RESEARCH ARTICLE OPEN ACCESS

Structural Performance improvement of Vehicle in Side Impact (UN R95) Using Finite Element Method

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ABSTRACT
In this paper, investigation of side impact performance and the resulting injuries to the Humanoid Dummy which seat position on the Impact side. Side Impacts are one of the most serious injury impact. According to accident statistics, 30% of deaths from traffic accidents occur as side collision. Side impacts mostly happed due to sudden or unnoticed left or right turn. Similar to frontal impact, side impact don't have seat belt or improved restrain system. Also there is very less crush space from barrier to dummy to absorb the impact Kinetic Energy. So it is little tough to control the crash energy propagation to the compartment area. During the side impact, due to less crush space, the impact load will quickly transferred to the occupant. In this research, improving the side structure of vehicle to reduce the structure deformation and effectively manage the barrier KE along the dummy kinematics to have less injury to the dummies.
Keywords – Side Impact, Side Collision, Side Crash, ECE-R95, SINCAP, FEA, LS Dyna Non Linear.

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I. INTRODUCTION

Protecting people inside crashes is challenging because the sides of vehicles have relatively little space to absorb energy and side occupants, unlike the fronts and rears, which have substantial crumple zones. Automakers have made big strides in side protection by installing side airbags and strengthening the structures of vehicles.

Rear seated occupants are facing more fatally injuries. The occupants siting on the Non-impact side are getting very less injury compared with hitting side occupants. Rear seated occupants of belted drivers are 3.28 times more like to belted compared to rear seat occupants of unbelted drivers. In additional unrestrained occupants are facing 5.96 times higher injury compared with restrained occupants. [1].

The WLIRC data base 1995-1998 contains 92 side impact cases. Sixty four cases were with occupant seated position during side impact. Also, there is no subsequent collision or rollover. The injury are described on the basis of body region and severity. The most frequent injury are chest/abdomen -49%, head/face-24%, pelvis/lower extremity -14%, neck/spine-4%. Followed by brain and heart injuries. The heart injuries were present in 6 cases only. This side impact studies carried out with older occupants, female occupants, and unrestrained occupants [2].

In this lateral collision literature review, collected various information from the side impacts. Side impacts are one of a serious automotive vehicle injuries problem. After frontal impact, there are more probabilities to this side impacts. In every year around 9400 deaths occurring due to the lateral collision of vehicle. In the review of fatality data, found that 31.8% of passenger car fatalities occur in crashes, where the primary direction of fore is lateral to the vehicle. Various in depth studies show that occupant obtaining serious or even fatal injuries due to the side impact. The most frequent direction of primary impact is at 9 o click. [3]

II. FINITE ELEMENT MODEL INFORMATION

FE Model of Vehicle was dissembled and verified with BOM thickness and material information. Full view of vehicle shown in the Fig 1 and 2. Full vehicle model has converted from design model to the FEA model by using appropriate elements and joints.

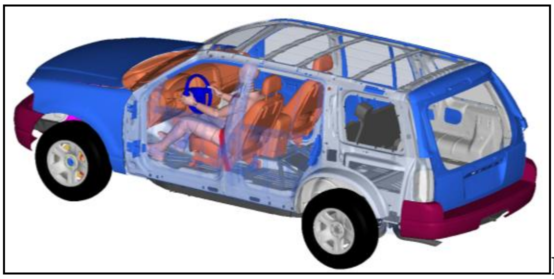
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Figure 1 Vehicle ISO View

