Design Evaluation & Improvement Analysis of Vehicle Structural Crashworthiness using CAE in IIHS Frontal Crash Test

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Abstract*: Present day advancement in numerical solutions and advanced computational power has given a new dimension to the design and development of new products. Computer Aided Engineering (CAE) is widely used in the automotive community to reduce testing, prototype building, and design improvement in the design cycle. Design modifications were aimed to get controlled energy absorption, stable passenger compartment with aim of reduced intrusions and occupant safety.In the course of developing a passenger vehicle, automotive manufacturers must take into account numerous regulatory and corporate requirements. One of the most important such requirement is Frontal offset deformable barrier test. In this test condition, the vehicle traveling in the forward direction, impacts a deformable barrier that is offset to the driver's side of the vehicle. The barrier face is perpendicular to the direction of travel and overlaps 40% of the front of the vehicle. The scope of this project is to evaluate the performance of a sedan passenger car and to further improve its crashworthiness during an offset frontal impact event. It is demonstrated that utilization of the complete passenger compartment stiffness, continuity in the load carrying members and extending these members until rear of the passenger compartment significantly reduces intrusions during offset frontal impact.

Keywords*: IIHS frontal offset crash, Crash energy management, Crashworthiness, LS Dyna.

I. INTRODUCTION

Vehicle crashworthiness and occupant safety are the two most important aspects that are considered in the automotive industry today. The demands on vehicle design have increased enormously in order to satisfy safety regulations and this has led the safety engineers to perform various tests to evaluate the crashworthiness and occupant safety at the early stage of development. Offset barrier crash tests are conducted at 64.4 ± 1 km/h (40 ± 0.6 mi/h) and 40 ± 1 percent overlap. For verification test results submitted by auto manufacturers, the impact speed can exceed the 1 km/h tolerance.

The test vehicle is aligned with the deformable barrier such that the right edge of the barrier face is offset to the left of the vehicle centerline by 10 ± 1 percent of the vehicle's width.Vehicle crashworthiness connotes a measure of the vehicle's structural ability to plastically deform and yet maintain a sufficient survival space for its occupants in crashes involving reasonable deceleration loads.

In general, the goal of vehicle crashworthiness is an optimized vehicle structure that can absorb the crash energy by controlled vehicle deformations while maintaining adequate space so that the residual crash energy can be managed by the restraint systems to minimize crash loads transfer to the vehicle occupants. The scope of this report is limited to structural crashworthiness. Structural design for crashworthiness seeks to mitigate two adverse effects of a crash – (1) rapid deceleration of the occupant compartment, and (2) crush of the occupant compartment survival space. As a result, the modern automotive body structures include progressive crush zones (crumple zones) to absorb part of the crash kinetic energy by plastic deformations.

1. Crashworthiness requirements

Some of the general structural crashworthiness requirements are,

A. The front structure with crumple zones should deform in a controlled manner and absorb the crash kinetic energy resulting from frontal collisions by plastic deformation and prevent intrusion into the occupant compartment, especially in small overlap tests, frontal offset crashes and collisions with narrow objects.
B. It must deform plastically in a short period of time (milliseconds) to absorb the crash energy in a controllable manner.
C. Under the rear crash deformable rear structure should maintain integrity of the rear passenger compartment and protect the fuel tank.
D. Properly designed side structures and doors should minimize intrusion in side impact and prevent doors from opening due to crash loads.
E. The roof structure should be properly reinforced such that NVH and safety aspects will be addressed in rollover crashes
F. Accommodate various chassis designs for different power train locations and drive configurations.

To evaluate the structural integrity engineers conduct similar full-scale tests for side impact test. Moving deformable barrier strikes the target vehicle at 64 kmph in SINCAP, 50 kmph in ENCAP, IIHS & JNCAP. IIHS barrier hits the target vehicle perpendicularly and SINCAP barrier hits the target vehicle at a crab angle of 27 deg having particular mass and stiffness into the left or right side of the vehicle from some initial speed 64 kmph. In this test, side impact dummies ("SID" for the US and "EURO SID1" for Europe) are used in the driver and outboard rear seat locations.

