

B-pillar Load Transfer Mechanism in Side Collision

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ABSTRACT

Based on side collision testing that the Insurance Institute for Highway Safety in the United States has been conducting, a technology was created that can reduce the amount of B-pillar deformation and also generate a high load. In a side collision, it is necessary for the greater part of the load received from the barrier to be supported by the bending of the B-pillar. This was addressed by creating a new load path in the B-pillar. The new load path is able to support the lateral load input from the barrier as an axial load in a downward direction in the vehicle body. This increases the load from the initial time of collision and reduces bending deformation. A load transfer mechanism in the B-pillar cross-section was added for the axial load and this was realized by a load path to the side sill. The structure of the load transfer mechanism was decided through theoretical calculation and simulation. A prototype was fabricated with a load transfer mechanism in a mass-produced B-pillar. Drop tests with the prototype proved that the load generated on the B-pillar was doubled so that the amount of deformation could be reduced to one-fifth.

1. Introduction

Demand for automobile safety performance continues to intensify, and preventative safety technology that helps stop accidents before they happen is making remarkable progress. Meanwhile, there is also the constant enhancement of collision safety standards that mitigate damage when accidents occur, and the Insurance Institute for Highway Safety (IIHS) in the United States continues to conduct research focusing on correlations between safety performance rating points and death rates⁽¹⁾. Future application of new testing criteria (hereinafter, the New IIHS MDB) is planned in order to enhance vehicle safety in side collisions⁽²⁾.

Figure 1 shows an overview of the New IIHS MDB. The weight of the deformable barrier (hereinafter, barrier) is increased from 1500 kg to 1900 kg, and the velocity at which the barrier collides with the vehicle is also increased from 50 km/h to 60 km/h⁽²⁾. This is equivalent to a 1.8-fold increase in collision energy.

Toward the realization of a carbon-free society, it is expected that future automobiles will have equipment such as large-capacity batteries and hydrogen tanks. This will

increase the vehicle body weight, calling for even more energy absorption⁽³⁾.

The authors therefore anticipated future themes for side collisions, and focused on the New IIHS MDB, which is presently the highest energy testing criteria.

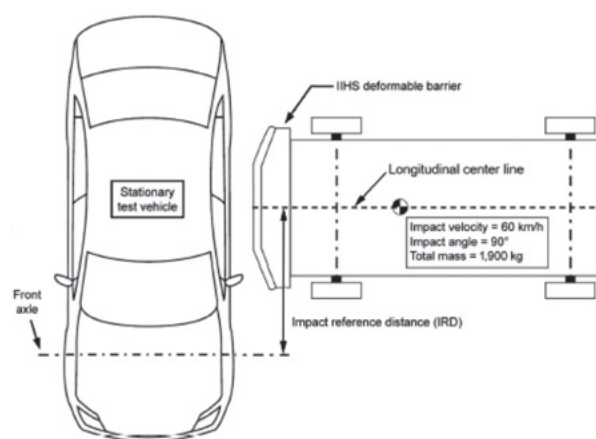


Fig. 1 Deformable barrier alignment with test vehicle

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In the present vehicle body structure, the input load from a side impact originates in the B-pillar (the pillar between the front and rear seats) and is transferred to the side sill, roof side rail, floor cross member, and roof cross member⁽⁴⁾. The barrier collides with the lower part of the vehicle body, so bending deformation occurs with the largest deformation on the lower side of the B-pillar. Safety performance is rated by the two items of distance from the location with the largest deformation to the seat center, referred to as structure, and the dummy injury criterion. Structure is classified into four levels by size, and smaller amounts of deformation receive better ratings. From these perspectives, the B-pillar is a key structure for side collisions.

Research on the B-pillar so far has included control of the deformation mode by deformation mode prediction⁽⁵⁾ and the partial softening method⁽⁶⁾, and weight reduction by application of high-tensile steel⁽⁷⁾⁻⁽¹⁰⁾, etc. However, none involved major advances in the B-pillar structure, and methods such as addition of reinforcing parts and increased thickness were used to generate a large load with small deformation. These lead to increased vehicle body weight, and there are also limits to reinforcement in consideration of limitations on welded plate thickness.

This research therefore took as a representative case the New IIHS MDB, which is the highest energy criteria in side collision testing, and created a new load transfer mechanism that enables the B-pillar to generate a high load with small deformation.

2. B-pillar Load Enhancement Concept

2.1. Load Generation Method of Conventional Structure

Figure 2 shows a diagram of the deformation when input is received from the barrier. The barrier is composed of a protruding part indicated in red that simulates a front bumper beam and a honeycomb structure general part indicated in blue. It deforms according to the shape of the vehicle body. When the B-pillar receives the distributed

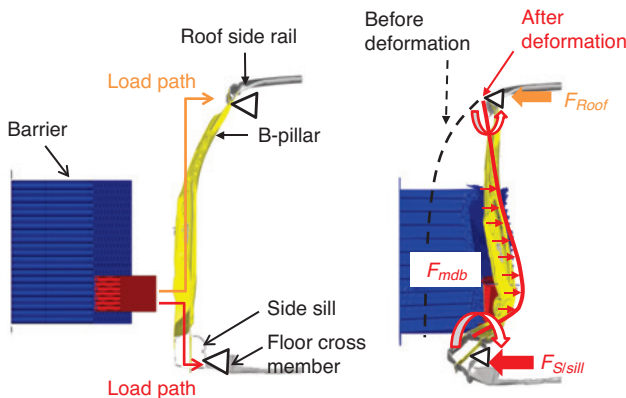


Fig. 2 Deformation mode of B-pillar in conventional structure

load from the barrier (hereinafter, F_{mdb}), the lower side functions as a load path to the roof side rail and the side sill while undergoing the largest bending deformation.

Force applied to a part in a bending direction is disadvantageous in terms of load generation compared to force in an axial direction⁽⁴⁾. In a high-energy collision such as the New IIHS MDB, the B-pillar bending deformation increases further and the tensile inputs to the roof side rail and side sill support parts also increase. The conventional structure is mostly subject to bending deformation, so a large amount of deformation is needed before the highest load is reached. For this reason, the general method is to increase the B-pillar load and reduce the amount of B-pillar deformation and the load on the support parts. This is done by increasing the size and thickness of the B-pillar cross section, which contribute greatly to bending, and by adding reinforcing parts.

