

Load Distribution by Rear Bumper Beam in FMVSS 301R Test Protocol

Atsushi HASEGAWA¹
Tomohiro SHIMIZU²

Takayuki FUJII¹
Yusuke MIURA³

Norikazu MATSUURA¹

ABSTRACT

In the present research, technology was established for compliance with Federal Motor Vehicle Safety Standard (FMVSS) 301R, which is a US regulation addressing rear-end collisions. The FMVSS 301R test procedure is an offset impact test using a deformable impact barrier. In offset impact tests, there is a large difference in load input between left and right frames, and there is less deformation in the non-collision-side frame, meaning the side that does not impact with the barrier. Attention was therefore focused on the rear bumper beam, and steps were taken to increase the energy absorption of the non-collision-side frame by having the load from the barrier transferred equally to both frames. The rear bumper beam was structured so that the load input from impact with the barrier would become symmetrical. The stretch bending manufacturing method was used for practical implementation of this concept, and the beam was shaped so that it could be located within the design space of mass-production vehicle. Verification was conducted using a prototype that supposed mass production, demonstrating that the difference in input between the left and right frames, which formerly was large, could be reduced and a more nearly symmetrical load distribution achieved.

1. Introduction

Amid growing demands for automobile safety performance, active safety technology to keep accidents from happening is undergoing prominent advances. Meanwhile, the demand for passive safety technology that mitigates the damage of accidents that do occur also remains high, and official organizations are continuously updating passive safety procedures. Conformance with passive safety regulations in the North American region poses particular challenges, and it is in that context that the present research takes on the subject of FMVSS 301R, which addresses rear-end collisions.

The impact conditions in FMVSS 301R are defined as 70% offset impact by means of a deformable impact barrier (hereafter referred to as barrier). However, the impact conditions in regions other than North America are full-lap impact using a flat barrier. Furthermore, the speed of the impact by barrier to vehicle is 80 km/h, which is 30 km/h faster than the full-lap impact conditions. Consequently, the FMVSS 301R impact conditions call for the vehicle body and barrier to absorb as much as approximately three times more energy. Given the present state of vehicle body

construction, the greater part of this energy will be absorbed by the frame on the side that collides directly with the barrier (hereafter, collision-side frame).

Vehicle weights are anticipated to increase in the future as they are mounted with high-capacity batteries due to electrification and so on. As a result, even more impact energy will need to be absorbed by vehicle bodies. The general means used include raising the reaction force on the vehicle body and increasing the crushable zones. Various measures could be considered for the former, including the application of high-tensile steel with higher strength⁽²⁾⁻⁽⁴⁾, the addition of reinforcing members, and an increase in the thickness of framework segments, but these measures would contribute to increased weight in the vehicle body. As to the latter means, increasing the crushable zones would impact both occupant space and cargo capacity.

The approach here, therefore, has been to take measures on the construction of the vehicle body that would enhance energy absorption by the non-collision-side frame, which is an approach where active measures had not been successfully employed up to this point. The structure of the rear body generally comprises a rear bumper beam that is connected to the left and right rear frames. The rear bumper

¹ Automobile Center

² BENTELER Automotive K.K.

³ SOLIZE Engineering Corporation

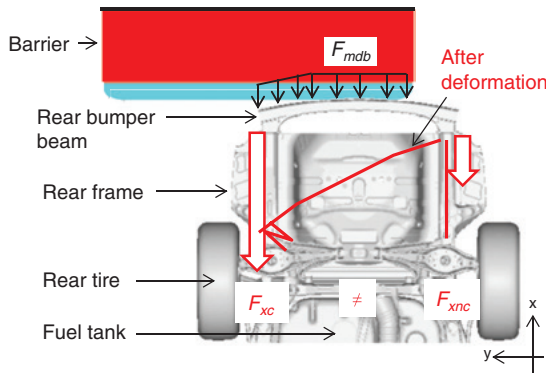
beam is an important structural member that is the first to receive input from the barrier, and research on it has mainly related to design and enhancement of low-speed crash performance⁽⁵⁾⁻⁽⁷⁾. There is also some research⁽⁸⁾ that applies to high-speed collision regulations like FMVSS 301R, but not much.

The purpose of the present research has been the construction of a rear bumper beam that would reduce the difference in load input to the two sides of the frame and increase energy absorption by the non-collision-side frame in the FMVSS 301R procedure.

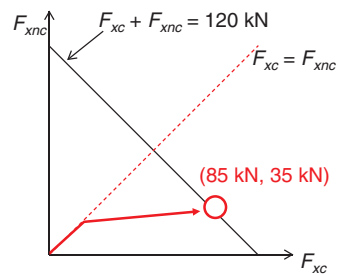
2. Load Distribution by the Rear Bumper Beam

2.1. Load Path in the Conventional Structure

A rear bumper beam of conventional structure that conforms to the test conditions for low-speed crashes is designed to generate a load of from 100 to 120 kN. Figure 1(a) shows schematically how a total load of 120 kN is applied from the barrier to the left and right rear frames under FMVSS 301R test conditions. Here F_{mdb} is the distributed load applied from the barrier to the rear bumper beam, F_{xc} is the load transferred from the rear bumper beam to the collision-side frame, and F_{xnc} is the load transferred to the non-collision-side frame. The barrier is deformed along the geometry of the rear bumper beam so that the input distribution shows the extent of contact by the barrier



