DESIGNING THE FRONT FRAME RAIL FOR INCREASED ENERGY ABSORPTION IN A FRONT OFFSET CAE ANALYSIS

Sameer Gupta
Honda R&D Americas, Inc.
USA

Paper # 282

ABSTRACT

This paper follows the process of development of a front frame rail sub-assembly design structure to improve energy absorption in a front offset impact. Static crush analysis using LS-DYNA was conducted for this evaluation. The front section of the white body was crushed to determine the initial performance of the frame rail in the area located near the lower dashboard and front floor. The mode of the frame rail deformation in an impact was determined to be the cause of the weak performance of the initial structure. The critical parts of the frame rail were studied and several design ideas were proposed. A final structure evolved after evaluating multiple designs using CAE analyses. The new design structure improved the mode of deformation of the frame rail reducing the lower dashboard intrusion while absorbing more energy and was considered to be acceptable for improved offset performance of the vehicle.

INTRODUCTION

The structure of a vehicle is designed to absorb energy and protect its occupants in various types of crashes that occur on the road each year. Most of these are frontal crashes. In the 40 mph offset test, 40 percent of the total width of the vehicle strikes a deformable barrier on the driver side. The results of the crash test are based on structural performance, restraints/dummy kinematics and injury measurements. The front offset crash has therefore been an important factor for people in the purchase of a vehicle.

This simulation study was performed to improve the front frame rail structure so that it met the requirements set for an offset crash. CAE was considered to be an essential tool in this process of identifying the critical areas in the frame rail and improving the frame rail structure for better offset performance. The finite element models were made up of parts from the full vehicle and statically crushed to determine their energy absorbing and deformation characteristics. The criterion for evaluation for the frame rail area was to improve the level of energy absorption and reduce deformation. This paper will follow through the various design ideas considered, discussed, analysed and evaluated until the structure of the front frame rail was finalised for better energy absorption and consequently better offset performance.

BASE MODEL – BACKGROUND OF THE FRONT FRAME RAIL STRUCTURE

The front left side frame rail of the model was extracted from the full car model and crushed statically using LS-DYNA to determine how much force was being transmitted through the side frame rail cross-section and to study its mode of deformation.

This model comprised of all the parts needed to improve offset performance including stiffeners in the frame rail, the lower dashboard and all bolt on parts in the selected area. It was used to analyze the proposed counter measure ideas and provide design direction to reduce lower dashboard intrusion. The smaller model took less time to run than a full offset crash model thereby helping to evaluate several design ideas at a faster rate.

In the x direction, the model included part of the front side frame rail and its connecting parts to the lower dashboard and the front floor (-40 mm to 1050 mm with reference to the front shock tower). In the y direction, the model was cut off from the side sill to just beyond the front floor frame (-660 mm to –300 mm if the center line is taken as y=0). Parts of the lower dashboard, lower dashboard stiffener, outrigger front side and the front floor were included in the model. A bolt-on stiffener had already been added to the bottom of the front frame rail to prevent large deformations under the front floor structure as shown in Figure 1. Increase in thickness of various parts was also an option for improved performance of the general area under investigation but that would have resulted in an increase in mass which was not very desirable as a counter measure.

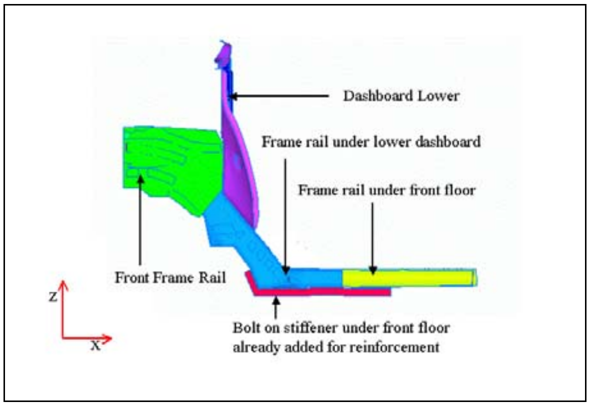

Figure 1. Base model: Bolt-on stiffener shown in yellow rail (left side view)

Boundary Conditions

The front floor was constrained in all directions (see Figure 2). The front side frame cross section was rigidly attached to a steel plate which was used to crush the side frame at a velocity of 1000 mm/sec. The model was run for 250 ms (milliseconds) since the maximum intrusion in the lower dashboard was not expected to exceed 250 mm. Force through the back plate used to crush the strcuture was used to calculate the energy absorbed by the side frame.

