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Developments on Occupant Safety during Frontal Collision of Vehicle

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Abstract: **Automotive vehicles play a vital role in our daily life. Major accidents occur due to frontal collisions which cause serious injuries and disabilities. To prevent the collision some improvements, need to be done for the vehicles especially the safety measures to reduce the injury level of the occupants the nature of the vehicle structure is the ability to convert kinetic energy to deformation of the structural parts which results intrusion of the front part of the vehicle. This will severely harm the occupants who cannot able to withstand the heavy load during the collision. To prevent this sudden impact, the passive safety system is implemented to reduce the deceleration loads (G-Force). This research is based on the development of the occupant safety during the frontal collisions. In practice, the body structures include the front structure with crumple zones to absorb the kinetic force energy and during the impact the vehicle should maintain the integrity of the passenger compartment while controlling the impact deceleration pulse. The aim of the research is to reduce the stiffness in the front part of the chassis or to create a crumple area to deform the structure in a short time (milliseconds) and to absorb the impact energy in a controllable way. The structural rigidity should also be consistent with ride and handling and must be compatible with other vehicles on the road so it is not too soft or too aggressive. The main objective of the research is to reduce the frontal impact of the occupant safety by measuring the Intrusion and deceleration pulse with crash avoidance and crashworthiness.**

Keywords: **Dummy study, FEA Analysis, Frontal Collision, LS-Dyna Explicit, Occupant Safety, Full vehicle Analysis, ECE-Frontal Impact, ECE-R94.**

I. INTRODUCTION

In this contemporary world, automotive industry is evolving gradually accelerating. Today, automotive industry safety efforts focus on crash worthiness, crash avoidance. The biggest challenge in the industry is developing adequate and competent engineering to meet the vehicle by improving the safety standards.

A collision of a vehicle is an unexpected event that occurs when a vehicle collides with another vehicle or a stationary object. Due to this, may happen death, injury and some financial issues.

Generally, the vehicle is equipped with certain structure to prevent the loads/force from outside. In front it is covered with crumbled structure and the instrumental panel is to restraints force to fall within the range of occupant tolerance decelerations which transmitted are manageable. Chassis are made to withstand the entire upper body of the vehicle and to maintain the gravity. The deformable rear structure to maintain integrity and side structures are covered with doors to minimize intrusion and strong roof structure for roll over protection.

In addition, vehicles are developed with a restraint systems such as energy-absorbing steering columns, three-point belts, front and side air bags and head restraints to reduce the risk of injury. All the systems are design and developed to work in harmony with the vehicle structure.

This project deals only with structural crashworthiness and related injury biomechanics issues. The crashworthiness is a modification of vehicle structure that can transfer the crash energy by controlled vehicle deformations while maintaining adequate space so that the residual crash energy can be dissipated by the restraint systems to minimize loads transfer to the vehicle occupants.[1].

There are certain requirements need to be followed for this research based on some safety standards. We are following based on the European Regulation R94 Frontal Impact collision.

II. CRASHWORTHINESS REQUIREMENTS

There are certain crashworthiness requirements while performing the simulation for reducing the impact of the occupants are listed below,

1. Deformable yet stiffer front structure with crumple zones to absorb the crash simulation.

2. Deformable front and rear structure to maintain integrity of the passenger compartment.

3. Properly designed restraint systems that work in harmony with the vehicle.

4. Structure to provide the occupant with optimal ride down and protection in different interior spaces and trims.

III. SAFETY CRITERIA FOR FRONTAL IMAPCT

1. Residual steering wheel displacement, measured at the centre of the steering wheel hub, shall not exceed 80 mm in the upwards vertical direction and 100 mm in the rearward horizontal direction.

2. Vehicle speed at the moment of impact shall be 56 -0/+1 km/h. If the impact speed was more than this and the vehicle met the requirements, the test shall be considered satisfactory.

3. The head performance criterion (HPC) should not exceed 1000. And Head G force value should not exceed 80G for more than 3ms.

4. The thorax compression criterion (ThCC) is determined by the absolute value of the thorax deformation and shall not exceed 50 mm. The viscous criterion (V * C) is calculated as the instantaneous product of the compression and the rate of deflection of the body and shall not exceed 1.0 m/s.

5. The femur force criterion (FFC) is determined by the compression load expressed in kN, transmitted axially on each femur of the dummy and measured shall not exceed the force-time performance criterion at 9070N at 0ms and 7580N within 10ms.

6. The tibia compression force criterion (TCFC) shall not exceed 8 kN.

7.The displacement of the tibia with respect to the femur is measured at the knee sliding joint with a CFC of 180.The movement of the sliding knee joints shall not exceed 15 mm.

8. During the test no door shall open, and no locking systems of the front doors shall occur. To release the dummies from their restraint system which, if locked, shall be capable of being released by a maximum force of 60 N on the center of the release control.

9. Maximum leakage rate from fuel feed installations after collision shall not exceed 30 g/min.

10. Observe energy balance, maximum sliding energy and hourglass energy should be within agreeable limit.

11. Need to check the B pillar acceleration in X, Y and Z direction and deformation of complete vehicle. Plot plastic strain for fuel system to find out possible damage in fuel system. Observe airbag and seat belt system output and occupant injuries. [6], [8].

IV. BASE VEHICLE FEA SIMULATION

For this simulation, sedan full vehicle finite element model which have been validated for full frontal collision tests and are modified the structure for this studies. The below shown images is the baseline model for simulation. [5].

Figure 1: Finite Element Model of Baseline

The TABLE 1 is the summarize of the baseline model

Table 1: FEA Details of Model

Parts	226
Nodes	62681
Shell Elements	51384
Solid Elements	3554
Beam Elements	171

1. *Front Rail Design*

The front rail is designed to resist the load carrying to the engine compartment and to resist the torsion. The perpendicular cross-members are also used for the stability and maintain CoG of the vehicle. It can resist bending moment, shear force and torsional moment whereas Straight beam carries only bending moment and shear force. The torsional moment appears due to beam's geometry, its centroid of geometry does not lie on its length.

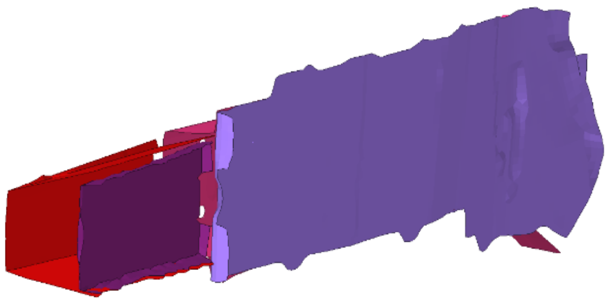


Figure 2: Front rail of Baseline

2. *Occupant Details*

H-point (Hip point) is the relative position of hip of an occupant. So this is the pivot point between the torso and upper leg portions of the body. This point is relative to the floor of the vehicle. At the same coordinate of hip point, a hip joint will be present in the 50 percentile male occupant.[6]

R-point (Seating Reference Point) is the hip point of the occupant referred by manufacturers when designing a vehicle and in more detailed describes the relative position of the seated dummy's hip point, while the seat is positioned in the full rear, full down position.[3],[6]

Occupant H-point Co-ordinate:

X= -1900.000

Y=324.790

Z=636.350

Figure 3: crash dummy

Figure 4: 50%ile dummy model

The crash dummies are full scale anthropomorphic test device (ATD) that simulate the dimensions, weight proportions and articulation of the human body. The following are requirements for human models are geometry, dimension, mass distribution, centre of gravity, inertia, joint stiffness, degrees of freedom, realistic kinematics.