II. IIHS FRONTAL OFFSET TEST

In USA, beginning in 1995, the Insurance Institute for Highway Safety (IIHS) initiated a program using a frontal offset test to rate safety in cars. At a speed of 64.4 ± 1 km/h (40 ± 0.6 mi/h) and 40 ± 1 percent overlap offset barrier crash tests are conducted. The right edge of the barrier face is offset to the left of the vehicle centerline by 10 ± 1 percent of the vehicle's width such that the test vehicle is aligned with the deformable barrier. The vehicle width is defined as "The maximum dimension measured between the widest part on the vehicle, excluding exterior mirrors, flexible mud flaps, and marker lamps, but including bumpers, moldings, sheet metal protrusions, or dual wheels.

A total of 14 locations are marked on the driver side interior and exterior of the vehicle, and their longitudinal, lateral, and vertical coordinates are recorded using a coordinate measurement machine (CMM). A right-handed, three-axis orthogonal coordinate system is used for these measures: longitudinal (rear to front is positive), lateral (right to left is positive), and vertical (bottom to top is positive). Measuring locations of vehicle intrusions are Steering column (one point), Lower instrument panel (two points), Brake pedal (one point), Toe-pan (three points), Left footrest (one point), Seat bolts (typically, four points), A-pillar (one point) & B-pillar (one point) Along with the vehicle interior measuring locations, the closing of the distance between the A- and B-pillars are the measuring points of the Institute's structural ratings. The pre-crash and post-crash locations of these points are measured with respect to a coordinate system which is positioned on the passenger side B-pillar.

III. FINITE ELEMENT MODEL BUILDINGAND ANALYSIS

The model is prepared using Hypermesh and Primer as pre-processor. In the first phase of the project, full vehicle model will be divided into sub-assemblies to reduce the model build and post-processing time. In the conventional method of vehicle integration, the full vehicle will be in a single file with all connections. This will result in difficulty in visualizing the required part, for design modification and also while post processing. Ls Dyna has *Include option to include different files to form a single file. Using this option, full vehicle model is divided into number of assemblies such as BIW, Chassis, Instrument panel, Hood, Doors etc.

Ford Taurus Full vehicle model are represented by combination of elements-shell, solids, joints, springs etc. All major sheet metal parts are modeled by using linear first-order (3-or 4-noded) shell elements at the part's mid surface. Belytschko–Tsay shell elements are used for these parts. All solid elements are modeled using Hughes-Liu element formulation. Meshing is done using Hypermesh pre-processor.

IV. MATERIAL DESCRIPTION

Some of the materials which are used in the FE model are as shown in Table 1.

Table 1. Material details

Sl No	Material	Material description	ρ (Kg/mm^3)	E(GPa)	μ
1	Aluminium	Elastic	2.50E-06	76	0.3
2	Steel	Elastic	7.89E-06	210	0.3
3	Rigid	Rigid	7.89E-06	210	0.3
4	Steel	Piecewise_linear_plasticity	7.89E-06	210	0.3
5	Plastic	Piecewise_linear_plasticity	1.20E-06	2.8	0.3
6	Foam	Low_density_foam	6.00E-08	0.00786	NA
7	Aluminum	Piecewise_linear_plasticity	2.50E-06	70	0.22

Deformable shell and solid parts are modeled using elasto-plastic material (MAT_PIECEWISE_LINEAR_PLASTICITY) with true stress vs. effective plastic strain curve as input. All casting parts are modeled as rigid parts (MAT_RIGID).

1. Material assumptions

A. In the physical parts, there is variation of material properties within each part due to the working of the material in the forming and assembly process. Material properties of sheet metal parts are assumed to be uniform throughout the part because this variation is not well understood, and it is usually not available.

B. The strain rate effects of the materials used are not included. These are assumed negligible in most parts.

C. Material tearing is not included in the simulation.

V. UNITS

One should be careful about use of consistent units while using CAE commercial packages. In this study SI system units are used.

	(a)	(b)	(c)
Length unit	meter	millimeter	millimeter
Time unit	second	second	millisecond
Mass unit	kilogram	tonne	kilogram
Force unit	Newton	Newton	kiloNewton
Young's Modulus of Steel	210.0E+09	210.0E+03	210.0
Density of Steel	7.85E+03	7.85E-09	7.85E-06
Yield stress of Mild Steel	200.0E+06	200.0	0.200
Acceleration due to gravity	9.81	9.81E+03	9.81E-03
Velocity equivalent to 30 mph	13.4	13.4E+03	13.4