2.2. New Conceptual Approach to Load Generation

The basic principle for increasing the load generated by the B-pillar is to apply the balance of moments to transfer the lateral load received from the barrier to an axial load in the vertical direction. Figure 3 shows the schematic diagram of this principle. A clockwise moment is generated when a lateral load F_y is applied to the part fixed to the side sill. This moment is balanced with the counterclockwise moment generated by the vertical load F_z received from the side sill. That is to say, the lateral load can be increased by increasing the vertical axial load.

Figure 4(a) shows a structural diagram of application of this basic principle to the B-pillar. A two-part mechanism (hereinafter, load transfer mechanism) composed of a loading part (hereinafter, L/Part) and a support part (hereinafter, S/Part) was added in the cross section in the lower part of the B-pillar. The L/Part and S/Part contact each other at the slope, as indicated by the blue arrow, and are joined only halfway around the circumference in the

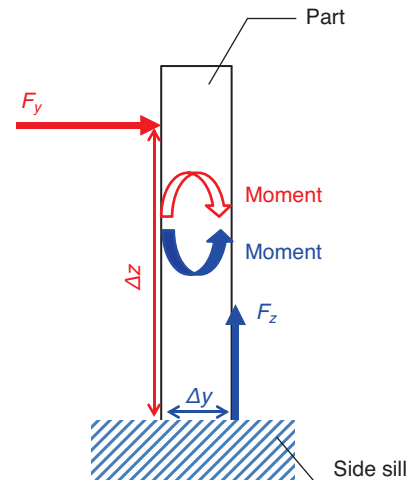


Fig. 3 New basic principles of load transfer

range indicated by the red line starting from junction O in the center of the slope. The S/Part is placed on the upper surface of the side sill via a base plate.

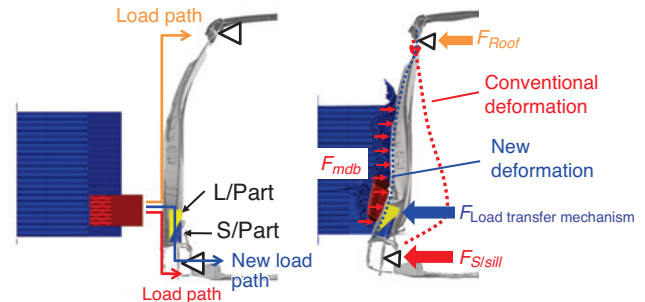
When the lateral load from the barrier is applied, the B-pillar contacts the L/Part and the load transfer mechanism deforms, as shown in Fig. 4(b). The L/Part rotates around junction O, converting the lateral load to the downward direction and transferring it to the S/Part. The semicircular range of the S/Part on the cabin interior side is pressed from the L/Part, generating an axial load in the vertical direction. As a result, the load transfer mechanism creates a new load path that transfers the load to the side sill and floor cross member. Here, F_{y-LP} indicates the lateral load applied from the B-pillar to the L/Part and F_{z-SP} indicates the axial load generated by the S/Part. That is to say, F_{y-LP} and F_{z-SP} have a balanced relationship between the moments originating from junction O, thereby F_{y-LP} can be determined by setting F_{z-SP} and the respective lengths Δy and Δz from junction O over which F_{y-LP} and F_{z-SP} act.

Figure 5(a) shows a conceptual drawing of the load and deformation when the load transfer mechanism is installed in the B-pillar. The blue arrow in the left figure shows the new path by which the load from the barrier is transferred via the load transfer mechanism to the side sill. The axial load of the load transfer mechanism increases the load generated by the B-pillar, which greatly crushes the barrier. Compared with the red dotted line that indicates the conventional structure with large bending deformation of the B-pillar, the amount of deformation is greatly reduced

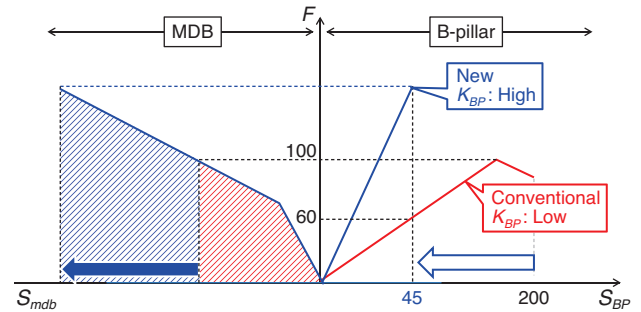
in the new structure indicated by the blue dotted line.

Figure 5(b) shows a conceptual diagram of the effects of the load and amount of deformation. The vertical axis represents the load and the horizontal axis represents the amounts of barrier deformation S_{mdb} and B-pillar deformation S_{BP} . The new structure indicated by the blue line reaches the highest load with a small amount of deformation. As a result, the load gradient (hereinafter, K_{BP}) obtained by dividing the highest load by the amount of deformation becomes larger than that of the conventional structure. The amount of energy absorbed by the barrier increases as indicated by the blue shaded area, so the burden on the B-pillar decreases.

As shown above, the B-pillar load enhancement concept is to use a load transfer mechanism to create a transfer path that supports the load in the axial direction and to increase the load gradient K_{BP} .

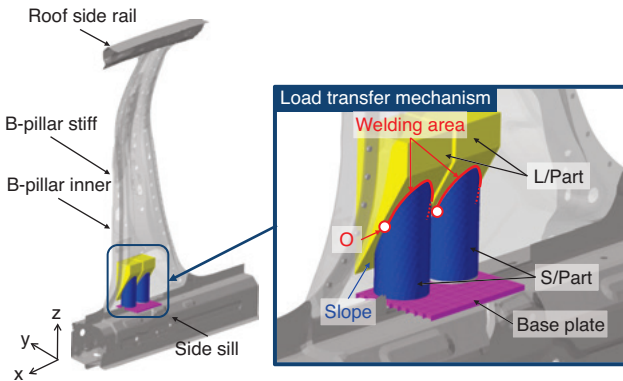


(a) Conceptual drawing of load paths

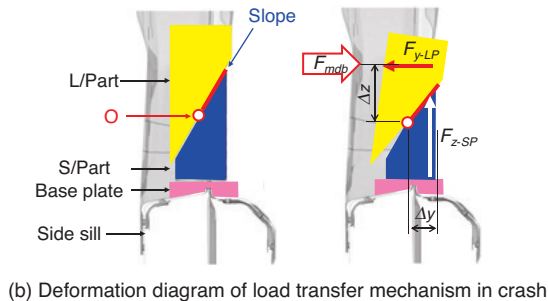


(b) Relationship between force and stroke

Fig. 5 Deformation mode of B-pillar in new structure



(a) Structure of load transfer mechanism



(b) Deformation diagram of load transfer mechanism in crash

Fig. 4 Diagram of new structure

3. Load Transfer Mechanism Performance Requirements and Creation of Design Method

Section 3.1. establishes the target load for realizing the concept described in Chapter 2. Subsequent sections formulate the slope angle, the lateral clearance with the B-pillar, and the S/Part collapse load, which are the three main design variables of the load transfer mechanism, and create a design method. The combined load with the load

transfer mechanism installed in the B-pillar was verified by simulation and the reasonableness of the design method was confirmed.

