

# Development of Front Pillar for Visibility Enhancement

Yoshiharu HASEGAWA\*

Hiroshi FUJITA\*

Takeharu ENDO\*

Masaaki FUJIMOTO\*

Junya TANABE\*\*

Masaki YOSHIDA\*\*\*

## ABSTRACT

In order to reduce blind spots during driving, a front pillar has been developed that enhances the driver's diagonal forward visibility.

Physiological and psychological studies conducted internally indicated the existence of a more favorable front pillar width that enables essentially a continuous field of vision between the front window and the side windows, and which would not induce a sense of visual incongruity to the driver.

A new pillar structure was developed in order to realize a target pillar width, and at the same time maintain vehicle performance. The new structure uses ultra-high-strength hydroformed steel tubes as the main framework. Indirect spot welding and arc laser hybrid welding are used to mount the new structure in the body framework.

## 1. Introduction

It is said that approximately 90% of the external information that a driver needs to drive a car is taken in visually. It is therefore clear that visibility performance is an important element in controlling a vehicle. A blind spot produced by the front pillar is one factor that impedes forward visibility during normal driving. The reduction of this blind spot could be expected to be effective in enhancing visibility.

The reduction of the size of the blind spot to less than the human interocular distance would reduce it to zero, and the development of a pillar structure to realize this has been reported<sup>(1)</sup>. The research discussed in this paper newly focused on understanding visibility performance from a dynamic perspective, and determined the physiological and psychological effect of the size of physical blind spots on the percipient when moving objects are perceived visually. In addition, the project determined a more favorable pillar width, and developed a body structure and production technology that would enable a pillar of this width to be used without adversely affecting the rigidity, strength and performance features of automobiles.

## 2. Study on Pillar Visibility from a Dynamic Perspective and Establishment of Appropriate Pillar Width

### 2.1. Concept of Visibility Involving Front Pillar

The front pillar sometimes acts as an impediment when a driver is attempting to follow an object with their eyes.

However, during driving, visual information is in constant motion, and it can be conjectured that if the thickness of the pillar was decreased to a specific level or below, the exterior scene flowing between the front window and side window would be experienced by the driver as seamless. That is, even when, in physical terms, the visual field was discontinuous, the driver would be continuously aware of objects of visual perception without the pillar acting as an impediment. Studying pillar width from this perspective would enable a more favorable pillar width for visibility performance to be determined.

### 2.2. Establishment of Driving Scenarios

In order to study pillar visibility, it was first necessary to establish driving scenarios. Turning left or right at an intersection and cornering can be projected as typical scenarios in which the front pillar affects visibility.

\* Automobile R&D Center

\*\* Honda Engineering Co., Ltd.

\*\*\* MARUJUN CO., LTD.

Observation of drivers in these scenarios shows that when turning at an intersection, there is rapid and extensive movement of the driver's line of sight around the front pillar as they attempt to visually distinguish a variety of obstacles. In addition, as the vehicle turns extensively, the front pillar moves across the object of visual perception in a short period of time.

The movement of the driver's line of sight in relation to the pillar is therefore rapid, and the impediment of visibility represented by the pillar is instantaneous.

By contrast, during cornering, the driver's line of sight is stable in order to focus on a point of the curve, and the objects of visual perception are in the distance. Because of this, the movement of the line of sight is slow, and the impediment of visibility represented by the front pillar is continuous.

Studying the field of vision during cornering and conducting a performance evaluation would therefore represent a valid method of establishing target values. Curves are constructed with various curvature radii, and are designed based on the magnitude of the radius and the road structure ordinance<sup>(2)</sup> that stipulates vehicle speed in relation to the curvature radius.

Test results showed that during normal driving, the driver's line of sight is focused on a point 3 seconds ahead in the direction of motion, to enable prediction of the situation in front of the vehicle. Superimposition of the driver's line of sight over curves constructed on the basis of road structure ordinances indicated that an R30 curve represented the most severe condition for drivers, with the front pillar sitting in the line of sight and becoming an impediment. Studies were therefore conducted on the basis of a scenario of a vehicle traveling around an R30 curve at 30 km/h, the speed established for a curve of this radius by road structure ordinances, while the driver watched a forward obstacle. Figure 1 shows the driver's line of sight when turning different curves.

### 2.3. Method of Study

Visual tracking tests using a test stand were conducted as a method of studying driver's continuous visibility when turning.