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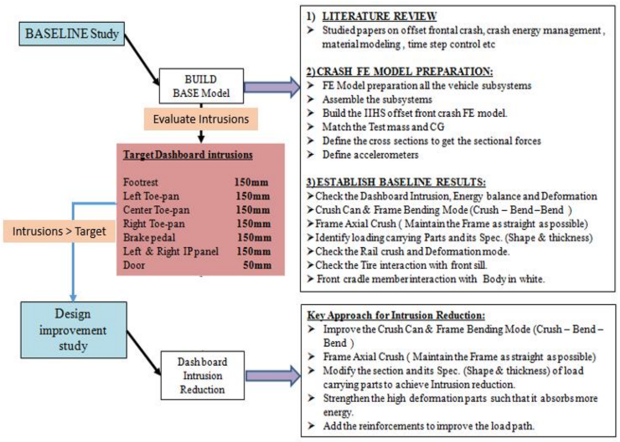
VI. METHODOLOGY



1. Step wise approach

Literature reviews on offset frontal crash, crash energy management carried out by referring SAE papers, books, magazines.

A. Ford Taurus 2000 finite element model for offset frontal crash simulation will be set up using HYPERMESH and Primer.

B. The full vehicle model is divided into sub-assemblies to reduce the model build time and post-processing time. These Subassemblies will be similar to the one in assembly lines.

C. Subassembly contents are renumbered as per predetermined numbering series to avoid clashes. This will be helpful to recognize the parts while post-processing by their part identification number.

D. Finite element analysis is carried out with the application of input parameters and boundary conditions in LS DYNA.

E. The model is debugged for any missing contacts, connections and modeling errors and rerun the model as applicable, and results comparison with test would be carried out.

F. Observations are made from the baseline simulation and design improvements will be carried out to reduce passenger compartment intrusion.

G. Design iteration results are compared to the baseline design.

VII. BASELINE MODEL OBSERVATIONS

Baseline model simulation results are studied in detail and all the major findings are listed below.

A. Floor deforms excessively which makes passenger compartment less stiff. The main reasons for the higher deformation are that the chassis rails are connected directly to the floor and BIW rails are only till the mid of the floor thus not supporting the complete floor.

B. Behavior of the chassis during impact is rigid, thus not absorbing sufficient impact energy. Complete chassis moves with very less deformation towards the passenger compartment causing high amount of deformation in dashboard and floor.

C. Crush box serves the purpose partially by axially deforming at the front portion and the rear portion absorbing energy slightly.

D. Engine parts were not interacted with passenger compartment which is good from intrusion point of view.

E. BIW main rails are connected directly to dashboard area and then extended to rocker area. This may result in increased intrusion as dashboard may not be able to provide required reaction force to the deforming rails.

F. There is less survival space available during the impact.

VIII. DESIGN IMPROVEMENTS

It could be assumed that the simplest means for avoiding major deformation extending far into the passenger compartment would be to significantly reinforce the front end structure. However, this is not an appropriate solution, for several reasons. First of all, the resulting high forces induced in a stiffer front side member must be supported at the firewall, which is a relatively weak area. As a consequence, the appropriate way of designing a car for frontal collisions with only partial overlap must be to

➢ Reinforce the passenger compartment, the survival space for the occupants, in particular, to stiffen the firewall.

➢ Distribute the impact forces into as many parts of the structure as possible.

Therefore the main focus for the design modifications is to stabilize the passenger compartment. Based on the observations from baseline results two design iterations are carried out.

Design iteration-1

Below are the design strategies which are implemented in design iteration-1.

A. From the baseline model observation, it can be noted that load from front chassis rails were transferred to floor and then to the longitudinal BIW rail which supports the floor. This causes floor to deform excessively. To avoid this, longitudinal BIW rails are designed with a flange which will be bolted to the chassis rails as shown in the figure 1.

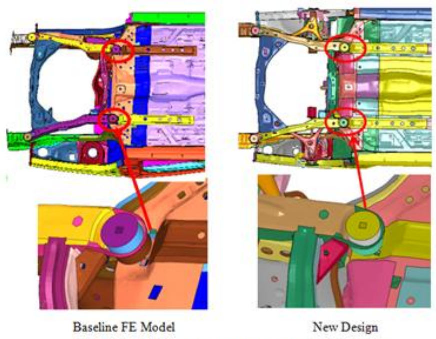


Fig1. BIW rails with modified flange

B. BIW rails are until middle of the floor in baseline model. The load is not completely distributed to the floor in this design which results in excessive local deformations and also complete passenger compartment stiffness is not utilized for providing the reaction force to the crush zones. The load path with the additional rail is shown by arrow mark in figure 2. This new part is welded at front to the baseline rail and to floor at rear portion.

