of both vehicles
$dis \max$:	The maximum value of combined total of displacement for both vehicles

The following relational equations are obtained based on combination of two springs of both vehicles in series.

$$dis = d_1(dis) + d_2(dis) \quad (3)$$