First, test equipment was prepared consisting of a test stand modeled on a real vehicle on which the width of the front pillars could be changed, with a large screen in front. Figure 2 shows the test equipment. A point modeling the movement of an obstacle at a point 3 seconds ahead of a vehicle traveling around a simulated R30 curve at 30km/h was projected on the screen. Test subjects sat in the test stand and followed the point projected on the screen with their eyes, while the movement of their line of sight at different front pillar widths was monitored using an eye mark recorder. Test results for different front pillar widths were compared.

Next, a subjective evaluation was conducted using the same equipment. An image of front view when cornering

an R30 curve at 30 km/h was projected on the screen, and test subjects evaluated the feeling of the visual image over a pillar using a point system. The rated evaluation items for different pillar widths are the level of visibility and presence or absence of odd feelings.

## 2.4. Test Results

### 2.4.1. Ocular tracking characteristics

Figure 3(a) shows an example of results of measurements of the changes of the test subjects' line of sight when they were demonstrating smooth pursuit eye movement following the point on the screen, as measured using an eye mark recorder.

The vertical axis shows the various pillar widths, while the horizontal axis shows horizontal location where the object of visual perception was moving on the screen. Circles show the positions at which the test subjects' eye movements stopped; the size of the circles indicates the length of time for which eye movements were stopped. The shaded part shows an area in which the pillar represented a visual obstacle. These results indicate that the subjects' eye movements stopped even outside the area in which the pillar represented a visual obstacle. That is, even when the lines of sight of the test subjects appeared

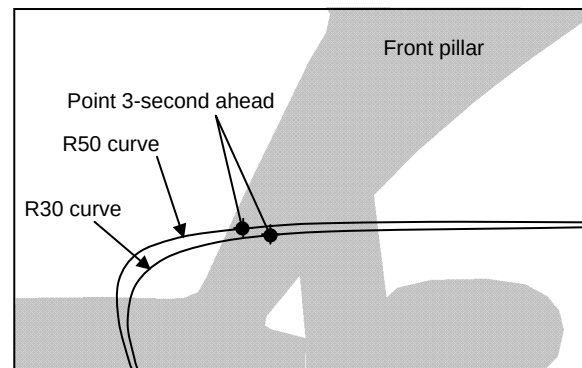


Fig. 1 Driver's visual field on driver side curve

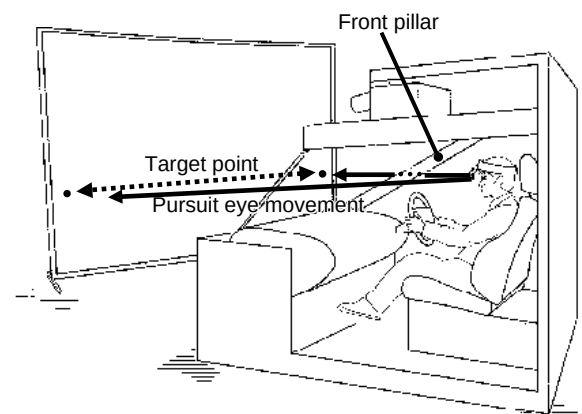


Fig. 2 Test equipment

to be moving smoothly following the point in the absence of a visual obstacle, the data showed that slight stops in eye movement occurred as the point was being followed. This is believed to be a physiological phenomenon of human visual perception that occurs during smooth pursuit eye movement. It was judged that when a visual obstacle corresponding to a pillar is part of the visual field, when the point being tracked visually crosses the pillar, the line of sight shifts to the point at which the point is expected to reappear, and the eyes stop, waiting for the reappearance of the point. The project therefore focused on the change in the length of time for which the eyes stopped moving in the area in which the pillar represented a visual obstruction as the width of the pillar was increased.

First, the length of time for which the eyes stopped moving outside the area in which the pillar represented an obstruction was studied, after which lengths of time for which the eyes stopped that were longer than these lengths of time were isolated from the data. Figure 3(b) shows

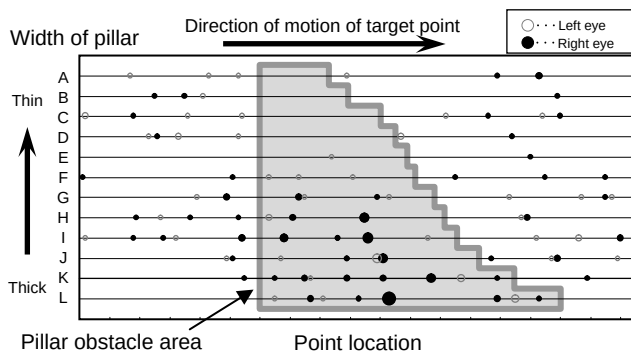


Fig. 3 (a) Points at which eye movement stops

points, isolated from the data in Fig. 3(a), at which the eyes stop for an extended period.