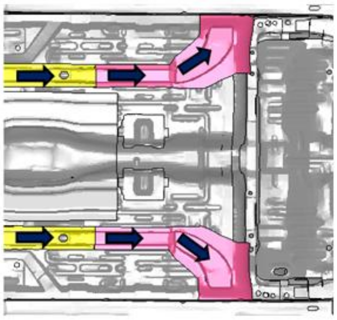
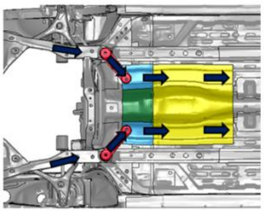


Fig 2. New BIW rail to distribute the impact load

C. The load path is only through BIW rails at the left and right side of the vehicle. A portion of it can be diverted to the middle portion of the floor with the addition of new parts. This will improve in load distribution and help to reduce plastic deformation in passenger compartment. New parts shown in figure 3 are designed to divert the impact load.

D. Floor and dashboard at the driver side is excessively folding. To stabilize this area, a new reinforcement is added. This part is welded to the floor. The part is having 1.2 mm thickness and assigned with steel material. It is as shown in the figure 4.

E.



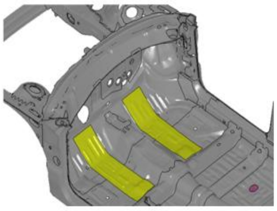
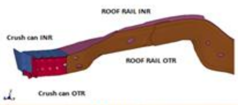


Fig 3. New parts designed to divert the impact load **Fig 4. New part added to stabilize floor and dashboard**

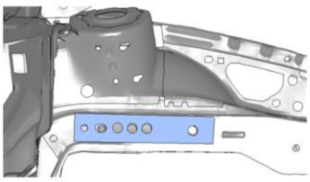
F. Bumper crash can was not getting crushed axially, observed that they are acting as stiff members. Also side front rail members are not deforming but they are bending suddenly in the baseline design. So need to soften the bumper crash can and front side rail members. Gauge of bumper crash can and front side members are down gauged by 10-15%. This helps in reducing the total vehicle mass figure 5.



S.No:	PART NAME	MATERIAL	Thickness(mm)	MASS(kg)
			Baseline	
1	Crush can OTR (LH)	440Mpa	2	1.21
2	Crush can INR (LH)	440Mpa	1.9	1.029
3	side rail OTR (LH)	780Mpa	2.4	2.334
4	side rail INR (LH)	780Mpa	2.1	5.17
			Total mass	9.743
			Design iteration-1	
1	Crush can OTR (LH)	440Mpa	1.2	0.72
2	Crush can INR (LH)	440Mpa	1.2	0.65
3	side rail OTR (LH)	780Mpa	2.2	2.14
4	side rail INR (LH)	780Mpa	1.8	4.43
			Total mass	7.94
			Net mass decrease	1.803
			Total mass decrease (LH & RH)	3.606

Fig 5. BOM comparison of baseline & design iteration1

G. We know that bending is considerably less efficient for energy absorption than the axial mode. An additional reinforcement of 1.0 mm thick is added to the BIW front rails. It is as shown in the figure 6.



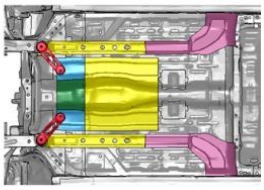


Fig 6. New reinforcement to avoid bending **Fig 7. New parts added to stabilize passenger compartment**

Figure 7 shows bottom view of the vehicle with above design changes. Total increase in vehicle mass is 2.566 kgs due to above design modifications.

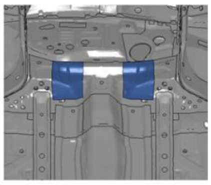
Design iteration-2

Below are the design strategy derived from design iteration-1 results which are implemented in design iteration-2.

A. New reinforcements are added to the dashboard as shown in figure 8. This is to make dashboard stiffer. The part is of 1.4 mm thick with steel material.

B. Optimized the part which is added in design iteration-1 to divert more load through it. The part is as shown in the figure 9.

C. Removed the front rail reinforcement added in the design iteration-1. Even though BIW front rail bending is avoided with the addition of this reinforcement, it increased dashboard intrusions.