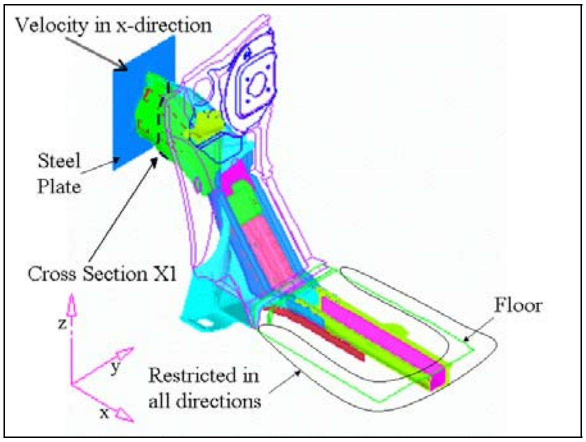

Figure 2. Boundary conditions of the static crush model used for frame rail analysis.

Result of the Base Model

The static crush model behaved in a satisfactory manner and met the expectation of providing adequate design direction for the development. The final shape of the structure (shown in Figure 3) showed deformation in the concerned area under the dashboard lower and the connection to the floor.

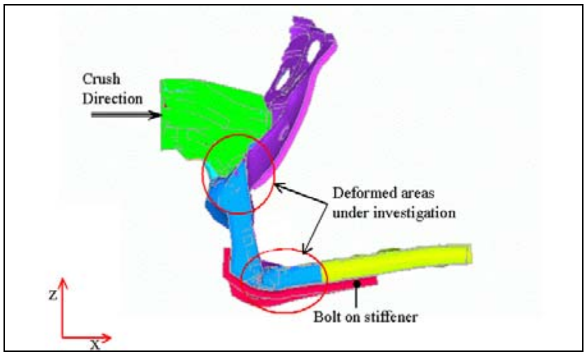

Figure 3. Final shape of the static crush model used for frame rail analysis showing concerned areas of deformation.

Multiple Designs

Several design ideas were put forth to increase energy absorption by the frame rail. Among them were:

- Reducing thickness of bolt-on stiffener;
- Increasing thickness of bolt-on stiffener;
- Increasing welds between the lower dashboard and the front floor;
- Increasing the thickness of a frame rail stiffener under the front floor that was welded to the inside of the frame rail;
- Increasing thickness of stiffeners under the lower dashboard.

All of these ideas were analyzed to determine the trends and understand the structure. Results of all of these are not discussed here since most of the ideas mentioned above were used as a stepping stone to the final design. However, four proposals emerged as possible solutions as a result of these analyses.

THE FIRST FOUR IDEAS

To reduce deformation in the areas indicated in Figure 3, three parts at certain locations (see Figure 4 and 5) were suggested. Each part was added separately to the base model and compared for its effectiveness. Finally, all three parts were added for the fourth iteration (see Table 1).

Table 1.
Parts added to the base model

No.	Part Name	Thickness (mm)
1.	End Stiffener	2.0
2.	Rear Support Stiffener	2.0
3.	Floor Bulkheads	2.0
4.	All 3 stiffeners	