(a) Schematic diagram of load paths



(b) Relationship between F_{xc} and F_{xnc}

Fig. 1 Load distribution of conventional structure under FMVSS 301R condition

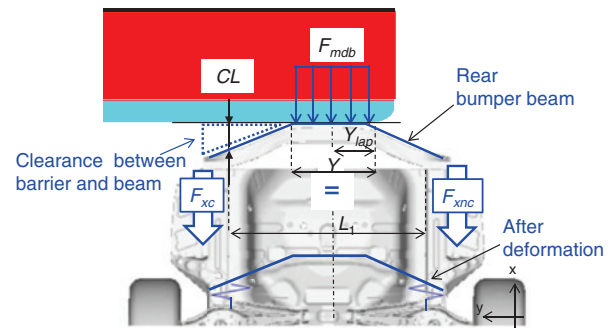
skewed toward the impact side. Figure 1(b) shows the relationship between F_{xc} and F_{xnc} . The red dotted line represents $F_{xc} = F_{xnc}$, or in other words, the state in which left and right frames receive equal load input. The red circle marks the load balance at the point when a rear bumper beam of conventional structure generates a load of 120 kN. In a conventional structure, the difference in load input to the left and right frames is large, by a factor of two or more, and as shown in Fig. 1(a), the non-collision-side frame, where the transferred load is smaller, is deformed less than the collision-side frame. This tendency is particularly strong in the case of a rear bumper beam with the geometry that skews the load distribution to the impact side.

2.2. Conceptual Approach to the New Rear Bumper Beam

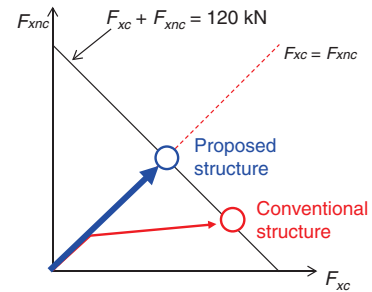
In order to reduce the difference in load input from the rear bumper beam to the left and right frames, the area of load input from the barrier needs to be made symmetrical. Since the deformation characteristics of the barrier differ according to the load range, the approach here considers two load ranges: the load range up to 120 kN that corresponds to low speed crash conditions (hereafter, lower load phase); and the load range larger than 120 kN (hereafter, higher load phase).

2.3. Conceptual Approach of Lower Load Phase

Figure 2(a) shows the relationship between F_{xc} and F_{xnc} in lower load phase. The addition of a flat section at the



(a) Schematic diagram of load paths



(b) Relationship between F_{xc} and F_{xnc}

Fig. 2 Load distribution in lower load phase

middle of the rear bumper beam causes the load input from the barrier to be limited to the extent of the flat section. The provision of the clearance shown by the blue dotted line in Fig. 2(a) further causes a time lapse until the point when the barrier and portions of the rear bumper beam other than the flat section come into contact. This causes input from the barrier F_{mdb} to act symmetrically with respect to the rear bumper beam. As shown by the blue line in Fig. 2(b), F_{xc} and F_{xnc} are distributed equally.

From the above perspective, a mound shape as shown by the blue line in Fig. 2 (a) was determined for the shape of a rear bumper beam capable of providing a flat section and clearance.

2.4. Conceptual Approach of Higher Load Phase

The method for generating a load in the range above 120 kN that is equivalently distributed is to collapse the barrier and have the rear bumper beam collide with the flat barrier plate. The state of input when this happens is shown schematically in Fig. 3(a). $F_{FLAT-plate}$ is the distributed load that is applied from the flat barrier plate of the barrier to the rear bumper beam. Then the extent of input from the flat barrier plate becomes only the flat section of the rear bumper beam, and as shown by the blue line in Fig. 3(c), symmetrical input is obtained even in the load range above 120 kN.

In the transitional phase that moves from the lower load phase to the higher load phase, the input temporarily loses its symmetry, as shown in Fig. 3(b). The strength per unit area of the barrier (hereafter, the collapse strength) is defined by standards, so that F_{xnc} displays the transitional

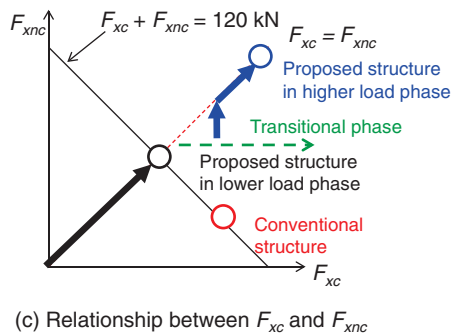
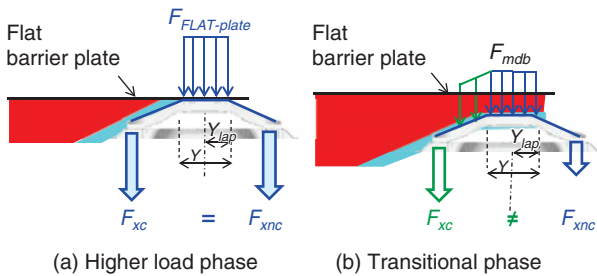


Fig. 3 Load distribution in higher load phase

characteristic whereby it does not increase, as shown by the green dotted line in Fig. 3(c).

As shown in Fig. 4(a), the barrier is made up of the bumper honeycomb (hereafter, B-honeycomb), which has high collapse strength, and the face honeycomb (hereafter, F-honeycomb), which has low collapse strength. By making the vertical overlap Δz of the barrier and the rear bumper beam smaller as in Fig. 4(a), the F-honeycomb with its lower collapse strength is caused to deform more readily. As shown in Fig. 4(b), the barrier can be collapsed when the load is low, so the range of the transitional phase can be limited as much as possible.

On the other hand, when the vertical overlap is larger, as shown in Fig. 4(c), then after the F-honeycomb deforms, the B-honeycomb becomes collapsed as in Fig. 4(d). The extent of the transitional phase is broadened as a result.

