USING CAE TO EVALUATE STRUCTURAL FOAM ALTERNATIVES IN B-PILLAR AND BUMPER DESIGNS

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ABSTRACT

This study examined the viability of using structural foam designs as lightweight alternative in B-pillar and bumper designs. The B-pillar was evaluated for side impact performance with respect to intrusion, while the rear bumper was evaluated for low speed impact performance with respect to intrusion and energy absorption. Typical stamped steel structures were used as baselines. Structural foam designs were evaluated using simulation and iterated until similar performance was achieved. Simulation results showed that the final design iteration of both the B-pillar and rear bumper achieved performance equivalent to the baseline with the benefit of reduced weight.

INTRODUCTION

There are several government requirements that an automobile must meet concerning its crashworthiness and occupant safety before it can be sold all over the world. Vehicle OEMs often conduct several types of crash tests to assure that these requirements are met. One such test is for Side Impact. It involves a Moving Deformable Barrier (MDB) colliding with a vehicle on the side at an angle of 27 degrees while moving at a resultant velocity of 33.5 mph. Injury numbers are calculated from accelerations measured using test dummies placed in the vehicle. Over the past several years, the use of Computer Aided Engineering (CAE) has increased in the automotive field to improve occupant protection and crash performance. This saves money by reducing the number of actual tests performed, usually on high cost prototypes, and time, by reducing the vehicle development cycle. In this instance however, CAE has been utilized in investigating a new material – structural foam – to evaluate its impact on crash performance and possible weight savings.

This simulation study was based on maintaining the current performance of the vehicle in the side impact and 5 mph rear bumper pole tests while reducing weight through the use of structural foam. Two structural areas were chosen for evaluation: (1) the B-pillar area to reduce side impact intrusion and (2) the rear bumper for reducing intrusion and increasing energy absorption. A finite element model of the vehicle was made and simulated to determine performance. The current vehicle was considered to be the base line model. Parts from the selected areas were then either removed or replaced by new designs including the structural foam. The criterion for evaluation for the B-pillar area was to maintain the same amount of intrusion as the base line with no change in deformation mode. Similarly, the rear bumper area was evaluated for intrusion and energy absorption in a 5 mph pole test. Both models were considered having met the target if they performed at the same level as their corresponding base line model. This paper will be roughly divided into two parts discussing the side impact and the rear bumper designs respectively.

STRUCTURAL FOAM APPLICATION ON PARTS

Before going into the details of the actual models and the results, the method of structural foam application and how it is an integral part of the design process is explained.

Structural foam is a high strength, low-density epoxy material. It is malleable and adheres to a carrier. Any metal can be a carrier for the structural foam, but steel is normally used (see Figure 1). The carrier can be as thin as the aluminum foil normally used in the kitchen up to about a millimeter. Typically it is 0.6 mm to 0.8 mm thick. The structural foam itself is typically 4 mm thick but more can be applied if a gap between surfaces needs to be filled. The carrier with the foam is installed during the body assembly, then cures and typically expands 50% from its original thickness during the paint baking process.

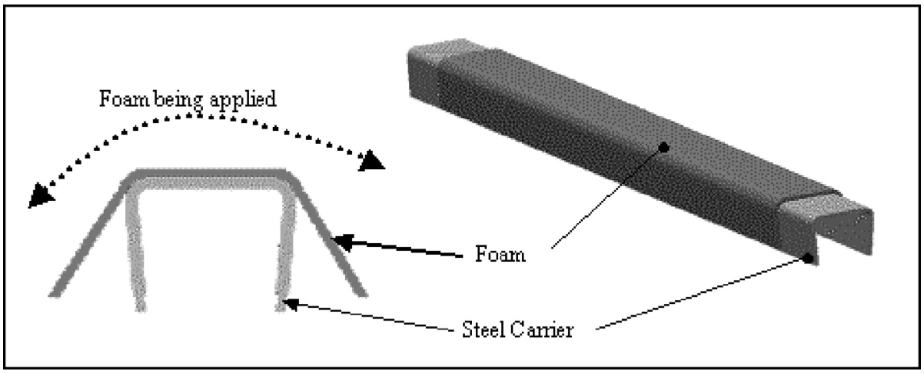

Figure 1: Epoxy structural foam is applied to the steel carrier before heat treatment.

The foam is constrained between the carrier and another part of the car body on the other without any air gaps. Heat treatment expands the foam within this cavity with out air gaps and it hardens upon cooling (see Figure 2).