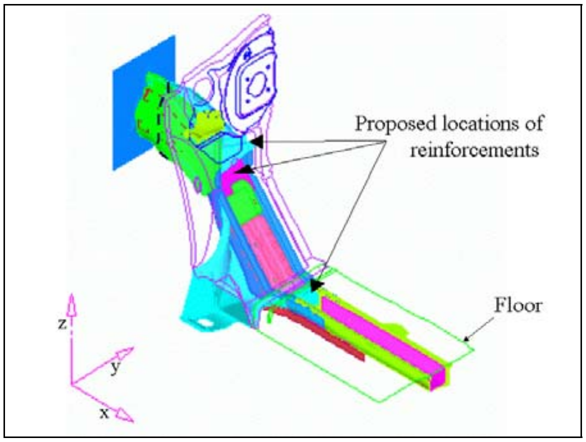

Figure 4. Areas to be reinforced

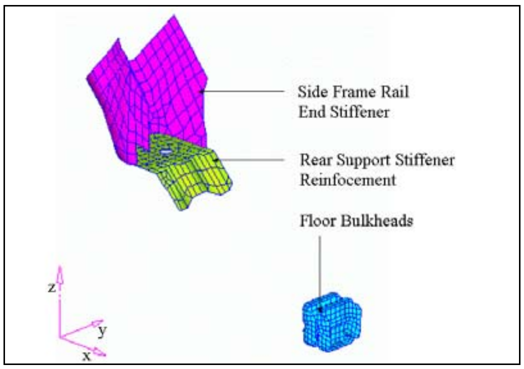

Figure 5. The three counter measure parts to be evaluated individually

Results of the Four Proposed Ideas

To evaluated the effectiveness of these parts, the force vs displacement curve was a good indicator of how much energy was being absorbed. The cross-section X1 (shown in Figure 4) was chosen so that the resistance offered by the new parts was adequately measured. A graph of the force vs displacement curve is shown in Figure 6.

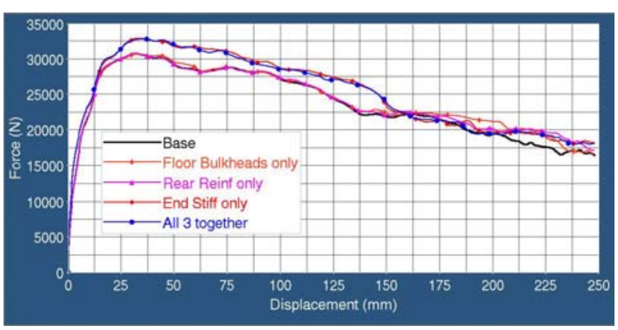

Figure 6. Force vs Displacement curves for all 4 design ideas.

Analysis of Results

The mode of deformation of the side frame rail at the end stiffener location matched the already tested crashed car. From the graphs and the deformation of the side frame rail it was concluded that among all of the counter measures applied, most of the increase in energy absorption was due to the end stiffener. The rear support stiffener had negligible effect while the floor bulkheads had a smaller effect in energy absorption. The floor bulkheads however did prevent "pinching" of the front floor frame stiffener thereby maintaining the cross section at the base of the rear end front side frame in the front floor at the base of the lower dashboard. Maintaining that cross section helped in reducing the chance of triggering deformations.

The energy absorbed at the cross section X1 was compared by calculating the area under the Force vs Displacement curves shown in the graphs above. The percentage improvement due to each of the individual counter measure ideas is shown in a Table 2. The model with all the three stiffeners absorbed the most energy when compared to the base model. The model with just the rear support stiffener was the least effective of the ideas proposed.

Table 2.
Percentage comparison of the energy absorbed

No.	Model	Energy Absorbed $x10^6$ Nmm	% difference with baseline
0	Baseline Model	5.868	
1	Base + End Stiffener	6.24	6.48%
2	Base + Rear Support Stiffener	5.97	1.79%
3	Base + Floor Bulkheads	5.99	2.04%
4	Base + all 3 stiffeners	6.27	6.83%

Action on Results – L-Shaped Bulkhead

Using the data obtained from the energy absorbtion graphs and by the animation of the model, the rear support stiffener was deemed ineffective and was removed from the counter measure package. Similarly the front floor bulkheads also did not contribute much to the structure but since they kept the front floor frame stiffener from collapsing inwards, they were kept. The end stiffener seemed to have had the most effect out of the 3 parts added to the model. To prevent the torsional deformation of the rear end front side frame and the rear support stiffener, a L shaped bulkhead (thickness 2.0 mm) was proposed on top of the end front frame stiffener to maintain its cross section in that area (shown in Figure 7).