3.1. Establishment of B-pillar Target Load

First, the B-pillar target load under the New IIHS collision conditions was established. Figure 6 shows the relative positions of the barrier and the B-pillar. The areas where the barrier contacts the B-pillar are designated I and II, and the areas where the load is input via the door beam to the B-pillar are designated III, IV, and V. The barrier surface pressure is specified for each area, so once the input range to the B-pillar is determined, the load F_{mdb} generated by the barrier can be approximated from Eq. (1). Due to the action-reaction relationship, the load F_{BP} generated by the B-pillar at this time is equal to F_{mdb} . Here, $F_{mdb,i}$ is the load generated by the barrier in each area, $P_{mdb,i}$ is the surface pressure, $A_{mdb,i}$ is the surface area, and K_{air} is the air spring constant.

$$F_{mdb} = \sum_{i=1}^5 F_{mdb,i} = \sum_{i=1}^5 P_{mdb,i} \times A_{mdb,i} \times K_{air} = F_{BP} \quad (1)$$

Next, the amount of B-pillar target deformation was established. The target amount of deformation for the full vehicle body was determined from the amount of energy absorption when the barrier has been crushed to the greatest extent, and this was then used to calculate the target value for the amount of B-pillar deformation. The amount of energy absorbed by the vehicle body ΔE_{CAR} due to collision between the MDB and the vehicle body can be expressed using the laws of conservation of energy and momentum of the vehicle body and the barrier, as shown in Eq. (2)⁽⁴⁾. Here, M_{CAR} is the vehicle body weight, M_{mdb} is the barrier weight, V_0 is the collision velocity of the barrier, and ΔE_{mdb} is the energy absorption of the barrier.

$$\Delta E_{CAR} = \frac{M_{mdb} M_{CAR}}{2(M_{mdb} + M_{CAR})} V_0^2 - \Delta E_{mdb} \quad (2)$$

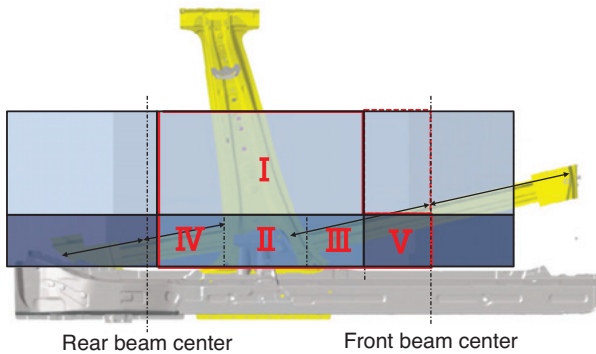


Fig. 6 Schematic diagram of B-pillar and MDB contact area

ΔE_{CAR} can also be expressed using the vehicle body reaction force F_{CAR} and the amount of vehicle body deformation S_{CAR} , as shown in Eq. (3). In this case, due to the action-reaction relationship, the theoretical highest load generated by the vehicle body reaction force F_{CAR} is equivalent to $F_{mdb-max}$ and can be obtained from the contact area between the barrier and the vehicle body in the same manner as Eq. (1).

$$S_{CAR} = \frac{2\Delta E_{CAR}}{F_{CAR}} = \frac{2\Delta E_{CAR}}{F_{mdb-max}} \quad (3)$$

Next, taking S_{CAR} as the sum of the amount of B-pillar deformation S_{BP} and the amount of door deformation S_{DR} , the B-pillar load gradient K_{BP} was calculated using a simple linear spring system such as shown in Fig. 7. Here, assuming a door load gradient K_{DR} of 2.0 kN/mm, the value of K_{BP} needed to satisfy the target amount of deformation is 2.5 kN/mm. S_{BP} can also be expressed as shown in Eq. (4) using K_{BP} and the F_{BP} from Eq. (1). This determines the B-pillar target amount of deformation S_{BP} .

$$S_{BP} = \frac{F_{BP}}{K_{BP}} \quad (4)$$

By substituting the values in Table 1 for the variables in Eqs. (1) to (4), the B-pillar target load and amount of deformation needed for a completed vehicle were calculated as $F_{BP} = 166$ kN and $S_{BP} = 66$ mm. Here, the vehicle was considered to be an ordinary C category, and the vehicle weight M_{CAR} was set at 1500 kg. The relationship between the target load and displacement is as shown by the

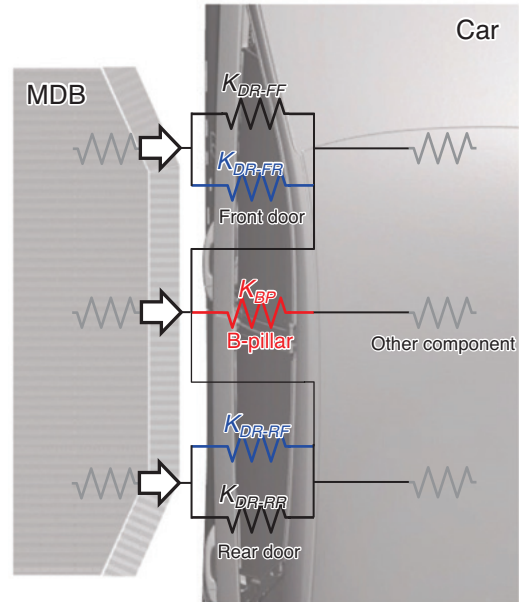


Fig. 7 Spring system of B-pillar and front and rear doors

Table 1 Numerical values used to derive targets

Variable	Value	Variable	Value	Variable	Value
$P_{mdb,1}$	140 kPa	$A_{mdb,1}$	$2.8 \times 10^5 \text{ mm}^2$	K_{air}	1.3
$P_{mdb,2}$	325 kPa	$A_{mdb,2}$	$1.4 \times 10^5 \text{ mm}^2$	M_{mdb}	1900 kg
$P_{mdb,3}$	325 kPa	$A_{mdb,3}$	$1.4 \times 10^5 \text{ mm}^2$	M_{CAR}	1500 kg
$P_{mdb,4}$	325 kPa	$A_{mdb,4}$	$1.4 \times 10^5 \text{ mm}^2$	V_0	60 km/h
$P_{mdb,5}$	1100 kPa	$A_{mdb,5}$	$5.0 \times 10^4 \text{ mm}^2$	K_{BP}	2.5 kN/mm
				K_{DR}	2.0 kN/mm