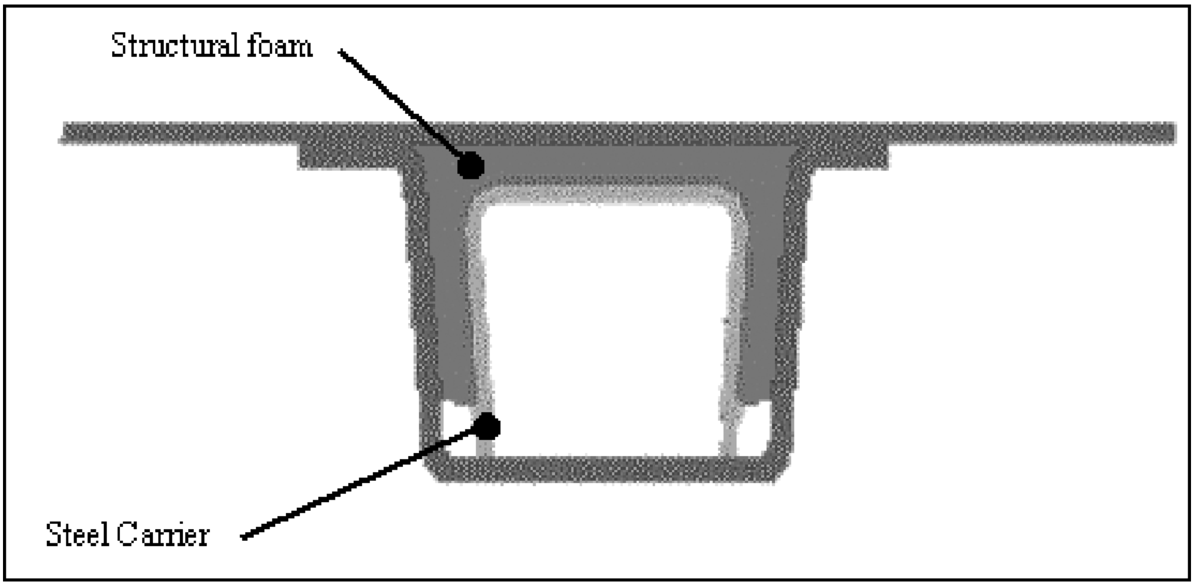

Figure 2: Example of the foam application

The properties of the foam were modeled using the LS-DYNA material number 24 (MAT_PIECEWISE_LINEAR_PLASTICITY).

SIDE IMPACT ANALYSIS

B-pillar - Model Background

A finite element model of the vehicle was created using shell elements. Several non-structural components (e.g. engine, battery, etc.) were represented by rigid meshes of their exterior surfaces. The shell thickness for each rigid body was specified to equal the component's actual mass. Mass elements were used to specify the seat structure, passengers and spare tire. The suspension systems were created using bar elements. The side impact cart with the MDB was assigned an initial resultant velocity of 33.5 mph coming in at an angle of 27 degrees to the lateral as shown in Figure 3.

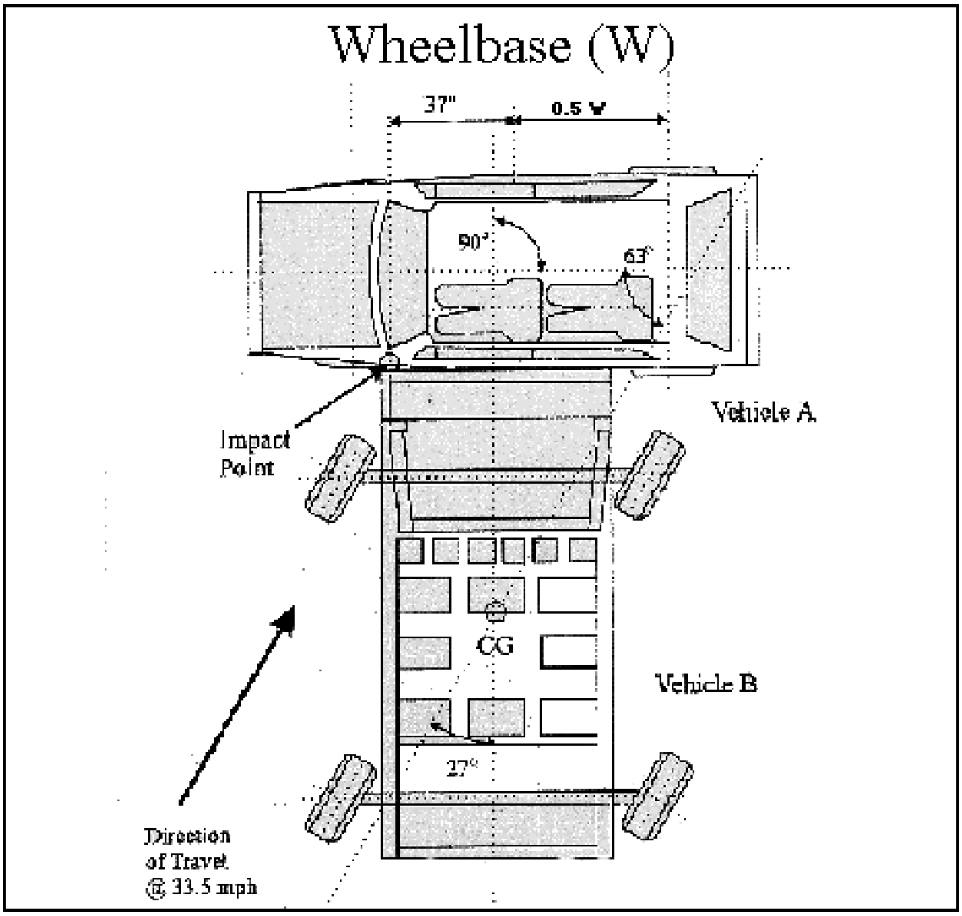

Figure 3: Side Impact test configuration

B-pillar - Base Design

Application of structural foam in any design can be a pre-design or a post-design process. In pre-design, the vehicle is designed knowing the effects of structural foam and how the foam would affect various performance parameters. In the post-design process, the vehicle design has been completed but needs improvement in performance or other requirements. Since this was a research study, the post-design approach was used to evaluate the effects of structural foam. The objective was to maintain base line performance with the new structural foam design.

As can be seen in Figure 4, the base model of the B-pillar construction consists of the inner and outer panels with some stiffeners in between to increase stiffness in that area.