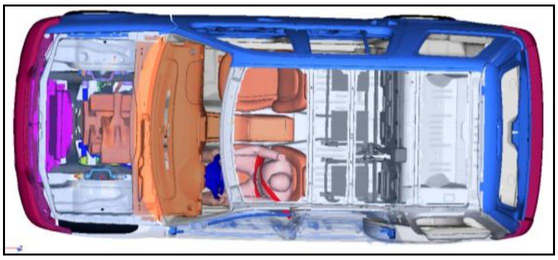

Figure 2 Vehicle TOP View

1.1 ELEMENT PARAMETERS

The sheet parts of the vehicle has model with shell elements (Quad and Triangular). The meshing has made in the mid plane of the components and thickness assigned to that elements, these elements will extrude both side equally to represent the thickness. Casting parts, thickness more than 6mm parts, foam has modelled with hexa penta elements. Bolts are model with 1D-beam elements with corresponding diameters. Welds are represented by using DYNA SPOT Weld elements. All joints of vehicle modelled with appropriate joints like Spherical joint, revolute joint, universal joint, Translation Joint, and lock Joints. All element Types with their counts has shown in the Fig 4.

Elements average size is 5mm. and the quality parameters are shown in the Fig 3.

Target element size: 5.000
Calculation method: OptiStruct
Advanced

	On	Checks	Color	Calculation Method	Fail
1	☑	Minimum size		Minimal normalized height	2.000
2	☑	Maximum size			20.000
3	☑	Aspect ratio		OptiStruct	5.000
4	☑	Warpage		OptiStruct	15.000
5	☑	Maximum interior angle quad			140.000
6	☑	Minimum interior angle quad			40.000
7	☑	Maximum interior angle tria			120.000
8	☑	Minimum interior angle tria			30.000
9	☑	Skew		OptiStruct	40.000
10	☑	Jacobian		At integration points	0.600
11	☐	Chordal deviation			1.000
12	☑	Taper		OptiStruct	0.600
13	☑	% of trias			15.000

Figure 3 Element Quality

ELEMENT	904726
ELEMENT_BEAM_ELFORM_1	185
ELEMENT_BEAM_ELFORM_2	258
ELEMENT_BEAM_ELFORM_3	52
ELEMENT_BEAM_ELFORM_6	45
ELEMENT_DISCRETE	46
ELEMENT_MASS	478
ELEMENT_SEATBELT	283
ELEMENT_SEATBELT_ACCELEROMETER	14
ELEMENT_SEATBELT_SLIPRING	1
ELEMENT_SHELL	752808
ELEMENT_SOLID	149958
ELEMENT_TSHELL	598

Figure 4 Element Type and Numbers

1.2 CONSTRAINED CONNECTION

In the vehicle connection, Joints, extra nodes, Nodal Rigid Bodies and spot weld options has used. Joints used to represent the actual joints in the physical vehicle. Additional Extra Node option for connecting rigid parts with deformable parts. With NRB, the bold connection and another connection location were modelled. Spot weld connection to represent the physical spot with the actual diameter. Complete vehicle spot welding highlighted in Fig 6.

CONSTRAINED	9719
CONSTRAINED_JOINT_UNIVERSAL	2
CONSTRAINED_JOINT_CYLINDRICAL	3
CONSTRAINED_EXTRA_NODES_NODE	20
CONSTRAINED_JOINT_SPHERICAL	21
CONSTRAINED_JOINT_STIFFNESS_GENERALIZED	27
CONSTRAINED_JOINT_REVOLUTE	61
CONSTRAINED_RIGID_BODIES	112
CONSTRAINED_EXTRA_NODES_SET	187
CONSTRAINED_NODAL_RIGID_BODY	2444
CONSTRAINED_SPOTWELD	6842