The results showed that the points at which the length of time for which the eyes stopped was extended almost all occurred within the area in which the pillar represented an obstacle, and in addition, that when the pillar width was narrowed beyond a specific width, no points at which the eyes stopped moving remained. Based on this, it was judged that there is no longer any effect from the pillar as a visual obstacle, and that pillars narrower than a specific width would enable an object of visual perception to be tracked continuously, without breaks.

#### 2.4.2. Subjective evaluation

Test subjects' evaluation of their feeling of the visual image became better as the pillar became narrower, but evaluations of the feeling of visibility peaked at specific pillar widths, and the points given declined as the pillar became narrower than these specific widths. Figure 4 shows the subjective characteristics. Subjects commented

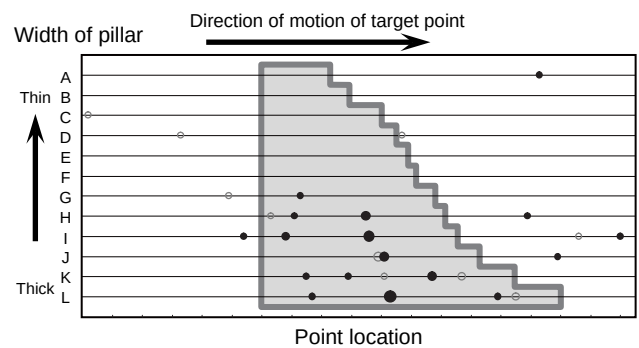


Fig. 3 (b) Points at which eye movement stops

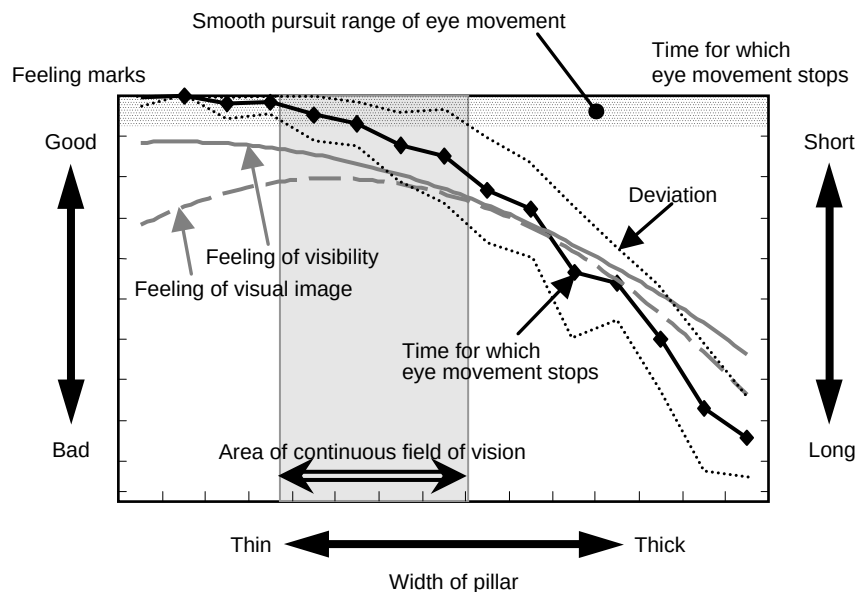


Fig. 4 Eye movement characteristic and subjective rating

that when the pillar became too thin, they felt a sense of oddness, and that the sense of the pillar appearing and disappearing made them uneasy. When a subject watches a distant screen when the width of the pillar is less than the width of the eyes, either the left or right eye can see the image on the screen, and in theoretical terms the blind spot is zero. It is thought that under these conditions, one eye can see the pillar, while the other eye cannot, producing a state of binocular rivalry<sup>(3)</sup>, which occurs when the eyes present differing visual information. From these results, it may be concluded that there is a more favorable pillar width.

### 2.5. Setting Pillar Width Targets

The study of ocular tracking characteristics, a human physiological phenomenon, and subjective characteristics, a human psychological phenomenon, showed that there was a more favorable pillar width at which the eye was able to track an object of visual perception continuously, and at which there was little sense of incongruity in the field of vision. Figure 4 shows ocular tracking characteristics and subjective evaluations. The range for ocular tracking characteristics includes variations in the periods of time for which the movement of the eyes have stopped within the area of the pillar. The time for which movement is stopped decreases as the width of the pillar decreases, until it becomes less than the length of time that the eyes stop movement during smooth pursuit movement. If the subjective characteristic discussed above is superimposed over this, it can be seen that the length of time that the eyes stop for the pillar width, close to the peak of the subjective characteristic, is also less than the length of time that the eyes stop during smooth pursuit movement. From these results, this pillar width was adopted in this project as the target width in order to realize continuous visibility.