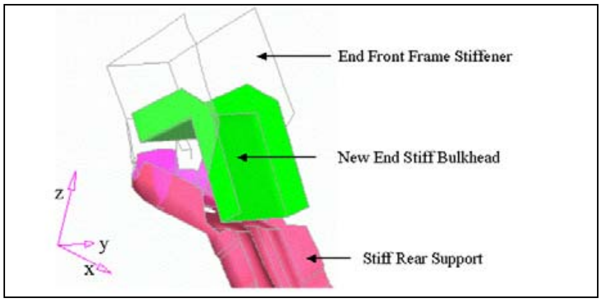

Figure 7. Proposed L-shaped bulkhead

The model was re-analyzed with the L-shaped bulkhead and the results indicated a significant improvement over the previous counter measure package. The results of this particular analysis are not discussed here because [1] they were preliminary and [2] the design was replaced by a similar part that was more convenient to manufacture and is discussed later in this paper.

TWO NEW DESIGNS

The two front floor bulkheads were re-designed slightly to increase their stiffness and included in two new designs that resulted from the preliminary analysis and are discussed below.

1. <u>Two part design</u>: This was essentially a refined L-shaped bulkhead shown above. The initial construction of the parts was crude and was used to determine the trend. They were modified to incorporate manufacturability concerns. Figures 8 and 9 show the difference in the old and the new design.

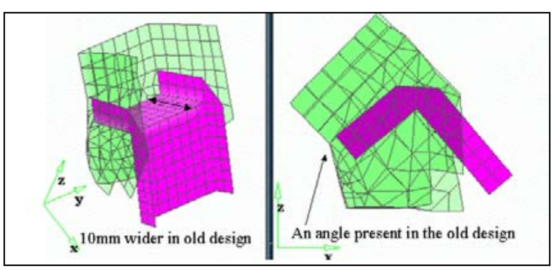

Figure 8. End stiffener and L-shaped bulkhead. (old design).

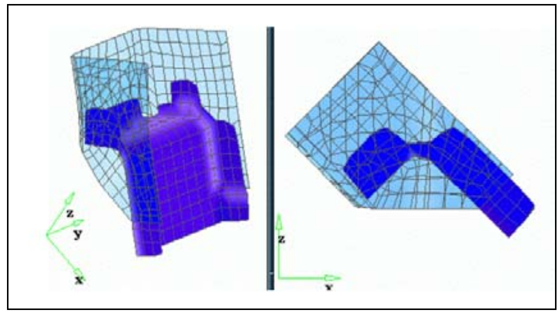

Figure 9. End stiffener and bulkhead re-designed after considering manufacturability.

2. <u>Single part design</u>: The end stiffener and the L-shaped bulkhead were combined into a single stiffener (Figure 10) to bring down the cost by reducing the number of parts to be manufactured and assembled.

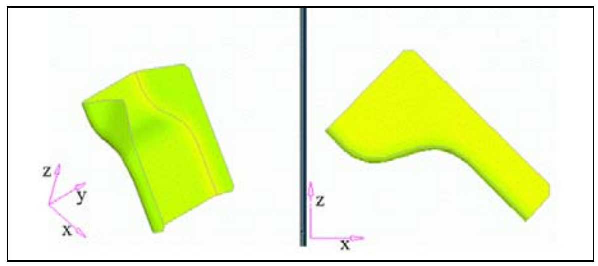

Figure 10. Two parts combined into one.

Results of the Two New Designs

These two new designs along with the front floor bulkheads were replaced in the original model and re-analyzed using the same boundary conditions as shown in Figure 2 to determine which design would be more likely to reduce lower dashboard intrusion.

The Force vs Displacement curves at the cross section for the two new designs are compared in Figure 11. The graph shows that the single part design was marginally better up to 110 ms and significantly better after that.