The percentile means the part of population which is taken into account. i.e. The HIII 50% represents that 50% of world's population comes under this category. [4]

3. HAND CALCULATION

A) Impact Force Calculation

In order to verify the FE results, we have cross verified the values with the hand calculation. The fig 5 and 6 show the comparison between the hand calculation and FE results of the Impact force.

$$\text{Impact Force} = \frac{m_1 v_1 - m_2 v_2}{dt}$$

Mass = 1023kg

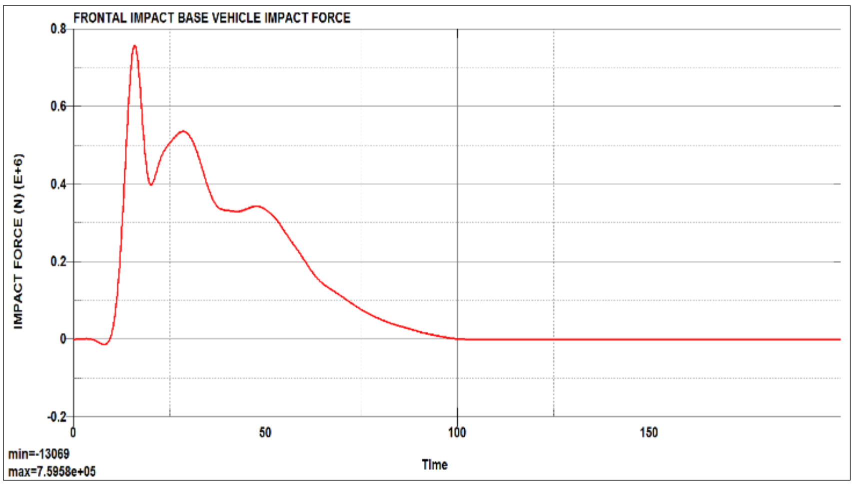
Velocity = 56 kmph

Peak impact time = 0.022 sec

$$\text{Force} = \frac{1023^* (56^*1000/3600)}{0.022}$$

Force = 723333.33 N

Figure 5: Hand calculation of Impact force



Graph 1: FEA Solver output of Impact force

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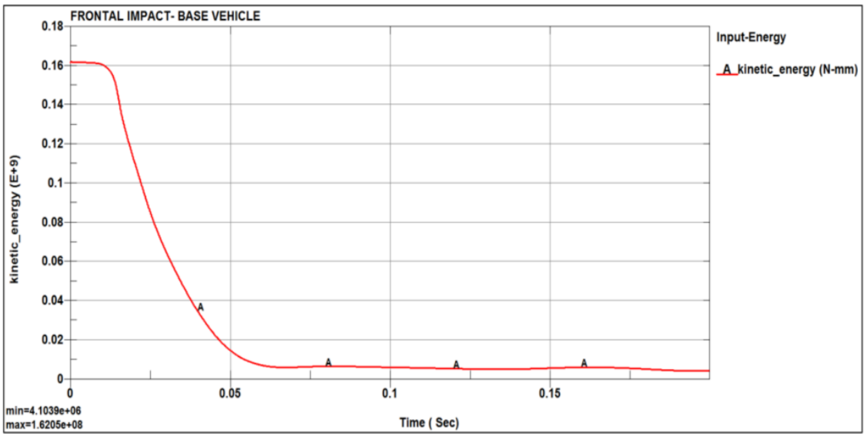
B) Kinetic Energy calculation

In order to verify our FE results, cross verified the values with the hand calculation. The fig 6 and Graph 2 shows the comparison between the hand calculation and FE results of the Kinetic Energy.

$$\text{Kinetic Energy} = \frac{1}{2}(\text{Mass}*\text{Velocity2})$$
$$= 1/2\left(1023*\frac{(56*1000*1000)^2}{3600^2}\right.$$
$$= 123770370.4$$
$$= 1.24 \text{ X } 10^8 \frac{(10^3 \text{ kg} * 10^{-6} \text{ m}^2)}{\text{Sec}^2}$$
$$= 1.24 \text{ X } 10^5 \text{ N-m/Sec or Joules}$$

Figure 6 Hand calculation of Kinetic Energy

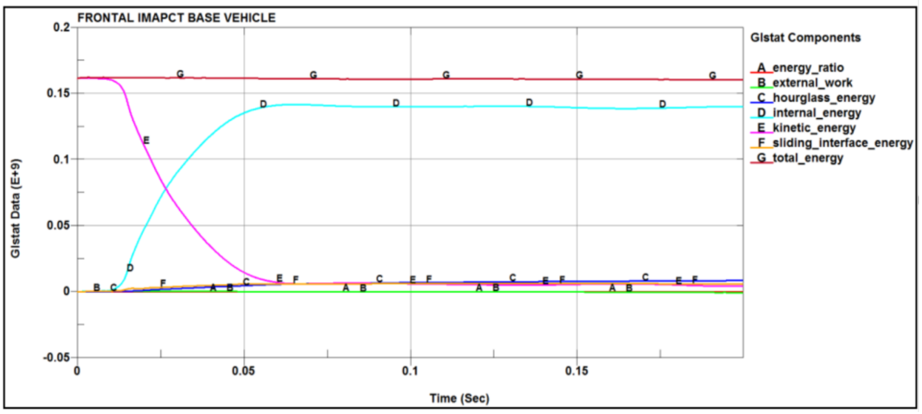


Graph 2: FEA Solver output of Kinetic Energy

Hand calculation is almost matches with the FE value. Hence our simulation is reliable and correct.

4. *ENERGY CURVES*

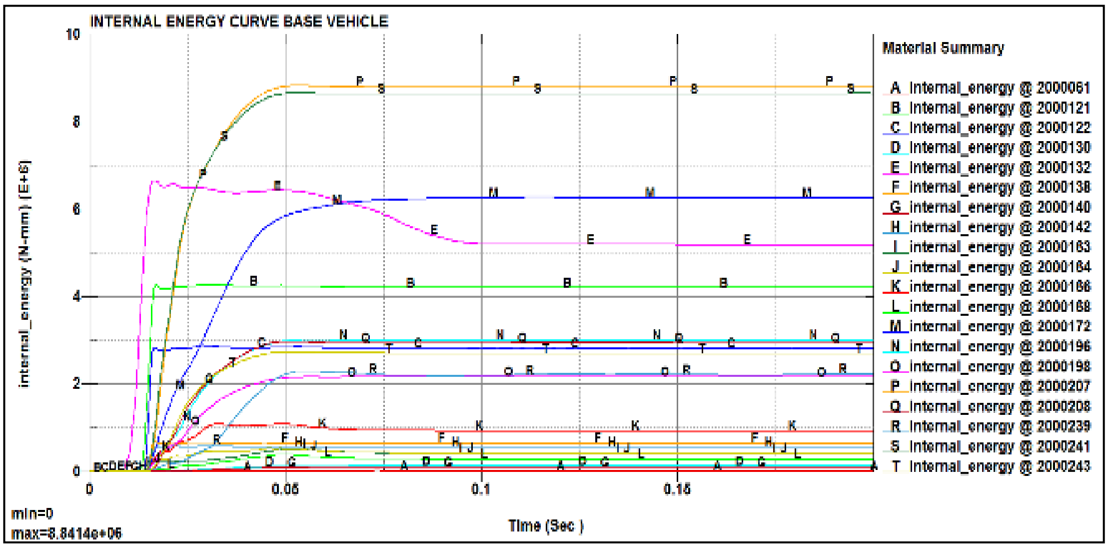
During the impact the kinetic energy dissipate into vehicle deformation in the form of internal energy away from occupant. Here the energy dissipation rate directly proportional to the injury of the occupant.



Graph 3: FE of All Energy

The total energy of the simulation is constant, and from the Graph 3, only energy transformation is Kinetic Energy is converted in to the Internal Energy by the way of deformations.