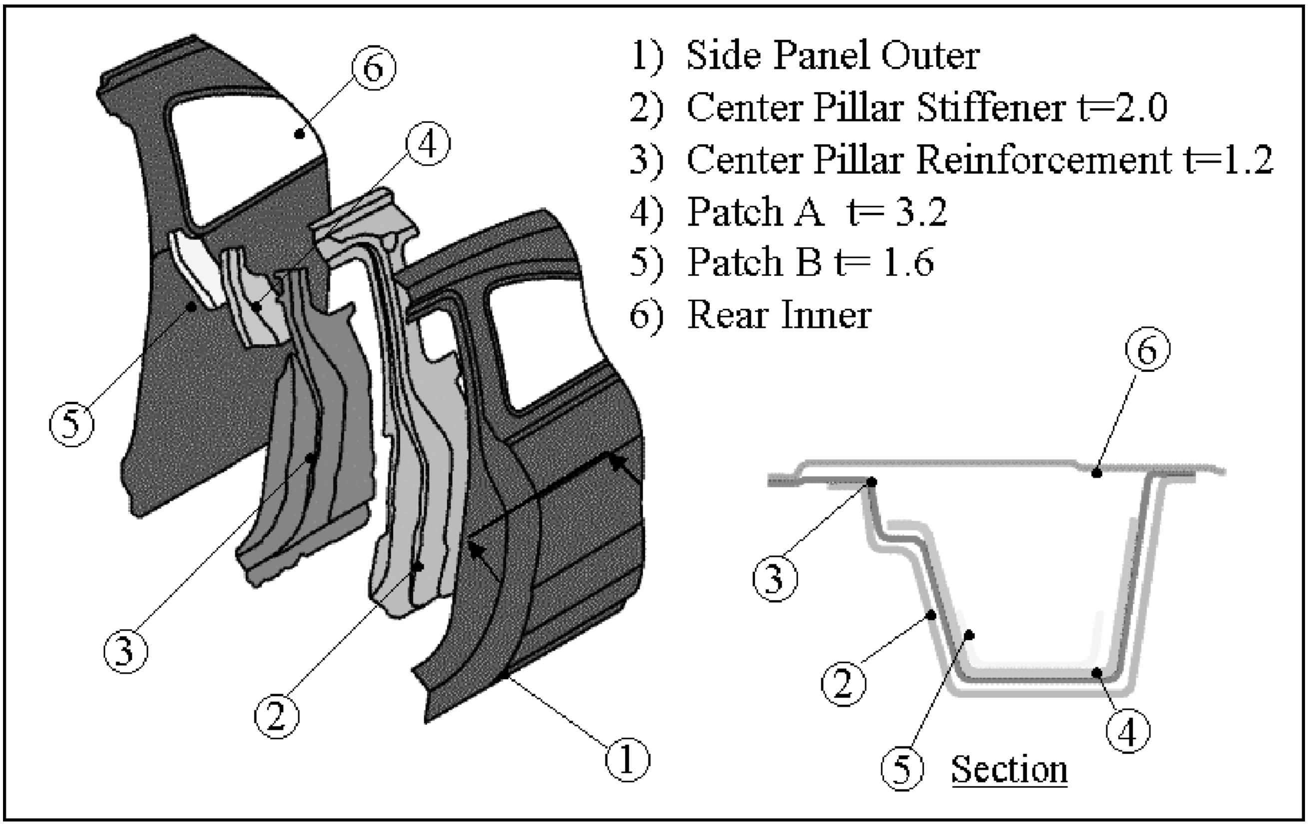

Figure 4: How the B-pillar comes together

The cross-section taken through the middle part of the structure shows the design modifications taken to reduce intrusion.

B-pillar - Structural Foam Design

The base design was modified keeping in mind the issues of performance, cost and weight. In the new design, the two stiffeners named patch A and patch B were removed from the base model, the center pillar stiffener was reduced in thickness from 2.0 mm to 1.6 mm and structural foam was added between the center pillar stiffener and the center pillar reinforcement. Minor adjustments were made to these parts to maintain a 6 mm uniform thickness of the structural foam. After heat treatment the structural foam was expected to expand and form a tight bond between the adjoining parts. The new design structure is shown in Figure 5.

B-pillar - Side Impact Results

Results were obtained from the base and the new design models after they were run through the side impact test methodology described earlier. The criterion of evaluation was the deformed shape of the B-pillar. The deformed shape is shown in Figure 6 and the intrusion values are shown in graphical form in Figure 7. The shape of the B-pillar was very similar to that obtained in the original base design. For the intrusion numbers, nodes were selected all along the B-pillar from the roof to the floor.