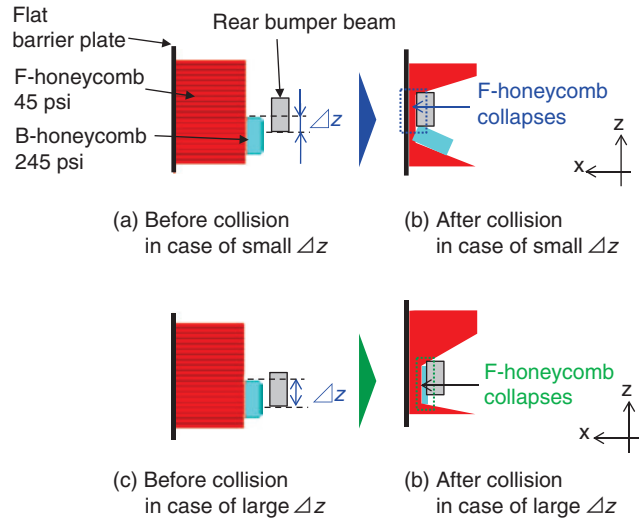


Fig. 4 Differences in collapse modes by Δz

3. Basic Rear Bumper Beam Shape Calculations

The basic structure for the rear bumper beam that will result in symmetrical load input to the rear frame was verified by theoretical calculations and by simulation. This confirmed the validity of the conceptual approach described in preceding sections.

3.1. Length of Rear Bumper Beam Flat Section

Verification was performed first for the length of the flat section provided at the middle of the rear bumper beam. As was shown in Fig. 2(a), Y is the length of the rear bumper beam flat section where the load is received and Y_{lap} is the length from the center of the rear bumper beam to the end of the barrier. L_1 is the distance between the left and right rear frames. Equations (1) and (3)

represent the load equilibrium when the rear bumper beam is taken as a beam, while Eqs. (2) and (4) represent the moment equilibrium. The relationships of Y with F_{xc} and F_{xnc} were obtained by theoretical calculation using these equations. Taking a mass-production sedan as the basis, Y_{lap} was defined as 250 mm.

$$\begin{aligned} \text{When } Y < 2Y_{lap}, \\ F_{xc} + F_{xnc} = F_{mdb}Y \end{aligned} \quad (1)$$

$$\int_{\frac{L_1 - Y}{2}}^{\frac{L_1 + Y}{2}} F_{mdb}y dy - F_{xnc}L_1 = 0 \quad (2)$$

$$\begin{aligned} \text{When } Y \geq 2Y_{lap}, \\ F_{xc} + F_{xnc} = F_{mdb} \left(Y_{lap} + \frac{Y}{2} \right) \end{aligned} \quad (3)$$

$$\int_{\frac{L_1 - Y}{2}}^{\frac{L_1 + Y}{2} + Y_{lap}} F_{mdb}y dy - F_{xnc}L_1 = 0 \quad (4)$$

Figure 5 shows the results of the theoretical calculations. The horizontal axis is the length Y of the flat section. The vertical axis is the ratio F_{xnc} / F_{xc} of the input load on the left and right rear frames. When $Y < 2Y_{lap}$, the extent of the load input from the barrier becomes bilaterally symmetrical at the center of the vehicle so that $F_{xnc} / F_{xc} = 1.0$. When $Y \geq 2Y_{lap}$, the extent of the load input from the barrier becomes asymmetrical so that $F_{xnc} / F_{xc} \leq 1.0$. Consequently, in order to have equal load input to the rear frame, Y needs to be equal to or less than two times Y_{lap} . Verification was conducted from this point with $Y = 500$ mm.

When Y is determined, the load input to the left and right rear frames can be calculated using Eq. (5).

$$F_{xc} + F_{xnc} = P_{mdb} \times A = P_{mdb} \times Y \times Z_{mdb} \quad (5)$$

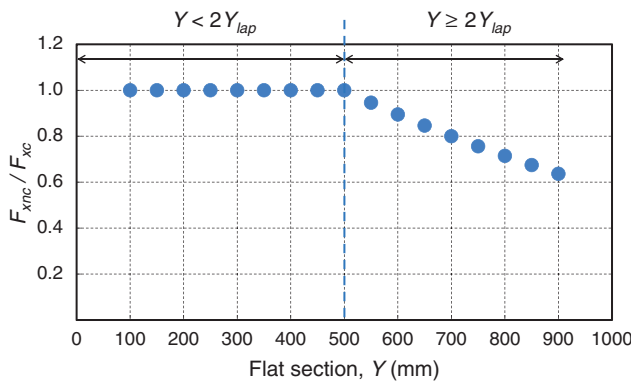


Fig. 5 Relationship of bumper beam length Y and F_{xnc} / F_{xc}

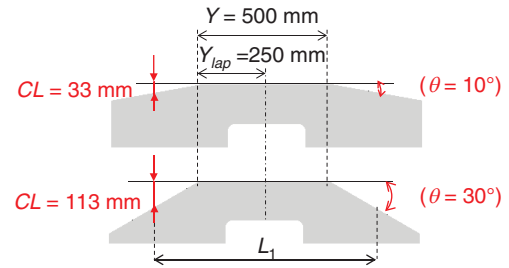
Here, P_{mdb} is the barrier collapse strength of 45 psi, A is the theoretical maximum area of the barrier where deformation is caused by the rear bumper beam, and Z_{mdb} is the prescribed dimension of 559 mm for the barrier height in the z direction. Given these values, $F_{xc} + F_{xnc} = 120$ kN. In other words, equal loads of 60 kN each are distributed to the left and right rear frames.