5. *ENERGY TRANSFORMATION*



Graph 4: FE of All Energy

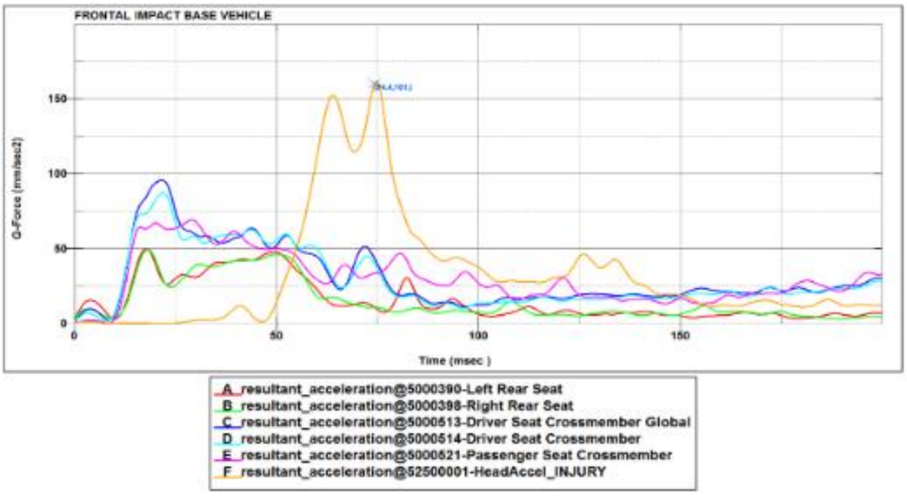
According to Newton`s law, energy can be neither created nor destroyed. During the impact force all the energy are converted into internal energy. The Graph 4 shows the parts of the internal energy absorbed during the simulation. Also Table 2 shows, Component wise Energy absorption during the impact.

Table 2: Component Energy Absorption

Component ID	Component Name	BASE-Model-Internal Energy (N-mm)
2000061	Radiator-Bottom member	2.41E+07
2000121	Front-Rail-LH-C-Section	4.29E+06
2000122	Front-Rail-RH-C-Section	2.88E+06
2000130	Front-Upper-Suport-frame-L	1.37E+05
2000132	Front Bumper	6.66E+06
2000138	Front-Rail-RH-Vertical member	6.83E+05
2000140	Front-Upper-Suport-frame-R	1.12E+05
2000142	Front-Rail-LH-Vertical member	5.99E+05
2000163	Rear-Rail-RH-Vertical member	5.15E+05
2000164	Rear-Rail-LH-C-Section	5.29E+05
2000166	Rear-Rail-RH-C-Section	1.90E+06
2000168	Rear-Rail-LH-Vertical member	3.94E+05
2000172	Firewall	6.28E+06
2000196	130_floorsupprt2left	3.01E+06
2000198	Left-Floor	2.17E+06
2000207	Floor Right Support member-2	8.80E+06
2000208	Floor Right Support member-3	2.97E+06
2000239	FloorTunnel	2.30E+06
2000241	Floor Left support member-2	8.66E+06
2000243	Floor left supportmember-3	2.73E+06

6. *G-FORCE VALUES*

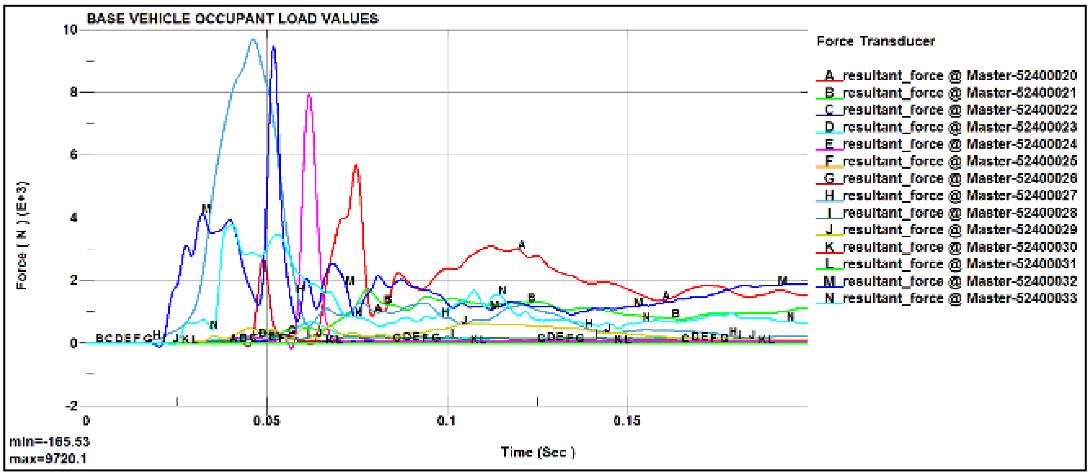
G-forces are a measure of the kinetic energy that your body is exposed to, mostly during acceleration or deceleration. 1g corresponds to gravity. In an accident, however, your body can experience a tremendous amount of power in a very short time. The Graph 5, shown G force is taken various places during the crash simulation.[2].



Graph 5: G-Fore Curves

7. OCCUPANT FORCE

The force experienced by the impact of the vehicle come into contact with occupant. A significant amount of kinetic energy is absorbed by the body. Graph 6 shows, the occupant load values absorbed during the impact.



Graph 6: Occupants Fore Curves

Table 3, shows the force values of various parts during frontal collision. [7].

Table 3: Occupants Fore

FT ID	NAME OF PART	BASE VEHICLE FORCE (N)	SAFETY Load (N)
52400020	HEAD	5715	**4580**
52400021	NECK	1705	**3300**
52400022	CHEST	235	**2460**
52400023	LEFT UPPER HAND	683	**2530**
52400024	RIGHT UPPER HAND	7960	**2530**
52400025	LEFT LOWER HAND	22.87	**2530**
52400026	RIGHT LOWER HAND	2698	**2530**
52400027	**coxa** (HIP)	9720	**6700**
52400028	**Femurs-**RIGHT UPPER LEG	352	**7580**
52400029	**Femurs-**LEFT UPPER LEG	630	**7580**
52400032	**Tibia-** RIGHT LOWER LEG	9477	**8000**
52400033	**Tibia-** LEFT LOWER LEG	3797	**8000**

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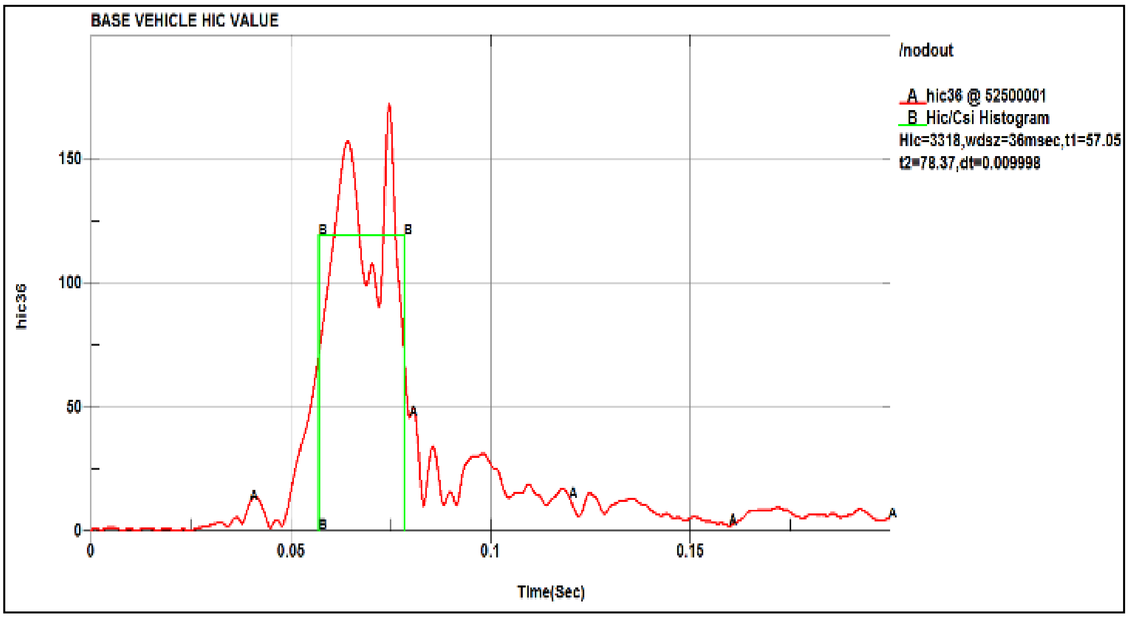
8. HEAD INJURY CRITERIA