## 3. Basic Structure of Front Pillar for Visibility Enhancement

### 3.1. Analysis of Main Factors in Pillar Width in Conventional Structure

The target established in the preceding section was considerably narrower than the conventional front pillar and could not be achieved using the conventional pillar structure. Therefore, it was judged that it would be necessary to consider a new structure. First, the conventional structure was reexamined from the perspective of reducing the width of the pillar. The cross-section of the normal orientation of a conventional front pillar shown in Fig. 5 indicates that the width of the pillar in relation to the direction of the line of sight is determined by three elements: the windshield adhesive area, the door sash area, and the closed section area between them. Reducing the width of these elements would reduce the width of the front pillar. However, the

windshield adhesive area and the door sash itself are basic structural sections that are necessary to the existence of surrounding parts, and they cannot be removed. In addition, they are parts that are already minimized to some extent. Given this, it was clear that the key to narrowing the front pillar was moving the windshield adhesive area and the door sash closer together in the remaining area.

### 3.2. Method of Narrowing Front Pillar Cross-section

Based on the results of the study conducted in the preceding section, the following two methods were judged as being effective in reducing the width of the front pillar: First, ultra-high strength tubes would be used to reduce the width of the closed section area, while maintaining the achievement of a high level of strength.

In addition, as a method of moving the door sash and the windshield adhesive area closer together, the flange that represents one element determining the width of the front pillar would be removed, and the windshield adhesive area would be situated directly on top of the closed section area. Using these methods, the goal of the project was to balance the achievement of the target reduction in the sectional width with the achievement of strength and rigidity.

### 3.3. Details of Formation of Section Using Hydroformed Tubes

Figure 6 shows an outline of the front pillar section proposed above, in which the windshield adhesive area is moved directly on top of the closed section area and the closed section area is formed using hydroformed tubes. The section is discussed in detail below.

First, the pillar width in the direction of the line of sight was reduced by removing the flange from the windshield adhesive area, and connecting the outer panel directly to the closed section area. Indirect spot welding,

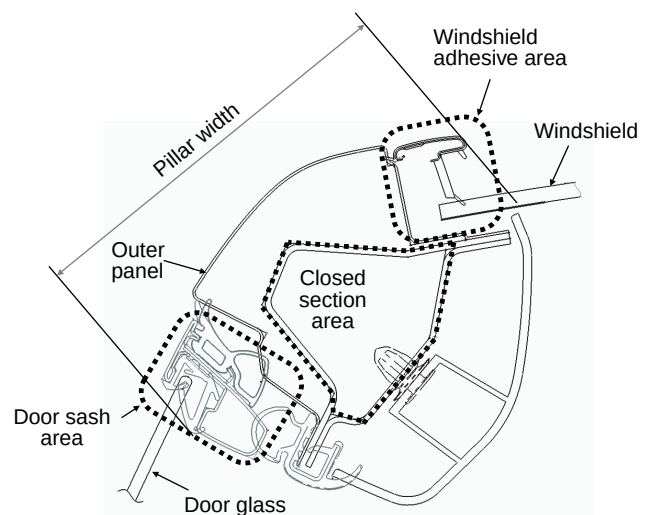


Fig. 5 Conventional section of front pillar

a single-sided access welding technique, was used to connect the two. Indirect spot welding will be discussed in detail later in this paper. Reinforcing structures were employed to enhance the performance of the section, and arc laser hybrid welding was used to connect these to the closed section area. This is also a single-sided access welding technique, and will be discussed in more detail later in the paper. All the components to be mounted in the cabin were fitted in an area in which they would have no effect on the width of the direction of the line of sight. Settings were also reexamined to further minimize the door sash and the windshield adhesive area. The hydroformed tube was used to form the basic section as a quadrangular structure. A simple sectional shape is maintained around the entire general area of the pillar by allocating each of the different functions – the outer connection face, the earth face for the single-sided spot weld, the mounting face for the mounted parts, and the seam welded section of the tube – to different sides of the quadrangle. This helps prevent sudden changes in the section, and increases formability while maintaining impact strength.