black line in Fig. 8. In order to examine only the B-pillar component, this research did not input a load from the door. Therefore, the load of 51 kN received from the barrier in area V was excluded, and the B-pillar targets were $S_{BP} = 46 \text{ mm}$ and $F_{BP} = 115 \text{ kN}$, as shown by the red line in Fig. 8. In addition, Fig. 5(b) shows that the B-pillar with the conventional structure generates a load of around 60 kN when the target amount of deformation of 46 mm is reached. Therefore, the F_{y-LP} demanded of the load transfer mechanism was determined to be $115 - 60 = 55 \text{ kN}$.

3.2. Angle of Load Transfer Mechanism Slope

Next, an examination was conducted to determine the angle of the load transfer mechanism slope. Figure 9 shows the relative positions of the load transfer mechanism and the barrier protruding part. Assuming that the load transfer mechanism receives a uniformly distributed load from the barrier, the load input point is the center of the height between the lower edge of the barrier and the upper edge of the L/Part (hereinafter, O'). Here, expressing the S/Part radius as Δy , the distance from the junction O to O' as Δz , the distance from O' to the lower edge of the S/Part as H , and the slope angle of the contact surface between the L/Part and S/Part as θ , F_{y-LP} , and F_{z-SP} can be expressed according to the balance of moments, as shown in Eqs. (5) and (6).

$$F_{y-LP} \cdot \Delta z = F_{z-SP} \cdot \Delta y \quad (5)$$

$$\Delta z = H - (h + \Delta y \tan \theta) \quad (6)$$

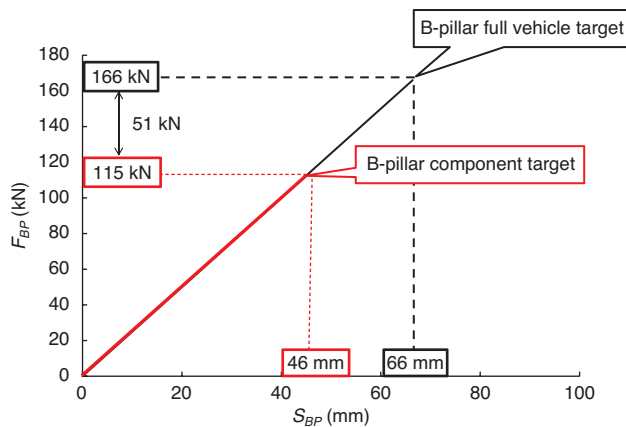


Fig. 8 B-pillar target displacement and load

The size of the load transfer mechanism was set at $Z = 150 \text{ mm}$ and $Y = 50 \text{ mm}$ in consideration of placement in the lower part of the B-pillar. In order for the cylindrical part of the S/Part on the cabin interior side to generate a stable axial load, the height h from the lower surface was set at 20 mm to achieve the shortest dimension on the cabin exterior side of the S/Part. It can be estimated from Eq. (6) that F_{z-SP} will be 175 kN when $\theta = 30 \text{ deg}$ and 112 kN when $\theta = 60 \text{ deg}$. Theoretical examination indicated that increasing the slope angle θ reduces Δz , enabling the generation of a large F_{y-LP} with a small F_{z-SP} and an efficient increase in the B-pillar load.

The combined performance with the load transfer mechanism installed in the B-pillar was confirmed by simulation using LS-DYNA, and the slope angle that results in generation of the highest load at the target amount of deformation was examined.

Figure 10(a) shows the analytical model. The B-pillar is joined to the roof side rail and the side sill. The load transfer mechanism is placed in the B-pillar opening with the lateral position set in the center part of the side sill. The boundary conditions of the front and rear end faces of the roof side rail and side sill are defined as completely fixed to exclude the influence of rotation or deformation of the boundary parts. The B-pillar model is defined by shell elements with a mesh size of 5 mm. By contrast, the barrier model is defined by a rigid body element with the same shape as the protruding part of the New IIHS MDB, and forced displacement of 1 m/s is applied to obtain the relationship between the quasi-static load and displacement of the B-pillar. Evaluation was performed for the three cases of a slope angle θ of 30 deg, 45 deg, and 60 deg, as shown in Table 2. Figure 10(b) shows the shape of each load transfer mechanism. The L/Part is defined by a rigid body element, and the S/Part is defined by a shell

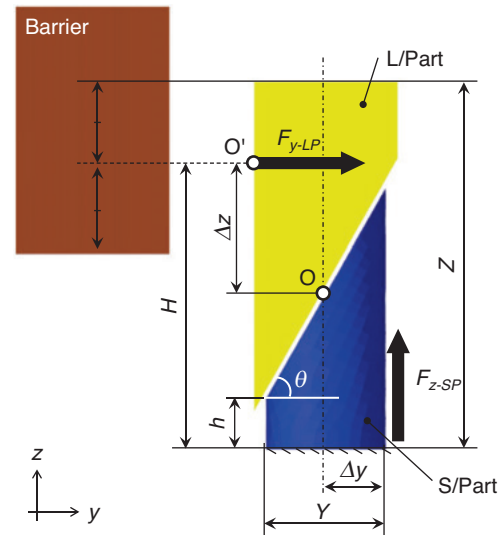


Fig. 9 Schematic diagram of load transfer mechanism

Table 2 Parameter used for investigation of different θ

	Model 1	Model 2	Model 3
θ	30 deg	45 deg	60 deg
$\Delta y/\Delta z$	0.31	0.36	0.49

element simulating 590 MPa-grade high-tensile steel with a thickness of 1.5 mm.

Figure 11 shows the relationship between the B-pillar load F_{BP} and amount of deformation S_{BP} . In the models with the load transfer mechanism installed, the load began to increase at the timing of the amount of deformation indicated by the arrow. This roughly coincided with the lateral clearance of 20 mm between the B-pillar and the load transfer mechanism shown in Fig. 10. As in the theoretical calculations, the load for the case with $\theta = 60$ deg increased to around double that of the conventional model and exceeded the target load of 115 kN at the target amount of deformation of $S_{BP} = 46$ mm indicated by the black dotted line.