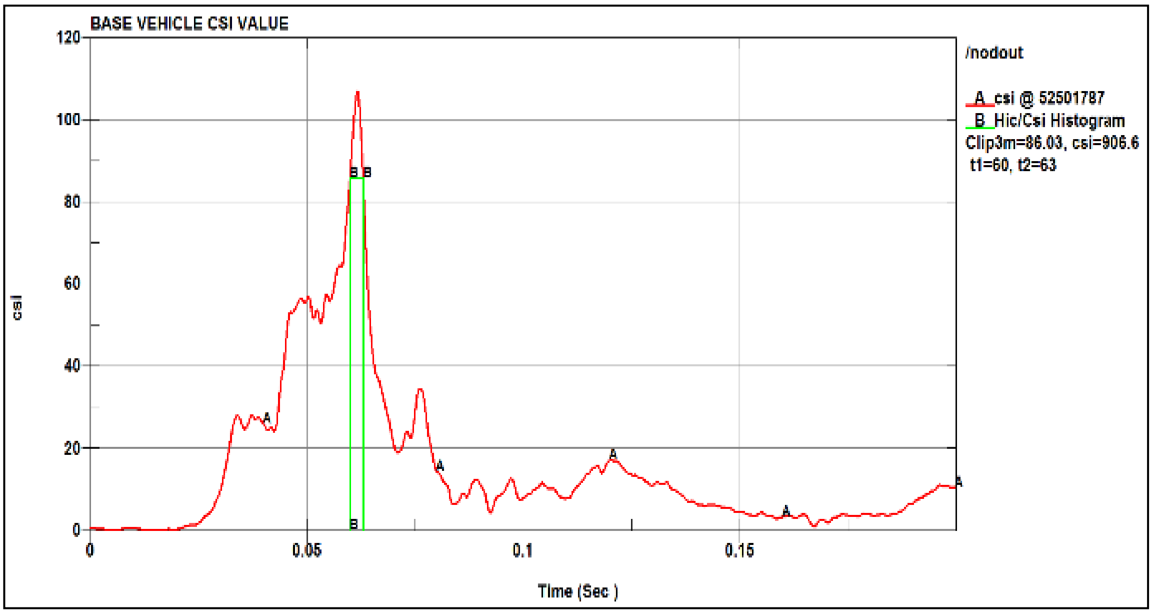
HIC value is 3318 which is more than the safety requirement of the front impact. The maximum HIC should be around 1000. Hence baseline model fails to meet the requirement, hence it is failed.



Graph 7: HIC of the baseline model

9. CHEST INJURY CRITERIA

CSI value is 906.6 shown in the Graph 8, which is less than the safety requirement of the front impact. The maximum CSI value should be less than 1000. Hence baseline model to meets the requirement, hence it is passed.



Graph 8: CSI of the baseline model

10. DEFORMATION OF BASE MODEL

From the fig 5, 6, 7 shows the impact zone of the front structure is crushing severely and damage to the front portion and affects the occupant heavily. The front rail portion and engine compartment areas are totally crushed. The occupant carpet zone is hitting the floor and hood is crushed and opened during the impact.