3.2. Clearance Between the Barrier and Rear Bumper Beam End

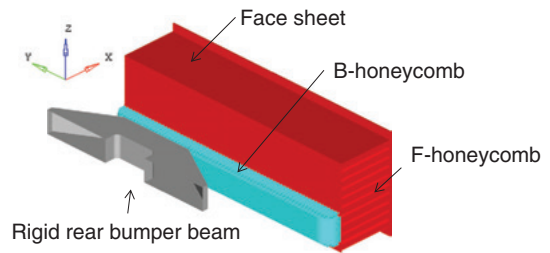
Next, a simulation was conducted to examine how much clearance is needed between the barrier and the end of the rear bumper beam. For the rear bumper beam model, Y_{lap} was defined as 250 mm, and the model was made a rigid element model of the kind shown in Fig. 6. The barrier was modeled using shell elements.

The measurement locations for clearance CL are indicated by red arrows, showing that they are located along lines extending from the frames. Based on the bending angle of 10° for mass-production vehicles, CL was evaluated with the bending angle θ from 10° to 60° as a parameter shown in Table 1. The rear bumper beam was fixed in place and the barrier was caused to crash into it at 80 km/h. LS-DYNA was used as the solver for the simulation.

Figure 7 shows barrier deformations for each of the simulation condition. It was found that when CL was subjected to increases from 33 mm to 168 mm, the area enclosed by blue lines in the figure increased in size. When CL was increased past 168 mm, the range of contact with the barrier was limited to the flat section of the rear bumper



(a) Rigid model of rear bumper beam



(b) Setup for simulation

Fig. 6 Simulation model for investigation of barrier clearance

Table 1 Parameters used for clearance investigation

	CAE01	CAE02	CAE03	CAE04	CAE05	CAE06
θ	10°	20°	30°	40°	50°	60°
CL	33 mm	72 mm	113 mm	168 mm	240 mm	346 mm

beam. It was also found that the deformed shape of the barrier had inflection points of the kind shown by blue circles in the figure.

When the distance Δx of this inflection point from the flat section of the rear bumper beam was calculated, it was found to be 105 mm. Unless the inflection point is in contact with the rear bumper beam surface, the contact with the barrier will be limited to the flat section, so that a figure of 105 mm or greater can be considered an approximate guide to the value of CL sought for the rear bumper beam.

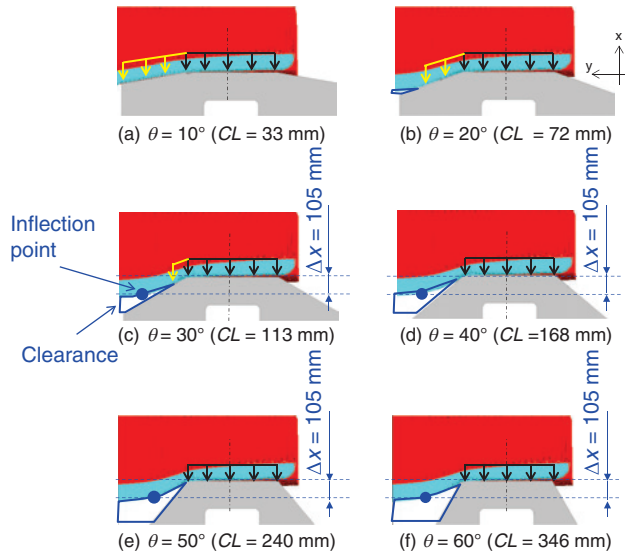


Fig. 7 Barrier deformation with different initial clearances

Figure 8 shows the load balance between left and right obtained by simulation. The results are divided into two groups based on the barrier deformation drawings in Fig. 7. Figure 8(a) shows Group 1, where $CL < 168$ mm, and Fig. 8(b) shows Group 2, where $CL \geq 168$ mm. The round marks in the figure show the points where the total load becomes 120 kN. It is apparent that in Group 1, these round marks approach more closely to the black dotted line marking an equally distributed load condition as the clearance increases. It was also found with Group 2 that no major changes in the load characteristic were observed, and that the general target figure of 60 kN for symmetrical load distribution had been achieved.

Figure 9 shows the relationship of clearance CL and the ratio F_{xnc} / F_{xc} of the input load on the left and right rear frames. The curve in the figure is a function approximation of results for the three Group 1 models. When CL was assigned the same 105 mm value as the Δx described earlier, then F_{xnc} / F_{xc} calculated by approximation yielded the value 0.85. It was found, therefore, that providing a clearance of 105 mm or more as an approximate guide would yield a

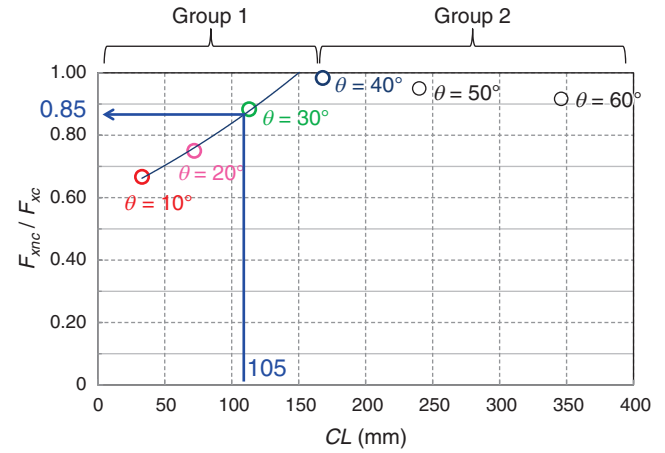
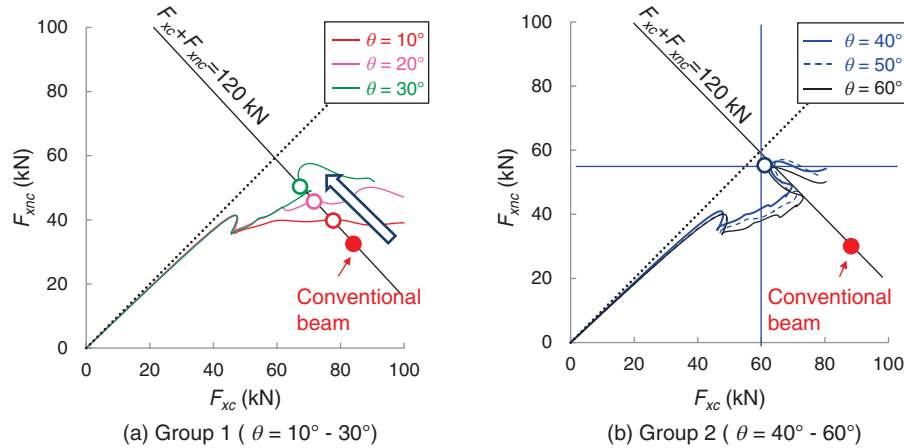
Fig. 9 Relationship of clearance and F_{xnc} / F_{xc} 