Figure 5 FE Connections

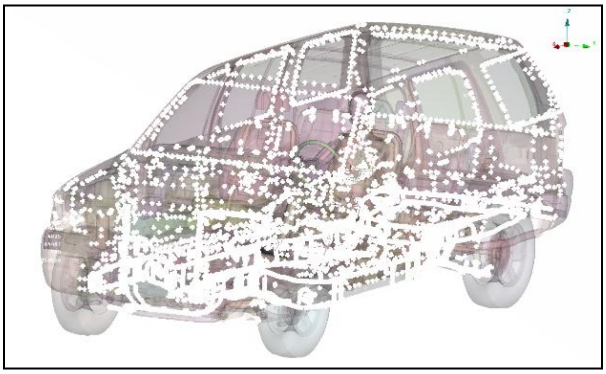

Figure 6 FE Spot weld Connections

1.3 LS DYNA MATERIAL INFORMATION

LS Dyna has comprehensive material library, in the vehicle components are made with lots of different material, which should model in the FEA with appropriate material card, also the rate of loading should be considered for high impact simulations. If some mistake modelling of material will lead to large changes in the behavior of components. All list of material card used in the model shown in the Fig 7. Elastro-plastic materials are modelled with MAT24 card, with strain rate dependent stress strain curves.

MATERIAL	1135
MAT71 MAT_CABLE_DISCRETE_BEAM	1
MAT_B01 MAT_SEATBELT	1
MAT_S02 MAT_DAMPER_VISCOUS	1
MAT26 MAT_HONEYCOMB	2
MAT123 MAT_MODIFIED_PIECEWISE_LINEAR_PLASTICITY	2
MAT_S05 MAT_DAMPER_NONLINEAR_VISCOUS	2
MAT83 MAT_FU_CHANG_FOAM	3
MAT_S01 MAT_SPRING_ELASTIC	4
MAT_S04 MAT_SPRING_NONLINEAR_ELASTIC	4
MAT3 MAT_PLASTIC_KINEMATIC	7
MAT6 MAT_VISCOELASTIC	14
MAT77 MAT_OGDEN_RUBBER	14
MAT66 MAT_LINEAR_ELASTIC_DISCRETE_BEAM	16
MAT7 MAT_BLATZ-KO_RUBBER	17
MAT57 MAT_LOW_DENSITY_FOAM	23
MAT1 MAT_ELASTIC	82
MAT9 MAT_NULL	90
MAT20 MAT_RIGID	301
MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY	551

Figure 7 FE Materials

2000112	MAT_PLASTIC.111	☑	210000.	7.89E-9	2000013	370.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000113	MAT_PLASTIC.112	☑	210000.	7.89E-9	2000013	370.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000114	MAT_PLASTIC.113	☑	210000.	7.89E-9	2000013	370.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000115	MAT_PLASTIC.114	☑	210000.	7.89E-9	2000013	370.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000116	MAT_PLASTIC.115	☑	210000.	7.89E-9	2000008	240.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000117	MAT_PLASTIC.116	☑	210000.	7.89E-9	2000008	240.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000118	MAT_PLASTIC.117	☑	210000.	7.89E-9	2000011	200.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000119	MAT_PLASTIC.118	☑	210000.	7.89E-9	2000008	240.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000120	MAT_PLASTIC.119	☑	210000.	7.89E-9	2000008	240.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000121	MAT_PLASTIC.120	☑	210000.	7.89E-9	2000008	240.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000122	MAT_PLASTIC.121	☑	210000.	7.89E-9	2000008	240.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000123	MAT_PLASTIC.122	☑	210000.	7.89E-9	2000008	240.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000124	MAT_PLASTIC.123	☑	210000.	7.89E-9	2000008	240.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000125	MAT_PLASTIC.124	☑	210000.	7.89E-9	2000008	240.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000126	MAT_PLASTIC.125	☑	210000.	7.89E-9	2000008	240.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000127	MAT_PLASTIC.126	☑	210000.	7.89E-9	2000013	370.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000128	MAT_PLASTIC.127	☑	210000.	7.89E-9	2000015	300.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000129	MAT_PLASTIC.128	☑	210000.	7.89E-9	2000011	200.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000130	MAT_PLASTIC.129	☑	210000.	7.89E-9	2000015	300.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000131	MAT_PLASTIC.130	☑	210000.	7.89E-9	2000011	200.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000132	MAT_PLASTIC.131	☑	210000.	7.89E-9	2000015	300.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000133	MAT_PLASTIC.132	☑	210000.	7.89E-9	2000013	370.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000134	MAT_PLASTIC.133	☑	210000.	7.89E-9	2000013	370.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000135	MAT_PLASTIC.134	☑	210000.	7.89E-9	2000013	370.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000136	MAT_PLASTIC.135	☑	210000.	7.89E-9	2000014	400.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000137	MAT_PLASTIC.136	☑	210000.	7.89E-9	2000014	400.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000138	MAT_PLASTIC.137	☑	210000.	7.89E-9	2000013	370.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000139	MAT_PLASTIC.138	☑	210000.	7.89E-9	2000013	370.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY
2000140	MAT_PLASTIC.139	☑	210000.	7.89E-9	2000015	300.	MAT24 MAT_PIECEWISE_LINEAR_PLASTICITY