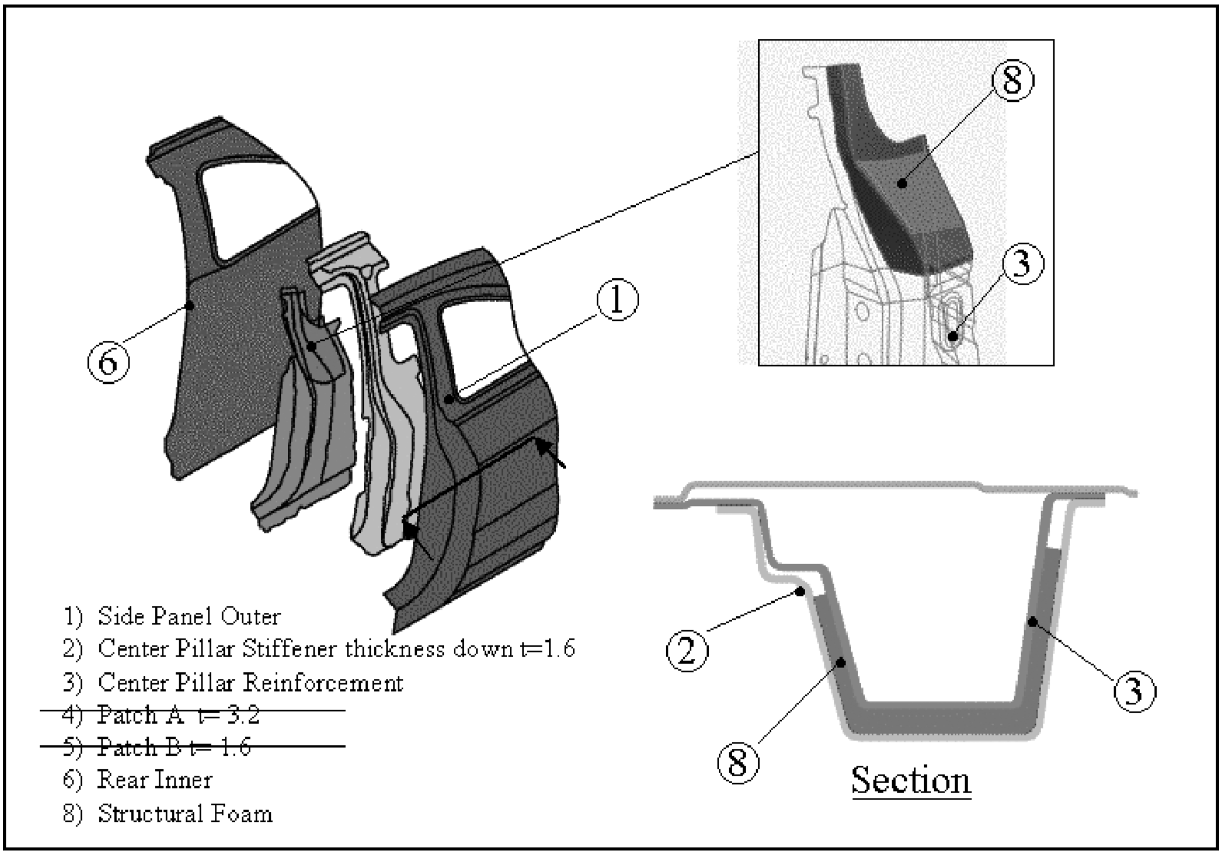

Figure 5: The Structural Foam B-pillar Design

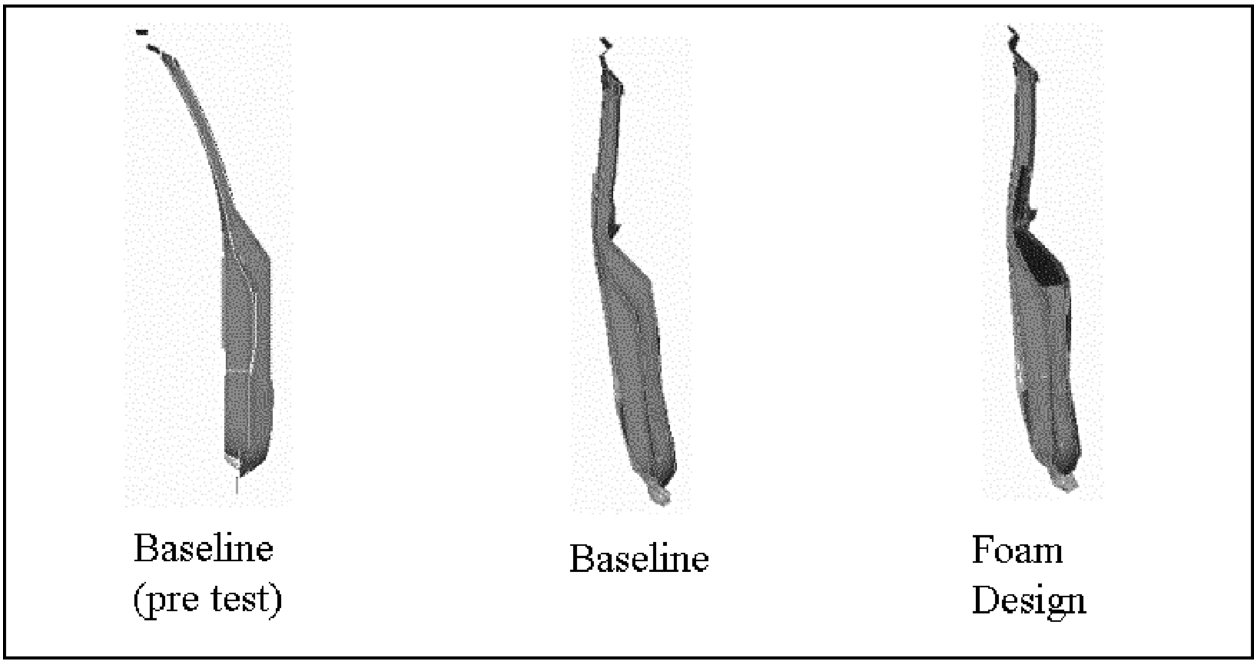

Figure 6: B-pillar Mode of Deformation – Front View

The deformation of these points was measured in the y-direction. The intrusion of the structural foam design falls almost right on top of the base design. Figure 8 shows the deformed shape of the structure.