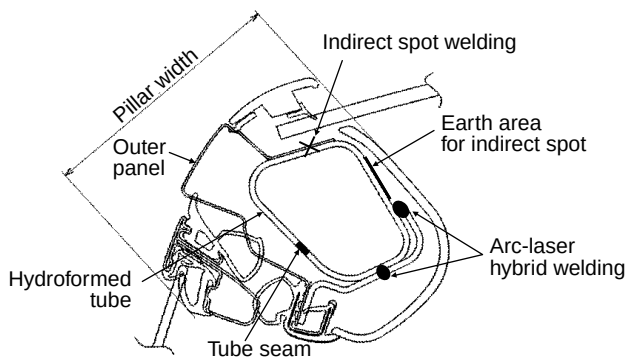


Fig. 6 Proposed section for increased visibility

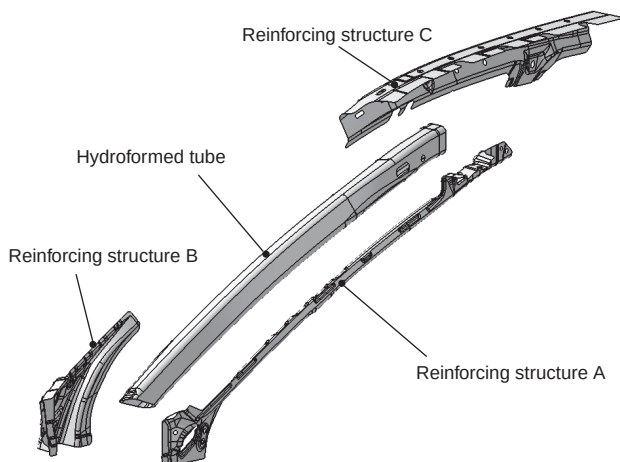


Fig. 7 Structure of front pillar using hydroformed tube

### 3.4. Structure of Front Pillar Using Hydroformed Tubes

Figure 7 shows a schematic of the structural parts, which will be discussed in detail in this section. The hydroformed tube has a straight form.

Given that the reduction of the cross-sectional area would reduce the load capacity of the hydroformed tubes and thus increase the degree of deformation of the pillar in a front collision, this structure helps ensure that the input during a collision is received by the section as much as possible in an axial direction rather than as bending force in order to reduce the deformation of the pillar. It also results in the simplification of the shape and a consequent increase in productivity. The face of the pillar inside the vehicle body is subject to compressive stress due to bending in a front collision. To help ensure strength during a front collision, reinforcing structure A is attached to the entire inner face of the pillar as an efficient means of increasing strength. To help ensure effective transmission of input during a front collision in the axial direction of the hydroformed tube and produce a sectional area equivalent to that of the conventional section at the same time, reinforcing structures B and C are attached to the surrounding body framework parts, resulting in the achievement of an equivalent level of strength and rigidity in the body as a whole as a conventional model, thus satisfying body performance specifications. The ability to easily optimize structural parts, the materials from which they are formed, and their thickness, in order to reinforce the uniform (hydroformed) closed section area parts in the appropriate places with the appropriate structures can be pointed to as one of the merits of hydroformed structures. Highly specialized single-sided access welding techniques were used to connect the hydroformed parts and the reinforcing structures. The parts in Fig. 7 are used to form the framework of the pillar, and single-sided access welding employing arc laser hybrid welding was used for connections within the complete front pillar, minimizing the need for special equipment and procedures.

In addition, in achieving the connection between the completed front pillar and the surrounding body structural parts, mating flanges were used with reinforcing structures to enable direct spot welding to be employed, except where indirect spot welding to the outer panel was employed.

The use of equipment that enables procedures to be conducted using standard facilities, and the accuracy that can be guaranteed using conventional management techniques, makes this a structure that can be considered for mass production.

## 4. Formation Techniques

### 4.1. Hydroformation

#### 4.1.1. 980 MPa-class steel tubes

To form the structures described in Sections 3.2 to 3.4, hydroformable 980 MPa steel tubes were developed. The

basic concepts underlying this development will be discussed in this section.

Dual phase steel was selected for the steel sheet, to help ensure that the tube remained formable following the machining history applied in the production process, i.e., to help ensure surface cracks are prevented from forming in the corner radius section and produce stretchability during hydroformation, in addition to producing a weldable, corrosion-resistant, and more available hydroformed tube.

In setting the characteristics of the tubes, values were chosen that enabled the achievement of a balance between strength and formability. The lower limit for strength was determined by the strength of the part. It was necessary to set the upper limit for strength with consideration of the considerable effect of the bending resistance of the material on stretchability during hydroformation. Figure 8 shows the relationship between deformation resistance and stretchability. As the deformation resistance of the material increases, the corner radius that can be formed also increases. Therefore, the strength range was set between the upper limit strength at which the corner radius needed for the pillar could be formed, and the lower limit strength needed to help ensure the strength of the part.