Fig. 8 Load balance of frames for different bending angles

high input load ratio. Verification was conducted from this point with $CL \geq 105$ mm.

3.3. Vertical Overlap of Barrier and Rear Bumper Beam

An investigation was made of the vertical overlap that is needed in order to collapse the F-honeycomb and obtain a greater load distribution effect. The same conditions as in the previous section were used with the model for simulation. For the geometry of the rear bumper beam, CAE03 ($CL = 113$ mm, $\theta = 30^\circ$) from Table 1 was used. The simulation was carried out with vertical overlap Δz of 150 mm, 80 mm, 70 mm, and 60 mm as shown in Fig. 10.

Figure 11 shows cross-section of barrier deformation in section XZ at the middle of the rear bumper beam. With $\Delta z = 150$ mm, both F-honeycomb and B-honeycomb are collapsed. With $\Delta z = 80$ mm and 70 mm, there was deformation in the upper part of B-honeycomb and in F-honeycomb. It was found that with $\Delta z = 60$ mm, however, there was greater rotation of B-honeycomb and it was mainly F-honeycomb that collapsed.

Figure 12 shows the state of deformation in section XY at location AA shown in Fig. 10. The black lines and black dotted lines show the respective location after deformation of B-honeycomb and F-honeycomb. With $\Delta z = 150$ mm and 80 mm, both B-honeycomb and F-honeycomb are collapsed.

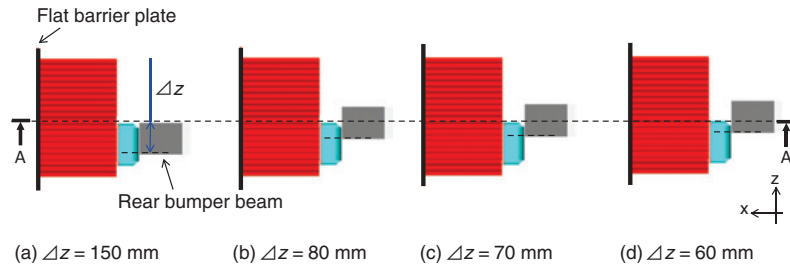


Fig. 10 Barrier and bumper beam overlap amount

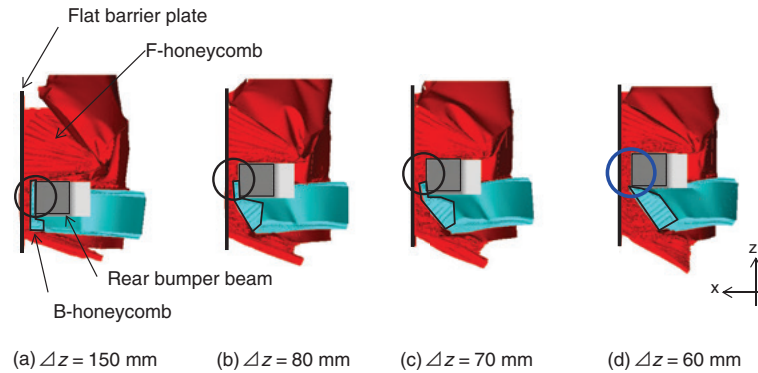


Fig. 11 Barrier deformation in section XZ

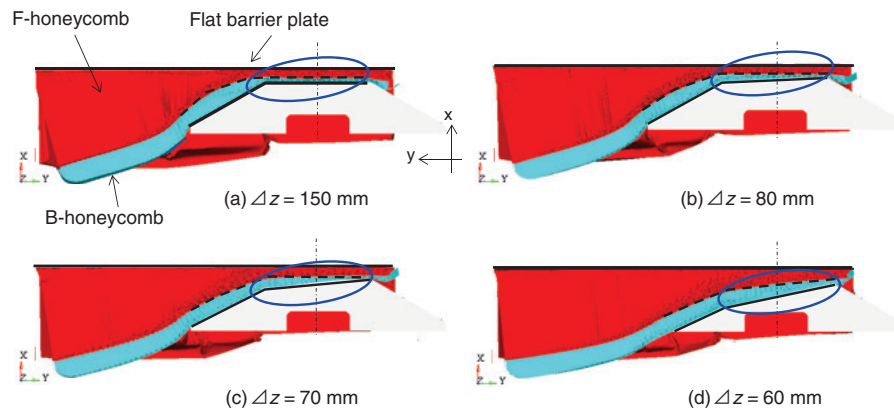


Fig. 12 Barrier deformation in section XY

It is apparent that when the vertical overlap decreases from 80 mm, however, there is less deformation of B-honeycomb inside the blue outline.