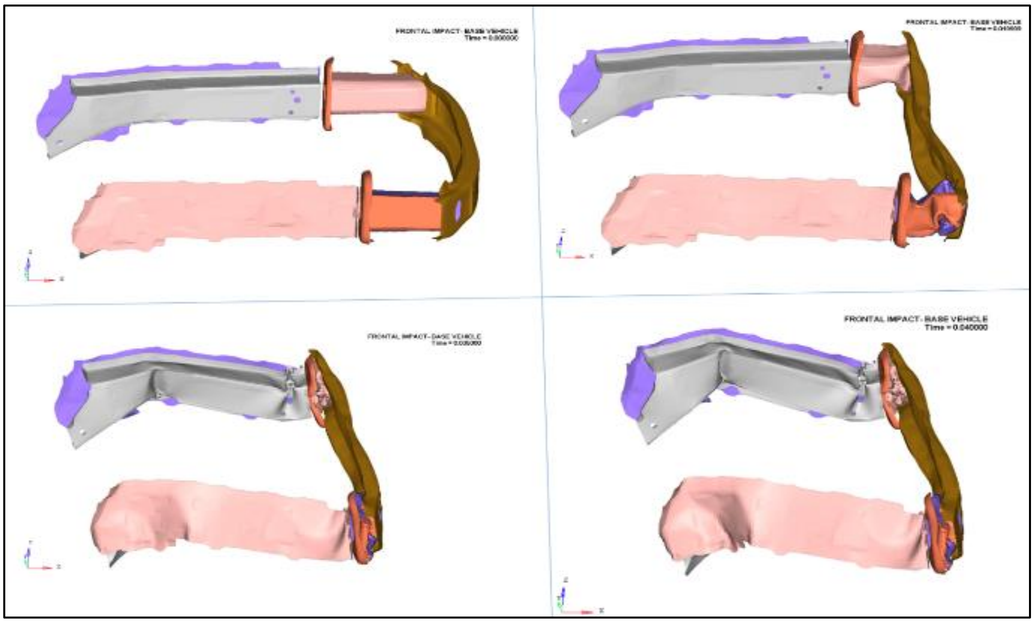


Figure 5: Deformation of the baseline model

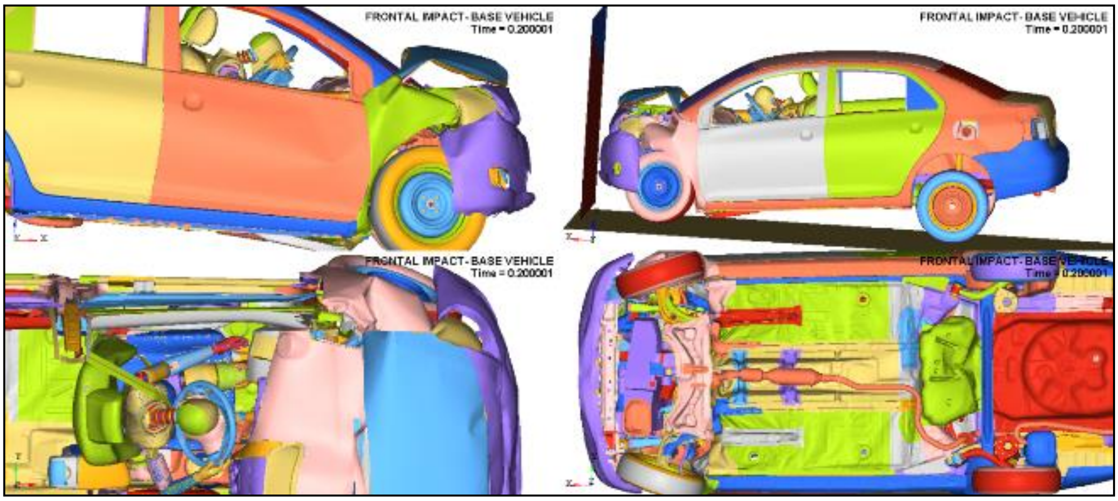


Figure 6: Intrusions of the baseline model

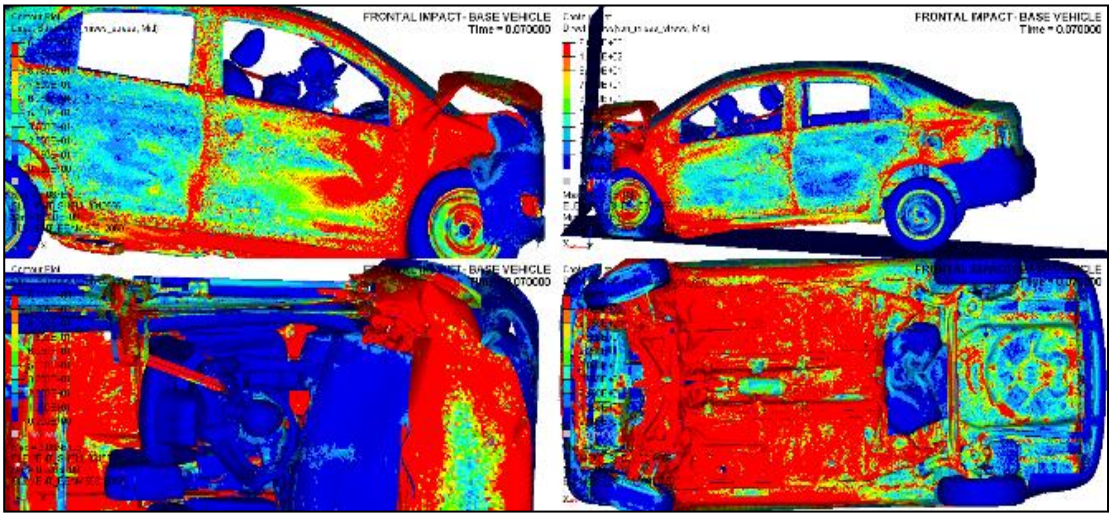


Figure 7: Stress plot of the baseline model

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11. SUMMARY OF BASE MODEL

From the Table 4, summary of the results, we can inference the baseline model.

1. Head G force value is crossed 80G, so it fails to meet the safety criteria.

2. Chest Injury criteria is in the safe value.

3. Neck force also in the safe criteria.

Table 4: Results of the baseline

PARAMETER	OUTPUT VALUES FOR BASE VEHICLE
Head G-Force	161 G
HIC	3318
CSI	906.6
HEAD	5715 N
NECK	1705 N
CHEST	235 N
LEFT UPPER HAND	683 N
RIGHT UPPER HAND	7960 N
LEFT LOWER HAND	22.87 N
RIGHT LOWER HAND	2698 N
coxa (HIP)	9720 N
Femurs-RIGHT UPPER LEG	352 N
Femurs-LEFT UPPER LEG	630 N
Tibia- RIGHT LOWER LEG	9477 N
Tibia- LEFT LOWER LEG	3797 N

The baseline model is not safe for the occupant and it's not meet the safety requirements, in order to meet the requirement, need to do some modifications and made some design suggestions.

V. DEVELOPMENT ACTIVITIES

Design Modification:

There are three design modification in the development and improvement of the vehicle which would improve the occupant safety during the impact of the crash.

A) Stamping and Features

B) Honeycomb crush Box

C) Front cross connection member

There are two energy transfers in the vehicle structure during impact, Primary energy transfer is made through Crush box and modifications in front rail. The secondary energy transfer is made through front suspension connection member.

A) Stamping and Features

During the frontal crash collision, the major cause of serious injuries and deformation occurs on the front portion the rail. It will take more intrusion to prevent the energy transfer to the driver compartment region.

The longitudinal load transfers from the front rail to the compartment thought the engine compartment and suspension region. So, the occupant will experience a minor injuries, while contact with the car interior or penetrating parts during the collision.

As a consequence, our aim is to design a better car body front rail with too stiffness which leads to increase deceleration forces with too much intrusions in the front rail. The front structure rail designed is neither too stiff nor too week by adding striations on the front vertical member and front rail.

This design modification of full frontal overlap gives maximum energy absorption by the stiffness parts in the front region to around 40 per cent, this means during the first half of the crash, nearly half of the total amount of crash energy is absorbed.

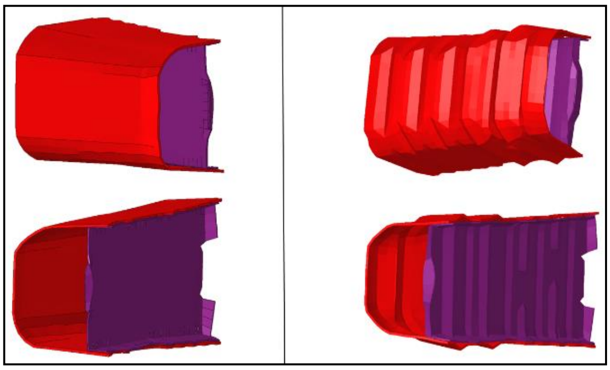

Figure 8: Striations added

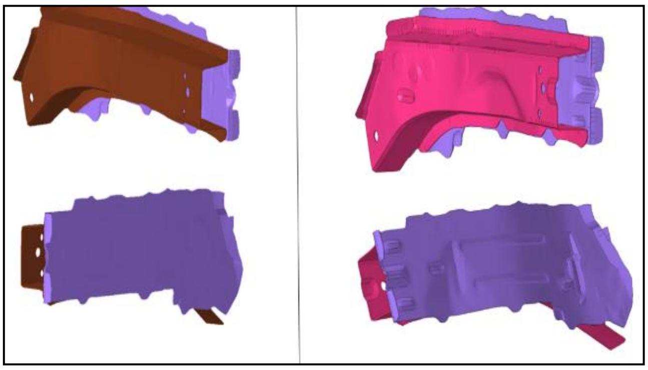

Figure 9: Surface modification

Then remaining 60 per cent of the crash energy will not absorbed by the front structure rail. The remaining energy must be absorbed by the passenger compartment. In order to prevent the energy transfer, we added the vertical beads in the front rail C channel to control the crushing in the vehicle axis. So, the amount of energy transfer to the driver compartment will reduce.

B) Honeycomb Crush Zone

Crushing box placed inside of front rail. It will help to absorb more energy, due to this the load propagate to the occupant will reduce. This crushing zone, we increase the stiffness of the front rails and we provided the transverse peak and valley type surface on the front rails.

When a vehicle includes all the loads travelling at certain speed will have inertia/momentum, continue to forward with that direction and speed. This will help to control the longitudinal crushing and energy will absorbed by honeycomb crushing box. The high stiffness will reduce the vehicle intrusion values by absorbing high energy and resist to bend and it is more stable.

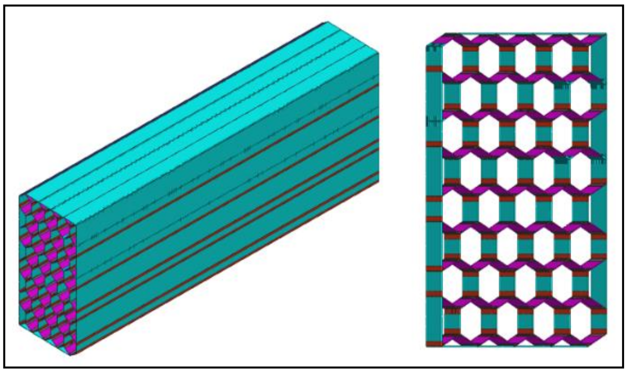

Figure 10: Honey comb crush box zone

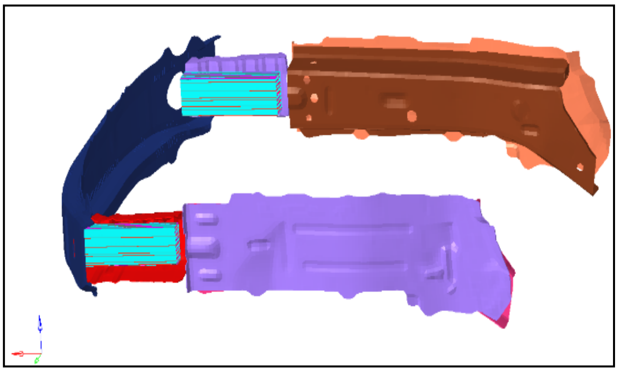

Figure 11: Honey comb in the front rail

C) Front Cross Connection Member

To represent the front cross suspension energy transfer of the vehicle, four non-linear springs with stiffness are two springs connected with the upper members (rails) and two springs connected with the lower members of the vehicle frontal structure.