#### 4.1.2. Hydroformation

Because the deformation resistance of the material was high, high pressures had to be applied during hydroformation.

Preforming and pre-bending procedures are normally conducted prior to hydroformation, but in this project, modifying the press direction in the clamping process of hydroformation and performing section squeezing at the process enabled the preforming procedure to be done away with. The pre-bending procedure uses a press bending process that does not employ standard bending equipment such as rotary draw bending machines, thus reducing the initial investment for equipment.

Modifications have also been made to the hydropiercing procedure used to cut holes in the material during hydroformation, with the main purpose of enabling

accurate holes to be cut to function as position references in the following procedures. Reducing press droop around hole edges and handling scrap material represent issues in the hydropiercing procedure.

If the droop around the hole edges is large, the holes will not function as position references. The relationship between variables such as hydro pressure and hole diameter and the degree of drooping was therefore studied, and the hydropiercing conditions were optimized to enable the holes to function as position references. As an example of the results of these studies, Fig. 9 shows the relationship between hydro pressure and degree of drooping.

It was predicted that scrap material from the piercing might remain in the front pillar cross-section or settle in the die, thus reducing production efficiency and potentially resulting in production mishaps and the like. In order to assist in avoiding these issues, a method was developed in which the hole is not completely punched through, leaving the scrap attached to the piece being produced (Fig. 10). After the hole has been used as a position reference in later procedures, a laser is used to cut a complete circle around the hole (the dotted line in Fig. 10), removing the scrap material from the finished product.

In addition to enabling the pillar to be narrowed, as discussed in Section 3.2., hydroformation of the part in this manner has a variety of other benefits.

The first of these is that it enables a sufficient degree of freedom in the design of the front pillar, because it

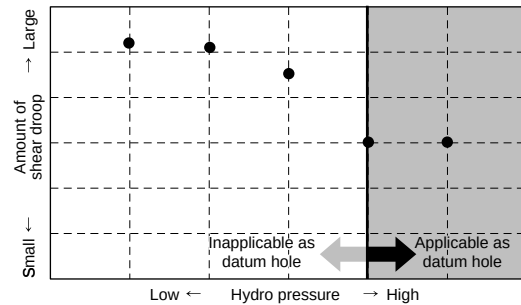


Fig. 9 Relation between hydro pressure and amount of shear droop

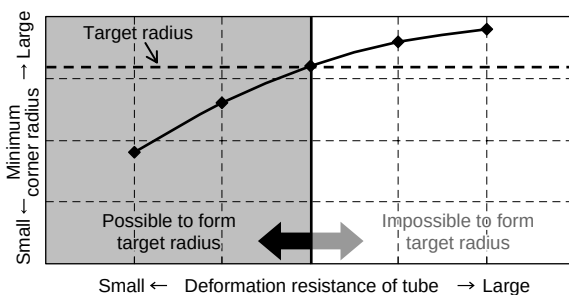


Fig. 8 Relation between deformation resistance of tube and corner radius

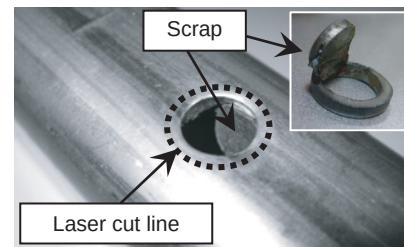


Fig. 10 Shape of hydro pierce

enables continuous variation of the sectional shape. Figure 11 shows representative sectional shapes of the front pillar developed in this project.

In addition, the rigidity of the formed component, resulting from the use of the closed section, helps to ensure good form stability with minimal spring-back. Figure 12 shows the points at which dimensional accuracy in the new front pillar was measured, and Fig. 13 shows the results of measurements of dimensional accuracy for the prototype in the initial prototype stage. These results indicate that a high level of dimensional accuracy was obtained from the initial prototype stage.