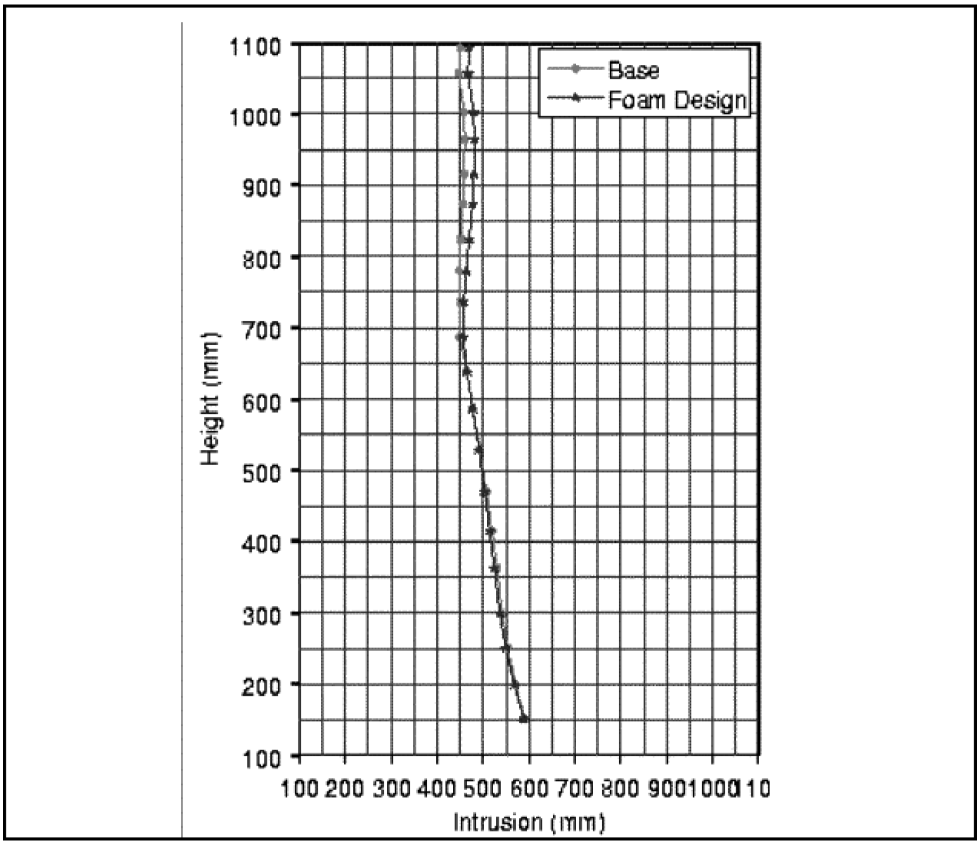

Figure 7: Graph of B-pillar Intrusion

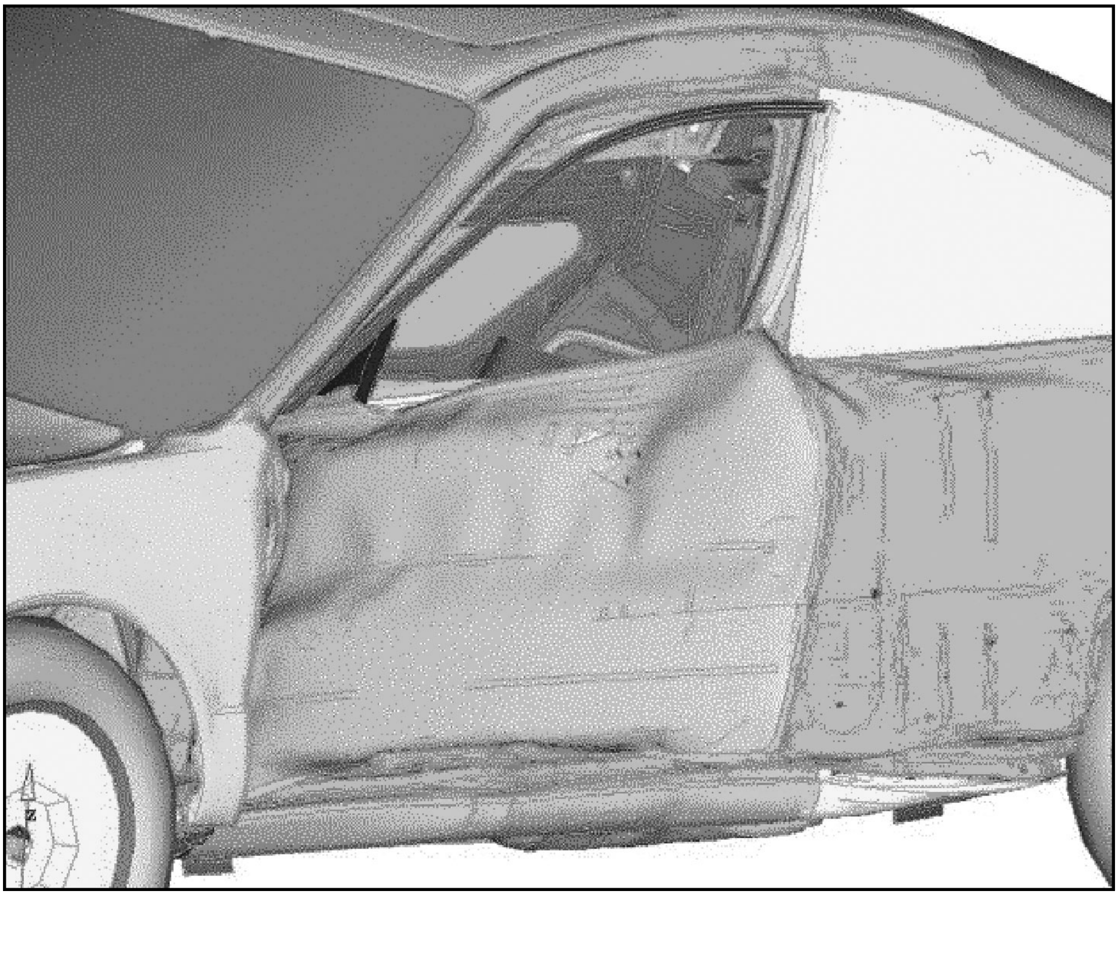

Figure 8: Deformed structure of the vehicle after Side Impact

Table 1: Difference in B-pillar between Base and Structural Foam Model

	Part Name	T (mm)	Mass (kg)
1	Center Pillar Stiffener	2.0->1.6	-1.28
2	Patch A	3.2	-1.34
3	Patch B	1.6	-0.25
4	Structural Foam	6.0	0.175
	Total Savings		**-2.695**

BUMPER 5 MPH POLE TEST ANALYSIS

Rear Bumper – Model Background

One of the more severe low speed crash tests is conducted on the rear bumper to cover a broader range of impacts occurring in actual crashes. The 5 mph pole test consists of a rear bumper impacting with a solid steel pole 180 mm in diameter. The evaluation of the test is based on the damage endured by the bumper and body.