It was found from the above results from analysis of the barrier deformation in sections XZ and XY that with a vertical overlap of 80 mm or more, both F-honeycomb and B-honeycomb deform, and at 60 mm or less, deformation occurs mainly in F-honeycomb. An intermediate state of deformation was also shown at 70 mm. It was found from this that a vertical overlap Δz from 60 mm to 70 mm makes it more likely that the F-honeycomb will collapse and the rear bumper beam will be brought into contact with the flat barrier plate.

Figure 13 shows the changes in load input to the left and right rear frames plotted by overlap amount. From the lower load phase to the transitional phase, a change from (a) to (b) occurs in every case in the figure. At $\Delta z = 60$ mm, the change from the transitional phase to (c) occurs as the B-honeycomb collapsed more quickly, and the load distribution from that point on is nearly equal. At 70 mm, an equal load condition is again restored after (d). However, an equal load condition is not achieved even in a higher load phase at 80 mm and 150 mm, and the transition to (e) takes place with the relationship $F_{xnc} < F_{xc}$ remaining true. It was found from these results that $\Delta z \leq 70$ mm is an approximate guide for vertical overlap.

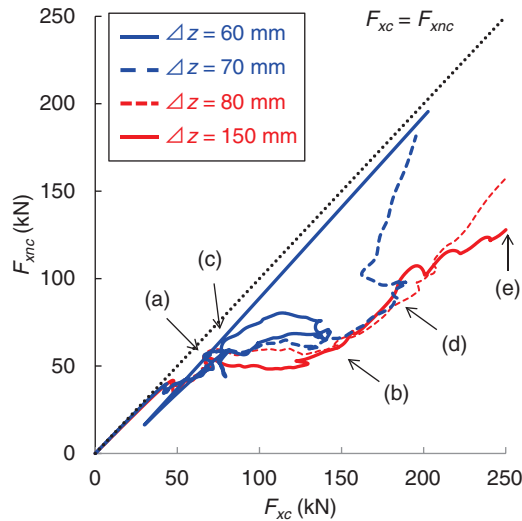


Fig. 13 Load balance of frames for different overlap amounts

4. Verification of Load Distribution Effectiveness

4.1. Practical Implementation of the New Rear Bumper Beam

In the course of demonstrating the validity of results achieved by investigation to this point, an investigation

was made into the practical implementation of a prototype that would fulfill the rear bumper beam design conditions described in section 3 and satisfy all the requirements for the design space of mass-production vehicle as well as manufacturability. As shown in Fig. 14, a shape that assures a clearance of 105 mm or more, as shown in section 3, was realized by providing multiple curved portions. As a manufacturing method that provides practical implementation of such a geometry, stretch bending⁽⁹⁾ of extruded aluminum material was adopted.

First, the formable range was predicted by theoretical calculations. The two constraint parameters for forming are the curvature R_3 and the length L_3 between the bending segments of the rear bumper beam shown in Fig. 14. The length of R_3 needs to be 300 mm or more, and $L_3/2$ needs to be 450 mm or more. The distance L between the two frames was set at 1100 mm, the same value as for mass-production vehicle, and L_2 needs to be 50 mm or more in order to provide a flat surface for the attachment points the rear frames. This means that the upper limit for $L_3/2$ is $(1100 - 2 \times 50)/2 = 500$ mm. Based on these forming requirements, the rear bumper beam was fabricated using the dimensions shown in Fig. 14.

4.2. Test Conditions

A prototype rear bumper beam was fabricated according to the conditions described in the previous section and was subjected to individual part testing. This used the drop weight test machine at the Hasaki Research and Development Center of Nippon Steel Corporation, which is capable of measuring the input load to the frames from the rear bumper beam and can also record imagery of the deformation.

Figure 15 presents images that show the test setup. The rear bumper beam was fixed in place on a flat plate with load cells interposed. The barrier was attached to the drop-weight and allowed to drop freely in the vertical direction. The status of barrier deformation was also recorded using a high-speed camera.

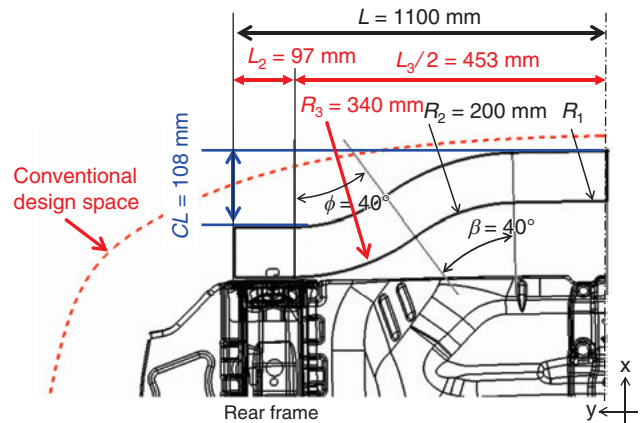


Fig. 14 Design space and parameters for stretch bending

The lower load phase test was conducted using a rear bumper beam with the conventional structure and a prototype of the new structure, and the results were compared. The energy was calculated from the bumper and barrier stroke amount when the reaction force reached 120 kN, and the test input energy was defined as 20 kJ.

The prototype differs from the rigid rear bumper beam in that the beam undergoes deformation. When the higher load phase test was conducted, therefore, a model simulating the prototype was created and verification of the vertical overlap was performed anew under the same conditions as described in Section 3.4. The results provided for a figure of 90 mm as a general guide to the overlap amount, and the test was therefore conducted under the two conditions of 80 and 90 mm. The input energy when impact occurred was obtained by adding the condition for the lower load phase to the energy needed to collapse the barrier. This total was 75 kJ.