During the crash the longitudinal load will transfer through the four springs/damper to the front structure, so that efficient energy absorption takes place and vehicle remains stable. Therefore, this will reduce the car from high energy transfer and resonance without affecting the other sub system.

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This front cross energy transfer suspension will work during frontal impact only, rest of the simulations and other situation it behaves like a connection member. If suspension has low stiffness, fatigue will occur, and it may affect the engine compartment area.

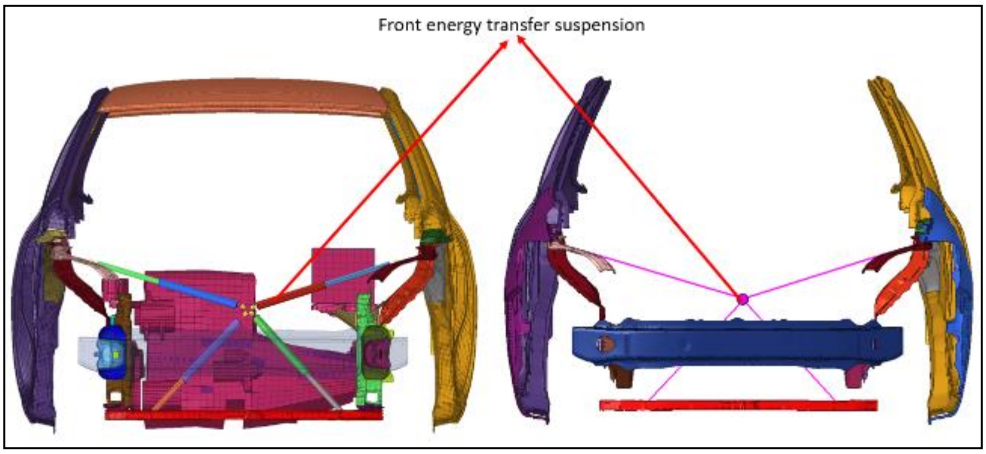


Figure 12: Front suspension connection member

Calculations for the Front cross suspension connection member

Impact Load from the Base vehicle model= 759580 N

Maximum allowed intrusion displacement in engine compartment area is =85 mm.

The selected suspension stiffness is 759580/85

= 8936.2 N/mm

Here suspension combined as top suspension and bottom suspension. So, for each suspension stiffness

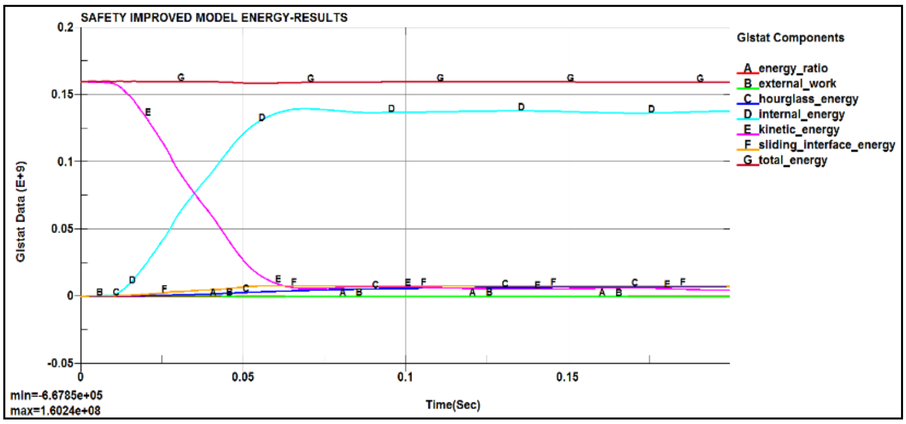
= 8936.2 / 2 = **4468.2 N/mm.**

VI. DEVELOPED VEHICLE FEA SIMULATION

Based on the baseline simulation and their results, modified some design suggestions and performed the new vehicle simulation to reduce the impact of the occupant. [5].

1. Energy Curves

During the impact the kinetic energy dissipate into vehicle deformation in the form of internal energy away from occupant. Here the energy dissipation rate directly proportional to the injury of the occupant.



Graph 9: Energy curve of the developed model

The total energy of the simulation is constant from Graph 9 and the only energy transformation is Kinetic Energy is converted in to the Internal Energy by the way of deformations.

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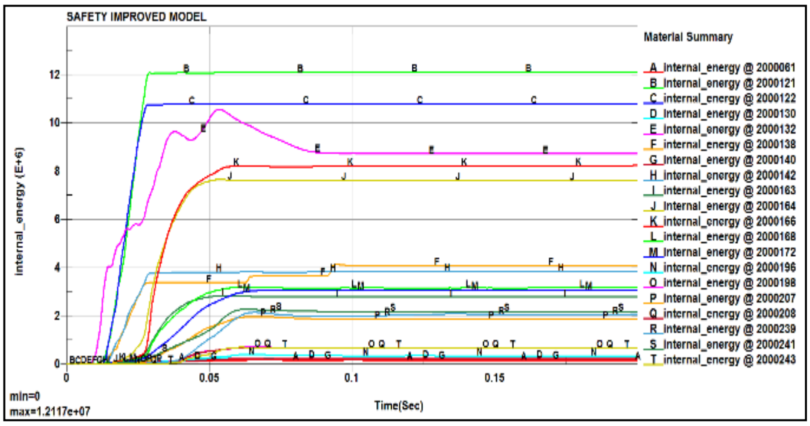
2. Energy Transformation



Graph 10: Internal Energy curve of the developed model

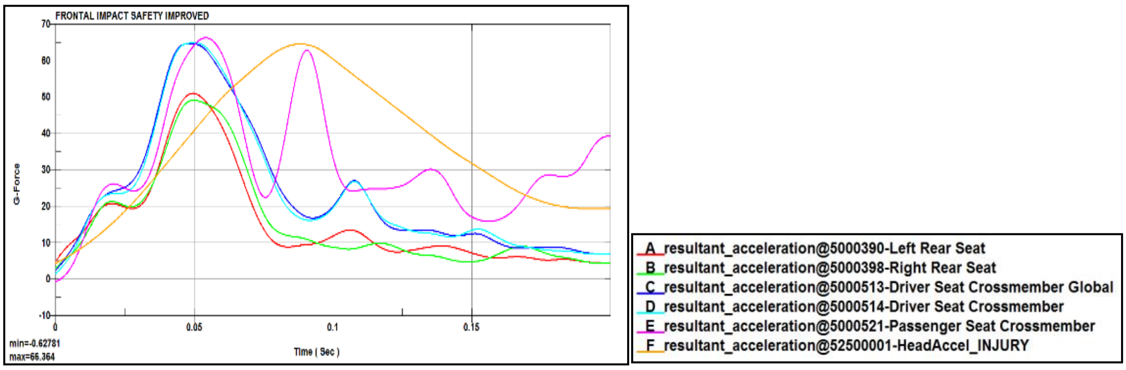
During the impact force all the energy are converted into internal energy. The Graph 10, show the parts of the internal energy absorbed during the simulation.