It was found from the above that when the S/Part buckling load F_{z-SP} is constant, F_{BP} can be changed according to the angle of the load transfer mechanism slope. In subsequent sections, the examination proceeded with the slope angle $\theta = 60$ deg.

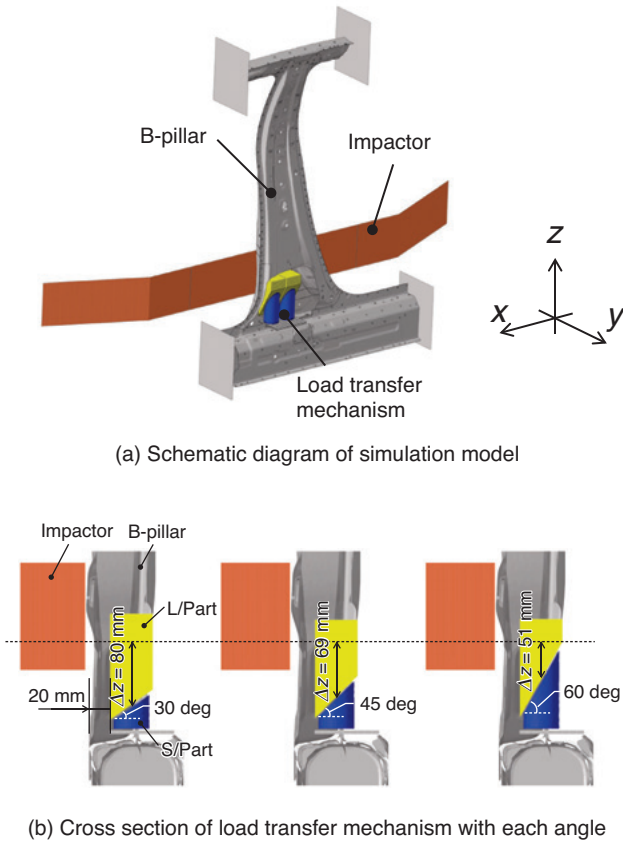


Fig. 10 Appearance of CAE model

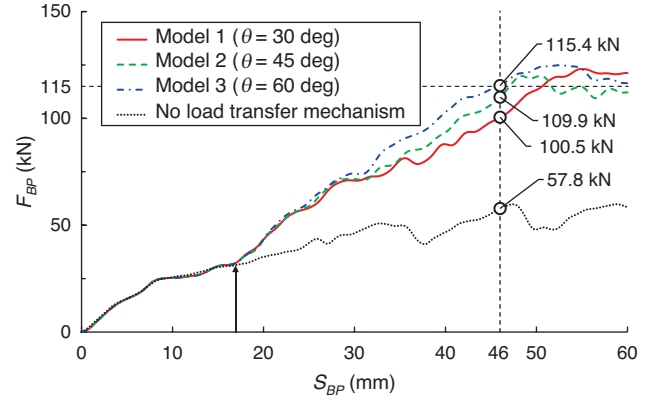


Fig. 11 Load displacement curves at different angles

3.3. Lateral Clearance between Load Transfer Mechanism and B-pillar

It was suggested in the previous section that the timing at which the load increases is related to the lateral clearance between the B-pillar and the load transfer mechanism. It is thought that the load path to the side sill activated at the timing when the B-pillar deformed to the extent that the clearance disappeared and the B-pillar contacted the load transfer mechanism.

Therefore, a clearance that enables the generation of a higher load at the target amount of deformation was obtained by simulation. Model 3 with the slope angle determined in the previous section was used to conduct simulations for a total of four cases with clearance CL of 5, 20, 30, and 50 mm between the load transfer mechanism and the B-pillar, as shown in Fig. 12.

Figure 13 shows the relationship between the B-pillar load F_{BP} and amount of deformation S_{BP} . F_{BP} was found to rise the earliest for the case with the small clearance of 5 mm. However, the case with $CL = 20$ mm exhibited the highest F_{BP} at the target amount of deformation. Figure 14 shows the deformation of the load transfer mechanism and B-pillar at the target amount of deformation. The B-pillar and the load transfer mechanism make contact when CL is from 5 mm to 30 mm, but do not make contact at $CL = 50$ mm.

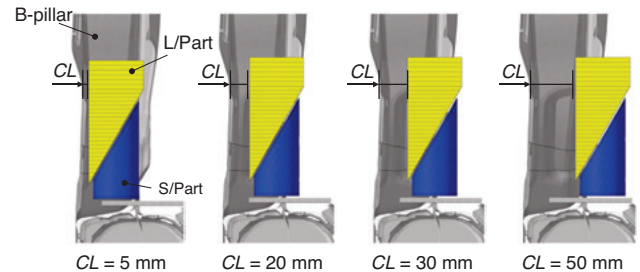


Fig. 12 Schematic diagram of different clearances

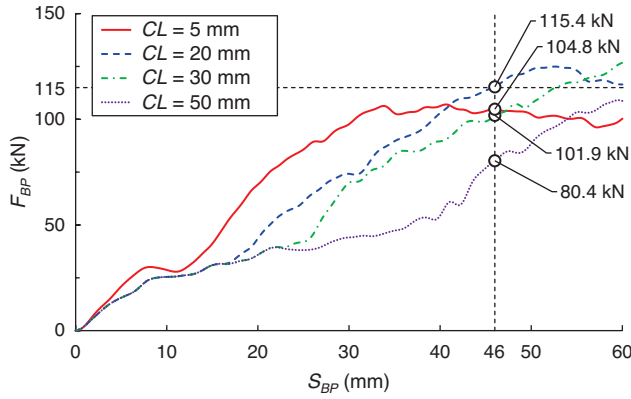


Fig. 13 Load displacement curves at different clearances

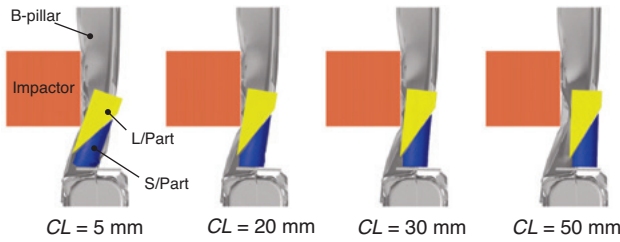


Fig. 14 Cross section of B-pillar and load transfer mechanism at $S_{BP} = 46$ mm

mm. As the clearance increases, the load path to the load transfer mechanism is delayed, and the load rising effect on the stroke of the B-pillar load will be reduced. However, if there is too small clearance, contact with the load transfer mechanism occurs earlier, and the S/Part buckles early and is unable to sustain the force to support the B-pillar.