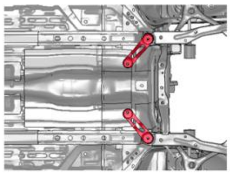
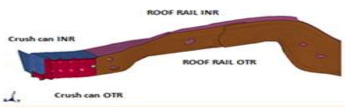


Fig 8. New Reinforcement added to dashboard **Fig 9. Optimized part to improve load carrying capacity**

D. Front portion of bumper crash can was crushed axially but the rear portion is not deformed. Front side members become very stiff and not absorbing energy. Thus softened the bumper crash can and front side rail members. Gauge of bumper crash can and front side member are down gauged by 20-30% further. This helps in reducing the total vehicle mass.

E. Total increase in vehicle mass in design iteration-2 is 0.8 kg due to the design modifications.



S.No:	PART NAME	MATERIAL	Thickness(mm)	MASS(kg)
			Baseline	
1	Crush can OTR (LH)	440Mpa	2	1.21
2	Crush can INR (LH)	440Mpa	1.9	1.029
3	side rail OTR (LH)	780Mpa	2.4	2.334
4	side rail INR (LH)	780Mpa	2.1	5.17
			Total mass	9.743
			Design iteration-2	
1	Crush can OTR (LH)	440Mpa	1.2	0.72
2	Crush can INR (LH)	440Mpa	1.2	0.65
3	side rail OTR (LH)	580Mpa	1.8	1.75
4	side rail INR (LH)	580Mpa	1.6	3.94
			Total mass	7.06
			Net mass decrease	2.683
			Total mass decrease (LH & RH)	5.366

Fig 10. BOM comparison of Baseline & Design iteration-2

IX. RESULT AND DISCUSSION

1. Baseline results

i. Plastic Deformation

Plastic strain in floor and dash board is a good indicator of Intrusion in passenger compartment. Figure 11 shows plastic deformation of floor and dashboard. The maximum plastic strain is around 63% is too high for the passenger compartment. Another criterion in frontal impact is that fuel should not leak due to impact. Figure 12 shows the plastic deformation of fuel tank. There is no major plastic deformation observed in the fuel tank. Maximum plastic strain is about 1.3%. Hence the possibility of fuel leakage is very less for the baseline model.

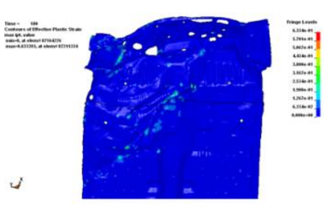


Fig11. Floor and dashboard plastic deformation

Figure 12. Fuel Tank plastic deformation

Figure 13 shows plastic deformation and deformation mode of bumper crush can and front rail member. Bumper crash-can axially not crushed and front rail member is bending at 70ms.

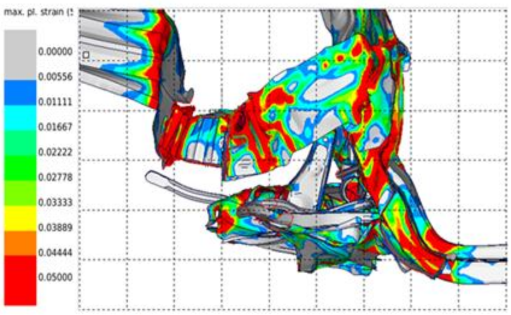


Fig13. Bumper crush-can and front rail member plastic deformation

ii. Intrusion Measurement

As per IIHS regulation, initial structural rating is based on comparison of intrusion measurements for the eight points in the passenger compartment Most of the points for the baseline model fall into the upper region of Acceptable rating. But brake pedal and left instrument panel intrusions fall into marginal region as shown in figure 14.

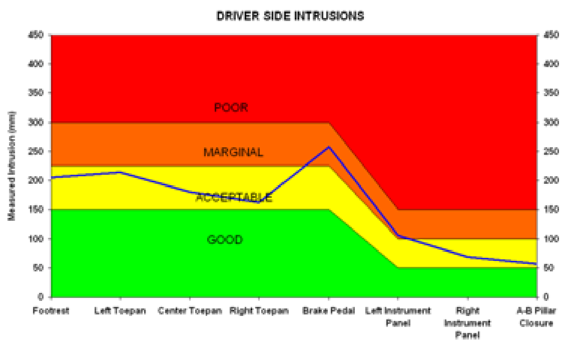


Fig14. Driver side intrusion for baseline model

iii. Load path

Load path for baseline simulation is as shown in figure 15. It can be seen that there is abrupt change in the force value for the BIW rail which supports floor. There is around 73% of reduction in force at this area making floor to fold up. This shows that passenger compartment is not providing enough reaction force to the deforming parts at the front. Hence behavior of the chassis during impact is rigid. Also it can be observed that load is not carried until rear portion of the floor. It is about 13.7KN before it reaches B-Pillar.