Figure 8 FE Materials MAT24

1.4 ASSEMBLY MASS AND COG INFO

The Mass of the vehicle has corrected with assembly level mass. Because kinetic energy of the vehicle depends on the vehicle mass also. The mass and center of gravity details are shown in the Table 1.

Table 1 Mass and COG information of vehicle

S.No	Assembly	Mass (Kg)	COG
1	Chassis	317	X=-2543.16 Y=-8.4368 Z=415.307
2	All-Upper Body	954.2	X=-2522.26 Y=9.6351 Z=868.38
3	Engine & Transmission	363.3	X=-1090 Y=-7.6504 Z=630.188
4	Radiator	30.56	X=-360.53 Y=4.3557 Z=675.66
5	Fuel Tank	49.05	X=-2590.53 Y=279.75 Z=333.221
6	Front Power Train	50.22	X=-965.25 Y=88.53 Z=345.53
7	Rear Power Train	107.4	X= -3597.62 Y= 6.304 Z=378.72
8	Front-Wheel assembly	155.7	X= -828.955 Y= 3.57 Z=388.9117
9	Rear-Wheel assembly	184.5	X= -3700.92 Y=-1.4466 Z=364.149
10	Exhaust System	32.23	X=-2349.22 Y=222.468 Z=357.5
	TOTAL MASS	2244.16	

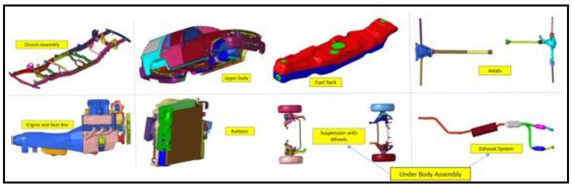

Figure 9 Vehicle Sub-assemblies

III. SIDE IMPACT LOAD CASE SETUP

For side impact test, target vehicle kept as stationary condition and another 950kg SUV Barrier hits the vehicle from the Driver side. The barrier center line and Diver H-Point are in same line of action. Impact maintained the height of around 300mm from the ground line. Initial velocity of 32 kmph is applied to the Barrier toward vehicle direction.

The target vehicle maintained with kerb mass and 50 percentile occupant in Driver seat and Q10 and Q6 Dummies kept in the Rear seat. Side impact setup shown in the Fig 10.

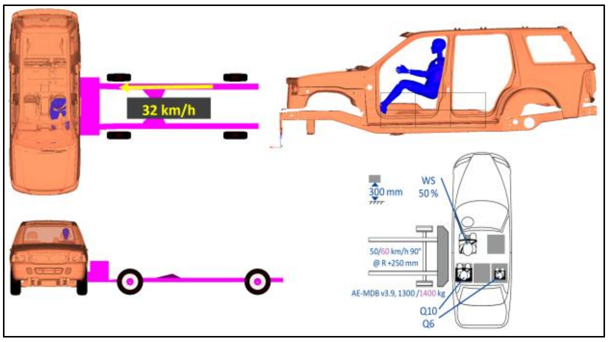

Figure 10 Side Impact setup

IV. SIDE IMPACT ENABLERS

In side impact collision cases, the load transfer from MBD to the vehicle side structure, and then structure deforms and it contact with dummy pelvis location. Due to this structure to pelvis contact the load has transferred to the occupant. As only a very small crumble zone is available during a side impact, so we have to ensure that the impact forces are distributed over a wide area.