From the above results, the clearance condition that produces the highest F_{BP} at the timing of the target amount of deformation is 20 mm.

3.4. S/Part Thickness

Taking the slope angle θ of the load transfer mechanism and the clearance determined in preceding sections as fixed values, when the input position Δz from the barrier changes, the F_{z-SP} needed to generate the necessary F_{y-LP} also changes, as shown by Eq. (5). The necessary S/Part thickness was therefore examined under the respective conditions of the New IIHS MDB and former IIHS MDB, which have different barrier collision heights.

The lower edge of the barrier in the New IIHS MDB is positioned 25 mm lower than that in the former IIHS MDB, as shown in Fig. 15. According to Eq. (5), $\Delta y/\Delta z = 0.49$ for the New IIHS MDB and 0.33 for the former IIHS MDB. Therefore, the S/Part load needed to generate F_{y-LP} equivalent to that of the New IIHS MDB under the former IIHS MDB conditions can be estimated as $0.49/0.33 \approx 1.5$

Table 3 Parameters used for investigation of impact point and S/Part thickness

Parameters	Former	New
θ	60 deg	
CL	20 mm	
$\Delta y/\Delta z$	0.33	0.49
S/Part thickness t	0.5 mm, 1.0 mm, 1.5 mm, 2.0 mm, 2.5 mm, 3.0 mm, 3.5 mm, 4.0 mm	0.5 mm, 1.0 mm, 1.5 mm, 2.0 mm, 2.5 mm

times the former value, or 167 kN.

Here, the reasonableness of the F_{z-SP} derived by theoretical calculation was confirmed by simulation using Model 3 with $CL = 20$ mm, as determined in Section 3.3. A total of 13 cases with S/Part thickness t as the parameter, as shown in Table 3, were evaluated with respect to the New IIHS MDB and former IIHS MDB barrier positions.

Figure 16 shows the relationship between F_{BP} and F_{z-SP} at $S_{BP} = 46$ mm. The black dotted line represents the F_{BP} target value, and the blue and red dotted lines respectively represent the F_{z-SP} target values derived by theoretical calculation at the New IIHS MDB and former IIHS MDB collision positions. The value of F_{z-SP} when the F_{BP} target

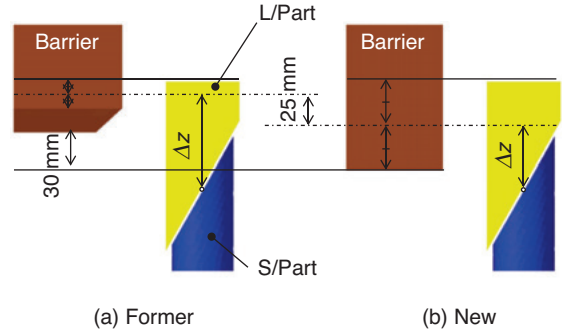


Fig. 15 Schematic diagram of relationship between positions of former and new IIHS MDB

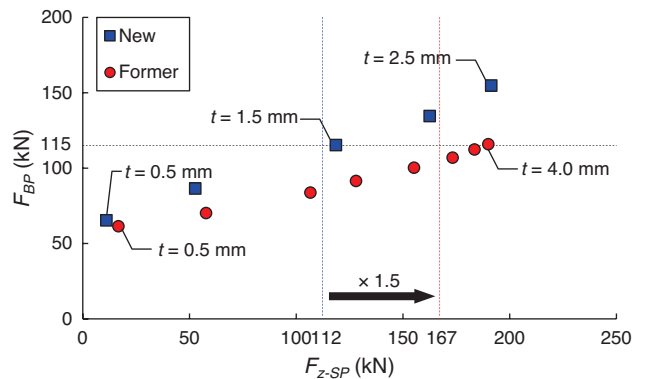


Fig. 16 Relationship between F_{BP} and F_{z-SP} at $S_{BP} = 46$ mm

value was reached was 119 kN ($t = 1.5$ mm) for the New IIHS MDB and 190 kN ($t = 4.0$ mm) for the former IIHS MDB, which roughly matched the theoretical calculation values.

As a result, the condition for achieving the B-pillar target load and amount of deformation is $t = 1.5$ mm or more for the New IIHS MDB and $t = 4.0$ mm or more for the former IIHS MDB.

4. Drop Test Results and Discussion

4.1. Prototyping of Load Transfer Mechanism

A prototype of the load transfer mechanism described in Chapter 3 was fabricated in order to prove the reasonableness of the examination results thus far. Mass-produced C category vehicle parts were used for the B-pillar and surrounding parts. The load transfer mechanism size was set to 150 mm long $\times$ 60 mm wide $\times$ 180 mm high to match the size of the B-pillar opening, as shown in Fig. 17(a) and (b). The L/Part had a lattice block cross-section shape, as shown in Fig. 17(c), and was strong enough to not deform in the drop test. The angle of the junction between the L/Part and the S/Part was set to 60 deg, as obtained in Section 3.2., and the clearance between the B-pillar and the load transfer mechanism was set to 20 mm, as per Section 3.3. The prototype S/Parts used $\phi 50$ general steel pipe made of STKM13C material with strength equivalent to the 590 MPa-grade high-tensile steel, and were fabricated in the thickness range of 0.6 to 2.6 mm generally used in vehicle body parts, as examined in Section 3.4. The fixed base plate was shaped with a sloped surface and a groove for placement on the upper part of the side sill. The mechanism was installed by fastening with bolts to the upper surface of the side sill via the fixed base plate.