The full body finite element model was reduced in size for this analysis. It was cut off just beyond the C-pillar and the mass removed was added as a point mass and distributed along the cut off portion of the model (see Figure 9). The pole was represented by a rigid half cylinder and was restricted not to move. The model was given an initial velocity of 5 mph in the x-direction and deformation measurements were taken at the center point of the rear bumper.

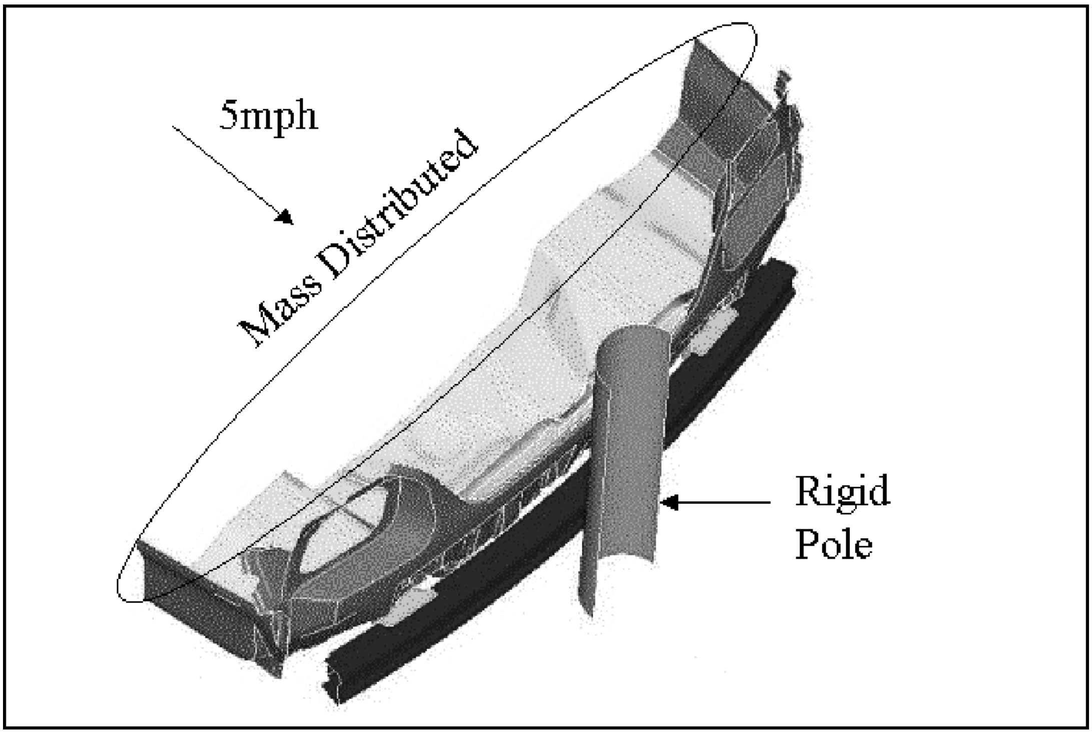

Figure 9: Bumper Model – Initial Conditions

Rear Bumper - Structural Foam Design

To better understand the design, the base model bumper and its cross-section is shown in Figure 10. Most of the reinforcements in this design were removed from the base model and replaced with a structural foam design (see Figure 11). The bumper beam thickness was reduced from 1.8 mm to 1.2 mm. A steel carrier and foam was added to replace the reinforcements.