The B-Pillars and side members along the vehicles flanks are mainly responsible for this. Both components are partly manufactured from ultra-high strength, hot formed high steel. The impact forces are transferred from B Pillar to the opposite side of the vehicle first and foremost via the transversely rigid seat and the center console.

A further load dissipation path runs from the base of the B pillar to cross member under the seat and transmission tunnel braces.

Asper base line study, identified the important load transfer path members are B-Pillar and its reinforcements, Roof bows, Sill, Transfers cross members. These parts stiffness increased by the way of design changes and material grade up. The fig 11 shows the various stiffness increased parts.

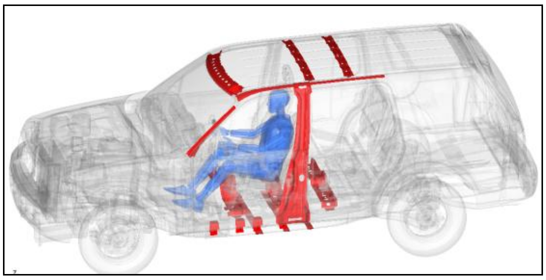

Figure 11 Major Load path

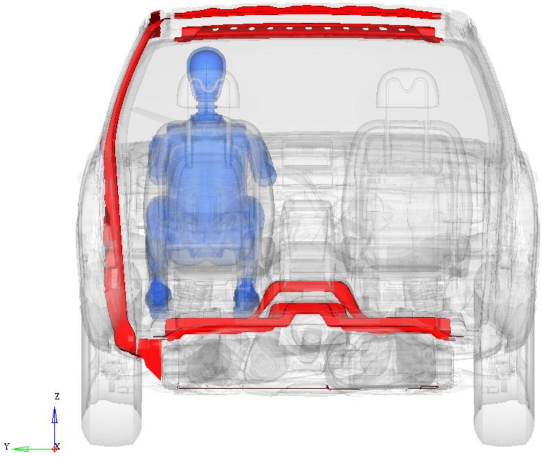

Figure 12 Load path Rear View

V. RESULTS COMPARISONS

5.1 Overall Deformation

The over view of deformation during side collision shown in the fig 13. Magenta colored barrier hits on the targeted vehicle driver side. Left picture is final improved results and right picture is base model. Also the occupant behavior shown in the fig 14, the driver moving the certain velocity toward outside of the vehicle. This will increase the head injury criteria.

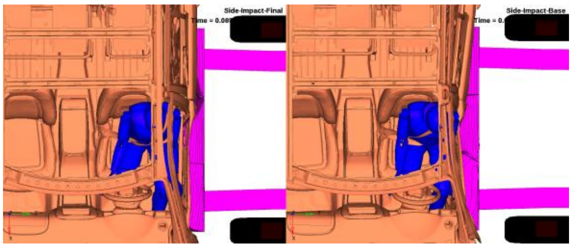

Figure 13 Occupant Intraction Top view

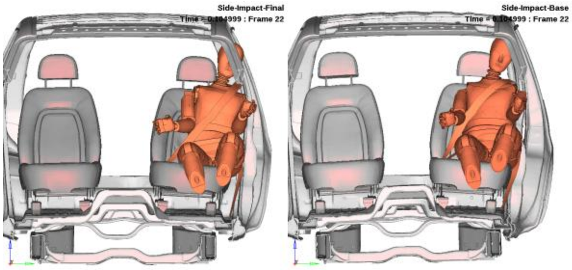

Figure 14 Occupant Intraction Front view

5.2 BIW Deformation

A further load dissipation path runs from the base of the B pillar to cross member under the seat and transmission tunnel braces. The comparison view of BIW plastic deformation shown in the fig 15. Picture of final improved vehicle shown the left side and Base vehicle shown in the right side of the picture. In the base vehicle Sill area and B Pillar has high plastic deformation. After improved the side structure, the deformation on the side structure has reduced drastically.