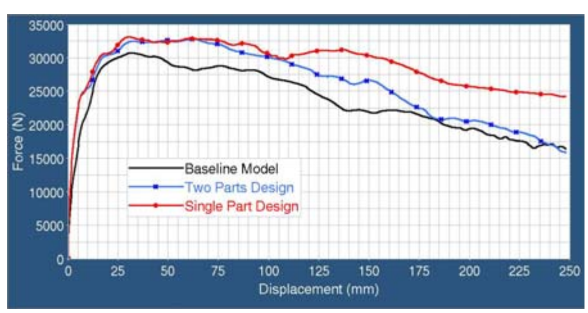

Figure 11. Force vs Displacement curves for the Two parts and one part designs.

In addition to the graphical data shown above, the deformation of the side frame rail and the area near the end stiffener was similar to the observed deformation of the actual test vehicle. In the side view (left view), the side frame rail was bending in the area of the end stiffener just in front of the joint with the rear end front side frame (see Figure 12). That reduced the intrusion into the dashboard lower since energy was being absorbed in the side frame rail. It also reduced the deformation of the side frame rail into the end stiffener area as seen in Figure 12.

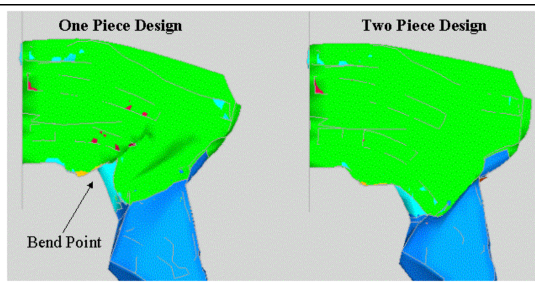

Figure 12. Side (left) view of the area of application of the end stiffener. Comparing the two designs.

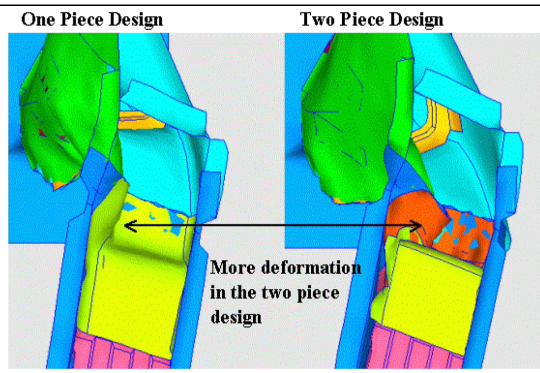

Figure 13. Rear view of the area of application of the end stiffener.

In the rear view, the deformation of the two part design on the right side of Figure 13 shows more deformation than the one part design on the left. The one part design preserves the cross section of the front frame rail in front of the dashboard lower allowing that to deform and absorb energy earlier in a crash. If energy is absorbed later in the crash, it results in a higher deformation of the lower dash board. Therefore, the single part design was considered to be better of the two. The energy absorbed at the first cross section of the frame rail for both designs is compared in Table 3. The animation of the models and the data above showed that the one part design was expected to further reduce lower dashboard intrusion when compared to the two part design by absorbing more energy.

Table 3. Percentage comparison of the energy absorbed by the two new designs

No.	Model	Energy Absorbed $\times 10^6$ Nmm	% difference with Baseline
0	Baseline Model	5.868	
1	Two part design + floor bulkheads	6.456	10.0%
2	Single part design + floor bulkheads	7.190	22.5%

The mass associated with the additional part and the bulkheads to the vehicle is shown in Table 4.

Table 4. Mass added to the vehicle

Part Name	Mass (kg)
End stiffener	0.41
Bulkheads (2)	0.15
Total	0.56

CAE Correlation with Test

Based on energy absorption, the static crush analysis of the two part design showed an improvement of 10.0 % over the baseline. After implementing the two part design and the front floor bulkheads in the actual test car, the lower dashboard intrusion after the offset test was reduced by 11.1%. The one part design was not tested due to schedule constraints.

CONCLUSION

The analysis showed that the one part design had an overall improvement of 22.5% in terms of energy absorption over the baseline model. The analysis of the frame rail resulted in a new design structure that could be implemented as a possible solution.

ACKNOWLEDGEMENTS

Thanks to various Design and Test engineers of Honda R&D Americas, Inc. for guiding the design and testing it respectively.

REFERENCES

LS DYNA Keyword User's Manual, Version 940.