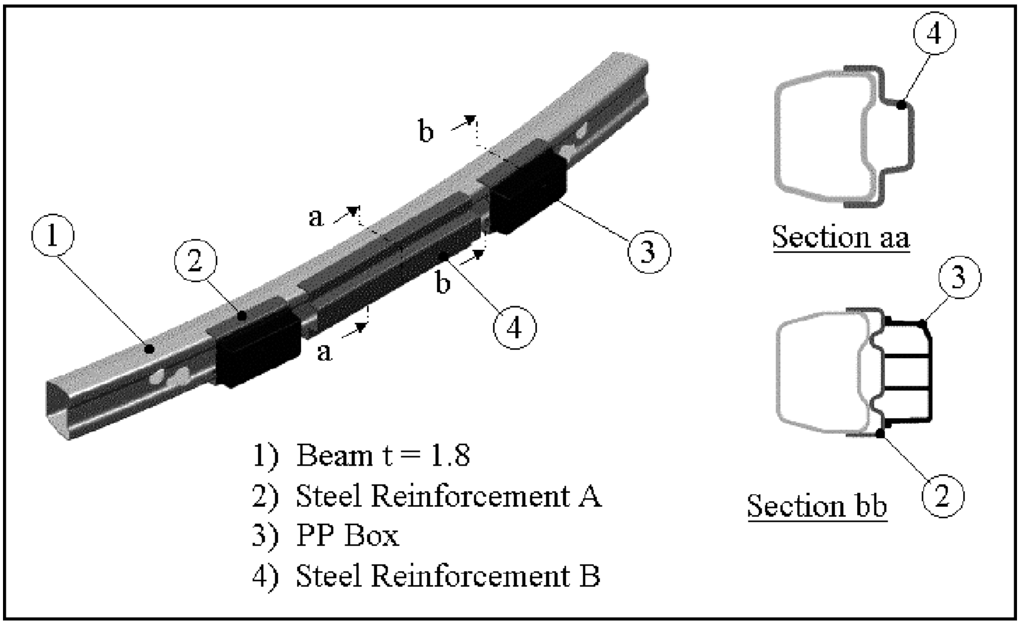

Figure 10: Base Bumper Design

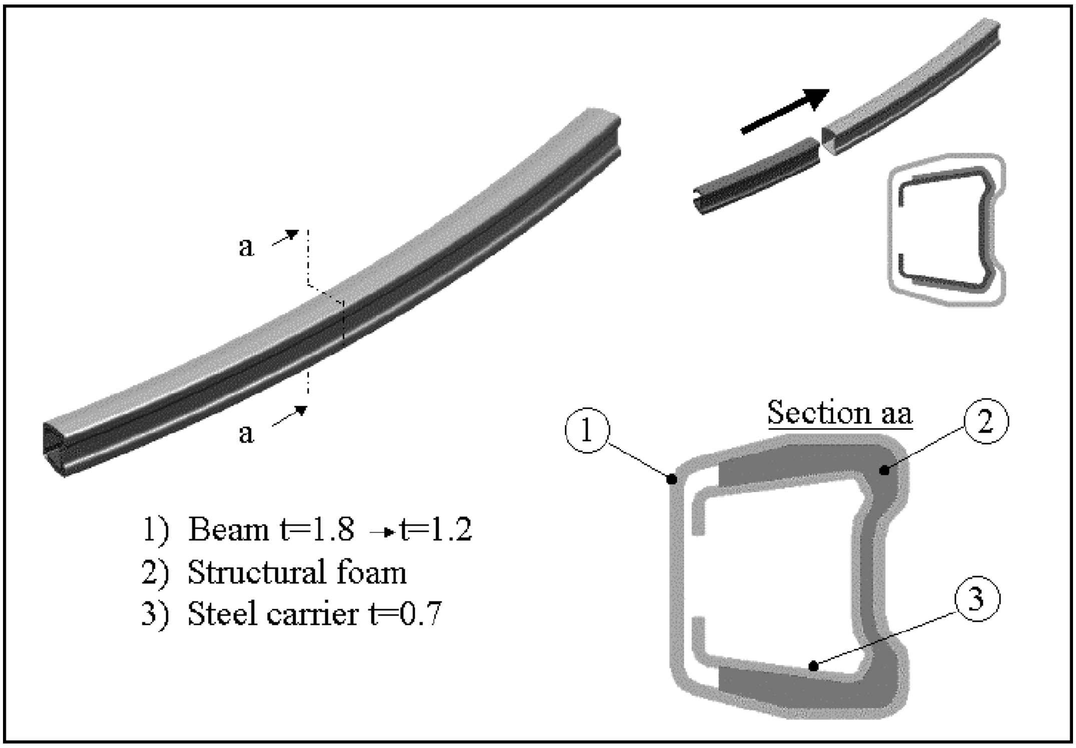

Figure 11: Structural Foam Bumper Design

Rear Bumper - 5 mph Pole Impact Results

In the base model, the bumper beam steel reinforcement absorbs most of the load. To maintain the same performance, the steel carrier and the structural foam forms a bond with the bumper beam. The shape and mode of deformation was found to be similar in both models (see Figure 12). The intrusion and energy absorption were also comparable as shown in Figure 13. Finally, a breakdown of the various parts can be reviewed in Table 2.