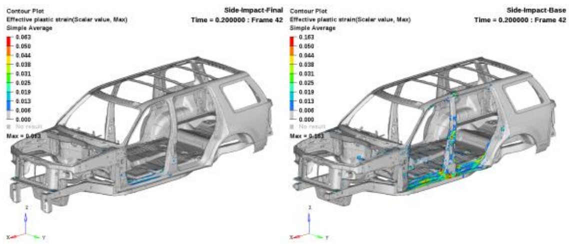

Figure 15 BIW Plastic Strain

The under body view of the vehicle shown in the fig 16.

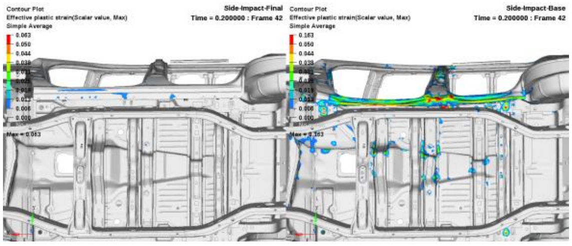

Figure 16 BIW Plastic Strain underbody view

B Pillar and sill location plastic strains are shown in the fig 17. After improving the structural stiffness of the side structure, the deformation reduced.

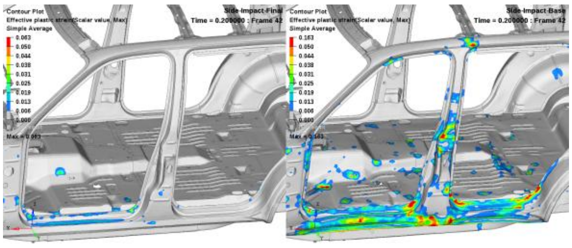

Figure 17 Body Side out Plastic Strain

5.3 Seat Performance

Seat structure also plays a vital role in the occupant injury. Good seat structure of seat will reduce the injury to the occupant. In the base vehicle seat not meet the safety requirement of the side impact. After detailed study of seat safety performance, Side members and recliner mounting location performance increased. The fig 18 shows the seat structure plastic strain between bases to improved structures.

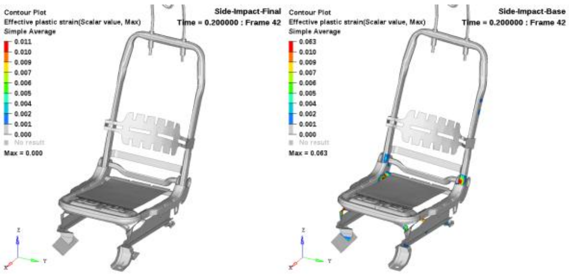

Figure 18 Seat Plastic Strain comparison

5.4 B Pillar Deformation

B-Pillar is the first and more load transferring part. The sectional view of B Pillar deformation measured locations shown the fig 19. And cut view of the deformation compared with base vehicle shown in the fig 20. Blue colored line represent the base vehicle B Pillar deformation view. Black line is the unreformed view of the section. Red colored line is the final improved vehicle sectional deformation. In the curve target lines also showed. Seat center line as Marginal and 50mm from the seat center line as Acceptable and 150mm from the seat center line as Good. So the final vehicle line is behind the good line.

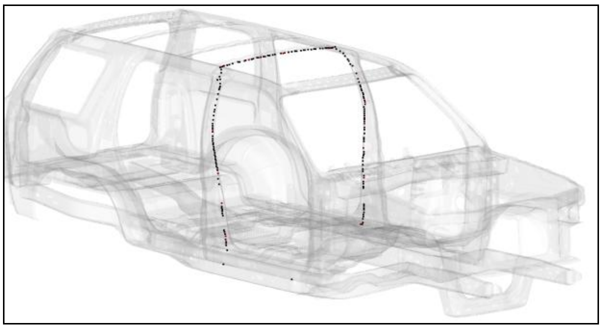
Figure 19 Points for B-Pillar Deformation