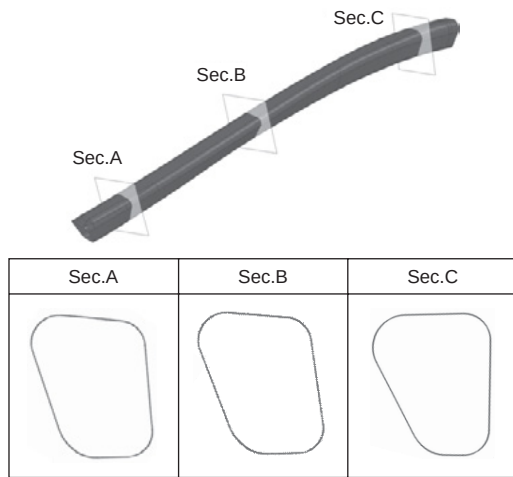


Fig. 11 Cross - section of hydroformed front pillar

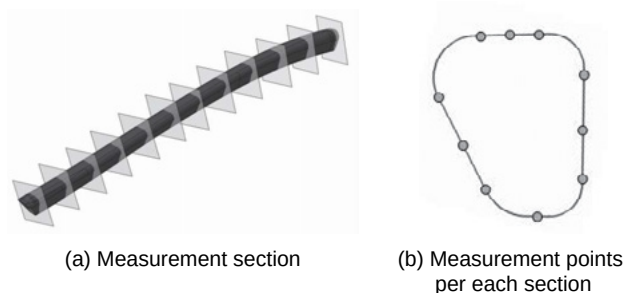


Fig. 12 Measurement positions of dimensional accuracy

| Dimensional accuracy<br>(Difference from<br>target dimension) | Frequency |
|---------------------------------------------------------------|-----------|
| 0.0-0.5 mm                                                    | 80%       |
| 0.6-1.0 mm                                                    | 11%       |
| 1.1-1.5 mm                                                    | 6%        |
| 1.6-2.0 mm                                                    | 3%        |

Fig. 13 Dimensional accuracy of front pillar at early trial stage

The achievement of a good level of form stability also increases the ease of die quality maturation. In the new front pillar, dimensional accuracy has been increased in the early stages of manufacture, chiefly by adjusting the position of the die cross-section, and this can be indicated as also having the advantage of reducing the time for die quality maturation.

## 4.2. Welding

Because the hydroformed part is a closed section structure, direct spot welding [Fig. 14(a)], the standard technique used on mass production lines, cannot be used. Instead, a welding technology that can form a connection with single-sided access is needed.

In selecting the welding techniques to be used in the development of the new pillar, the specifications of the materials to be welded and the structure of the mass production line were considered. As a result, indirect spot welding [Fig. 14(b)], which can be incorporated into the existing internal mass production line, was chosen as the welding technique for hydroformed part and thin sheets (the outer panels), and arc laser hybrid welding was applied for welding thick parts (reinforcing structures A-C in Fig. 7) to achieve desired part performance (strength and joint shape).

### 4.2.1. Indirect spot welding

Indirect spot welding was expected to display high productivity equivalent to that of the existing mass production method, but the fact that the current pathways are longer than in the case of direct spot welding promotes shunt current, and it is challenging to concentrate the current in the area being welded. This makes the determination of a method of controlling shunt current an issue in obtaining a stable welding quality. The following modifications were made to enable indirect spot welding to be conducted at the same level of tooling as the current mass production system:

- Optimization of welding conditions
- Optimization of earth position for control of shunt current
- Optimization of the order of the welds to enable control of shunt current

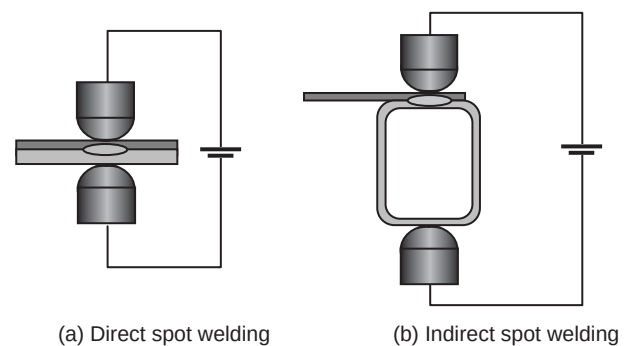


Fig. 14 Schematic design of spot welding

These modifications enabled the achievement of a stable weld quality. In addition, they enabled the maximum use to be made of existing mass production facilities, enabling facilities to be shared without the need for new dedicated welding procedures.

#### 4.2.2. Arc laser hybrid welding

Development was conducted to enable the use of arc laser hybrid welding to produce filler weld joints and lap joints [Figs. 15(a) and (b) respectively], depending on the type of joint that was necessary between the components.

Because the laser can also be used for filler weld joints, a deeper welding bead can be achieved from the initial stages of welding compared to conventional arc welding. Welding can be conducted at three times the conventional speed, and inaccuracies due to heat deformation of the product being welded can be controlled. In addition, the ease of execution of the technique produces a stable weld quality, even if there is a gap between the materials being welded.