Table 5: Internal Energy of respective parts in developed model

Component ID	Component Name	Developed-Model-Internal Energy (N-mm)
2000061	Radiator-Bottom member	1.75E+05
2000121	Front-Rail-LH-C-Section	1.20E+07
2000122	Front-Rail-RH-C-Section	1.07E+07
2000130	Front-Upper-Suport-frame-L	2.30E+05
2000132	Front Bumper	1.05E+07
2000138	Front-Rail-RH-Vertical member	4.14E+06
2000140	Front-Upper-Suport-frame-R	2.20E+05
2000142	Front-Rail-LH-Vertical member	3.83E+06
2000163	Rear-Rail-RH-Vertical member	2.82E+06
2000164	Rear-Rail-LH-C-Section	7.66E+06
2000166	Rear-Rail-RH-C-Section	8.20E+06
2000168	Rear-Rail-LH-Vertical member	3.17E+06
2000172	Firewall	3.02E+06
2000196	130_floorsupprt2left	3.90E+05
2000198	Left-Floor	7.02E+05
2000207	Floor Right Support member-2	1.96E+06
2000208	Floor Right Support member-3	6.89E+05
2000239	FloorTunnel	2.16E+06
2000241	Floor Left support member-2	2.26E+06
2000243	Floor left supportmember-3	6.95E+05
2000258	HoneyComb Crush Box	6.20E+07
2000262	Front-Suspension-Member	1.07E+06

3. G-Force Values

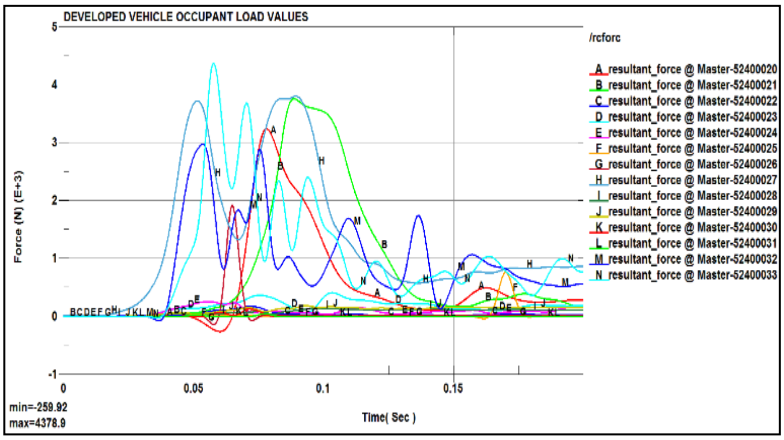
G-forces are a measure of the kinetic energy that your body is exposed to, mostly during acceleration or deceleration. 1g corresponds to gravity. In an accident, however, your body can experience a tremendous amount of power in a very short time. The Graph 11, shown G force is taken various places during the crash simulation.



Graph 11: G Forces of the developed model

4. Occupant Force

The force experienced by the impact of the vehicle come into contact with occupant. A significant amount of kinetic energy is absorbed by the body. The Graph 12, shows the occupant load values absorbed during the impact.



Graph 12: Occupant Forces of the developed model

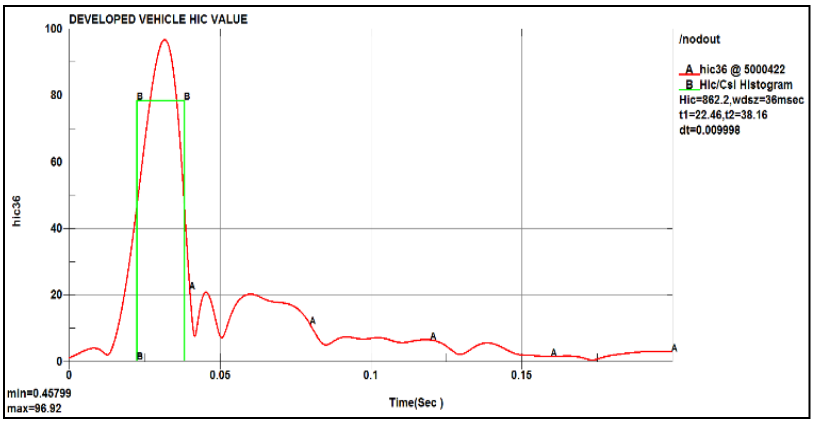
The Table 6, shows the various results and outputs taken from the occupant during the impact. [7].

Table 6: Individual occupant force parts of the developed model

FT ID	NAME OF PART	DEVELOPED VEHICLE FORCE (N)	SAFETY Load (N)
52400020	HEAD	3244	**4580**
52400021	NECK	3765	**3300**
52400022	CHEST	174	**2460**
52400023	LEFT UPPER HAND	410	**2530**
52400024	RIGHT UPPER HAND	257	**2530**
52400025	LEFT LOWER HAND	768	**2530**
52400026	RIGHT LOWER HAND	1925	**2530**
52400027	**coxa** (HIP)	3809	**6700**
52400028	**Femurs**-RIGHT UPPER LEG	144	**7580**
52400029	**Femurs**-LEFT UPPER LEG	188	**7580**
52400032	**Tibia**- RIGHT LOWER LEG	2982	**8000**
52400033	**Tibia**- LEFT LOWER LEG	4378	**8000**

5. Head Injury Criteria

HIC value is 882 which is less than the safety requirement of the front impact. The maximum HIC should be around 1000. Hence the developed model meets the requirement, hence it is passed.



Graph 13: HIC of the developed model

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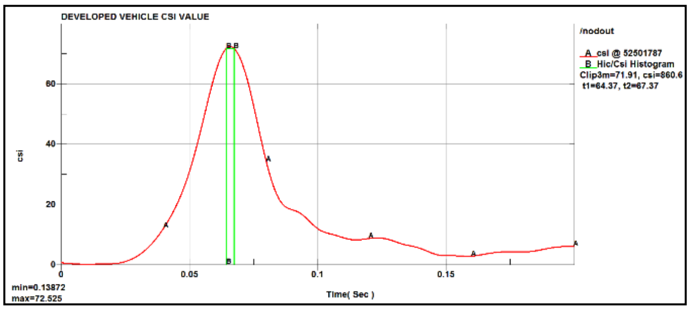
6. Chest Injury Criteria

CSI value is 860 which is less than the safety requirement of the front impact. The maximum CSI value should be less than 1000. Hence the developed model to meets the requirement, hence it is passed.



Graph 14: CSI of the developed model

7. Deformation of Developed Model

From fig 13, 14, 15 shows the impact zone of the front structure is crushing less and less damage to the front portion and affects the dash board lightly. The front rail portion and engine compartment areas are totally crushed.