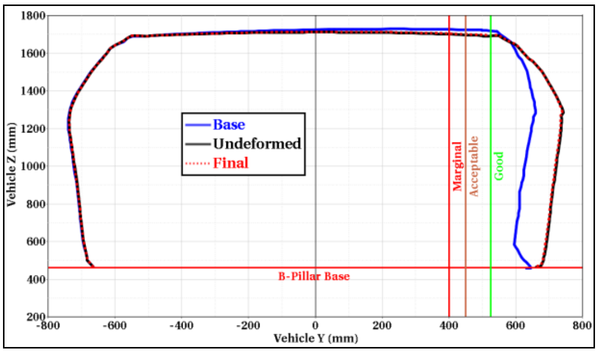

Figure 20 B-Pillar Deformation Plot

The intrusion measured at B-PLR below 60mm to the R Point. Blue is the base vehicle and Red is the Improved Final vehicle deformation. From the fig 21, good improvement observed on the final vehicle.

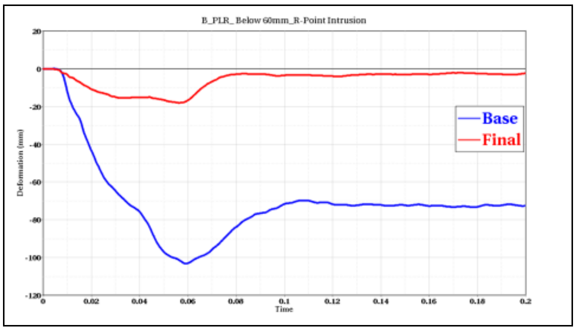

Figure 21 B-Pillar Intrusion

5.5 Roof Intrusions

Roof intrusion measured on the LH roof bows with respect to RH Side. Blue is the base vehicle and Red is the Improved Final vehicle deformation. This measurement shows the compartment crush on the top location. From the fig 22, the roof frame intrusion reduced on the final improved vehicle.

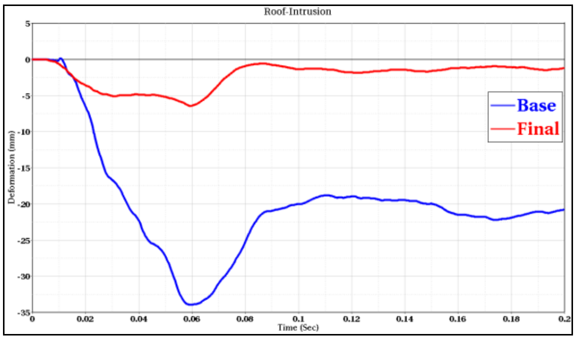

Figure 22 Roof Intrusion

Side structure intrusions measured on the LH side with respect to non-Impact side. The measured values shown in the fig 23. From this values, final improved vehicle structure behaving enough stiffness to resist the side impact.

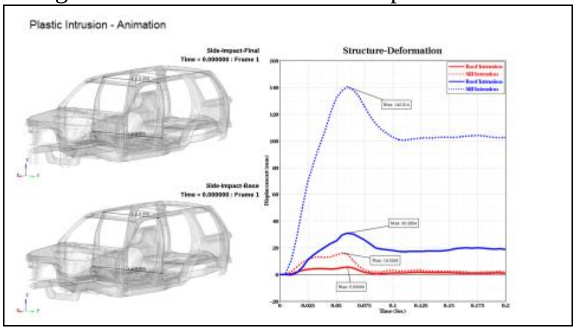

Figure 23 Side Structure Intrusion

5.6 Impulse transfer

The impact velocity measured on the vehicle structure at various location, this velocity will helps to find the momentum transfer from barrier to the vehicle. Also this rate of change of deformation velocity will gives the information about the structural rigidity.