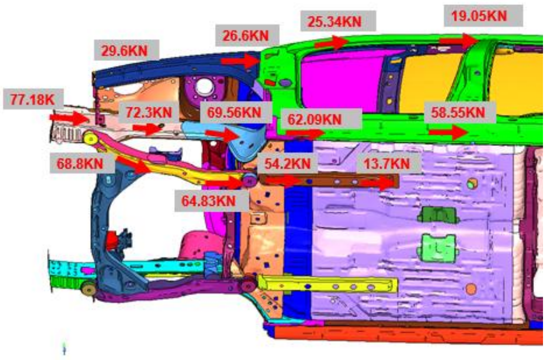


Fig15. Load Path for baseline model

2. Design iteration-1 results

i. Plastic strain in floor and dashboard

Figure 16 shows plastic deformation of floor and dashboard. The floor is completely stable with plastic strain of only 21%. Folding observed in baseline model floor is not present in the design iteration-1. However dashboard intrusion is not significantly reduced compared to baseline model. Figure 17 shows the plastic deformation of fuel tank. There is no major plastic deformation observed in the fuel tank. Maximum plastic strain is about 1.3%.

Fig16. Floor and dashboard plastic deformation

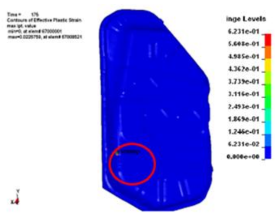


Fig17. Fuel Tank plastic deformation

Figure 18 shows plastic deformation and deformation mode of bumper crush can and front rail member. Bumper crash-can axially crushed but front rail member not deforming and exhibiting stiff response because of additional reinforcement.

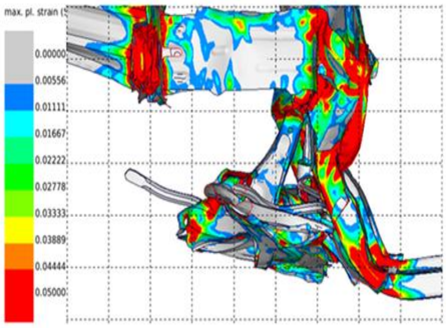


Fig18. Bumper crash-can & front rail member plastic deformation of design iteration-1

ii. Intrusion measurement

Floor deformation is significantly reduced with design iteration-1. But the dashboard intrusion is not reduced significantly. Many of the measuring point are present on the dash board and hence there is no significant reduction in the intrusion values compared to baseline model as shown in figure 19. The main reason for this is the addition of reinforcement in BIW front rails. This reinforcement resulted in highly stiff secondary energy absorbing parts causing them to intrude more into dashboard. This is the main reason to remove this reinforcement in design iteration-2.

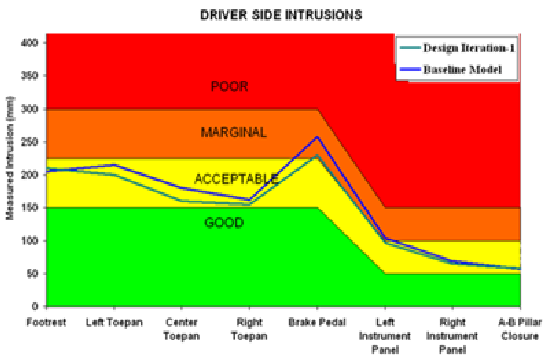


Fig 19. Comparison of Design Iteration-1 intrusion to base intrusion

iii. Load path

Load path for design iteration-1 is as shown in figure 20. It can be observed that force reduction is fairly uniform throughout the load carrying members. Also there is about 70% increase in the load through the BIW rails which support floor. About 20 KN of force is diverted through the secondary load path which is newly introduced in this design iteration. Thus complete passenger compartment is providing the necessary reaction force to the energy absorbers at the front. As a result, load at the BIW front rails and chassis rails are increased compared to baseline model. With this stiff and stable passenger compartment, deceleration pulse may increase in full frontal rigid barrier impact. It may be required to modify the design of primary and secondary energy absorbing members to reduce the deceleration pulse if it goes above the regulatory requirements which is beyond the scope of this project.