4.3. Lower Load Phase Test Results and Discussion

The test results were examined and discussed with reference to the effectiveness of load distribution in the lower load phase due to the flat section of the rear bumper beam and the clearance. The solid red line and solid blue line in Fig. 16 show the relationship between F_{xnc} and F_{xc} with the conventional structure and F_{xnc} and F_{xc} with the prototype respectively. The results for simulation of the prototype are also given by the dotted blue line. The load tendencies in the simulation generally match with the test results, substantiating the validity of the model implemented in the present research.

There is also a solid black line in the figure when the total of the loads input to the left and right rear frames reaches 120 kN. The arrows mark the timing for when the conventional structure and the prototype respectively reach

120 kN. With the conventional structure, the input load difference between the left and right frames was 45 kN, while with the prototype, the difference was only 3 kN. This indicates that a load input close to symmetrical was successfully achieved.

Figure 17 shows the state of barrier deformation 20 msec after impact. Image (a) shows the conventional structure and image (b) shows the prototype. With the conventional structure, the barrier deforms in a shape that follows the rear bumper beam geometry. With the prototype, however, the clearance marked by the blue circle has been secured and a load distribution that is close to symmetrical has been realized. These results successfully demonstrate that the rear bumper beam designed in the present research can realize symmetrical load distribution.

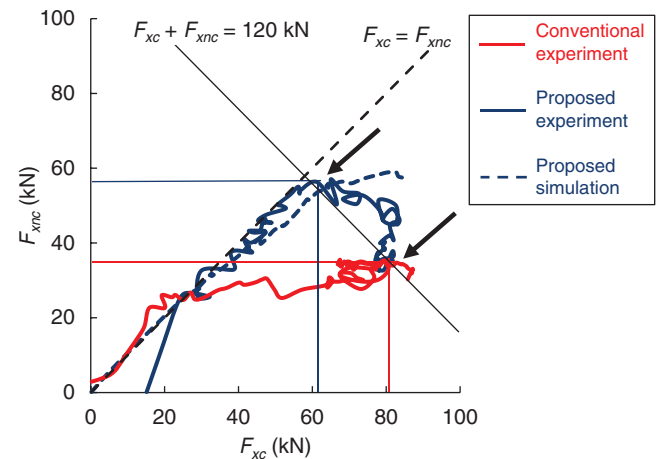


Fig. 16 Comparison of load balances with conventional and proposed bumper beams

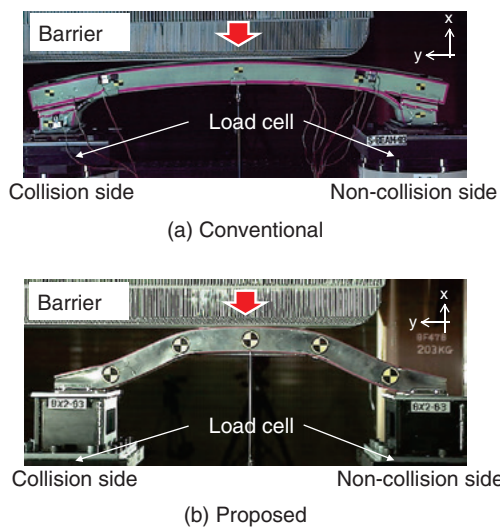


Fig. 15 Set up for drop test of bumper beams

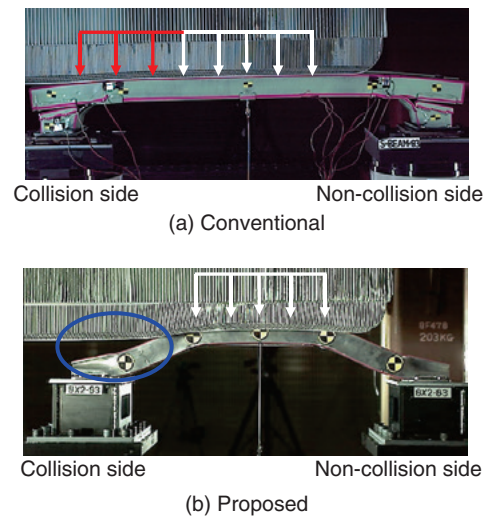


Fig. 17 Tested conventional and proposed bumper beams

At the same time, the validity of the length of the flat section of the rear bumper beam and of the magnitude of the clearance provided at both ends have also been verified.

4.4. Higher Load Phase Test Results and Discussion

The next step was verification of the effectiveness of the load distribution in the higher load phase. Figures 18(a) and 18(b) show the load balances on left and right at $\Delta z = 80$ mm and 90 mm, respectively. The intervals marked (1) in the figures are considered to be transitional phases. For 80 mm, this phase was continued until F_{xc} reached near 100 kN, and for 90 mm, near 170 kN. In either case, the transitional phase was passed and then, as shown by the black circles marked (2) in the figures, the load input again recovered to nearly symmetrical. As stated in Section 3.3., there is general agreement on the tendency toward symmetrical load input with collapse of the F-honeycomb and even in the higher load phase.

Figures 19(a) and 19(b) show section XZ of the deformed barrier at $\Delta z = 80$ mm and 90 mm, respectively. It was successfully confirmed that in either case the F-honeycomb collapsed and the rear bumper beam reached the flat barrier plate.

The portions colored blue in the figures show the approximate positions of the B-honeycomb after deformation. The dimensions given in the figures are the distances from the flat barrier plate to the upper end of the B-honeycomb. Comparison shows that this distance is 30 mm greater when $\Delta z = 80$ mm. This is thought to happen because the vertical overlap at 80 mm is smaller so that the rear bumper beam transitions to a condition that deforms the F-honeycomb more quickly. This is substantiation that the reason for the difference in the extent of the transitional phase is the difference in the amount of barrier deformation.