$F_{dummy} = F_{MDB} + d/dt \{ M_{pillar} * V_{pillar} \} - F_{structure}$

$F_{Dummy} = M_{dummy} * a_{Dummy}$

Note: M_{dummy} = Constant

The dummy force is directly depends on the acceleration of the dummy. This acceleration depends on the structure velocity and how it deforms. Initially vehicle in rest position, after hits by the barrier vehicle, the vehicle starts to reach certain speed, then it will attain the barrier speed. In the fig 23 shows the B-Pillar top velocity changes with respect to the time.

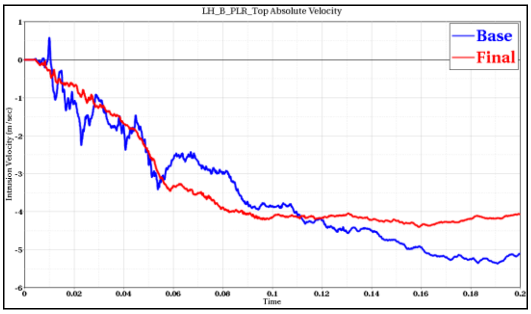

Figure 24 B-PLR Top Absolute Velocity Profile

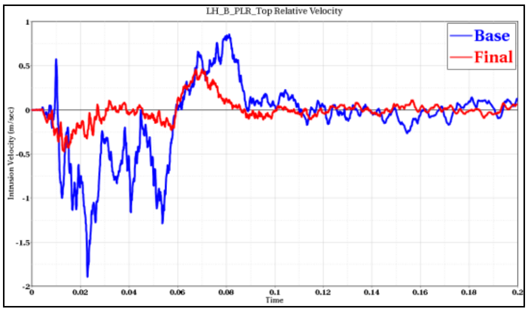

Figure 25 B-PLR Top Relative Velocity Profile

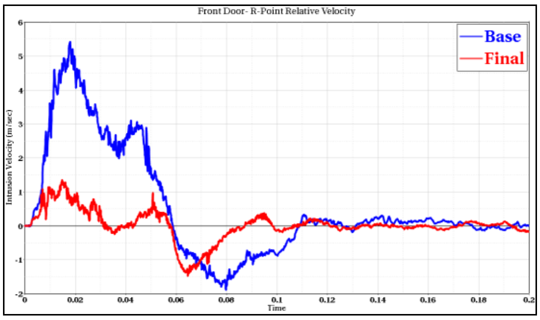

Figure 26 Front Door Relative Velocity Profile

The impact velocity measured on the vehicle structure at various location, this velocity will helps to find the momentum transfer from barrier to the vehicle. The head acceleration of occupant shown in the fig 24. The barrier hits with vehicle, after the side structure deforms and contact with occupant. This will create the injury on the occupant body parts. Head acceleration is an important parameter to identify the head acceleration. The graph shows base car results in the blue color and final improved vehicle acceleration in red color. Base vehicle head acceleration drops considerably after the side structure development.

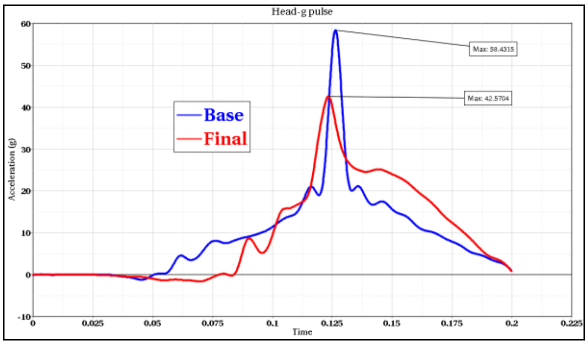

Figure 27 Occupant Head G Pulse Profile

VI. CONCLUSION

This side impact study shows the way and approaching method to improve the structural performance of the vehicle. The various root elements of side impact structures identified and contribution of each elements calculated by individual study. Finally combined all the side impact structure developments and evaluated overall safety performance improvements. The results shows the improvements of side impact safety from the base vehicle. This will helps to improve the vehicle market and safety rating.

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