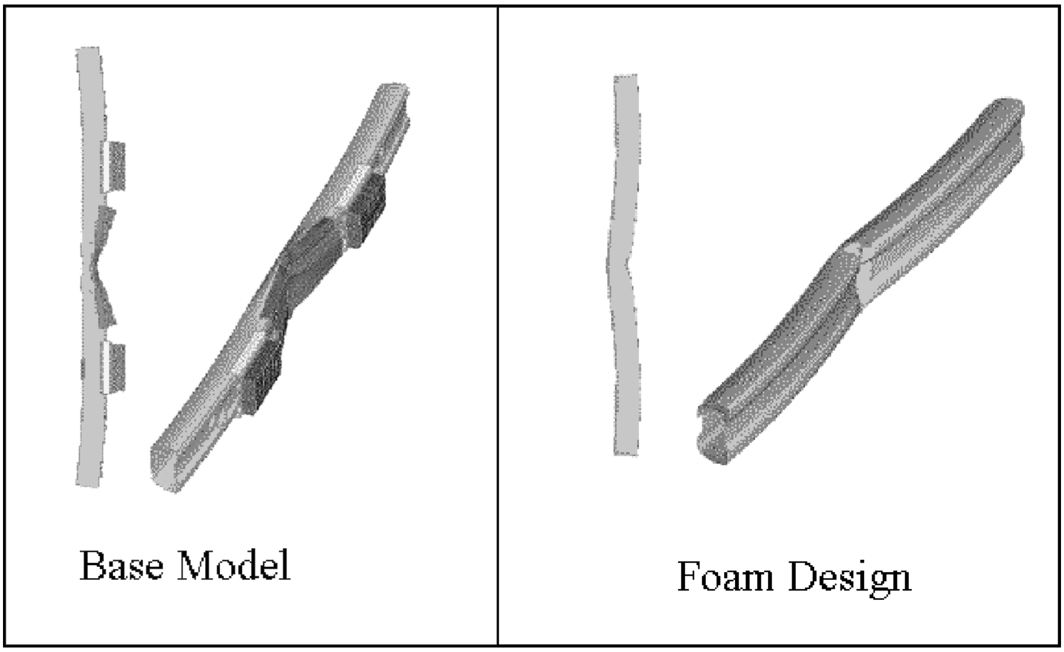

Figure 12: Deformed shape of Bumper models

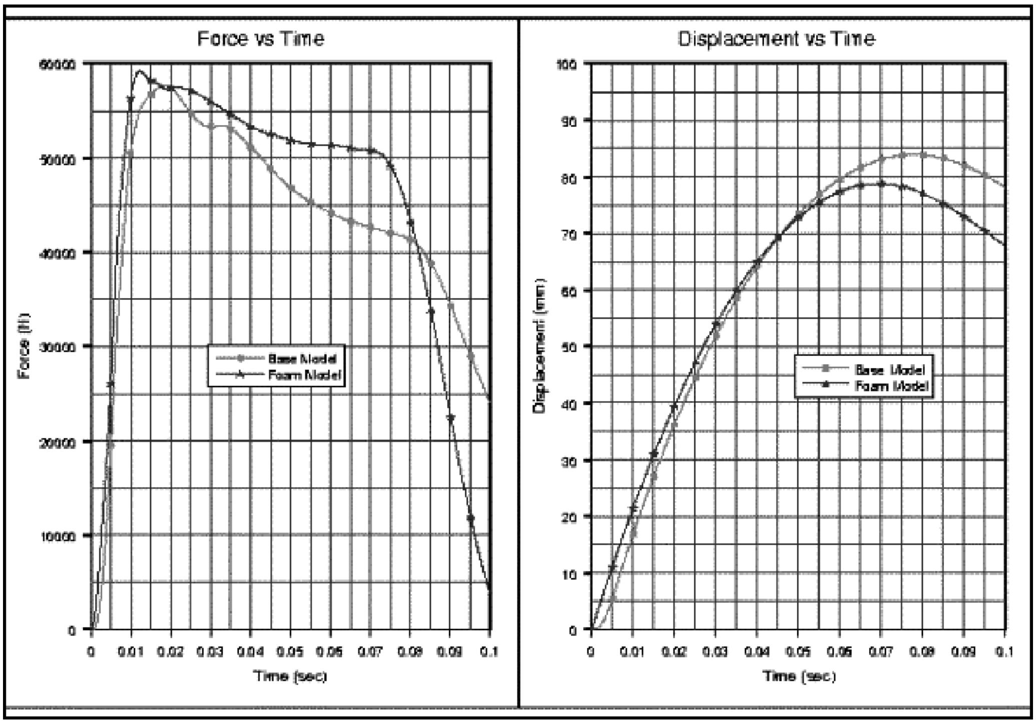

Figure 13: Graphs showing Energy absorption and Intrusion

Table 2: Difference in Bumper parts between Base and Structural Foam Model

	Part Name	T (mm)	Mass (kg)
1	Protector Rear Bumper Beam	1.8	-0.87
2	Rear Bumper Beam	1.8->1.6	-1.76
3	Support Plate	1.8	-0.74
4	Poly Propylene Boxes		-0.21
5	Steel Carrier	0.7	+1.62
6	Structural Foam	2.0-9.0	+0.81
	Total Savings		**-1.15**

CONCLUSION

The B-pillar showed a similar mode of deformation as the base model. It had similar intrusion numbers and reduced the original design by 2.7 kg. It was found to be comparable and was judged to be the same as the base model.

The rear bumper also showed that the structural foam design was similar in energy absorption and intrusion to the base model. It reduced the mass of the base design by 1.15 kg and was also judged to be successful.

Both the B-pillar and the rear bumper were found to be potential areas where structural foam could effectively replace steel and other materials and have an equivalent performance to their respective base models. There were possibilities of weight reduction in both areas as well.

ACKNOWLEDGEMENTS

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REFERENCES

LS-DYNA Keyword User’s Manual, Version 940.