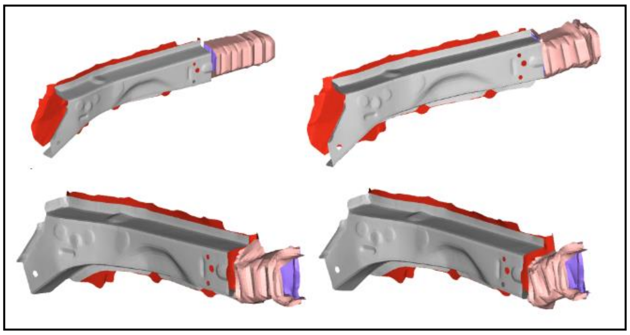


Figure 13: Deformation of the developed model

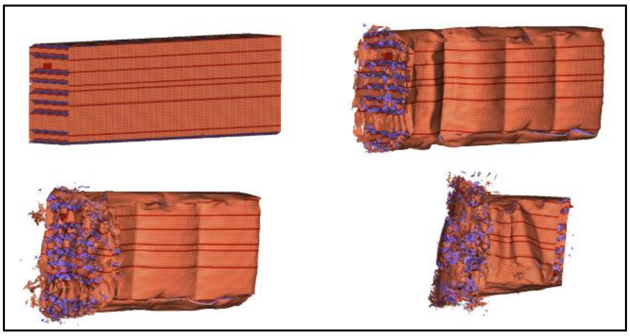


Figure 14: Intrusions of the crush box in developed model

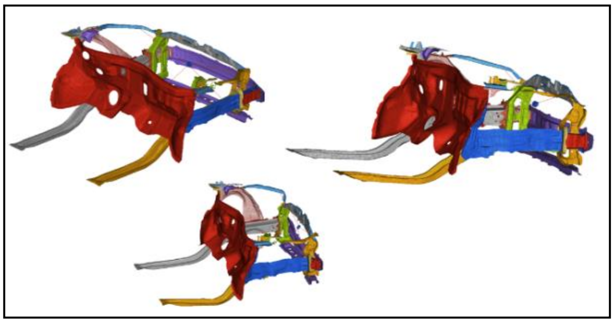


Figure 15: Intrusions of the developed model

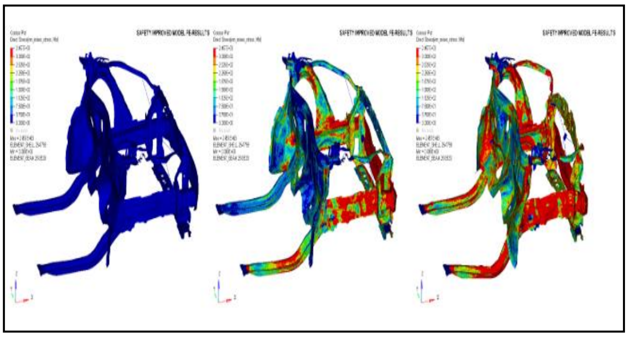


Figure 16: Stress plot of the dashboard in developed model

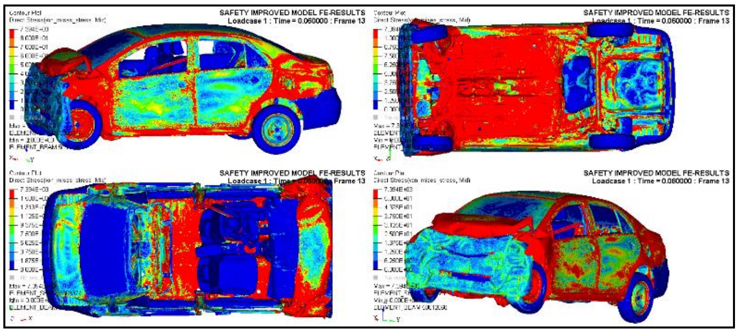


Figure 17: Stress plot of the developed model

From the fig 17 shows the impact zone of the front structure is crushes more and reduce the impact of the inboard crushes and reduces the dash board intrusions. The front rail portion and crush box areas are totally crushed locally to reduce the energy intrusions.

8. Summary of Developed Model

From the summary Table 7, results,

1. Head G force value is less than 80G, so it passes and meet the safety criteria.

2. Chest Injury criteria is in the safe value.

3. Neck force is above the safe criteria.

Table 7: Results of the developed model

PARAMETER	OUTPUT VALUES FOR DEVELOPED VEHICLE
Head G-Force	74 G
HIC	882
CSI	860
HEAD	3244 N
NECK	3765 N
CHEST	174 N
LEFT UPPER HAND	410 N
RIGHT UPPER HAND	257 N
LEFT LOWER HAND	768 N
RIGHT LOWER HAND	1925 N
coxa (HIP)	3809 N
Femurs-RIGHT UPPER LEG	144 N
Femurs-LEFT UPPER LEG	188 N
Tibia- RIGHT LOWER LEG	2982 N
Tibia- LEFT LOWER LEG	4378 N

The developed model is safe for the occupant and it's almost meet all the safety requirements. Only Neck force is above the requirement in the developed model, so in future development, also reduce the neck force in future design.

VII. CONCLUSION AND SUMMARY

Based on the two simulations and their results, inferred the Internal energy and forces between the simulations. The developed model is safe for the occupant and it's almost meet all the safety requirements. The crash analyses showed that intrusion was most reduced, and the combined injury index was largely reduced by change in design suggestions, whereas internal energy ratio was also compared and their results are plotted. Overlay plots were created by constraint response values between both developed and baseline simulations.

The Table 8 shows the comparison results of internal energy for both model.

Table 8: Comparison results of the Internal energy

Component ID	Component Name	BASE Model Internal Energy (N-mm)	Developed Model Internal Energy (N-mm)	Comments
2000061	Radiator-Bottom member	2.41E+07	1.75E+05	
2000121	Front-Rail-LH-C-Section	4.29E+06	1.20E+07	Absorbtion of the Enegry increased so the energy transfer to the occupants decreased
2000122	Front-Rail-RH-C-Section	2.88E+06	1.07E+07	
2000130	Front-Upper-Suport-frame-L	1.37E+05	2.30E+05	
2000132	Front Bumper	6.66E+06	1.05E+07	
2000138	Front-Rail-RH-Vertical member	6.83E+05	4.14E+06	
2000140	Front-Upper-Suport-frame-R	1.12E+05	2.20E+05	
2000142	Front-Rail-LH-Vertical member	5.99E+05	3.83E+06	
2000163	Rear-Rail-RH-Vertical member	5.15E+05	2.82E+06	
2000164	Rear-Rail-LH-C-Section	5.29E+05	7.66E+06	
2000166	Rear-Rail-RH-C-Section	1.90E+06	8.20E+06	
2000168	Rear-Rail-LH-Vertical member	3.94E+05	3.17E+06	
2000172	Firewall	6.28E+06	3.02E+06	Absorbtion of the Enegry decreased so the energy transfer to the occupants decreased
2000196	130_floorsupprt2left	3.01E+06	3.90E+05	
2000198	Left-Floor	2.17E+06	7.02E+05	
2000207	Floor Right Support member-2	8.80E+06	1.96E+06	
2000208	Floor Right Support member-3	2.97E+06	6.89E+05	
2000239	FloorTunnel	2.30E+06	2.16E+06	
2000241	Floor Left support member-2	8.66E+06	2.26E+06	
2000243	Floor left supportmember-3	2.73E+06	6.95E+05	
2000258	HoneyComb Crush Box		6.20E+07	Additional Energy absorbed
2000262	Front-Suspension-Member		1.07E+06	

The Table 9, Shows the comparison between base models to Developed model force values.

From this, only the failure value is Neck force value. Other than all the force values are below the safety criteria values.

Table 9: Comparison results of the force

FT ID	NAME OF PART	BASE VEHICLE FORCE (N)	DEVELOPED VEHICLE FORCE (N)	SAFETY Load (N)
52400020	HEAD	5715	3244	**4580**
52400021	NECK	1705	3765	**3300**
52400022	CHEST	235	174	**2460**
52400023	LEFT UPPER HAND	683	410	**2530**
52400024	RIGHT UPPER HAND	7960	257	**2530**
52400025	LEFT LOWER HAND	22.87	768	**2530**
52400026	RIGHT LOWER HAND	2698	1925	**2530**
52400027	**coxa** (HIP)	9720	3809	**6700**
52400028	**Femurs**-RIGHT UPPER LEG	352	144	**7580**
52400029	**Femurs**-LEFT UPPER LEG	630	188	**7580**
52400032	**Tibia**- RIGHT LOWER LEG	9477	2982	**8000**
52400033	**Tibia**- LEFT LOWER LEG	3797	4378	**8000**

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