As Fig. 16 shows, to produce a lap joint, the laser can be used to cut a keyhole (a deep wedge-shaped groove

for the welding bead) at the same time the hole is being widened and filled using arc welding. As a result, undercutting, which represents an issue when laser welding is used in isolation, can be controlled, even when there is a gap between the materials being welded. In addition, the technique produces a broader welding area than is the case when laser welding is employed in isolation, and helps to ensure stable welding quality. The use of the technique in mass production was focused on and a variety of factors that can result in variations in production (floating of the components, trimline deviations and the like) were considered, enabling welding conditions that would result in stable production to be determined.

These innovations have enabled the application of arc laser hybrid welding, which combines the strengths of arc welding and laser welding, in the manufacture of the newly developed pillar, and have established the conditions for stable production.

## 5. Conclusion

A more favorable front pillar width for the enhancement of visibility while driving was determined on the basis of ocular tracking characteristics, a physiological phenomenon, and subjective visual evaluation, a psychological phenomenon. The project produced the following outcomes:

- (1) If the width of the front pillar is reduced to a specific width, the pillar will not create any blind spot, and the driver's eyes will essentially be able to continuously follow an object of visual perception.
- (2) The more the width of the pillar was reduced, the better the test subjects' evaluation of their sense of the visual image became; however, if the pillar became too narrow, subjects experienced visual incongruities, indicating the existence of a more favorable pillar width.

That pillar width was narrower than the conventional width; in order to enable its realization, hydroformation and vehicle mounting techniques were developed, with the following results:

- (3) The properties of the steel tubes were set based on considerations of the strength and formability of the part, allowing stable production of hydroformed parts under fixed forming conditions.
- (4) Indirect spot welding and arc laser hybrid welding enabled the hydroformed pillar framework to be mounted in the vehicle, resulting in a sectional structure that reduced the width of the pillar.

The project discussed in this paper was able to determine methods of addressing the antagonism between the reduction of front pillar width for the achievement of a continuous field of vision and the ability to help ensure vehicle performance. The application of the front pillar for enhancing visibility, developed in this project, was enabled by the outstanding fit between the design concept of the new framework structure and the superior

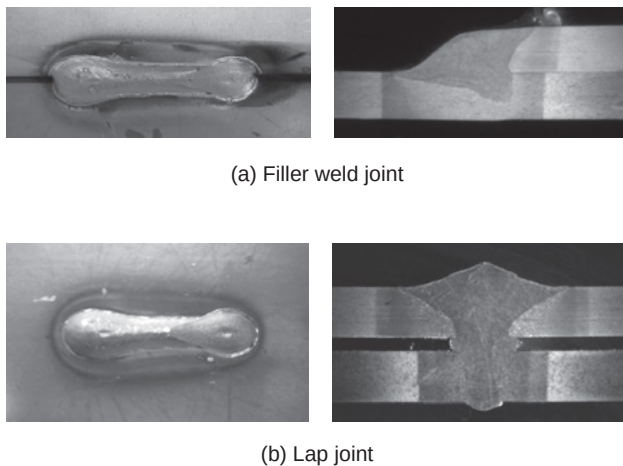


Fig. 15 Weld bead shape

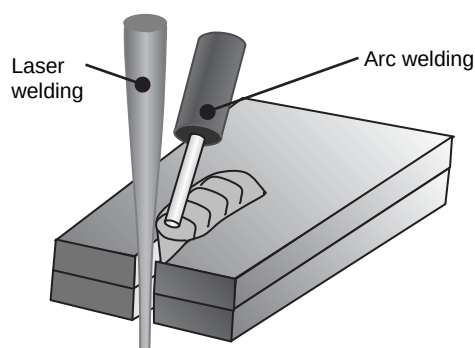


Fig. 16 Schematic design of arc-laser hybrid welding.

performance of hydroformation as a means of producing ultra-high-strength steel tubes, which are generally considered challenging to form.

## References

- (1) Kinoshita, Y. : Shikaku no Nai Furontopirakouzou no Kaihatsu, JSAE Annual Congress Proceedings, No. 1-07, 20075072, p. 1-3 (2007) (in Japanese)
- (2) Government Ordinance No. 320, Road Structure Ordinance, 15th article
- (3) Matsumiya, K.: Ryogan Shiyatousou Kenkyu no Shinten, VISION Vol. 14, No. 4, p. 151-164 (2002)(in Japanese)

## ■ Author ■



Yoshiharu HASEGAWA



Hiroshi FUJITA



Takeharu ENDO



Masaaki FUJIMOTO



Junya TANABE



Masaki YOSHIDA