The above successfully demonstrates that having the F-honeycomb collapse and having the flat barrier plate come in contact with the rear bumper beam results in symmetrical load input even in the higher load phase.

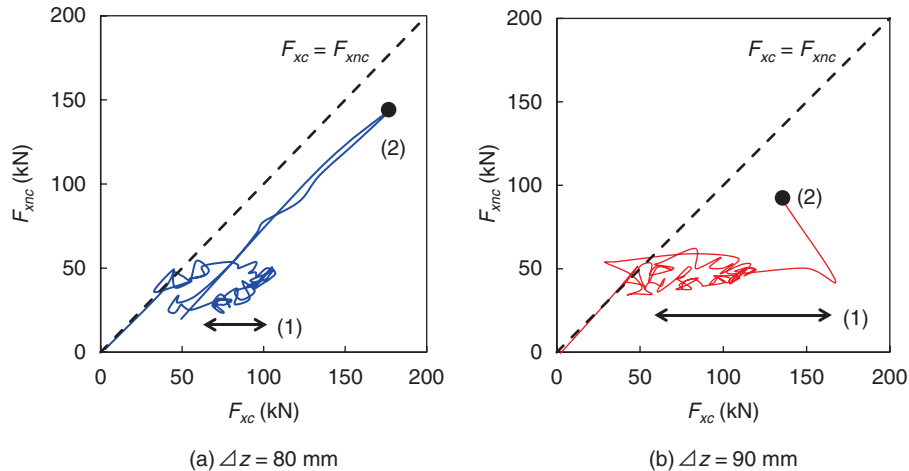


Fig. 18 Comparison of load balances with different lap lengths

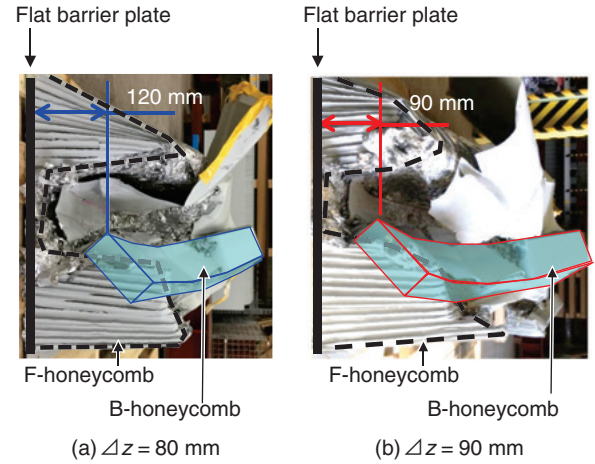


Fig. 19 Comparison of tested barriers with different lap lengths

5. Conclusion

A rear bumper beam was developed that is capable of reducing the input load difference between left and right rear frames under the test conditions of FMVSS 301R, which is a US regulation addressing rear-end collisions. Clarification was obtained of the conditions whereby load distribution is enhanced by the flat section of the rear bumper beam and the clearance provided at both ends of the beam. It was also clarified that load distribution is made possible even in a higher load phase by configuring the B-honeycomb and rear bumper beam to have a smaller vertical overlap.

The prototype rear bumper beam with the new structure was used to conduct drop tower test. This demonstrated that the input difference between left and right could be reduced from the lower load phase to the higher load phase.

It is anticipated that this technology will help enhance energy absorption by the non-collision side frame, and it appears likely to be usable even in next-generation vehicle bodies, which will probably be heavier.

References

- (1) NHTSA: Fuel System Integrity – Rear Impact, Laboratory test procedure for FMVSS 301R, U.S. Department of Transportation National Highway Traffic Safety Administration, (2009)
- (2) Okada, E.: Hottosutanpu to kōrudosutanpu, insatsu zasshi, Vol. 90, No. 7, p. 25-28, (2007) (in Japanese)
- (3) Fukuchi, H., Nomura, N.: Automotive Solution: Development of Hot Stamping with High Productivity, Shinnittetsu Sumikin giho, Vol. 402, p. 70-72, (2015) (in Japanese)
- (4) Maki, H., Takaki, N.: Application of Next-generation High-lambda-type High-strength Steel Sheets, Transactions of Society of Automotive Engineers of Japan, Vol. 48, No. 6, p. 1347-1352, (2017)(in Japanese)
- (5) Ishitobi, H., Fujiwara, A.: Deformation of Aluminum Bumper Beam in Corner Pendulum Impact Test, Transactions of Society of Automotive Engineers of Japan, Vol. 29, No. 2, pp. 97-102, (1998)(in Japanese)
- (6) Yabu, T., Yasuhara, S.: Development of Rear Bumper Beam Using Thermoplastic Glass Fiber-reinforced Plastic, Honda R&D Technical Review, Vol. 30, No. 1, p. 60-65
- (7) Mori, T., Hamano, H., Suzuki, T., Yoshitake, A., Hashimoto, Y., Iwase, I.: Application of Ultra-high Strength Steel Sheets to Bumper Beams, NKK Technical Report, Vol. 151, p. 17-21, (1995) (in Japanese)
- (8) Yasuhara, S., Egawa, Y.: A Study of Rear Frame Construction for Rear Offset Collision Mode, Transactions of Society of Automotive Engineers of Japan, Vol. 39, No. 6, p. 71-75, (2008)(in Japanese)
- (9) Paulsen, F., Welo, T.: A design method for prediction of dimensions of rectangular hollow sections formed in stretch bending, Journal of Materials Processing Technology, Vol. 128, Issues 1-3, p. 48-66, (2002)

■ Author ■



Atsushi HASEGAWA



Takayuki FUJII



Norikazu MATSUURA



Tomohiro SHIMIZU



Yusuke MIURA