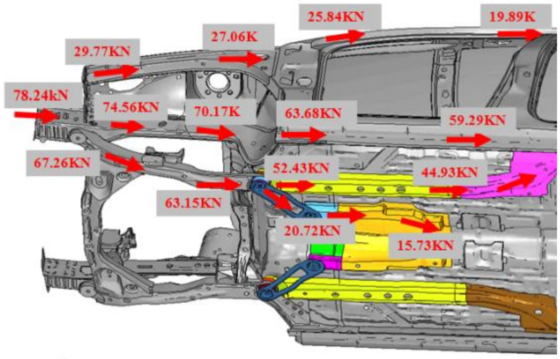


Fig20. Load path for design iteration-1

3. Design Iteration-2 Results

i. Plastic strain in floor and dashboard

Both floor and dashboard is stable with minimum plastic deformation as shown in figure 21. Excessive deformation which was observed near driver seat mount location in the baseline model is completely avoided in this design. Figure 22 shows the plastic deformation of fuel tank. Maximum plastic strain is about 3.5% which is well below the acceptable limit of 7%. Therefore possibility of fuel leakage is less for design iteration-2 model.

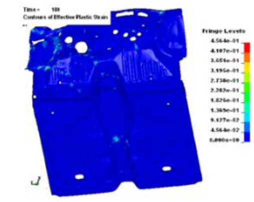


Fig 21. Floor and dashboard plastic deformation

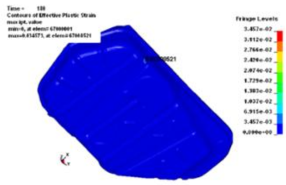


Fig 22. Fuel Tank plastic deformation

Figure 23 shows plastic deformation and deformation mode of bumper crash-can and front rail member. Bumper crash-can & front rail member axially crushed and plastically deformed. This axial mode helped to absorb more energy and reduced the dashboard intrusions.

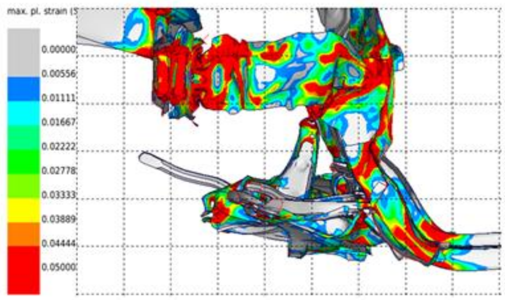


Fig 23. Bumper crash-can and front rail member plastic deformation

ii. Intrusion measurement

Figure 24 shows the intrusion values for design iteration-2. Intrusion are significantly improved compared to baseline model and now it fall into the upper region of Good rating. Both floor and dashboard are stable and only 22% of plastic deformation is observed compared to 63% in baseline model.

Since this design has good structural integrity of the safety cage, it will receive Good rating.

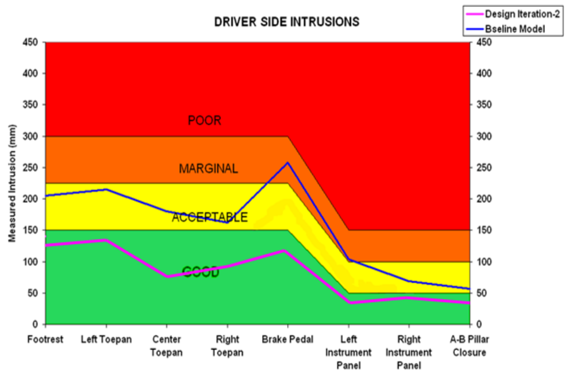


Fig24. Comparison of design iteration-2 intrusion to baseline intrusion

iii. Load path

Load path for design iteration-2 is as shown in figure 25. Similar to the design iteration-1 observation, force reduction is fairly uniform throughout the load carrying members. Also there is only 12.5% reduction in load for BIW rail which supports floor between front portion where chassis parts connect to it and rear portion. This indicates that load is carried till the rear end of the passenger compartment and hence there is no major plastic deformation observed in floor. In this design iteration, about 27 KN of force is diverted through the secondary load path. Also non-struck side of the BIW rails are carrying about 17.8KN of load which shows that with this design, the complete passenger compartment stiffness is utilized.