4.2. Drop Test Method

The combined performance of the B-pillar and load transfer mechanism to generate a high load with a small amount of deformation as designed was verified with drop

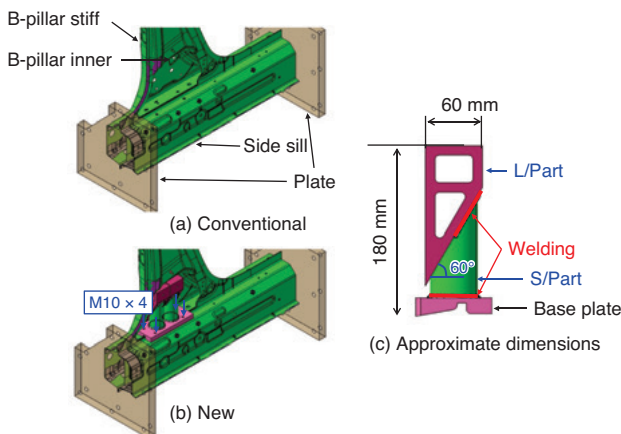
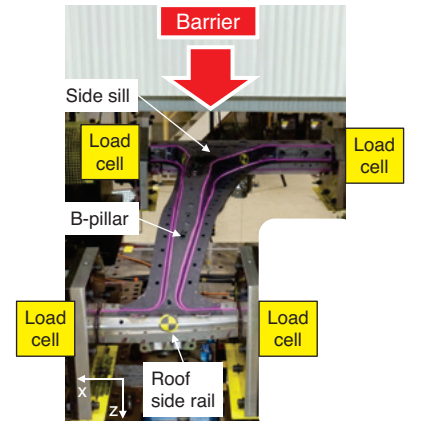


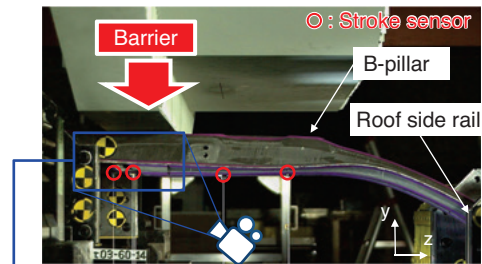
Fig. 17 Overview of load transfer mechanism

tests. Testing used the drop weight test machine at Nippon Steel Corporation's Hasaki Research and Development Center, which is capable of measuring the load and amount of deformation and can also record the deformation with images⁽⁶⁾. The barrier was attached to a weight and allowed to fall freely, and a high-speed camera was used to record the deformation of the test piece and the barrier.

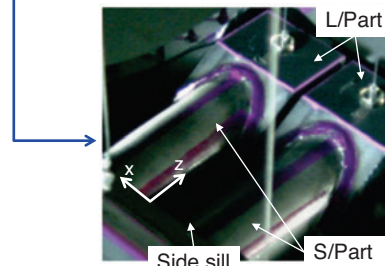
Figure 18(a) and (b) show how the test piece was set up. The test piece is composed of the B-pillar, side sill, roof side rail, and square end plates. The end plates were welded to both ends of the side sill and roof side rail, and were fixed to base plates via load cells to exclude the influence of rotation of the boundary parts. The test piece load was measured by load cells on the barrier side. Stroke sensors were attached in the locations indicated by the red circles in Fig. 18(b) and the amount of test piece deformation was measured. The deformation status of the load transfer mechanism was recorded from the video angle shown in Fig. 18(c).



(a) Test configuration diagram



(b) Moment of collision



(c) Video angle of L/Part and S/Part

Fig. 18 Set up for drop test

Table 4 Drop test conditions

	Test 01	Test 02	Test 03
Barrier	New IHS MDB		
Energy	24 kJ		
θ	60 deg		
CL	20 mm		
S/Part material	-	STKM13C	STKM13C
S/Part thickness	-	0.6 mm	1.4 mm

4.3. Drop Test Conditions

The drop test was performed with the three test pieces, Test 01 to Test 03, shown in Table 4. Test 01 with the conventional structure and Test 02 and Test 03 equipped with the load transfer mechanism were compared to confirm whether a high load can be generated within the target amount of deformation. In addition, Test 02 and Test 03 used a different S/Part thickness to verify that the B-pillar load F_{y-BP} can be changed. The energy of the B-pillar and the barrier when Test 03 reaches the target amount of deformation was calculated by simulation, and the input energy was set to 24 kJ.

4.4. Drop Test Results

Figure 19 shows the relationship between the load and amount of deformation of the B-pillar and the barrier. The red, green, and blue lines respectively indicate the results for Test 01, 02, and 03. The graph covers the range up to where the B-pillar reaches the target amount of deformation. The blue shaded area represents the B-pillar target load and amount of deformation, and the waveform inflection points are indicated by arrows. In Test 01 with the conventional structure, the inflection point appeared at an amount of deformation of 6 mm. The increase in load slowed following the inflection point, and the final F_{y-BP} at the target amount of deformation remained at 58

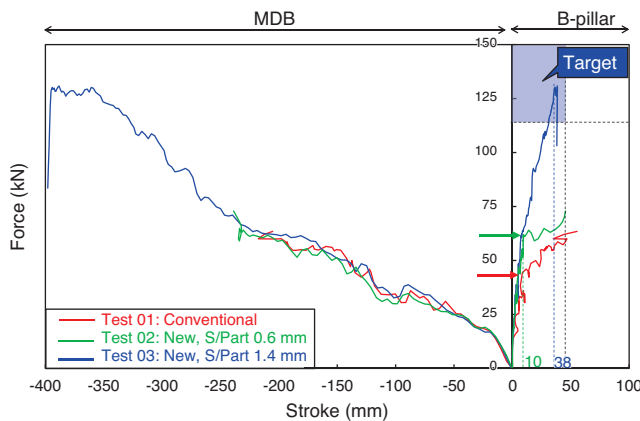


Fig. 19 Comparison of Force-Stroke curve with conventional and new structure

kN. In Test 02, the inflection point appeared at an amount of deformation of 10 mm, with F_{y-BP} reaching 60 kN at that time. There was small increase in load following the inflection point, indicating that the B-pillar target could not be reached with the strength of the 0.6-mm-thick S/Part. In Test 03, there was no inflection point, and the highest load of 130 kN was reached before arriving at the target amount of deformation. The load gradient at this time was $K_{BP} = 3.6$ kN/mm and the B-pillar target performance was achieved.

Figure 20 shows the course of deformation of the load transfer mechanism. In Test 02, S/Part buckling began from 60 ms, when the load reached 65 kN, and the buckling amount increased at 90 ms. In Test 03, only slight signs of buckling appeared around 90 ms, when the load reached 120 kN.

4.5. Consideration of Range of Load Increase by Load Transfer Mechanism

It was predicted from Section 3.3. that as the S/Part buckling increases, the axial load drops and the load supporting the B-pillar decreases. Therefore, focus was placed on the relationship between the S/Part buckling timing and the inflection point, and the effective range over which the load can be increased by the load transfer mechanism was considered.

In Test 02, the S/Part deformation and inflection point timings coincide, and it is thought that the range of deformation that increases the load is up to 10 mm. In Test 03, clear buckling does not occur in the S/Part, so there is no inflection point. That is to say, it can be inferred that the load was continuously generated and the S/Part continued to support the B-pillar up to the highest amount of deformation of 38 mm.