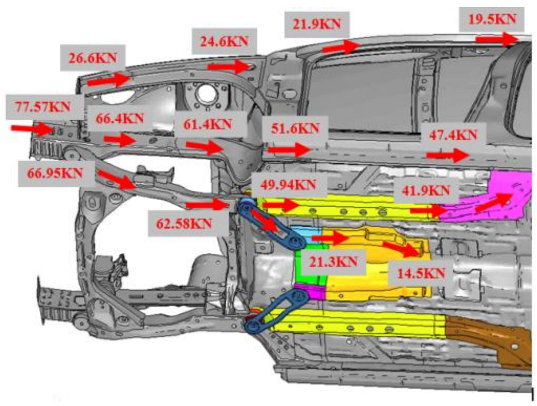


Fig25. Load path for design iteration-2

4. Result comparison

i. Energy absorbed by subsystems

Comparison of energy absorbed by subsystems is as shown in the figure 26. Energy absorbed by front chassis is increased for design iteration-2 due to the sufficient reaction force it receiving from the stable passenger compartment.

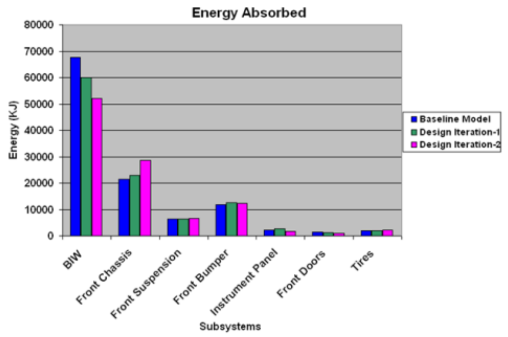


Table 2 shows percentage reduction for energy absorbed by floor and dashboard parts. Due to this reduction, energy absorbed by BIW is also decreased as shown in figure 23.

Table 2. Energy absorbed by floor and dashboard

Energy absorbed by Floor and Dash Panel			
Baseline Model (KJ)	Iteration 2 (KJ)	Reduction in Energy Absorbed (KJ)	Percentage Reduction (%)
9932.7	6725.2	3207.5	32%

X. CONCLUSION AND FUTURE SCOPE OF WORK

In this study, structure of a vehicle is modified with a viewpoint to reduce intrusions and improve the structural integrity of passenger compartment. The baseline model results are studied and from the observations, design modifications are carried out by modifying the load path. With design iteration-1, floor deformation is significantly reduced, but dashboard intrusions are not much improved. With design iteration-2, both floor and dashboard intrusions are significantly reduced and good structural rating as per IIHS is possible with this design which otherwise had marginal rating.

Following are the conclusions based on the results and discussion.

A. Utilization of the complete passenger compartment stiffness is needed for providing enough reaction force to the deforming parts at the front during an offset frontal impact. If the interface between the energy absorbing members and passenger compartment is not providing sufficient reaction force, the intrusion will be significantly increased.
B. Continuity in load carrying members helped to distribute the load to as many parts as possible and improved its load carrying capacity.
C. Extending the load carrying members until the rear portion of passenger compartment will help in reducing the load concentration and thus improves its stability.
D. For higher energy absorption axial mode is need to be achieved compared to bending mode.

E. Bending mode of bumper crush-can and front rail members is very important. Bending towards outward improved the dynamic crush.
F. Defining failure of engine mounts assisted in improving the energy absorption of front rail side members.
G. Front cradle interaction with Engine/ transmission, steering gear & Brake booster has to be avoided as it increases the floor deformation and dash panel.
H. Tire rotation towards inward need to be avoided as it hits the dash panel and increases the intrusions.
I. Hood panel has to deform and get folded at mid portion so that it doesn't struck the front windshield and cause the dummy injury.
J. As the physical test setup is time consuming and high on cost, finite element simulation provides a platform to carry out different design iterations with different parameters within a short turnaround time and also with lesser cost.

Future scope of work

I. The final design can be simulated for full frontal rigid barrier impact as per FMVSS208 and checked for its compliance. The passenger compartment is stiff and stable in the final design and hence deceleration pulse may increase in full frontal rigid barrier impact. If the deceleration pulse is increased above the regulatory requirements, design of primary and secondary energy absorbing members can be modified to reduce the deceleration pulse.

II. Modal analysis can be performed for the final design to check for the change in natural frequency of the model and also adequacy of connections for the new parts.

III. New and design modified parts which are added to stabilize the passenger compartment can be optimized and also manufacturability needs to be checked for these parts.

IV. Offset frontal crash for both baseline and final design can be performed with dummy in place and injury parameters can be measured and compared.

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