It was concluded from this that the range of deformation within which the load transfer mechanism increases the load is up to the bifurcation point for Test 02 and up to the highest amount of deformation for Test 03. This is shown in Fig. 21(a). In addition, Fig. 21(b) compares the amount of

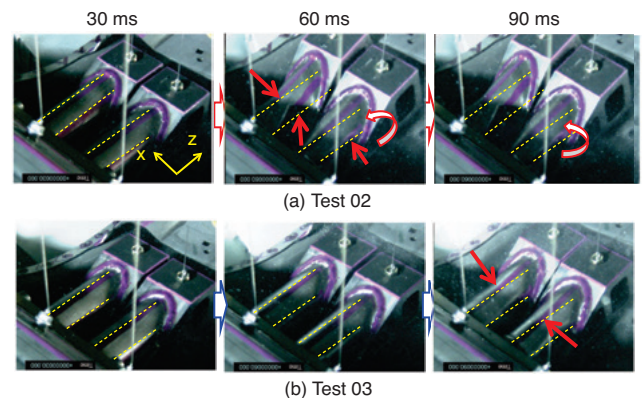


Fig. 20 Comparison of deformation modes of L/Part and S/Part

increase in the load at the respective timings of the amounts of deformation shown in Fig. 21(a). This increase was 20 kN for Test 02 and approximately 87 kN for Test 03.

The above indicates that a high load can be continuously generated by setting an S/Part thickness at which the S/Part can continuously generate an axial load without buckling.

4.6. Consideration of Amount of Energy Absorption and Effect to Reduce the Amount of Deformation

Figure 22 shows the amount of energy absorption at the timing of the target amount of deformation. The amount of energy absorbed by the barrier increased by 2.5 times to 20 kJ for Test 03 compared to 8 kJ for Test 01. In addition, Test 03 absorbed the entire input energy of 24 kJ, indicated by the black dotted line, but Test 02 absorbed 11 kJ less and Test 01 absorbed 14 kJ less. This deficit energy amount is approximately equal to the difference in the amount absorbed by the barrier.

Here, the estimated Force-Stroke at which the load increases along the extension of the Test 01 waveform to reach the same amount of energy absorption as Test 03 is shown in the red shaded areas in Fig. 23. The B-pillar load

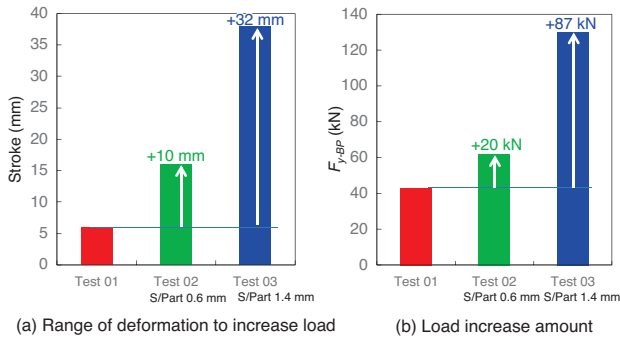


Fig. 21 Comparison of conventional structure and new structure effects

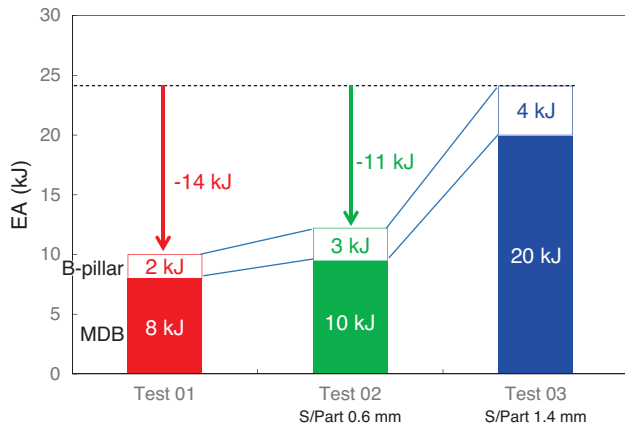


Fig. 22 Comparison of energy absorption with conventional and new structure

is expected to increase by up to 80 kN and the amount of deformation by up to approximately 180 mm. Comparison of the amount of B-pillar deformation using the drop test value for Test 03 and this estimated value for Test 01 indicates that installation of the load transfer mechanism can be expected to reduce the amount of B-pillar deformation by approximately 80%.

From the above, use of the load transfer mechanism to increase the B-pillar load enables increasing the amount of energy absorbed by the barrier and reducing the amount of B-pillar deformation as planned.

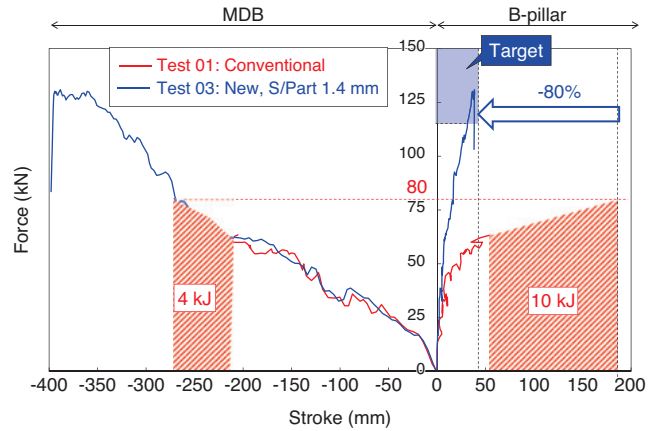


Fig. 23 Comparison of energy absorption with conventional and new structure

5. Conclusion

A concept that leads to further enhancement of vehicle body performance in side collisions was devised with a focus on the IIHS collision test conditions. A prototype model based on that principle was fabricated, and the ability to achieve the target performance was validated by drop tests. These results are summarized below.

- (1) The new concept was to support the lateral input from the barrier as an axial load in the downward direction in the vehicle body and create a load path to the side sill.
- (2) A two-part load transfer mechanism composed of an L/Part and an S/Part was added in the cross section in the lower part of the B-pillar.
- (3) The slope angle of the S/Part and L/Part, the clearance with the B-pillar, and the S/Part thickness were defined as parameters.
- (4) It was proved that in a prototype with the load transfer mechanism installed in the B-pillar, the load was doubled and it was estimated that the amount of deformation could be reduced to approximately one-fifth that of the conventional structure.

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